DESIGN AND DEVELOPMENT OF A COMPETITIVE WIRE SPLICING SYSTEM FOR THE AUTOMOTIVE WIRE HARNESS INDUSTRY

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M.Tech

In Manufacturing And Industrial Technology

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ABSTRACT

The work presented in this thesis is aimed at developing a very comprehensive system of manufacturing wire splices for automobile wire harnesses. Ultrasonic welding is increasingly being used in various industrial applications. Lack of a scientific data-base of its properties when applied to wire splicing is a major reason for lack of proper usage by the wiring harness industry and its subsequent acceptance by the end user. This thesis presents various experiments conducted to develop tensile strengths and electrical resistances of various types of ultrasonically welded wire splices. Crimping technology was evaluated for its mechanical strengths and electrical properties by conducting various experiments to make it possible for the industry to compare it with other alternative splicing technologies. The results are then compared with ultrasonic welding.

The next stage of this thesis discusses the economic feasibility of ultrasonic wire splicing. In order to find the number of ultrasonic welding machines required to meet a particular level of demand, which is a prerequisite for establishing the economic feasibility, a virtual model of the process and the manufacturing cell has been prepared and this model was used to study the dynamics of demand and the number of required machines. Simulation in manufacturing-problem-solving is being used very widely by researchers. Proper understanding and visualisation of the future of the factory and understanding and answering various questions related to the adoption of new technology, is another major reason why companies shy away from adopting ultrasonic welding systems. An advanced simulation tool namely QUEST was used to model the wire splice manufacturing cell of Alcatel and simulation studies were conducted to foresee how the production dynamics would be if ultrasonic welding machines were incorporated in place of crimping machines and various what if scenarios were developed and some vital production related questions were answered.

Material handling is a major bottleneck in any wiring harness manufacturing environment. Some conceptual designs are presented on automating the task of feeding wires to ultrasonic welding machines and transferring the wire assemblies from welding stations to different work stations, currently being done manually. A wire palletising system was designed to improve the productivity.

This thesis concludes that ultrasonic welding could be very effectively used for wire splicing and could be safely used in the manufacture of wiring harnesses for the automobile industry.

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I dedicate this thesis to my wife Madhavi

Contents

Chapter-1

1. INTRODUCTION TO THE THESIS AND OBJECTIVES OF THE RESEARCH PROJECT

Introduction

This chapter gives an overview of the current state of affairs of the wiring harness industry. After having established the back-ground of this research, an introduction is given to the current methods of manufacturing wiring harnesses. This research was carried out for Alcatel New Zealand Limited, the industrial collaborator for this activity.

1.1 Introduction to the wiring harness industry

Electrical wiring harness can be visualised as a kind of nervous system of many electrical systems in which it finds its place, with the mantle of reliably and efficiently transmitting the power falling on it. There are over 160 manufacturers of wire harnesses and fabricated lead wires for passenger auto, truck and other commercial and industrial vehicle applications in the world today [1]. There are many other major industries including white goods, brown goods, office/electronic data processing, control and industrial electronics, aerospace and others accounting for a multi billion dollar market world wide.

With today's advanced automotive control systems, manufacturers of electrical harnesses for vehicle use are faced with even more stringent requirements for reliable connections in their automotive harnesses, with the other industries the case being no different and far more demanding in some industries like aerospace. Increasing demands for on-board sensors and microprocessor controls create a need to achieve flawless wire terminations capable of reliably transmitting low-voltage signals. Even the slightest variation in resistance across a circuit will create havoc. In addition to the quality control by the various industries, there is an increasing emphasis on overall weight reduction of vehicles. A typical wiring harness assembly amounting to about 100 lbs, is a major area for considering weight reductions [1].

Furthermore, the manufacturing of cable harnesses and networks has, using traditional methods , been an extremely costly, labour intensive and monotonous process. Methods used to construct cable harnesses have necessitated long lead times, large series and a substantial amount of tied up capital. The cost of producing and installing cable harness represents a large proportion of the total manufacturing cost of any electrical system. For example, the cost associated with cables in a modern car represent the second largest item, after the engine but before the bodywork [2].

This need to achieve improvements in wiring harnesses has led to research in many institutions world wide, in the design, manufacturing and assembly of wiring harnesses.

It is high time for the New Zealand wiring harness industry to look at not only improving productivity but to drastically reduce the cost of manufacturing to compete in new markets. Besides the cost, a better quality and appearance to the product is a major thrust for the industry's success in the future.

1.1.1 The wiring harness manufacturing process

The most common method of manufacture, being adopted currently by the majority of the industry, is presented below.

The different operations involved in the manufacture of the wiring harness could be easily understood by looking at typical operations identified as following:

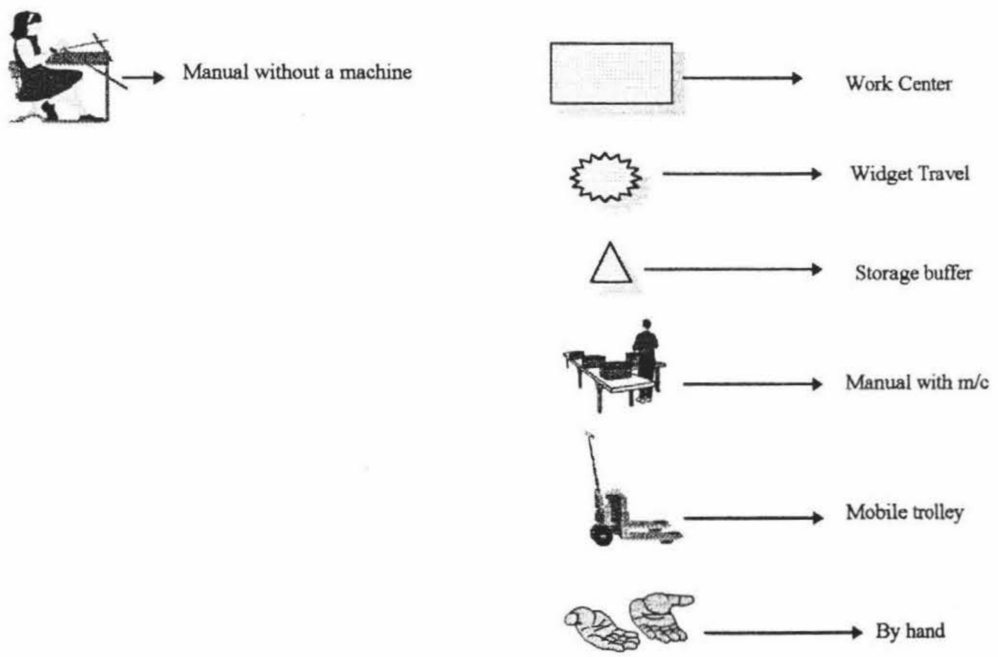


Figure 1-1, Legend to the system description

The system flow chart described below, uses the legend of various operations in the above Figure.

- Source, is the station where all the wires are cut and stripped-off the insulation at the ends, come and wait before going in for the next operation.

- Sorting is where, the wires are grouped on the information available from their route cards and sorting decides where the wires would go next.

- Wrapping is where the wires are individually wrapped to conform to the drawing of a specific joint that the wires are supposed to form.

- The next operation is where the wires are spliced before they go for joint encapsulation, where the joints are wrapped with insulation.

Wires coming from the storage facilities are cut to the desired lengths and stripped, ie., the insulation sheath at the wire ends are removed. This is made on one machine ie., the cutting and stripping is done in single stroke on one machine. The insulation at the wire ends is removed to facilitate the placement of other electrical terminals. This piece, known as "lead" goes further in the series of operations to get joined with other leads, then called J-lead, or may as a single lead go downstream.

In the next step of operations the electrical terminals are attached to the leads or J-leads by crimping machines . The other possible operations on these leads could be of sleeving or connector assembly.

Some cables need to be joined or spliced together to form a joint, known in the industry jargon as "internal join". This could be a down stream operation after the termination, sleeving or it could be a direct downstream from the cut and strip. These spliced wire splices, with terminals attached then go to the on board assembly.

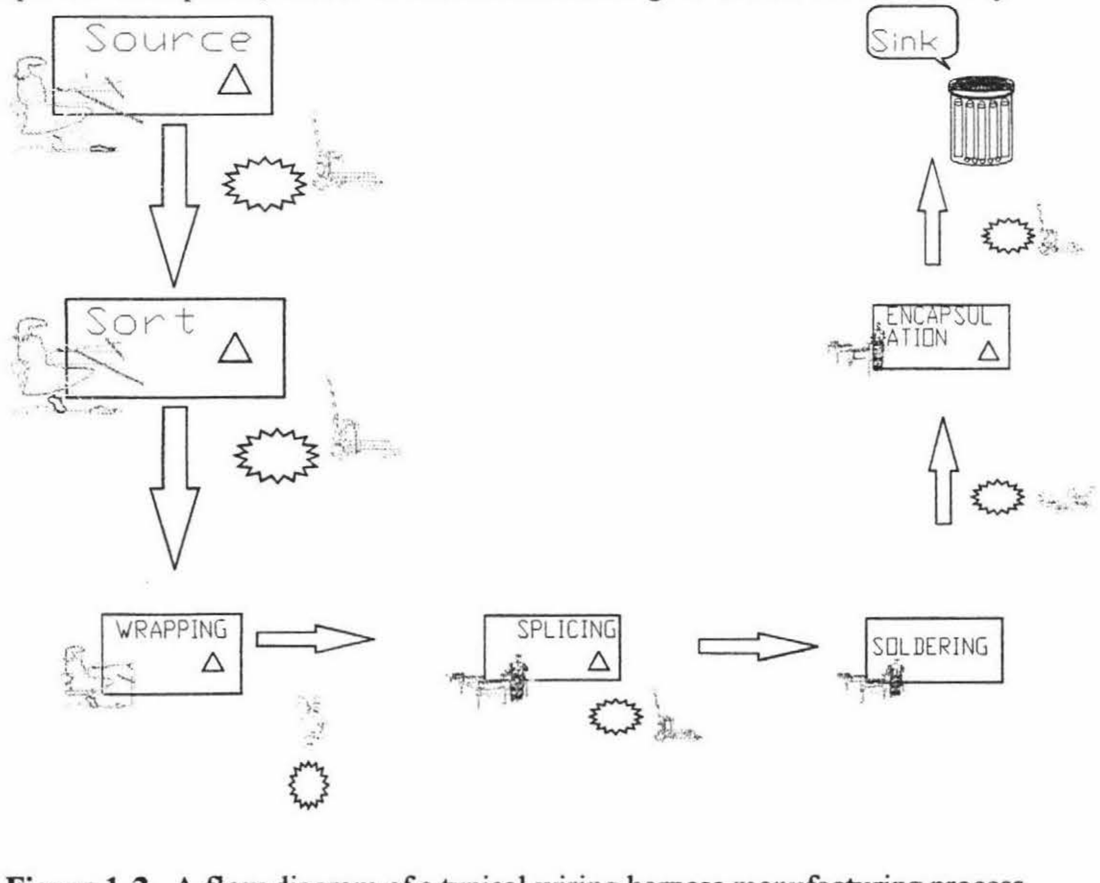


Figure 1-2, A flow diagram of a typical wiring harness manufacturing process

1.2 Wire splicing

Wiring harnesses typically contain several splice junctions of multiple wires. The number of splice junctions (in other terms called wire splices) coming in a wiring harness vary typically with the size and design of the harness. Nevertheless, irrespective of the number of wire splices, they are like nodal points prone to mechanical, electrical and chemical failures [6]. The overall reliability of the wiring harness, undoubtedly, depends on the reliability of the wire splices.

There are three major methods [3] of making the splices; the crimp method, resistance welding and ultrasonic welding, explained in section 2.1.

1.3 Objectives of the project

The objectives set out for this project, which was sponsored by The Foundation For Research, Science and Technology (FRST), Government of New Zealand, under the Graduate Research in Industry Fellowship (GRIF) [45], were:

- Evaluate the crimping technology, currently being used by many wiring harness manufacturers, to manufacture the wire splices. This was to be done by quantifying the electrical and mechanical properties.
- Study other alternative techniques of producing the wire splices and identify the one which is technically and otherwise superior among all the alternative techniques.
- Evaluate the identified alternative technique for its electrical and mechanical strengths, when used for wire splicing.
- Compare the crimping technique with the alternative technique on electrical and mechanical strengths and weaknesses.
- Help the industry in adopting the technology in the right technical form and help them in implementing the technology, to make it successful. Implementation of the technology is again divided into two sections:

1. Study the effect of the new technology on the production dynamics of the industry. Specifically on the factors like how the new technology would cope with the fluctuations in demand and other important production related factors. This was envisaged to be made by developing simulation models of the future plant, with machines using the new manufacturing technique and give feedback to the

industry.

2. Study the manufacturing aspects of the technology and come up with some solutions to some of the material handling problems. This was to be made by identifying the problems currently being faced and then come up with some conceptual solutions in terms of automatic part presentation systems and part transfer systems and produce a conceptual design.

1.4 Industrial collaboration

This project is made in industrial collaboration with Alcatel New Zealand Limited, a leading automotive wiring harness manufacturer in New Zealand.

Alcatel is one of the world's largest manufacturer and supplier of telecommunications equipment. Alcatel New Zealand is a major supplier to Telecom, providing locally designed and manufactured telephones and other sophisticated hardware and software products. Submarine optical fibre cable systems, printed circuit boards and wiring harnesses for the automobile industry are among the other products manufactured at the Alcatel's manufacturing plants in Masterton and Upperhutt [4].

This project was based at the Masterton plant which is concerned solely with the processing of electric cables into wiring harnesses for the automobile industry. The majority of these harnesses are manufactured for domestically assembled cars and commercial vehicles.

1.5 Preview of the thesis

In this section a brief overview of what is being presented in various chapters is discussed.

Chapter-2, presents the fundamental introductory discussion of different types of wire splicing techniques and a relative comparison is made between the three known types, viz., crimping, resistance welding and ultrasonic welding.

In Chapter-3 an attempt is made to bench mark the crimping technology, which is by far most widely used for making crimped wire connections. Experiments, which have been carried-out to quantify the mechanical and electrical strengths, are discussed and the results are presented.

Chapter-4, discusses the technique of making wire connections with ultrasonic welding. Quantification of the electrical and mechanical strengths have been made in this chapter.

In Chapter-5 a comparison is made between the crimped connections and ultrasonically welded connections. Electrical and mechanical properties are compared, besides a comparison of other factors such as the splice volume, appearance, modes of failure etc., is also made.

Economic feasibility of ultrasonic welding is discussed in chapter-6. A virtual model has been presented as a tool to study the dynamics of production and an attempt is made to use this to establish of economic feasibility.

How ultrasonic wire splicing could be implemented in an industrial environment, where crimping is the current method of splicing, is discussed in chapter-7.

Finally, the thesis is drawn to a conclusion after chapter-7.

Chapter - 2

2. WIRE SPLICING FOR AUTOMOTIVE WIRING HARNESSES- SOME FUNDAMENTAL COMPARISONS

Introduction

This chapter discusses some of the relative comparisons between crimping, resistance welding and ultrasonic welding methods of splicing wires, collated from various other researchers. After establishing a reasonably fair superiority of one of the two alternative techniques, a detailed discussion is made on some of the fundamental aspects of the presumed superior alternative technique.

2.1 Methods of manufacturing the wire splices

In a typical harness manufacturing facility, the manufacturing of an internal join comes in the 4th or 5th stage of the production, with wire cutting, stripping and termination being some of the pre-processing stages of production and fluxing, soldering and encapsulation being the post-process stages of production before going for the assembly on-board [5]. The proportion of operation time related to internal join (otherwise known as wire splices) manufacturing in the total wiring harness manufacturing time may be up to 15% [2], depending on the type of harness design. It is mainly a labour intensive activity with major components of the activity being handling of wires and preparation of wires for suitable presentation to wire joining.

There are different ways of producing spliced junctions. Traditionally, there have been two processes used most commonly and reliably. The crimping method of wire splicing is probably the oldest and the other one being resistance welding, before ultrasonic welding came into prominence.

2.1.1 Crimping

With this method, an operator crimps (terminates) the splice with a metal clip. The splice is then dipped in acid flux solution to clean the surface prior to solder dipping. The crimped assembly is then dipped into a liquid solder solution to maximise the mechanical and electrical reliability of the splice. This method of producing involves using a standard size of clip for a large variety of wire cross-sections at the point of junction.

Instead of using a standard size of crimp and soldering all the crimped connections, a more controlled operation is the one with different crimp dimensions for different sizes of wire joints and more control over the process by varying the crimp heights to obtain optimum electrical and mechanical efficiency. In this method only a certain range of cross-section of wires need to be soldered, the others show integrity without soldering.

The major disadvantages are :

a) Less control over the actual process, mostly dependent on the skill of the operator.

b) Little possibility of interfacing with advanced microprocessor based quality monitoring systems.

c) Heavy and bulky machinery with moderately high noise level which is non conducive to operator productivity.

d) Not an environmentally friendly process with lots of hazardous chemical fumes, heat and the generation of hazardous waste materials related to acid fluxing and dip soldering.

e) Involvement of consumables such as clips, flux and solder.

f) More labour intensive with multiple operations involved.

g) Not as flexible as other methods are for automation for the reason that machinery dimensions are very large and multiple operations are involved.

h) Difficulties may be encountered while encapsulating the soldered connections, as the formation of an icicle on the solderface can ruin the integrity of the encapsulation.

i) More electric power is used compared to some of the alternative technologies.

2.1.2 Resistance welding

This technique uses resistance to high electric current to create extremely high temperatures in electrodes. Under a compression force and the heat generated in these electrodes, the wires are melted and fused together. This was developed as an alternative to the crimping method before the invention of other methods [6].

The major disadvantages are :

a) Involvement of heat. There is a possibility of high temperatures making the copper brittle and leaving some of the wire strands out of the weld nugget.

b) Copper is extremely conductive to heat, hence very high temperatures are required to melt the copper.

c) The electrodes wear very quickly. The typical life of an electrode will be around 2,000 welds. The time involved in changing of the electrode may be as high as 20 minutes sometimes [46].

d) Copper oxide and other contaminates are deposited on the electrodes and they need to be periodically cleaned. Dressing is required for every 30 welds.

e) Difficult to weld different materials with different melting points and electrical sensitivity.

f) Problems associated with fast tool wear can affect the quality and its monitoring.

g) Health/safety hazards related to the burning electrodes.

h) More electric power is used in comparison to other alternatives.

i) Requirement of cooling medium to cool the tools.

2.1.3 Ultrasonic welding

Ultrasonic Welding occurs by the introduction of oscillating shear forces at the interface between two metals while they are held together under moderate clamping force. The resulting internal stresses cause elastoplastic deformation at the interface.

Highly localised interfacial slip at the interface tends to break up oxides and surface films, permitting metal to metal contact at many points. Continued oscillations breaks down the points, the contact area grows and diffusion occurs across the interface producing a structure similar to that of a diffusion weld. Ultrasonic welding produces a localised temperature rise from the combined effects of the elastic hysteresis, interfacial slip, and plastic deformation. The welding process is completed without having fully melted metal at the interface when the force, power, and time are set correctly.

Interface temperature rise is greater for metals with low thermal conductivity, such as steel, than for metals of high conductivity, such as aluminium or copper.

The advantages are:

a) Typical cycle times are less than one second

b) Joins many dissimilar metals

c) Uses no consumables such as clips, solder or flux

d) No adverse environmental effects

e) Manufacturers of ultrasonic machinery boast of an increased mechanical and electrical strength with this welding

f) Stringent cleaning may not be required as the welding operation involves dispersement of oxides films on the joining surfaces

g) No cooling medium is required

h) Easy to interface with microprocessor based control systems for efficient quality monitoring

i) Flexible layout of the machinery and compact size of the machinery is more suitable for automation of part presentation systems and other supporting automation

j) Portable welding is possible. It can facilitate onboard assembly of harnesses and avoid lots of material handling costs associated with bench type manufacturing of wire splices

k) Single window operations are possible. That is, multiple operations like encapsulation welding can be performed in one cycle and on one machine

l) Some research also shows the possibility of welding the wires without the insulation being stripped [7]. It easily penetrates through especially the high temperature (NEMA class F and class H) insulations such as polyurethane, polyester, polyimide and polyester poly-amide-imide

Major disadvantages are:

a) Limited to a cross-section of 3 mm^2 of thickness for the plate which is in contact with the sonotrode tip

b) Restricted to lap welds only and can't be used for butt welding

c) Can only be used for flat or minimally curved surfaces

d) Not suitable for joining tinned parts or wires

e) Higher capital costs than other joining technologies

f) High frequency of noise level produced by ultrasonic vibrations especially with high power level equipment, which requires sound reducing barriers or enclosures

Following is a summary chart of the relative comparisons of the three techniques discussed above:

Property for comparison	Crimping	Resistance Welding	Ultrasonic Welding
Control over process	L	M	H
Interfacing with advanced microprocessor based quality monitoring systems	L	M	H
Size of the machinery	H	H	L
Green process	X	X	√
Requirement of consumable	√	√	X
Typical cycle times	L	M	L
Distortion of the joint	H	H	L
Protrusions of the unwanted metal from the joint	H	L	L
Electrical power requirement	H	H	L
Temperature rise of the joint	L	H	M
Life of tools	H	L	M
Tools cleaning	L	H	L
Dissimilar metal joining	√	X	√
Quality monitoring	L	M	H
Safety/health hazards	H	H	L
Requirement of cooling medium	X	√	X
Joint's tensile shear strength	M	M	H
Joint's fatigue strength	M	M	H
Joint's electrical strength	M	M	H
Relative volume of the joint	H	M	L
%compression of the joint	L	M	H
Flexibility of the machinery layout	L	L	H
Portability of the machinery (possibility of hand held on board operation)	L	M	H
Possibility of welding without removing the insulation of the wires	X	X	√
Limitations of the joint cross-sectional area	L	M	H
Restriction on the type of weld	√	X	√
Restriction on the type of surface being joined (curved, linear, etc.,)	X	X	√
Suitability to join tinned parts/wires	√	X	X
Capital costs	L	M	H
Noise pollution	H	M	M
LEGEND: L= Low, M= Medium, H= High; X= Not possible, √= Possible			

Figure 2-1, Relative comparisons of three splicing methods

From the above table it is very obvious that ultrasonic welding is comparatively better than crimping and resistance welding. Though there are certain disadvantages like the limitation on the thickness of the material in contact with the sonotrode, which is at present 3 mm^2, and inability of the material with tinned coating to be welded, otherwise it offers more flexibility especially in terms of process capability, advanced quality monitoring and compactness of the machinery.

It is important at this stage to clearly understand and discuss some fundamental concepts of ultrasonic welding, and certain phenomenological considerations of this relatively new technique. Most of the issues relating to the ultrasonic welding, in general, discussed below are from reviews of literature on ultrasonic welding [3,6,7,8,9,10,11,12,13,14,15,41,42].

2.2 Ultrasonic welding-definition and general description

Ultrasonic welding is a solid-state welding process in which coalescence is produced at the faying surfaces by the local application of high frequency vibratory energy while the workpieces are held together under moderately low static pressure. A sound metallurgical bond is produced without melting of the base metal. There is minor thickness deformation at the weld location [7].

Typical components of an ultrasonic welding system are illustrated in Figure 2-2. The ultrasonic vibration is generated in the transducer. This vibration is transmitted through a coupling system in sonotrode, which is represented by the wedge and teed members. The sonotrode tip is the component that directly contacts one of the workpieces and transmits the vibratory energy into it. The clamping force is applied through at least part of the sonotrode, which in this case is the reed member. The anvil supports the weldment and provides reaction to the clamping force.

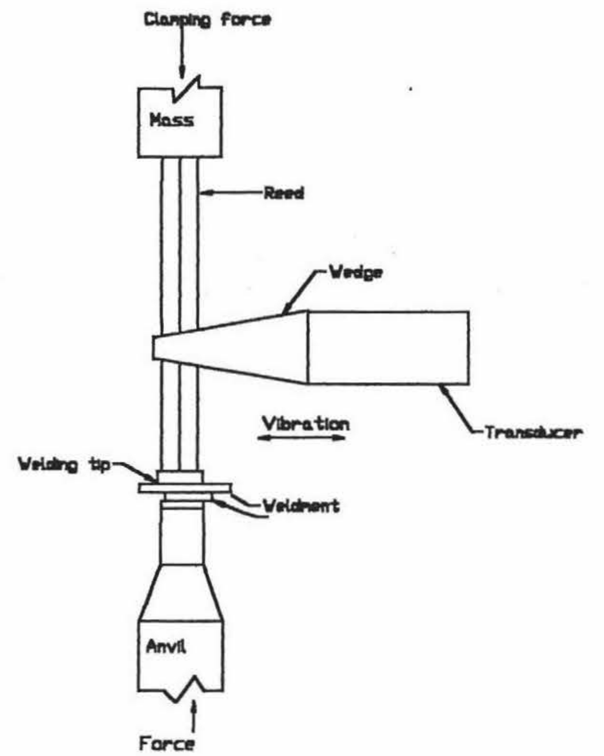


Figure 2-3, Ultrasonic welding system.

Ultrasonic welding is used for applications involving both monometallic and bimetallic joints. The process produces lap joints between metal sheets or foils, joints of wire or ribbon to flat surfaces, cross wire or parallel wire joints, and other types of assemblies that can be supported on an anvil.

2.3 Mechanism of the process

Ultrasonic welding is a solid-state welding process in which coalescence is produced at the faying surfaces by the local application of high frequency vibratory energy while the workpieces are held together under moderately low static pressure. A sound metallurgical bond is produced without melting of the base metal. Ultrasonic welding involves a complex relationship between the static forces, and moderate temperature rise in the weld zone. The magnitudes of these factors required to produce a weld are functions of the thickness, surface condition, and room temperature properties of the work-pieces.

2.3.1 Stress patterns

In all types of ultrasonic welding, static clamping force is applied perpendicular to the interface between the workpieces. The contacting sonotrode tip oscillates approximately parallel to this interface. The combined static and oscillating shear forces cause dynamic internal stresses in the workpieces at the faying surfaces that produce elastoplastic deformation.

Photoelastic stress models [9] reveal significant aspects of these stress patterns. With applied static force only, the stress pattern is symmetrical about the axis of force application. With the superimposition of a lateral force, such as that occurring during one-half cycle of vibration, the force shifts in the direction of this lateral force, and sheet stress is produced on that side of the axis. When the direction of the lateral force is reversed, as in the second half of the vibratory cycle, the shear stress shifts to the opposite side of the axis. During welding, shear stress shifts direction thousands of times per second.

As long as the stresses in the metal are below the elastic limit, the metal deforms only elastically. When the stresses exceed a threshold value, highly localised interfacial slip occurs, with no gross sliding. This action tends to break up and disperse surface films and permits metal-to-metal contact at many points. Continued oscillation breaks down surface asperities so that the contact area is produced. At the same time, atomic diffusion occurs across the interface, and the metal recrystallises to a very fine grain structure having the properties of moderately cold-worked metal [14].

2.4 Temperature developed in weld zone

Ultrasonic welding of metals at room temperature produces a localised temperatures rise from the combined effects of elastic hysteresis, localised interfacial slip, and plastic deformation. However, no melting of the weld zone metal occurs in a monometallic weld made under proper machine settings of clamping force, power, and weld time. Sections examined with both optical and electron microscopy have shown phase transformation, recrystallization, diffusion, and other metallurgical phenomena, but no evidence of melting [10].

Interfacial temperature studies made with very fine thermocouples and rapidly responding recorders show a high initial rise in temperature at the interface followed by a levelling off. The maximum temperature achieved is dependent upon the welding machine settings. Increasing the power causes an increase in the maximum temperature achieved [11].

Increased clamping force increases the initial rate of temperature rise, but lowers the maximum temperature achieved. Thus, it is possible to control the temperature profile, within limits, by appropriate adjustment of machine settings.

The interface temperature rise is also associated with the thermal properties of the metal being welded. Generally, the temperature produced in a metal of low thermal conductivity, such as iron , is higher than that in a metal of high thermal conductivity, such as aluminium or copper.

Temperature measurements during welding of metals having a wide range of melting temperatures show that the maximum temperature in the weld is in the range of 35 to 50 percent of the absolute melting temperature of the metal when suitable welding machine settings are used [3].

2.5 Energy delivered to the weld zone

The flow of energy through an ultrasonic welding system begins with the introduction of 60Hz electrical power into a frequency converter. This device converts the frequency to that required for the welding system, which is usually in the range of from 10 to 75 kHz. The high-frequency electrical energy is conducted to one or more transducers in the welding system, where it is converted to mechanical vibratory energy of the same frequency. The vibratory energy is transmitted through the sonotrode and sonotrode tip into the workpiece. Some of the energy passes through the weld and dissipates in the anvil support structure.

Power losses occur throughout the system in the frequency converter, transducer, sonotrode, and the interfaces between these components. However, with a well-designed system, as much as 80 to 90 percent of the input power to the converter may be delivered into the weld zone.

For practical usage, the power required for welding is usually measured in terms of the high-frequency electrical power delivered to the transducer. This power can be monitored continuously and provides a reliable average value to associate with equipment performance as well as with weld quality. The product of the power in watts and welding time in seconds is the energy, in joules or watt-seconds, utilised in welding.

2.6 Power requirements and weldability

The energy required to make an ultrasonic weld can be related to the hardness of the workpieces and the thickness of the part in contact with the sonotrode tip. Analysis of the data covering a wide range of materials and thicknesses has led to the following empirical relationship [3], which is accurate to a first approximation:

$$E=K(HT)^{3/2}$$

Where: E = electrical energy, j(W.s)
K = a constant for a given welding system
H = Vickers hardness number
T = thickness of the sheet in contact with the sonotrode tip

The constant K is a complex function that appears to involve primarily the electromechanical conversion efficiency of the transducer, the impedance match into the weld, and other characteristics of the welding system. Different types of transducer systems should have substantially different K values.

2.6.1 Weldability of copper alloys

Copper and its alloys, such as brass and gilding metal, are relatively easy to weld. High thermal conductivity does not appear to be a deterrent factor in ultrasonic welding as it is in the fusion welding processes [13].

2.7 Limitations

2.7.1 Thickness

There is an upper limit to the thickness of any metal that can ultrasonically be welded effectively because the power output of available equipment is limited. For a readily weldable metal, such as type 1100 aluminium, the maximum thickness in which reproducible high strength welds can be produced is approximately 0.0254mm; for some of the harder metals, the present upper limit may be in the range of 0.0381mm to 0.1016mm. This limitation applies only to the member of the weldment that is in contact with the welding tip; the other member may be of greater thickness [10].

On the other hand, very thin or small sections can be welded successfully. For example, fine wires of less than 0.00127mm diameter and thin foils of 0.0004318mm thickness have been welded [3].

Where a weld is difficult to achieve with available power levels, good quality joints might be made by inserting a foil of another metal in between the two workpieces. Three examples of this are: (a) 0.0005-in. foil of nickel or platinum has been used between molybdenum components; (b) beryllium foil has been welded to AISI type 310 stainless steel using an interleaf of thin type 1100-H14 aluminium foil; and (c) the weldable range of type 2014-T6 aluminium alloy has been extended by using a foil interleaf of type 1100-O aluminium [3].

For some metals, use of abrasive textured tips and anvils will decrease the required clamping force and the welding power. This may permit welding thicker sections with a particular machine size.

2.7.2 Geometry

Generally, ultrasonic welding can be used to join a metal within the thickness limitations of the process provided that there is ;

(1) Adequate joint overlap
(2) Access for the sonotrode tip to contact the parts
(3) An avenue for anvil support and clamping force application.

2.8 Applications in the wiring harness industry

2.8.1 Electrical connections

Electrical connections of various types are effectively made by ultrasonic welding. Both single and stranded wires can be joined to other wires and to terminals. The joints are frequently made through anodised coatings on aluminium or through certain types of electrical insulation. Other current-carrying devices, such as electric motors, field coils, harnesses, transformers, and capacitors, may be assembled with ultrasonically welded connections. A typical example is the field coil assembly for automotive starter motors. Ultrasonic welds are used here for joining aluminium ribbon to itself, to copper ribbon, to consolidated stranded copper wire, and to copper terminals.

2.8.2 Encapsulation

Ultrasonic welding is used to encapsulate wire joints. There are many publications which talk about the application of ultrasonic welding to encapsulate bottles, seals, electrical connections, and lots of other containers using plastic encapsulation material similar to PVC tapes [12] etc. It is not clear though at this stage wether it is possible to use the same machine and tooling as the one used for welding the material.

2.9 Process variables

The variables of ultrasonic power, clamping force, and welding time or speed are established experimentally for a specific application. Once determined, they usually require no adjustment unless there are alterations to the equipment, such as sonotrode tip changes or changes in the workpiece.

2.9.1 Ultrasonic power

The power setting may be indicated in terms of the high-frequency power input to the transducer or the load power (the power dissipated by the transducer-sonotrode-workpiece assembly). As previously noted, the power requirement varies with the material and thickness of the workpiece adjacent to the sonotrode tip.

The minimum effective power for a given application can be established by a series of tests from which a threshold curve for welding is plotted.

2.9.2 Clamping force

An ultrasonic welding machine usually provides a fairly broad range of clamping forces. The clamping force range of machines with hydraulic or pneumatic force systems can be modified by changing the pressure cylinder.

The function of clamping force is to hold the workpieces intimately together. Excessive force produces needless surface deformation and increase the required welding power. Insufficient force permits tip slippage that may cause surface damage, excessive heating, or poor welds. Clamping force for a specific application is established in conjunction with ultrasonic power requirements.

2.9.3 Welding time or speed

The interval during which ultrasonic energy is transmitted to the workpiece in spot, ring, or line welding is usually within the range of 0.005 second for very fine wires to about one second for heavier/larger sections. The need for a long welding time indicates insufficient power. High power and a short welding time will usually produce welds that are superior to those achieved with low power and a long welding time. Excessive welding time causes poor surface appearance, internal heating, and internal cracks.

The same factors of power and unit time are significant in continuous seam welding. With available equipment, the travel speed for hard, thick metals may be as low as 17.5 m/min. Thin aluminium, 0.0254 mm. thick, can be welded at speeds up to about 1750m/min.

2.9.4 Frequency adjustments

Adjustment of the frequency converter output to match the operating frequency of the welding system is necessary for good performance. A system has given nominal frequency, but the best operating frequency may vary with changes in the sonotrode tip, the workpiece, or the clamping force. The method of frequency adjustment varies with different types of frequency converters. After the setting is established for a specific welding set-up, usually no further adjustment is necessary.

2.9.5 Interaction of welding variables

For a given application, there is an optimum clamping force at which minimum vibratory energy is required to produce acceptable welds [9]. This condition can be established by plotting the threshold curve.

The technique consists of making welds at selected power and clamping force settings and conducting cursory evaluation of weld quality. For ductile, thin sheets and fine wires, a useful criterion of successful bonding is the ability to pull a nugget from one of the workpieces when peel tested. Welds in hard or brittle metals may be evaluated on the basis of weld strength or evidence of material transfer when peel tested. The threshold curve is normally derived as follows:

(1) The welding time is set at a reasonable value. One-half second is a good starting point for most metals. For very thin metals, a shorter weld time is usually used.

(2) Welding is started at low values of clamping force and power, and a series of test welds is made with incrementally increasing values of clamping force at a fixed power level. The welds are evaluated and the results plotted, indicating acceptable and unacceptable welds

(3) This procedure is then repeated at other values of ultrasonic power until an inverted bell-shaped curve is obtained.

This data will generate a curve separating the acceptable from the unacceptable welds. Welding is ordinarily done using the clamping force value for minimum acceptable power and a power level somewhat above the minimum. The product of the selected power and weld time is the total energy required. If welding time is decreased, then power must be increased accordingly. The threshold curve is a practical and efficient method for determining proper machine settings for all types of ultrasonic welds.

2.10 Advantages and disadvantages

Ultrasonic welding has advantages over resistance welding in that no heat is applied during joining and no melting of the metal occurs. Consequently, no cast nugget or brittle intermetalics are formed. There is no tendency to arc or expel molten metal from the joint as with resistance spot welding.

The process permits welding thin to thick sections as well as joining of a wide variety of dissimilar metals. Welds can be made through thin types of surface coatings and plating.

Ultrasonic welding of aluminium, copper, and other high thermal conductivity metals requires substantially less energy than does resistance welding.

The pressures used in ultrasonic welding are much lower, welding times are shorter, and thickness deformation is significantly lower than for cold welding.

A major disadvantage is that the thickness of the component adjacent to the sonotrode tip must not exceed relatively thin gauges because of the power limitations of ultrasonic welding equipment. The range of thickness of a particular metal that can be welded depends upon the properties of that metal.

In addition, the process is limited to lap joints. Butt welds can't be made because there is no effective means of supporting the workpieces and applying clamping force.

Conclusions

It is clear from the early part of the discussion that, ultrasonic welding has relatively higher tensile-shear strengths than resistance welding, epecially the smaller cross-sections of copper welds. A review of the literature on various fundamental issues of ultrasonic welding followed the discussion in the later part of the chapter. Whereas points like the strength of the joints made with ultrasonic welding and process capabilities of ultrasonic welding need to be determined practically, the other common issues relating to the process like the temperatures developed, weldability of the metals etc., have been compared using the research literature already available.

The next chapters discuss the quantification of electrical and mechanical strengths of crimped joints and this will be followed by those of ultrasonically welded joints.

Chapter - 3

3. BENCHMARKING THE CRIMPING TECHNOLOGY

Introduction

This chapter discusses in detail the benchmarking of the crimping technology which is being widely used by the industry currently to manufacture wire splices. It is necessary to have a clear understanding of the current practice to make it comparable with any other alternative. The aim of this chapter is to establish certain tangible strengths and weaknesses of the crimped wire splices.

After discussing the various design considerations, samples have been tested to quantify certain mechanical and electrical properties. Samples have been prepared at Alcatel New Zealand Limited.

3.1 Design considerations

The two elements forming the joint are the ferule and the wires. They are designed to give maximum strength to the joint. The strength has to be quantified to compare with other techniques of making the joint.

3.1.1 The joint

It is made by pressing a ferule[1] over the lap of wire strands which are made to overlap. It is as depicted in the following Figure:

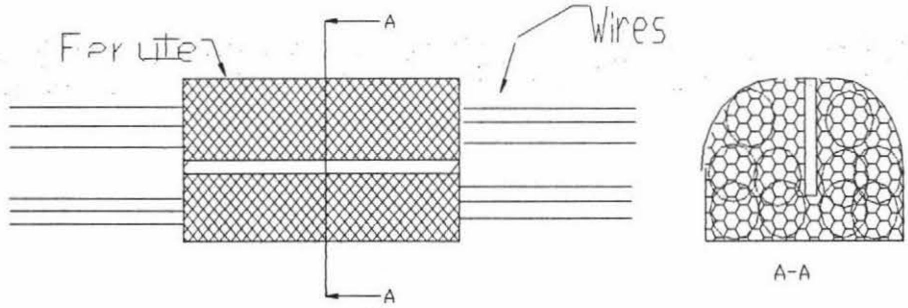


Figure 3-1, Wires, Ferule and their construction

[1] A brass clamp which is pressed over the material to form a joint

3.1.2 Ferules

According to the standards deyeloped by various manufacturers [48] of these ferules, the following are the major considerations for the design of the ferules

- Dimensions of the ferule (height, length and width)
- Specifications of wires for a specific ferule size (c/s area of wires, number of strands and c/s area of each of the wire strands)
- Material of the ferule (brass, coated brass with Nickel etc.,)

3.1.3 Wires

Following are the major design considerations for the wire, forming the splices

- Cross-sectional area of the wire(general specifications of wire)
- Number of wire strands
- Cross-sectional area of each of the wire strands
- Type of insulation

3.2 Strength of the joints

The joints are subjected to different types of mechanical, electrical and chemical loads. The joints are designed to withstand all these loads and have maximum life span with highest possible reliability. The most common mechanical failures of the joints will be as a direct result of static, dynamic or a combination of these two types of loads. One indicator to measure the static mechanical strength of the joints is the tensile strength[3], similarly the cyclic loading or dynamic loading is measured by the fatigue strength of the joint[9]. The resistance offered by the joint to the flow of current is a major indicator to quantify the electrical strength of the joint[12]. Joints of poor quality offer more resistance and may eventually result in burning of the joint as a result of heavy amount of electrical current and temperatures passing through the joint with high resistance. The resistance of the joint also varies with respect to time, soon after the production the resistance offered is different from that of the joint resistance which is measured after several days. The experiments described below were carried out on the latter conditions, i.e. all the joints were tested for their resistance after 60 days of their date of production. Corrosion formation on the joints though very crucial, enough care is taken by the manufacturers to encapsulate the joint and every precaution is taken in designing the wiring harness layout to avoid direct exposure of the internal joints to the outside atmosphere. It has not been studied in this thesis. The following is the discussion on the design considerations of the joint and the various experiments to determine the strength of the joints.

3.2.1 Mechanical aspects

3.2.1.1 Types of loads the joint is subjected to

Following is a list of the common types of mechanical loads that are envisaged to come on the splice joint either during manufacturing, assembly or during the harness life in the automobile.

1. Simple tensile force (pull along the long axis). Please refer to Figure 3-2

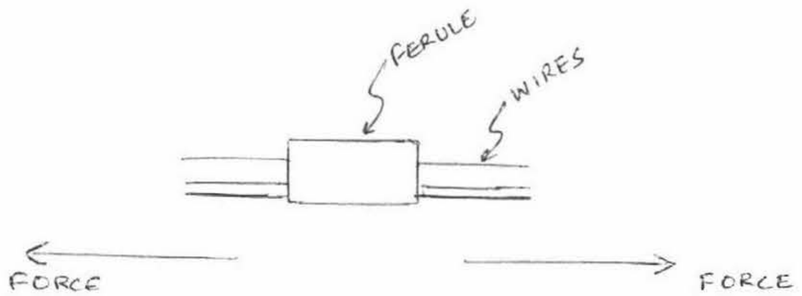


Figure 3-2, Simple tensile force on the joints

2. Torsional force - twist around the longitudinal axis- Refer to the Figure3-3

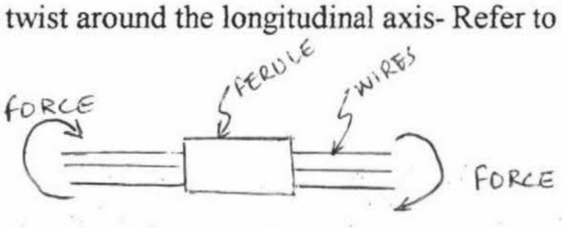


Figure 3-3, Torsional force that is exerted on the wire strands

3. Combination of tension and torsion

4. Fatigue (cyclic loading- torsional, bending, tensile)

3.2.1.2 Modes of failure of the ferruled joints

The joints after being subjected to any of the above types of mechanical load, may result in one of the following types of failures.

1. Complete pull out of the wire strands from the ferule, see Figure 5-7

2. Fracture of the wire strands at the neck of the joint, see Figure 5-9

3. Fracture of the wire strands away from the neck of the joint, see Figure 5-6

3.2.2 Electrical aspects

Wiring harnesses are made for either 6v or 12v [15] supply. The splices need to transmit electricity reliably without failing. Low voltage signal transmission is very important, because of increasing use of microprocessor based controls and more and more on board sensors in the automobiles. Any small variation in the voltage will result in hazards. It is important to study how the joint is behaving in terms of offering electrical resistance to the flow of current. There is also a possibility of joint burning off, if it is not strong and offering very high resistance.

3.2.2.1 Modes of electrical failure

An enormous amount of resistance could be developed, resulting in eventual burn off-while the joint is under no mechanical load or under mechanical load. It is important to measure the resistance offered by the joint under no mechanical load, to the flow of a standard amount of current, to quantify the electrical strength of the joint and the manufacturing quality.

3.2.3 Chemical aspects

The joint will be subjected to hostile environment prone to rusting and oxidation, if left without being insulated. It is very important to have a perfect insulation properly encapsulating the joint to avoid the oxidation and eventual rusting of the joint.

Failure could result from the rusting in terms of poor electrical conductivity and also reduced mechanical strength. Enough care is taken by the designers and manufacturers not to expose the joint to hostile environments. Chemical strength quantification has not been taken-up in this study for the reasons that, from the literature this type of failure is very rarely reported and the possibility of the chemical failure is very minimum. The limited resources of the project have been concentrated more on the electrical and mechanical studies. This could be taken up as an extension to the project.

3.3 Experimental design

It is apparent from the design considerations discussed above that, the crimp height does effect the properties of the joint. Tensile strength and electrical resistance change as the crimp height is changed. Varying the crimp height and studying the mechanical and electrical properties is one aspect of experimentation. It gives an idea of optimising the crimp properties by varying the process control parameters. The other important consideration in the design of experiments is the classification of the splices (i.e. the product or rather specification of the joint) by the cross mil area of the joints. Alcatel has a wide range of production, but the whole range could be simplified by considering the crossmil of the joint. Wires starting from 0.2 mm^2 to a max. of 5 mm^2 form in different combinations to make a variety of splices. Nevertheless, the joint area ranges from 1.5 mm^2 to 24 or even 32 mm^2. So, the most prominent joints, coming in some regular cross-sectional specification (refer Annexure-1) have been considered for experimentation. Another part of the experimentation was to quantify the mechanical and electrical strengths of the joints by varying the cross-section area of the joint, covering a broad range of the wire joints production of Alcatel.

A total of 25 groups of samples have been prepared. Annexure-2, gives the complete graphical and dimensional description of the different groups of samples. The selected samples cover a broad range of crossmil area of the splices produced regularly by the automobile wiring harness industry. There are 25 groups of samples, each group of samples consisting of five samples. Group 1 to group 18 have different cross sectional areas of their respective joints. Groups 19 to 25 have same cross sectional areas in each of the groups, but the crimp height changes from lowest possible height to highest possible height in each group.

			Property to be studied	
	Constant	**Varied**	**Electrical Resistance**	**Tensile Strength**
Crimp Height	√	X	√	√
Cross-Sectional Area	X	√	√	√
Number of types of experiments			**2**	**2**
Total no. of types of experiments = 4				

Table 3-1, Table showing the design of experiments

From the above design table it is evident that 4 classes of experiments need to be conducted. Each group needs to be tested for two major factors, which makes a total of 50 experiments.

3.3.1 Sample preparation for testing

Figure 3-4, illustrates the standard dimensions developed for samples. The following were the considerations in deciding the sample dimensions.

3.3.1.1 Length of wire strands:

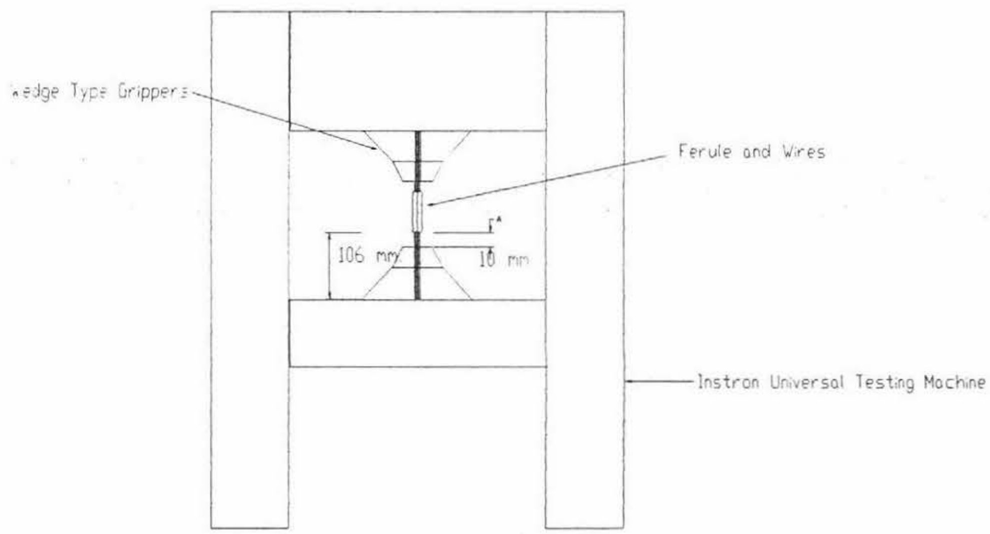


Figure 3-4, Standard dimensions developed for the samples, shown fixed for pull testing on the tensile testing machine (not to scale)

The length of the wire strands falling on either sides of the joint has been decided based on the consideration that more the length, the more the elongation of the wires getting reflected on the plot between elongation and load applied. So to minimise that unnecessary elongation and to exactly identify the amount of elongation that occurs within the ferule, the length has been fixed at 106mm on either sides of the ferule, this is against a length of 96mm of the wedge type grippers on the Instron 1195 Universal testing machine. This allows only 10mm to be out of the grips, shown as distance A in the Figure 3-4.

3.3.1.2 Amount of insulation sheath to be stripped off on either sides of the wires

5mm of insulation has been removed at the neck of the joint to enable access to the probes for measuring electrical resistance. On the other hand for mechanical testing, the presence of insulation within the grip length poses serious problems, like the slipping of the insulation material inside the grip, where the load recorded will not reflect the tensile behaviour of the joint. Hence, for tensile testing it was decided to remove the insulation sheath over the full length of the wires. A doubt may come as to the change in the tensile properties of the joint, when the insulation over the full length of the wires has been removed. Dummy experiments were run to study these kind of effects before the start of the actual tests. Many other interesting points were also studied during these dummy runs, such as the effect of single wire being pulled, to that of multiple wire pulling to study the tensile strength of the joint. These are summarised in the following section

3.3.2 Findings from the trial experiments

1) The change in tensile strength is negligible, over 10mm of wire/ferule/joint length with insulation removed compared to that of wires with insulation.

2) The second observation, probably the most important in terms of establishing a way of conducting experiment was that, the minimum load at which the joint fails, i.e., in other words the first failure if all the wires forming the joint get equally distributed nominal load, is less than the failure load that occurred when the wires were individually pulled. Both single strand pulling and multiple strands pulling were studied. It is found that any IJ, if pulled with load being exerted simultaneously on all the wire strands, would break at a lower load than, if pulled with load being exerted on a single strand. This could be for the reason that, there are more internal stresses trying to open up the ferrule in the case of multiple fixing than in single fixing. Another reason could be that, resultant forces are more in case of multiple fixing than in single fixing, causing wires to break at lower loads, because the resultant load is higher.

3.3.2.1 Gripping

Different options were studied and the dummy samples were run on many of the possible options, available at the Massey University Production Technology Laboratories. The basic criterion for the selection of the gripper was to see that load is evenly distributed on all the wire strands. Two major options were for consideration:

1. When all the wire strands coming on either sides of the joint are of equal cross section.

Wedge type grippers having knurled surface inside for gripping the wire strands were to be used. This is a standard gripper for the Instron universal testing machine. Dummy samples have been run on this gripper. The knurled impressions on the insulation were visually inspected and it was found that no slippage occurs between the gripper surface and the wire surface.

2. When the wire strands are of unequal cross sections.

When the wire strands have unequal cross sectional areas, the ends were trimmed-off the insulation and the copper strands were all clubbed and dip soldered together. Then using the same gripper as above, results were obtained satisfactorily. This has been observed to be satisifying for all the cross sectional (c/s) areas .The limitation for this gripper is that the maximum thickness it can take is 30 mm c/s area.

Soldering the ends of the wires enables the distribution of load equally, however care should be taken not to introduce any hardness into the material copper strands by excessive heating and cooling of the copper while soldering. This has been achieved by dip soldering, which achieves the soldering very effectively, without the wires being heated.

3.4 Study of mechanical properties

3.4.1 Objectives of the experiments

The objective of this experiment is to quantify the mechanical strengths of the joint, when the joint is subjected to different types of loads, as discussed in the above sections. Though the fatigue and torsional loads look important, they seldom come on the joints in real life application. Also, looking at the time priorities of the project, only the failures of the joint under tensile loads were considered.

3.4.2 Theory of the experiments

Quantifying the strength of the joint, could be made in any of the following ways:

1. Total force applied

This is a very straightforward quantification of the total load applied on the joint at the time of failure. This is measured in Newtons.

2. Normal stress applied across the total cross-section of the wires in the joint.

This is measured by the formula given below;

If c/s area **A = (Πd²/4) x no. of strands,**
where:

d = Diameter of each strand,

then stress can be obtained by

Where:

P= Load applied on the joint

3. Shear stress applied along the crimped section

When a load is exerted (pull) on either sides of the joint, there is a corresponding shearing action, which causes a shear on the joint cross-section. This is measured by the formula;

where:

P = load applied on the joint

a = compressed area across the cross section of the joint

4. Strain energy dissipated over the failure of the joint

If the amount of compression is measured then the strain energy (SE) can be measured by the following formula

Where:

σ = stress in N/mm^2
ε = strain

3.4.3 Apparatus used in the experiment

Instron 1195 universal testing machine was used for all the tensile strength tests for this project. The machine is capable of running at various pre set strain rates. Results can be plotted on a graph paper as variation of load to the strain.

3.4.3.1 Machine settings

Instron 1195 machine had to be set as per various requirements of the standards of the experiments. The machine settings are described in Annexure-3.

3.4.4 Standards used in the experiment

The experiments have been conducted in accordance with ASTM standard [Annexure-4] & Alcatel in house standard [Annexure-5] for crimped end connector examination.

3.4.5 Test procedure adopted

Referring to the available internal standards of Alcatel and to the standards of ASTM as stated above, following test procedure was adopted:

1. Prepare specimens of proper type, as described in annexure -6

2. Fix up proper machine settings as detailed in the annexure -3

3. Grip the specimen in the standard grippers, ensuring always that there is not too much of pre load being exerted on the joint and also to ensure that there is equal distribution of load on all the wire strands.

4. Apply load at the desired speed

5. Record the load Vs elongation plot on the plotter recorder

6. For each failure record the visual observations

7. Analyse the experimental results

3.4.6 Experimental results

The results on the failure loads of crimped connections are recorded in Annexure-7.

3.5 Study of electrical properties

3.5.1 Objectives of the experiments

The objective of the experiments conducted in this section is to quantify the resistance offered by the crimped joint to the flow of a standard amount of current. This reflects the electrical behaviour and quality of the joint. It also reflects the process capability by studying the variation of resistance within a particular cross sectional group of samples.

3.5.2 Theory of the experiments

To measure the resistance offered by the joint to the flow of current, a standard amount of current is passed through the joint, by measuring the voltage drop across the joint, by Ohms' law, the resistance is measured as;

Resistance = Voltage drop/current

3.5.3 Apparatus used in the experiment

A 6 Amps standard power supply, a Fluke digital multimeter with 10 micro ohms accuracy and set of specially made probes, which were made of brass and flat at the ends, were used.

3.5.4 Standards used

In house standard of Alcatel [annexure-8] was used in developing the experimental procedure and in selecting the apparatus for the experiment.

3.5.5 Procedure used

A standard amount of current of 1 Amp/sq.mm was sent through different combinations of two wire sets and the voltage drop across the joint, by placing the probes exactly before the neck of the joint (1mm), was measured. Then by Ohm's law the resistance was calculated. All the possible combinations of wires were checked individually in a similar way. Where there was a variation in the cross-sectional area of the wires, the largest of the combination was considered for designing the amount of current to be passed.

3.5.5.1 Repeatability of the experimental conditions

The experimental conditions such as room temperature (±14 °C), length and type of probes used (same probes have been used throughout the experiments), placement of the probes on the wire strands (a standard gauge length of 5mm) have been maintained very consistently, thereby minimising any errors in the results.

3.5.6 Experimental results

The results on the electrical resistance of crimped connections are recorded in Annexure-9.

3.6 Discussion and analysis of results

Two sets of experiments were conducted. One to record the tensile strength of the crimped joints and the other to record the electrical resistance of the joints. Samples were grouped in two different categories, one with 18 groups which basically differ with each other in their cross-sectional area of the joint. The other 7 groups of samples, each have a specific cross sectional area of the joint, but the crimp height is changed for each of the samples. Experiments were conducted on these two categories of samples. So, in all four sets of results were obtained.

Prior to conducting the experiments , certain factors such as the machine settings, type of gripping, wether the samples' ends should be soldered or not were to be decided. These factors which were not clearly stated in any of the standards, are crucial to the validity of the results obtained. Trial experiments were conducted and all these factors were decided before going in for the final experiments.

3.6.1 Tensile strength as a variation of joint cross-sectional area

As described in the earlier discussions in previous and current chapters, joint cross-sectional area is a measure of identifying and distinguishing the product at Alcatel New Zealand Limited, at the same time the joint cross-sectional area is a function of the tensile strength and electrical ressistance. The Figure 3.5, is a graphical representation of the variation of failure loads of the different groups of samples. It can be noted from the graph that the cross-sectional(c/s) area which is increasing from 1.5mm^2 to 17mm^2, has effect on the variation of the failure load. The failure load if plotted as a specific failure load ie., failure load/mm^2, the graph would be as shown in Figure 3-6.

It is evident from the Figure 3-6, that the failure load /mm^2, is higher for joints with low c/s area than for those of higher c/s areas. This anomaly is usually controlled by soldering of the joints, to make the tensile strength to coincide with minimum threshold value, which would be the level reached by the lower c/s groups in Figure 3.8

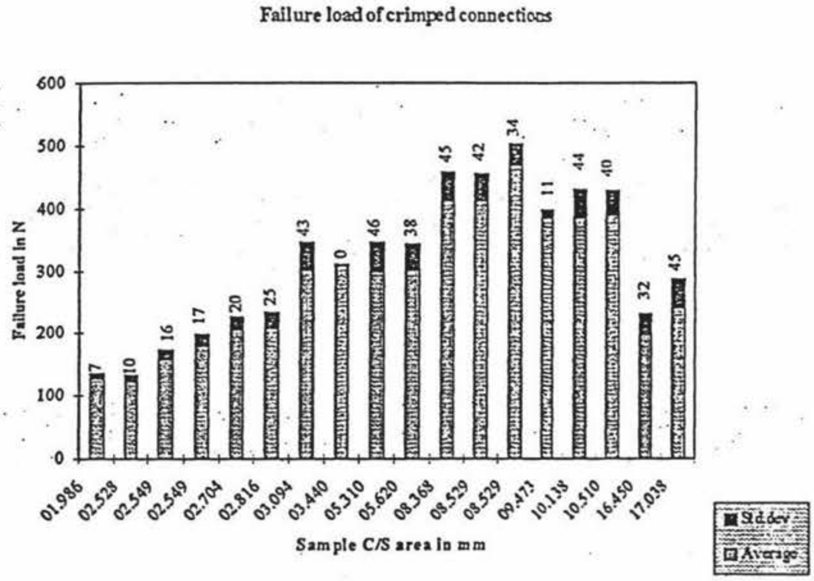


Figure 3-5, Variation of failure loads as the cross-sectional area of the joint changes

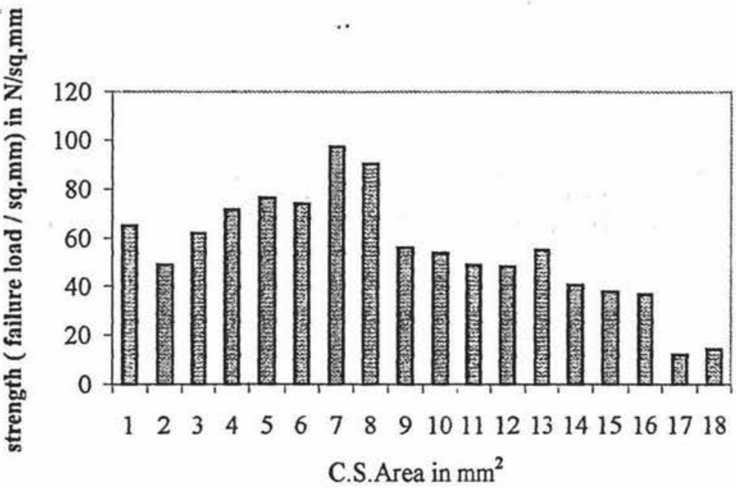


Figure 3-6, Variation of the tensile strength of crimped connections

Experiments have been conducted on joint cross-section ranging from 1.9 sq.mm to 20 sq.mm. Figure 3-7, has been plotted with trendlines to estimate approximate values of failure loads for joints above this range up to 32 mm^2. The equation which satisifes this trend is as following;

$$y = 0.0022x^4 - 0.0704x^3 - 1.1427x^2 + 46.534x + 38.474$$

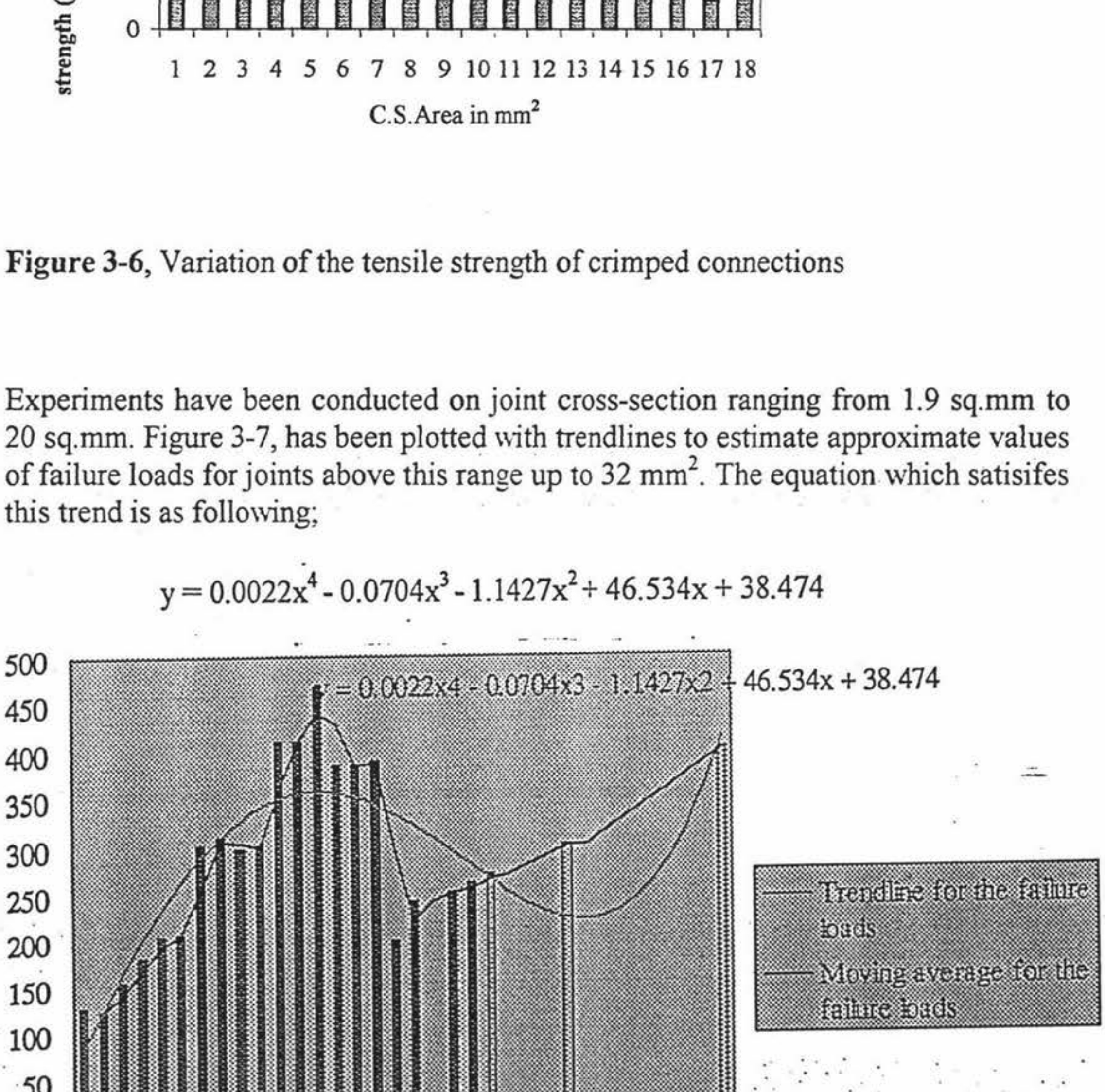


Figure 3-7, Failure loads of the crimped connections, with trendlines to estimate the tensile strength of joints above 20mm^2

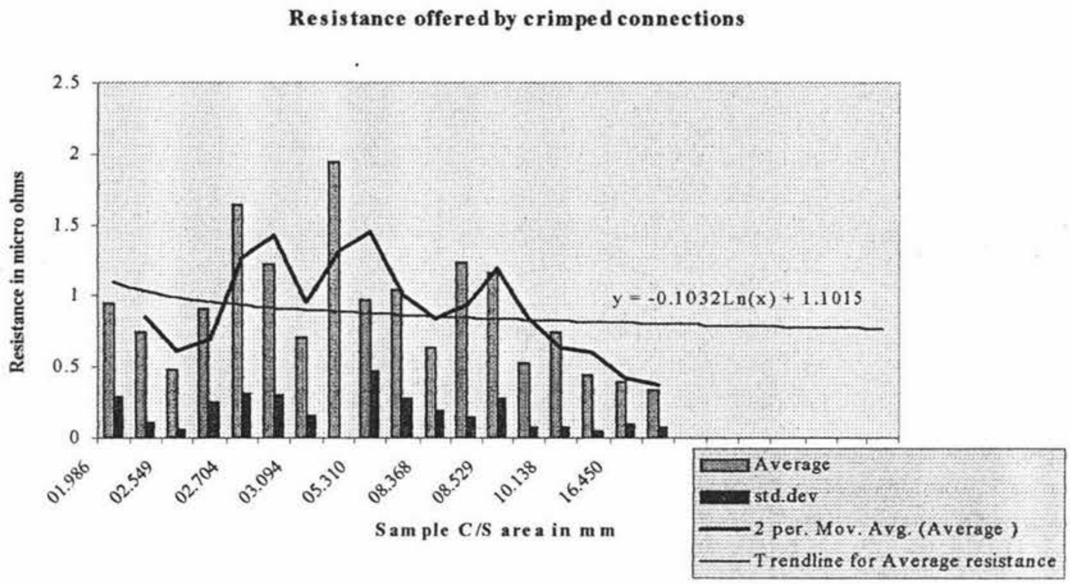


Figure 3-8, Variation of electrical resistance with changing cross-sectional area of the joint. Trendlines are shown to forecast the resistances above 20 mm^2

3.6.2 Electrical resistance as a variation of joint cross-sectional area

Figure 3-8 shows the variation of electrical resistance as a cross-sectional area of the splices is varied between 1.5 mm^2 to 17 mm^2. The resistance offered is more for lower cross-sectional joints than for higher ones. The resistance offered is also dependent on how the wires get distributed inside the ferule. The standard deviation reflects the process variation and the fact that the wires get distributed internally in different ways. This phenomenon is out of the operator's control. This shows the process control problems of the crimp method.

The trend line for average resistance which has a mathematical relation of ;

$$y = -0.1032\text{Ln}(x) + 1.1015$$

could be used very satisfactorily for extrapolating the resistance being offered by the joints over the 17mm^2 region.

3.6.3 Tensile strength and electrical resistance when the crimp height is varied

The next set of results are those from sample groups whose crimp height is varied and the tensile strength and electrical resistance are observed. Following are series of graphs which reflect the results recorded for sample groups 19 to 25.

Refer to Annexure-2 for a description of the samples in the groups from 19 to 25. The most common trend of the graphs is the two opposite shapes of the graphs. As the crimp height is varied from the lowest possible to the highest possible, the tensile strength initially increases and then decreases, whereas the electrical resistance initially decreases and then increases. There lies a range, over which the two properties show optimum values. This can be identified further as the optimum crimp height.

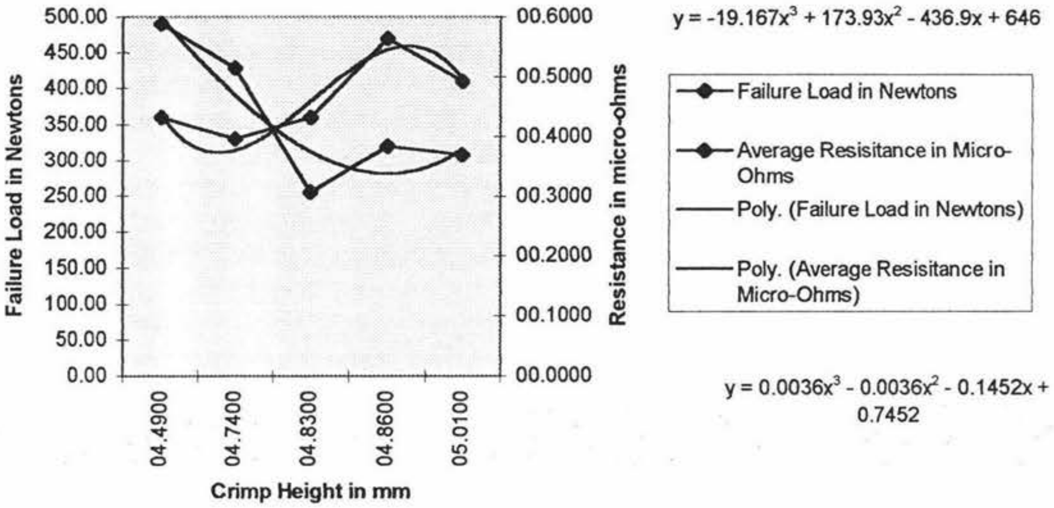


Figure 3-9, Variation of electrical resistance and failure loads with changing crimp height, for sample group G19

The graph shown in Figure 3-9 is a representation of the variation of electrical resistance and tensile strength as the crimp height is varied, for the sample group G19. The optimum values of the two performance indicators, tensile strength and electrical resistance, could be between a crimp height of 4.83mm to 4.86mm. Trend lines have been drawn to show how the variation of these parameters is over the measured crimp heights. The two mathematical relations shown in the graph above could be satisfactorily used to describe the trend of the two graphical relations.

The following graphs are similar to the above, for other sample groups of G20 to G25.

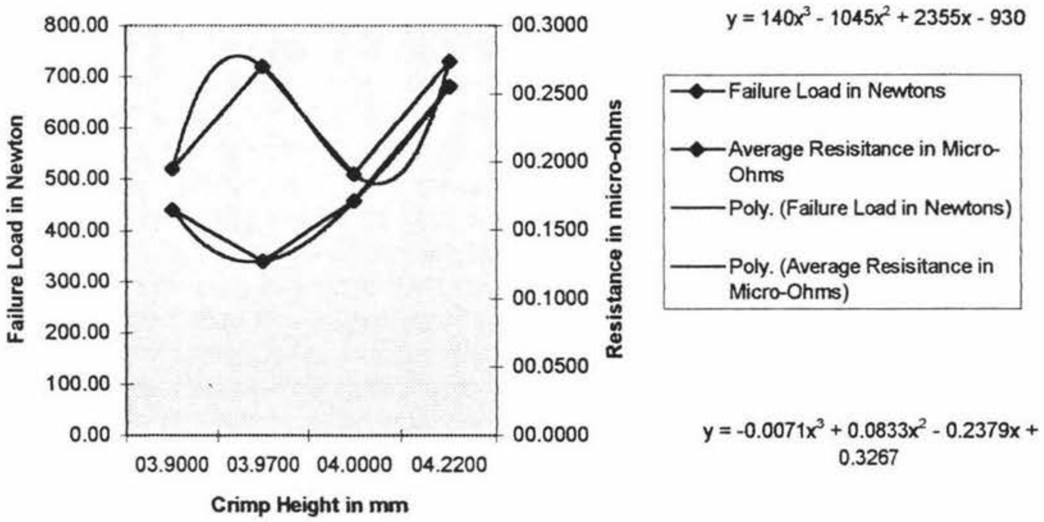


Figure 3-10, Variation of electrical resistance and failure loads with changing crimp height, for sample group G20

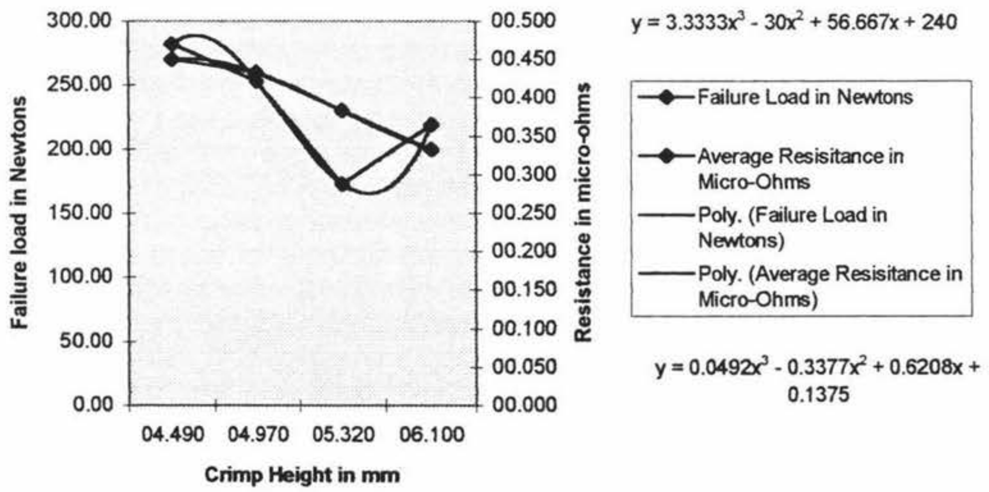


Figure 3-11, Variation of electrical resistance and failure loads with changing crimp height, for sample group G21

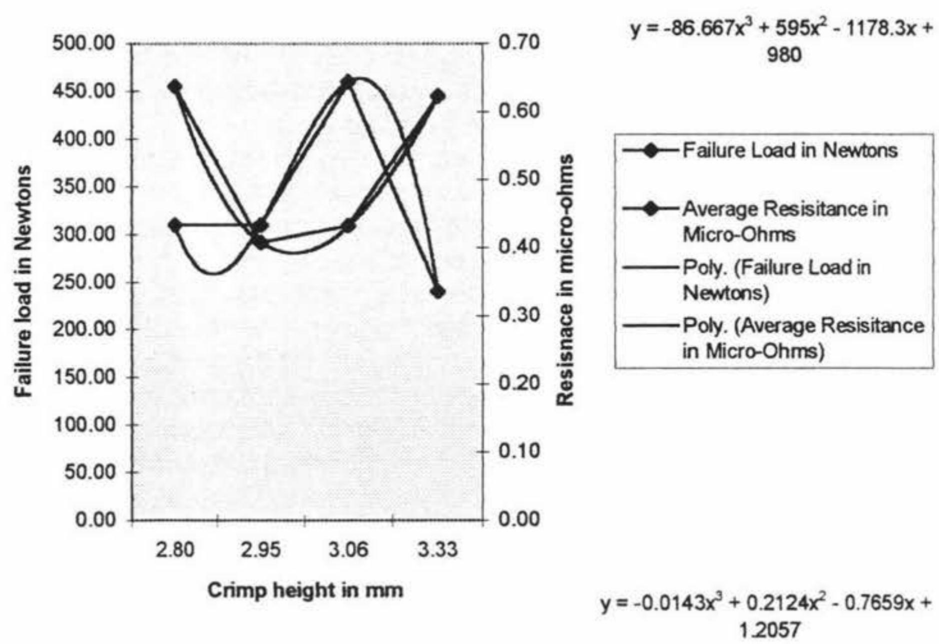


Figure 3-12, Variation of electrical resistance and failure loads with changing crimp height, for sample group G22

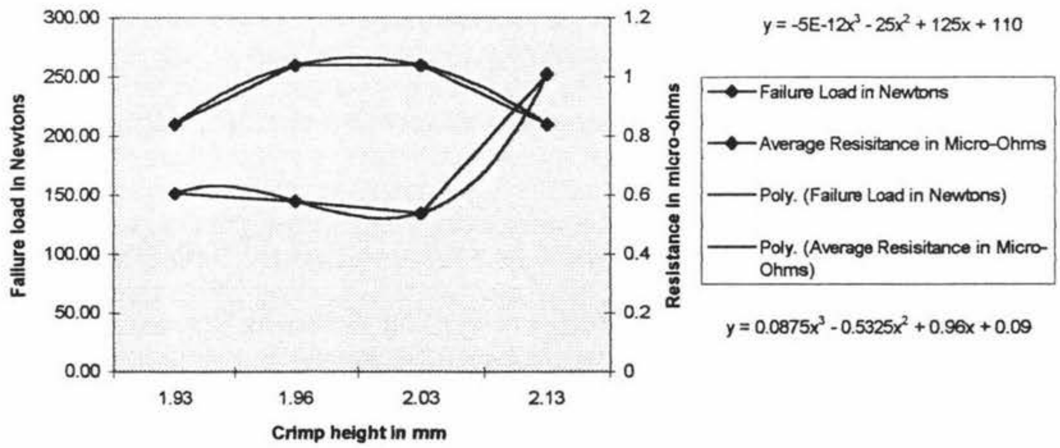


Figure 3-13, Variation of electrical resistance and failure loads with changing crimp height, for sample group G23

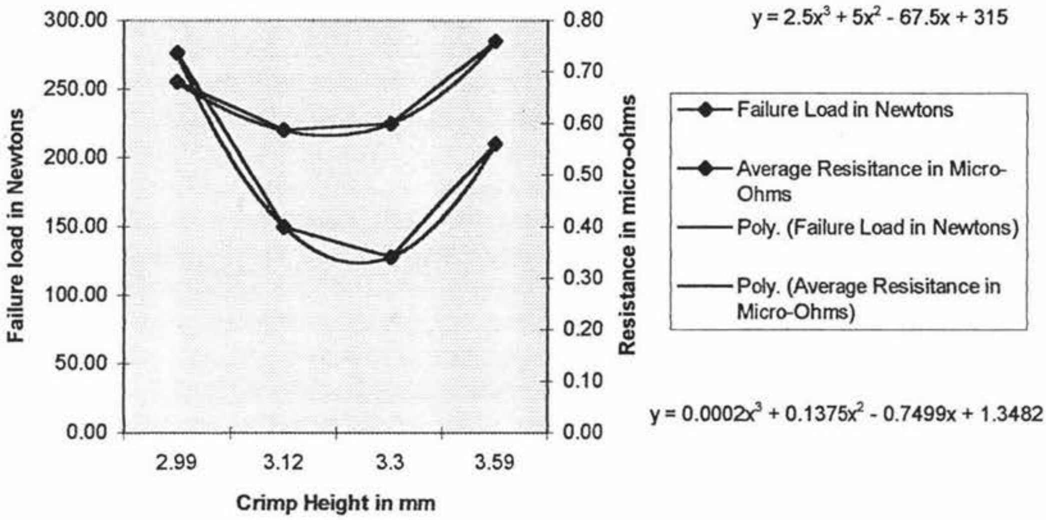


Figure 3-14, Variation of electrical resistance and failure loads with changing crimp height, for sample group G24

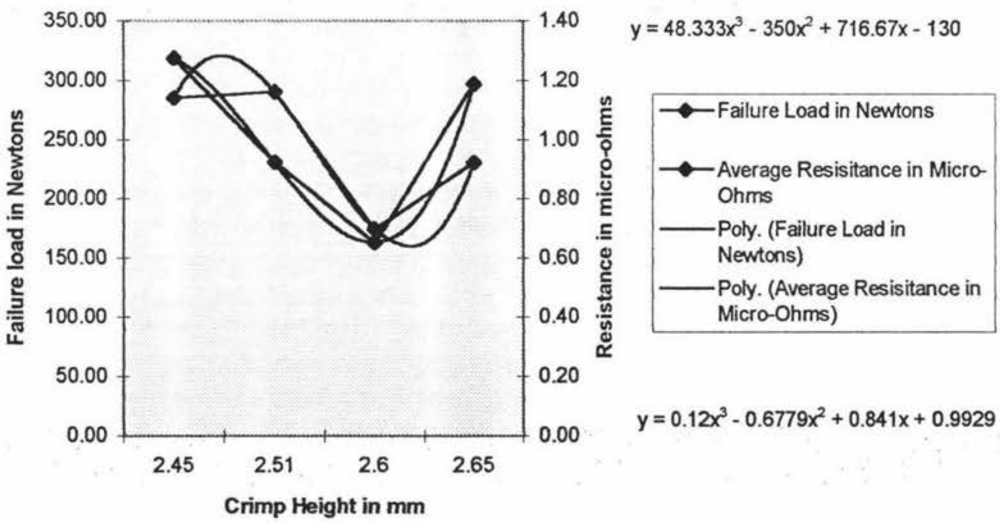


Figure 3-15, Variation of electrical resistance and failure loads with changing crimp height, for sample group G25

G20 to G25 are wire splices with a different individual c/s areas. The c/s areas of these sample gropus have been selected on the feed back of Alcatel. These joints are some of the widely produced range.

The graphs most commonly have a similar trend to that described for G19 above. These sample groups prove the point that the extreme lowering or extreme increase of the crimp height is not favourable. Optimum electrical and mechanical strengths are obtained for those with a crimp height which is inbetween the lowest and the highest. These individual plots can be utilised to find the optimum crimp height for a specifc cross-section of the joint in an individual group of sample.

Conclusions

The results indicate that, when the crimp height is varied, ie., increased between certain limits:

1. The tensile strength initially increases and then decreases (parabolic curve)
2. The resistance initially decreases and then increases (inverted parabolic curve)

This helps the process designer whether the current crimp height settings are matching with these experimental results or not.

When the crimp height is fixed and the cross sectional area of the joint is varied (ie., increased)

1. The tensile strength initially increases and then decreases, of course the higher cross sectional joints are usually soldered which increases the tensile strength by a small amount.

The standard deviation within the sample groups especially the higher cross sectional groups is moderately high reflecting the variation in the process and thus the lesser control over process variation .

2. The electrical resistance initially increases ie., for lower cross sectional joints it is low and high for higher cross sectional joints.

The base for comparison is made ready and the next task is to find the properties of the ultrasonically welded joints and then to compare them with those found in this chapter.

The next chapter discusses the ultrasonic connections and what are the mechanical and electrical strengths of the joints.

Chapter - 4

4. ULTRASONIC WELDING OF COPPER WIRE SPLICES

Introduction

This chapter discusses the fundamental aspects of ultrasonic welding and wire splicing using ultrasonic welding. Then a technical evaluation of the ultrasonic wire splicing is made by quantifying the electrical resistance offered by the joints and the tensile strength of the joints under shear-tension. Then, finally a comparison is made with the crimped splice properties to draw some tangible conclusions.

4.1 Ultrasonic welding

Ultrasonic Welding occurs by the introduction of oscillating shear forces at the interface between two metals while they are held together under moderate clamping force. The resulting internal stresses cause elastoplastic deformation at the interface.

Highly localised interfacial slip at the interface tends to break-up oxides and surface films, permitting metal to metal contact at many points. Continued oscillations break down the points, the contact area grows and diffusion occurs across the interface producing a structure similar to that of a diffusion weld. Ultrasonic welding produces a localised temperature rise from the combined effects of the elastic hysteresis, interfacial slip, and plastic deformation. The welding process is completed without having fully melted metal at the interface when the force, power, and time are set correctly.

Interface temperature rise is greater for metals with low thermal conductivity, such as steel, than for metals of high conductivity, such as aluminium or copper.

4.2 Technical factors involved in the study

Quality of the ultrasonic welding is measured in different ways. The most popular among them is the peel testing [3]. Peel tests consists of some mechanical arrangement to hold the test specimen and the weld in a fixture and then peeling off one of the components of the joint. The type of pull out of the weld gives an indication of the quality of the weld. The complete pullout of the weld nugget is considered to be the best weld. The other test is shear testing under tension. Both ends of the welds are held in jaws and they are separated at a standard rate of 100mm/minute [Annexure-10].

However, for the current purpose of quantifying the minimum load at which the joint fails, a similar testing as that adopted for crimp joint failure load measuring, was considered. The reason for considering this procedure of pulling all the wires off the joint simultaneously (cross tension) is that it is more reflective of the practical life conditions of the joint in the assembly and in use in automobiles. Also the presence of multiple wire combinations forming the joint posess severe practical problems in carrying out the peel tests effectively.

4.3 Experimental design and study

25 groups of 5 samples each were made , similar in construction to those of crimped wire splice specimens discussed in chapter-3. Each sample group represents a specific cross-sectional area of joint ranging from 1.5 mm^2 to 24 mm^2. This range of cross-section represents a substantial range of production of the industry. A similar construction of sample ensures the purpose of fair comparison between crimped wire splices and ultrasonically welded wire splices.

The main process control parameters are the time of application of ultrasonic energy at the joint, external pressure applied, and finally the frequency of the sonotrode. All the samples have been made for optimum tensile strength and electrical conductivity. Though an in depth study of how the process control parameters influence the weld quality and how to establish the optimum conditions were not made in this study, from the experience of the ultrasonic welding machine manufacturer, the samples have been made at their laboratories for optimum performance conditions.

A total of 25 groups of samples have been prepared. Annexure-2, gives the complete graphical and dimensional description of the different groups of samples which were selected, covering a broad range of cross-sectional area of the splices produced regularly by the automobile wiring harness industry. There are 25 groups of samples, each group of samples consisting of five samples.

Property to be studied		
Variable	**Electrical Resistance**	**Tensile Strength**
Cross-Sectional Area	√	√
Number of types of experiments	**1**	**1**
Total no. of types of experiments = 2		

Table 4-1, Table showing the design of experiments

From the above design table it is evident that 2 classes of experiments need to be conducted. Each group needs to be tested for two major factors, which makes a total of 50 experiments.

Though the fatigue tests seem to be important, the joint is designed in such a way that it is always placed at least 300mm away from any mechanical member or structure of the automobile which is subjected to repeated operations for example doors, seats etc., Research shows that the average fatigue life of ultrasonically welded copper plates of thickness 0.2mm, being more than 10^6cycles [3, 47], it doesn't seem to be a real threat. Ultrasonic welding almost forms a solid connection. The metallographic sections of ultrasonic connections also show the continuum of flow of the material. The amount of temperature raise in the section as discussed in the literature survey is less than 50% of the melting point. This level of temperatures does not induce any substantial amounts of hardness into the copper, causing any decrease in the strength of the copper strands. However, this project didn't consider the evaluation of fatigue strength for certain resource constraints.

4.3.1 Sample preparation for testing

This is similar to the crimped connections as described in chapter-3.

4.4 Study of mechanical properties

From the published literature on ultrasonic welding, especially the American Welding Society's literature on ultrasonic welding [3], a number of mechanical tests may be used to evaluate the weld quality. The property most frequently tested is shear strength. In addition, data is reported on cross-tension strength, micro hardness, corrosion resistance, and hermetic sealing properties. For the wire splicing tension-shear strength properties and electrical conductivity of the splice joints will be of great significance. There is no mention to what the standard tension shear destructive testing procedure should be, in any of the AWS or ASTM standards, however, mention is made that they could be similar to any other similar splice connection tension-shear testing.

4.4.1 Objectives of the experiments

Objectives of the experiments conducted in this section are to quantify the tension shear strength of the Ultrasonically welded wire splices. There is only one set of straightforward testing, varying the cross-sectional area of the joint.

4.4.2 Theory of the experiments

Quantifying the strength of the joint, could be made in any of the ways described in chapter-3

4.4.3 Apparatus used in the experiment

Apparatus used is the same as the one used for crimped connections testing as described in chapter-3. Machine settings and other dynamics are the same as those described in chapter-3.

4.4.3.1 Machine settings

Instron 1195 machine had been set as per various requirements of the standards of the experiments. The machine settings are described in Annexure-3.

4.4.4 Standards used in the experiment

The experiments have been conducted in accordance with ASTM Standard [Annexure-10] on testing ultrasonically welded wire connection pull testing, crimped end terminal pull testing as described in chapter-3 and Alcatel in house standard for crimped end connector examination as described in chapter-3.

4.4.5 Test procedure adopted

Referring to the available internal standards of Alcatel and to the standards of ASTM and other organisations as stated above, following test procedure is adopted.

1. Prepare specimens of proper type, as described in annexure-6

2. Fix up proper machine settings as detailed in the annexure-3

3. Grip the specimen in the standard grippers, ensuring always that there is not too much of pre load coming on the joint and also to ensure that there is equal distribution of load on all the wire strands.

4. Apply load at the desired speed

5. Record the load verses elongation plot on the plotter recorder

6. For each failure record the visual observations

7. Analyse the experimental results

4.4.6 Experimental results

The results which are analysed in the following discussions are recorded in annexure_11.

4.5 Study of electrical properties

4.5.1 Objectives of the experiments

Objective of the experiments conducted in this section are to quantify the resistance offered by the ultrasonically welded joint to the flow of a standard amount of current. This reflects the electrical behaviour and quality of the joint. It also reflects the process capability by studying the variation of resistance within a particular cross sectional group of samples.

4.5.2 Theory of the experiments

To measure the resistance offered by the joint to the flow of current, a standard amount of current is passed through the joint, by measuring the voltage drop across the joint, by Ohm's law, the resistance is measured as;

Resistance = Voltage drop/current

4.5.3 Apparatus used in the experiment

A 6 Amps standard power supply, a fluke digital multimeter with 10^{-6} ohms accuracy and set of specially made probes were used.

4.5.4 Standards used in the experiment

In-house standard of Alcatel [8] was used in developing the experimental procedure and in selecting the apparatus for the experiment.

4.5.5 Procedure used

A standard amount of current of 1 Amp/sq.mm was sent through different combinations of two wire sets and the voltage drop across the joint , by placing the probes exactly before the neck of the joint, was measured. Then by Ohm's law the resistance was calculated. All the possible combinations of joints are checked individually in a similar way. Where there was a variation in the cross-sectional area of the wires, the largest of the combination was considered for designing the amount of current to be passed.

4.5.6 Experimental results

Annexure-12 is a record of the results noted.

4.6 Analysis of the results

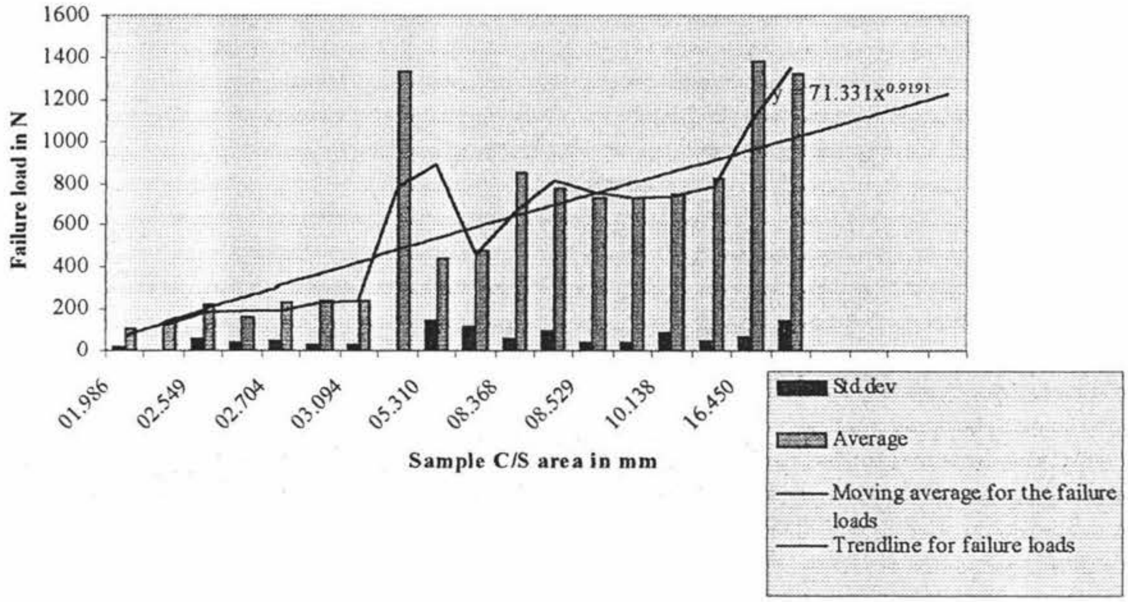


Figure 4-1, Variation of failure loads with increasing splice cross-sectional area

Figure 4-1 is plotted between failure load verses c/s area of the splice joints. C/s area is increasing between 1.9 mm^2 to 19 mm^2. Failure load is plotted on the y axis. Following is a discussion of the above graph;

4.6.1 Variation of failure loads with splice cross-sectional area

The Figure 4-1, is a graph showing the variation of failure loads as the cross-sectional area of the ultrasonic splice is varied. As it is evident from the graph the failure loads are directly proportional to the cross-sectional area, lower cross-sectional joints fail at lower loads than those of higher ones. The standard deviations are also not very significant reflecting the process consistency. The trendline which can be represented by the following mathematical relation could be used to forecast the splice failure loads above $20mm^2$

$$Y = 71.331\,(X)^{0.9191}$$

4.6.2 Variation of tensile strength for different cross-sectional joints

Figure 4-2, shows the variation of tensile strength for ultrasonic connections. This is the plot of specific failure loads in N/mm^2. It follows a polynomial relation of 3rd order. It gradually increases and then lowers down representing a typical polynomial relation. The trendline has been used to project the tensile strengths of the joints above the 20mm^2. The tensile strength is relatively higher for higher cross-sectional joints.

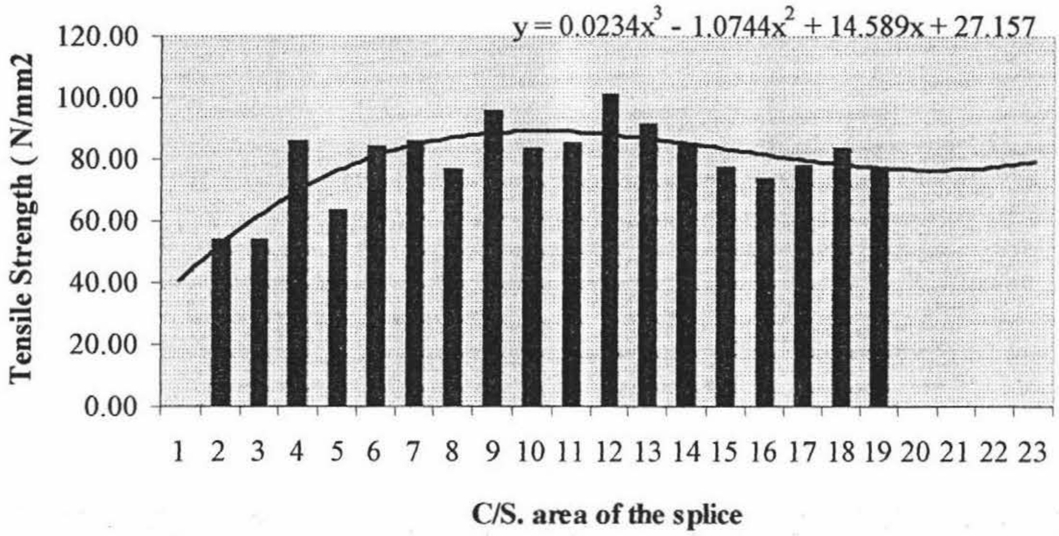


Figure 4-2, Variation of tensile strength of the ultrasonically welded splices

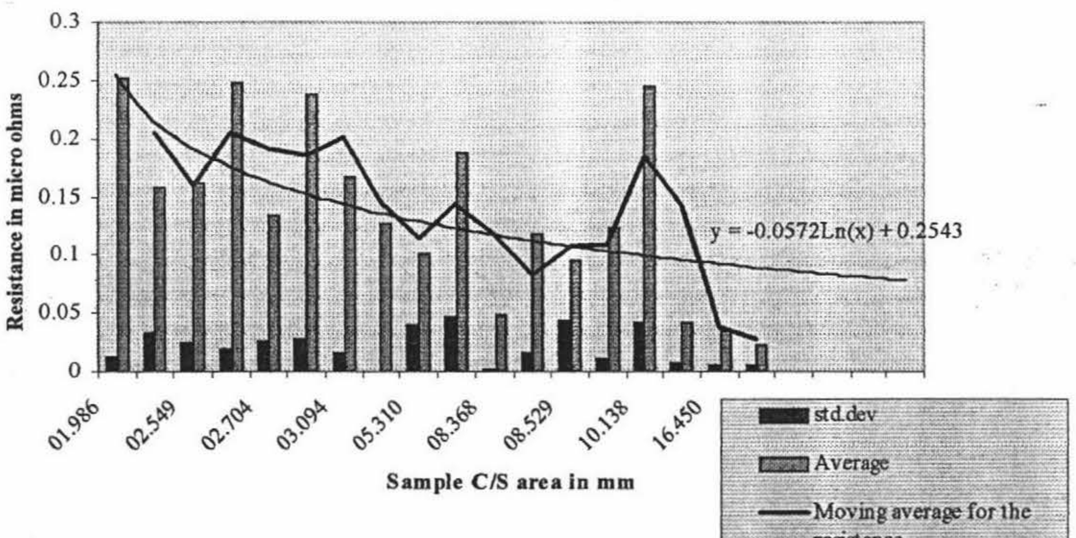


Figure 4-3, Variation of resistance with increasing splice cross-sectional area of the ultrasonically welded splice joint

4.6.3 Variation of resistance of splice connections with increasing cross-sectional area of the joints

The resistance curve doesn't reflect a perfect pattern, but it does show a trend of gradually leaning-off. The resistance offered by the higher cross-sectional area joints is more than for the higher cross-sectional joints. This behaviour is basically due to the fact that, the higher joints have more specific weight and also there is more compression of the copper in higher cross-sectional joints. Also the resistance is directly proportional to the length of the material and inversely proportional to the cross-sectional area of the material through which the current is passing through.

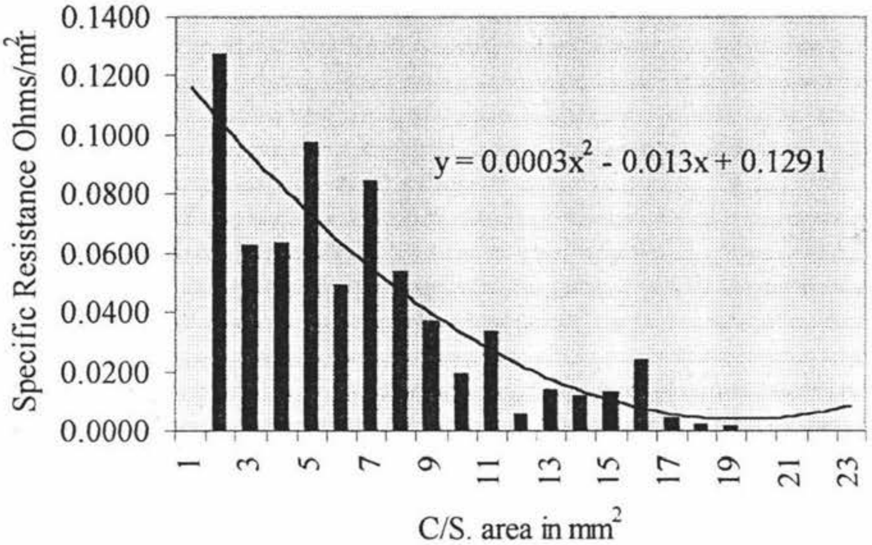


Figure 4-4, Variation of specific resistance (Ohms/mm^2), with increasing cross-sectional area of the ultrasonically welded splice joint

4.6.4 Variation of specific resistance of ultrasonically welded splice connection

Specific resistance is the resistance offered by a sq.mm of joint area. This measure is very high for a lower volume of joints and gradually grades off when it comes higher volumes. Though there is some inconsistency in the pattern, it could still be very satisfactorily represented by polynomial of 2nd order, as shown in the Figure 4-4.

Conclusions

A discussion has been presented on how the tensile and electrical strengths have been measured for the ultrasonically welded splice connections. The tensile strength of the connections was plotted and a mathematical relation that will very satisfactorily represent the trend of the plot has been produced. Specific resistance has been found to be higher for the lower cross-sectional joints.

The next stage of work involves a comparison of the two methods of splicing discussed in the two previous chapters.

Chapter - 5

5. COMPARATIVE STUDY OF ULTRASONICALLY WELDED SPLICES WITH CRIMPED WIRE SPLICES

Introduction

Having discussed the two methods of making wire splices, the crimp connections and ultrasonic connections, and then discussing how they are made and what are the individual strengths and weaknesses of the two methods, this chapter is devoted to the discussion on relative comparisons of the two methods. Tensile strength, electrical resistance are compared in the following sections. Different failure modes of different types of joints are also discussed. Finally the dimensional factors such as splice volumes are studied.

5.1 Mechanical properties

Samples that are tested in crimped and ultrasonic sections being similar in their construction, a straightforward and reasonable comparison could be made on the individual failure loads and the tensile strengths of splices of different cross-sectional areas.

5.1.1 Comparison of failure loads

Figure 5-1 shows in a graphical form the failure load comparisons of individual sample groups. It is evident from the graphs that the failure loads of lower cross-sectional joints of ultrasonically welded splice connections are significantly the same or slightly lower than those of crimped connections. A connection of approximately 2mm^2 of cross-sectional area has a slightly lower failure load. Whereas for the higher cross-sectional joints the failure loads are significantly higher for ultrasonic connections.

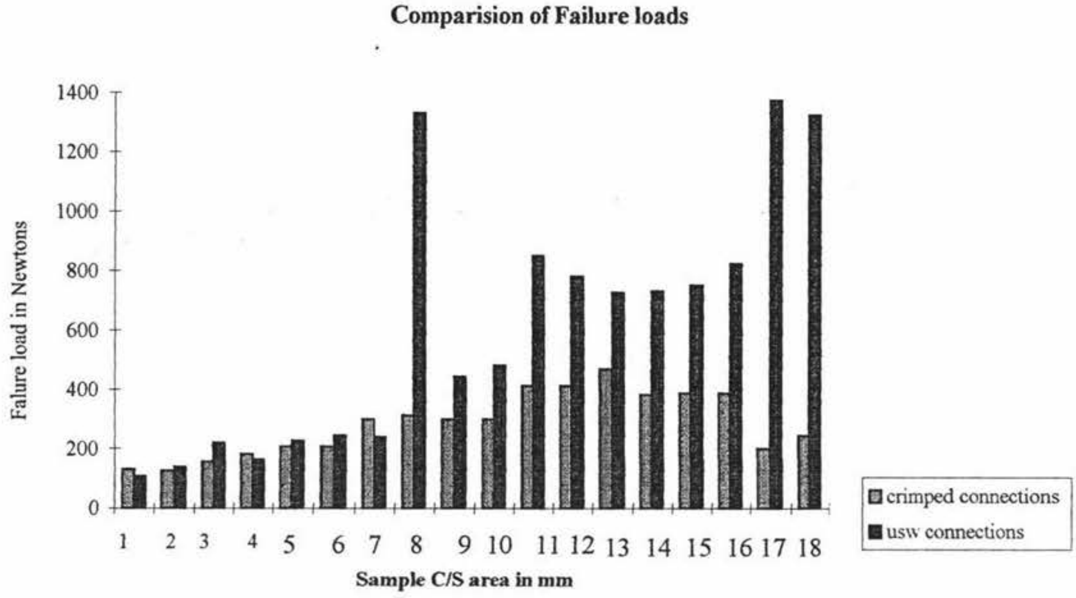


Figure 5-1, Comparison of failure loads of ultrasonic and crimped connections

5.1.2 Comparison of tensile strengths

Failure loads when divided with the specific cross-sectional areas of the joints, give an indication of the tensile strengths. Figure 5-2 shows a comparison of the tensile strengths of the two types of splices.

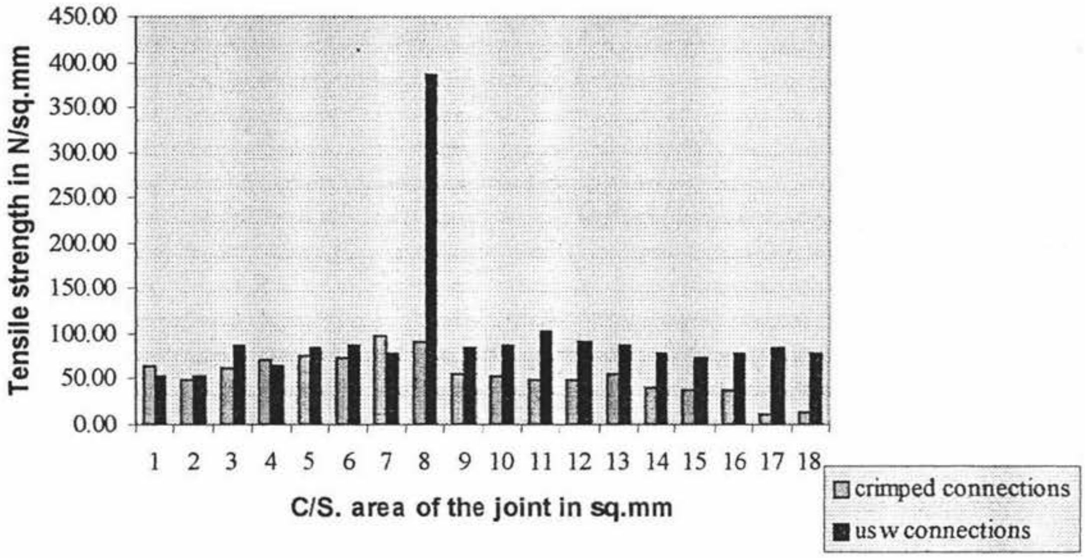


Figure 5-2, Comparison of tensile strengths of splice connections

It is evident from the above plot that, for lower cross-sectional joints the specific failure loads otherwise being measured as tensile strengths is lower for ultrasonic connections and for higher cross-sectional joints, the crimped connections show lower values, compared to ultrasonic connections.

5.2 Electrical properties

Resistance offered by the splice connections of different types which were quantified in the earlier chapters is compared under two major categories. First, a straightforward individual groups comparison is made then, specific resistances are compared, to compute the resistances per mm^2 of joint cross- section.

5.2.1 Comparison of resistance offered by individual cross-sectional samples

The resistance offered by the individual sample groups is compared in the Figure 5-3

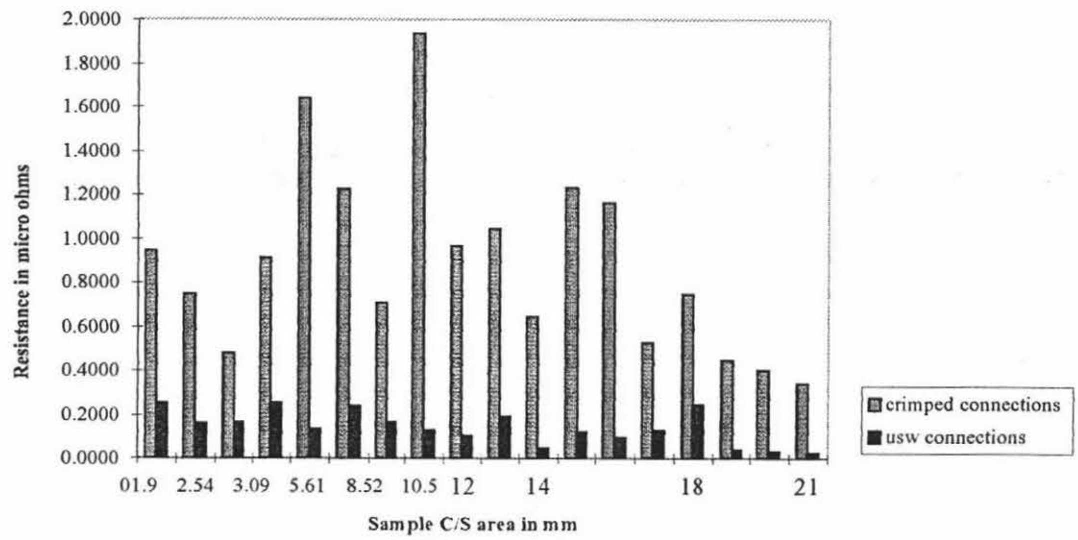


Figure 5-3. Comparison of electrical resistance of crimped and ultrasonic splice connections on individual group basis.

The above graph shows how, on an individual one to one basis the samples could be compared with each other. The difference between resistance offered by the connections of ultrasonically welded ones and those of the ones made with the crimping technology are very significant and they are very consistent over the entire breadth of the sample range cross-section, ie., between 1.9 mm^2 to 19 mm^2.

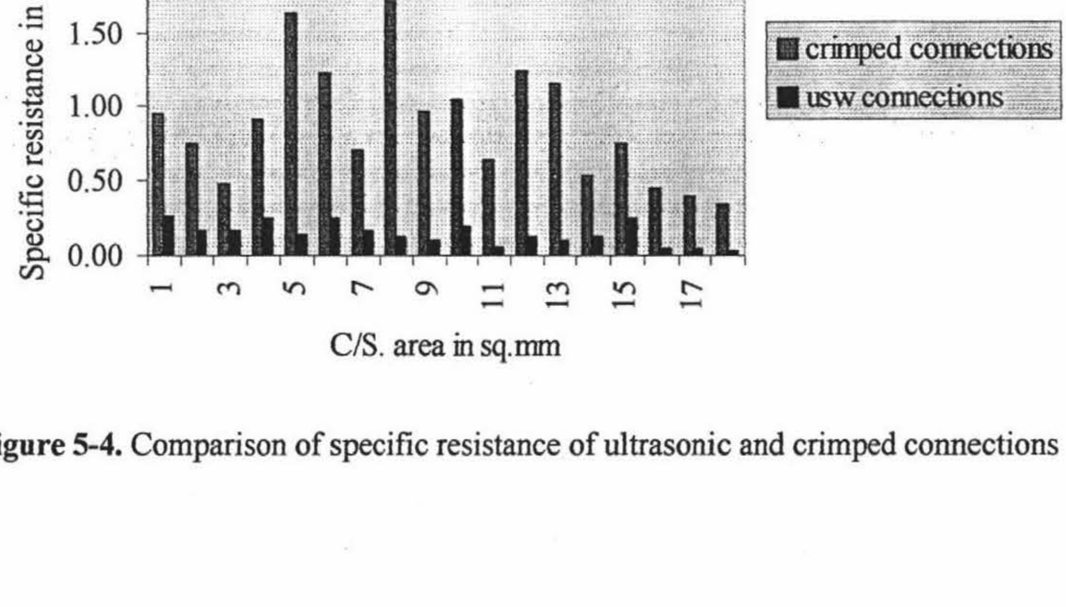


Figure 5-4. Comparison of specific resistance of ultrasonic and crimped connections

Specific resistance, which is measured as resistance (ohms) per mm^2 of joint area, is plotted in Figure 5-4 as a variation of the cross-sectional area of the joints. The trend is that the resistance offered in the case of crimped connections increases initially to about $9mm^2$ of the joint area and then gradually decreases at a gradual rate between $9mm^2$ and $19mm^2$. Whereas in the case of ultrasonically welded connections, the trend is that its more consistent without significant change . This shows that there is more consistency in-terms of process control in ultrasonic welding than in crimping.

5.3 Dimensional/geometrical properties

The volume of the joint is a measure of the weight of the joint and also a measure of the amount of insulation required in case of encapsulation of the joint. Joint dimensions have been measured and the values are recorded in annexure-13.

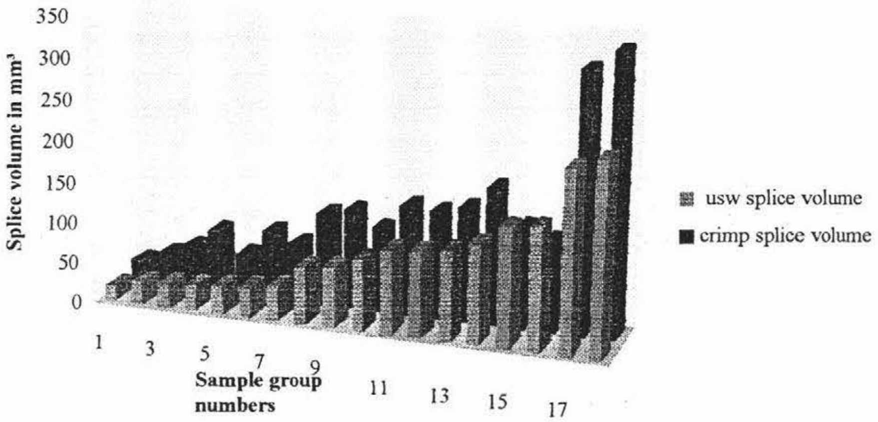


Figure 5-5, Comparison of splice volumes of splices made with ultrasonic welding and crimping.

The graph indicates that the splice volumes are consistently more for crimped connections compared to those of ultrasonic connections. This could be very easily explained by the fact that the crimp ferule adds an additional dimension to the splice volume.

However, there are two groups, G15 and G16, of samples which deviate from the above said trend. The reason is explainable in two ways :

1. As a ferule pressed to its maximum value, or could be even an under sized ferule for

that particular volume of copper or

2. It could be a variation of process control in ultrasonic welding. If there is a change in the amount of pressure applied on the joint at the time of welding, the volume of compression of copper is relatively lesser than the others which are pressed more. It could explained clearly after looking at the process parameters of the ultrasonic connection, ie. the time, pressure and the time of welding.

There is a relative very slight fall in the tensile strength of the ultrasonic joint for G16 which has a considerably lower volume than the crimped connection and also there is a slight increase in the resistance. This could be related to the process variation of ultrasonic welding.

The other explanation to this anomaly is the dip soldering of the joint. These two groups are usually dip soldered. Which might compensate the strength and resistance.

5.3.1 Failure modes under tensile loads

All the sample groups have been studied for their mode of failure, and it gave an insight into the type of fracture that would occur to the splice connection when extreme pull load at a uniform rate of 100 mm/min. is applied. Presented below are the major failure modes for crimped and ultrasonic connections.

5.3.1.1 Modes of failure of crimped connections

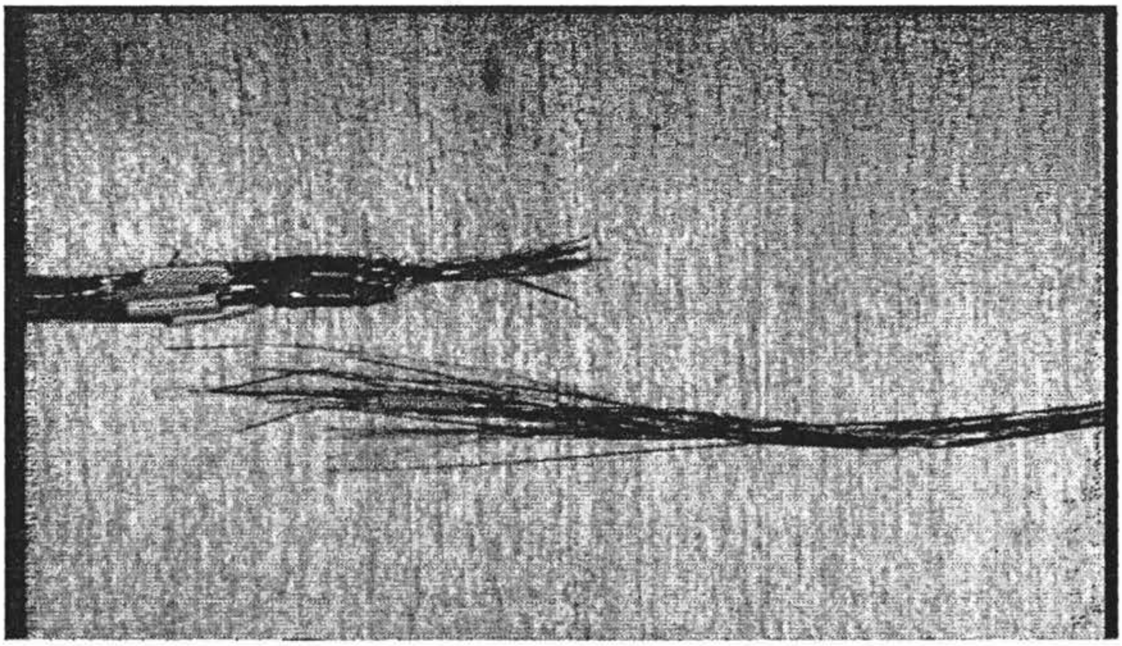


Figure 5-6, Failure of the copper wire strands of a crimped connection, by fracture of strands away from the crimped joint

The type of failure depicted in the Figure 5-6 is predominant in lower cross-sectional joints. The wire strands break away from the joint. This shows that the joint is stronger than the wire strands. This could also be due to any small nick that might come on the copper, while the insulation is being removed by the manufacturer. Also, if the distribution of load is not uniform on all the strands, this can happen. Every care has been taken to minimise these problems at the time of conducting experiments.

The next picture Figure 5-7 shows how the connections of higher cross-sectional crimped connections fail, by the complete pull out from the ferule.

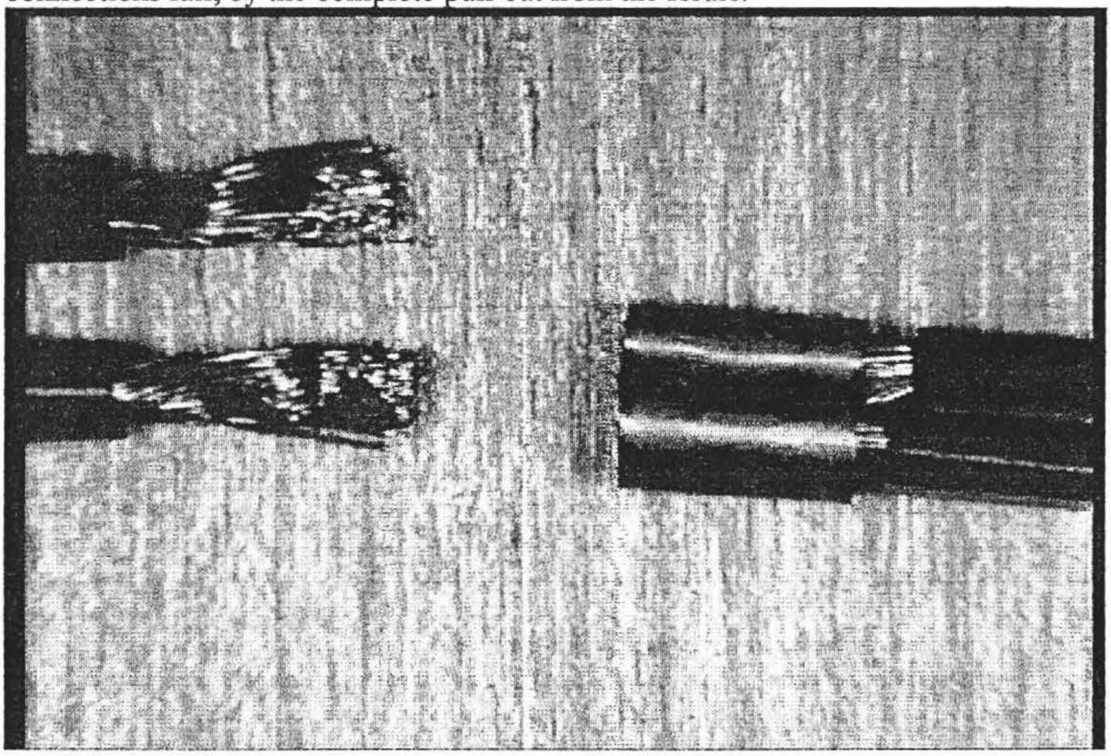


Figure 5-7, Failure of the wire strands of a crimped connection, by the complete pull out of the wires from the ferule (predominant in higher cross-sectional joints)

There is another set of failures, though not very common. These are a combination of pull out from the ferule and breakage of some strands away from the joint. This is depicted in the Figure 5-8.

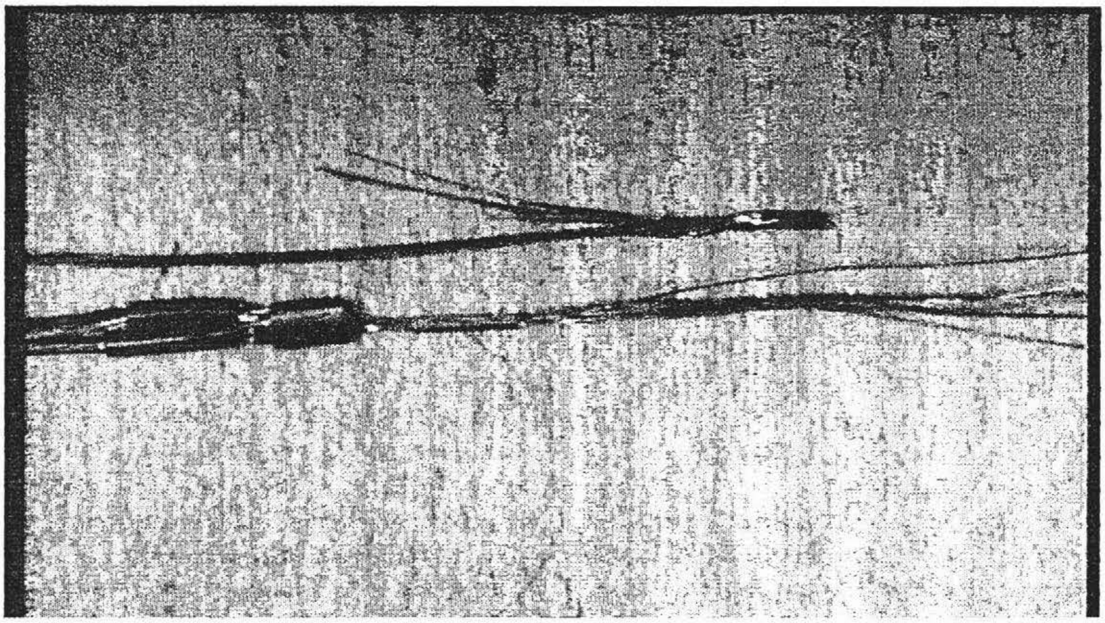


Figure 5-8, Failure of the wire strands of a crimped connection, by a combination of pull out of the wires from the ferule and fracture of the strands away from the joints (not a very common failure)

The next set of major failures are the failure of the wire strands at the neck of the joint. This is good example of crimp causing an excessive, damaging pressure on the copper strands. This is dominant in the joint between $3mm^2$ and $6\ mm^2$. This failure is captured in the Figure 5-9.

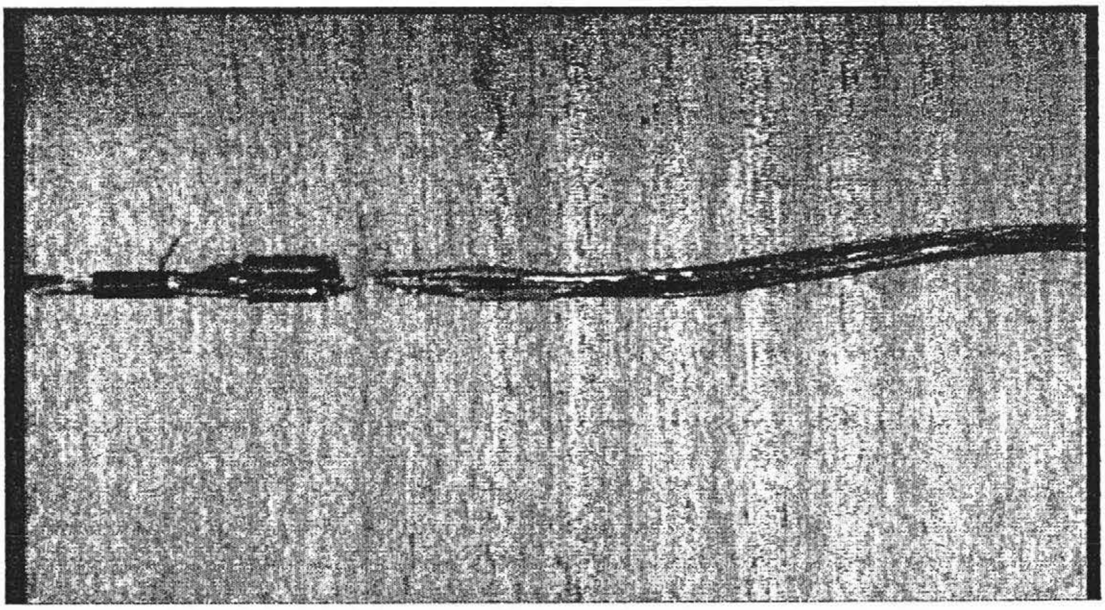


Figure 5-9, Failure of the wire strands of a crimped connection, by the complete fracture of the strands at the neck of the ferule (predominant in medium >3 & <6 cross-sectional joints)

5.3.1.2 Failure modes of ultrasonic connections

Types of failures are again either centred around the neck of the joint or away from the joint. But a very dominant failure mode is the shear fracture through the joint diagonally.

Figure 5-10 shows how the lower cross-sectional ultrasonic joints fail, by the fracture of strands away from the weld.

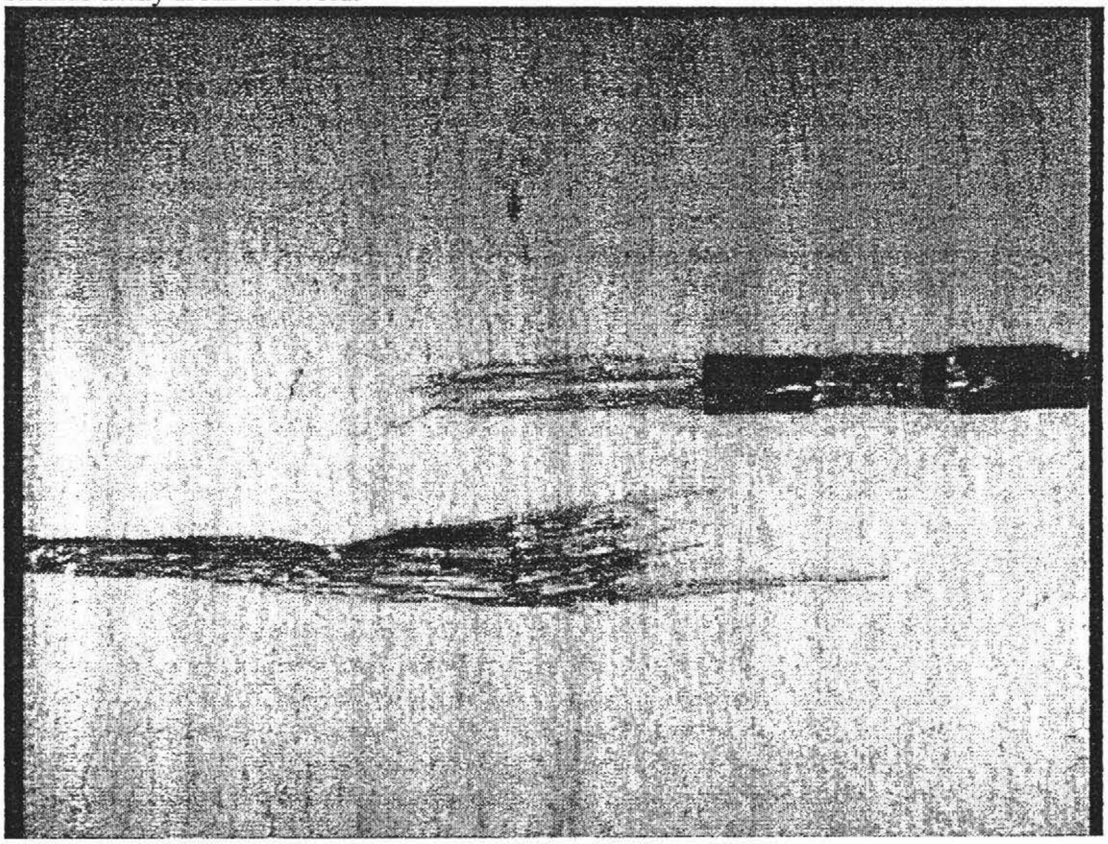


Figure 5-10, Failure of the wire strands of an ultrasonically welded connection, by the fracture of strands away from the weld (predominant in lower cross-sectional joints)

The next set , as shown the Figure5-11 , depicts the failure of the wire strands, by the complete fracture of the strands at the neck of the weld. This phenomenon is predominant in medium cross-sectional joints, ie. between $3mm^2$ and $6mm^2$ joints.

Figure 5-12, shows the failure of the wire strands by a complete fracture through the weld. This is predominant in higher cross-sectional joints.

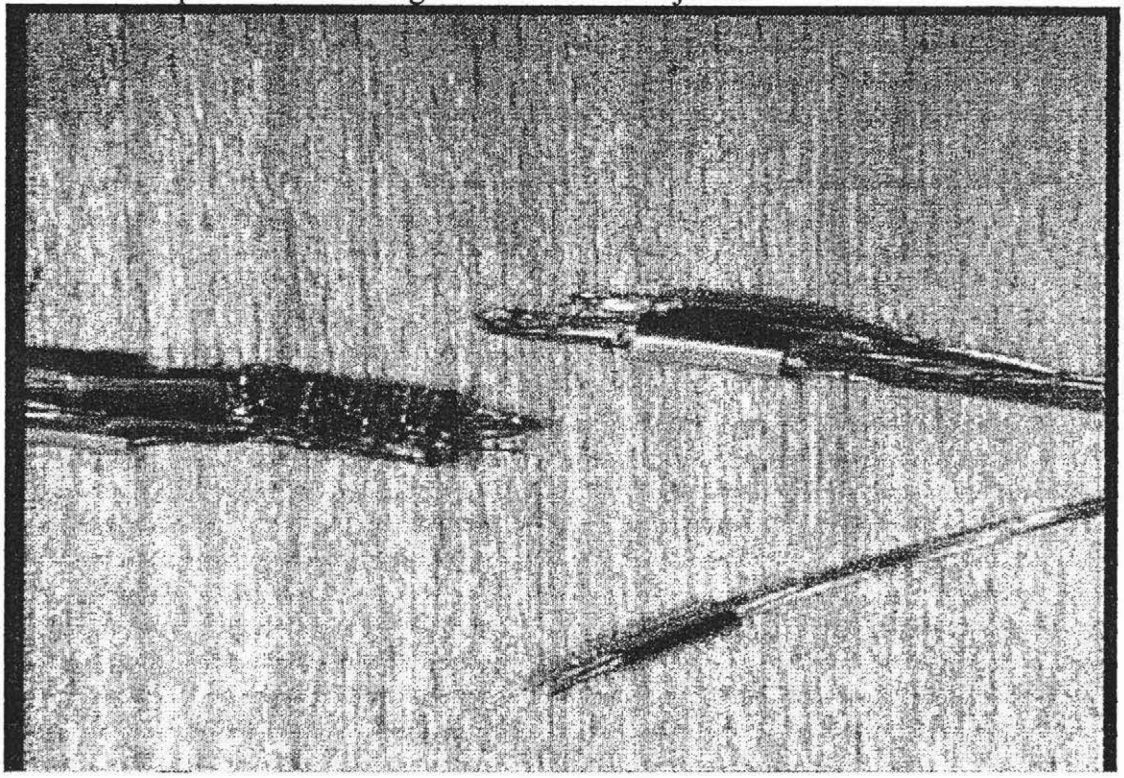


Figure 5-11, Failure of the wire strands of an ultrasonically welded connection, by the complete fracture of the strands at the neck of the weld (predominant in medium >3 & <6 cross-sectional joints)

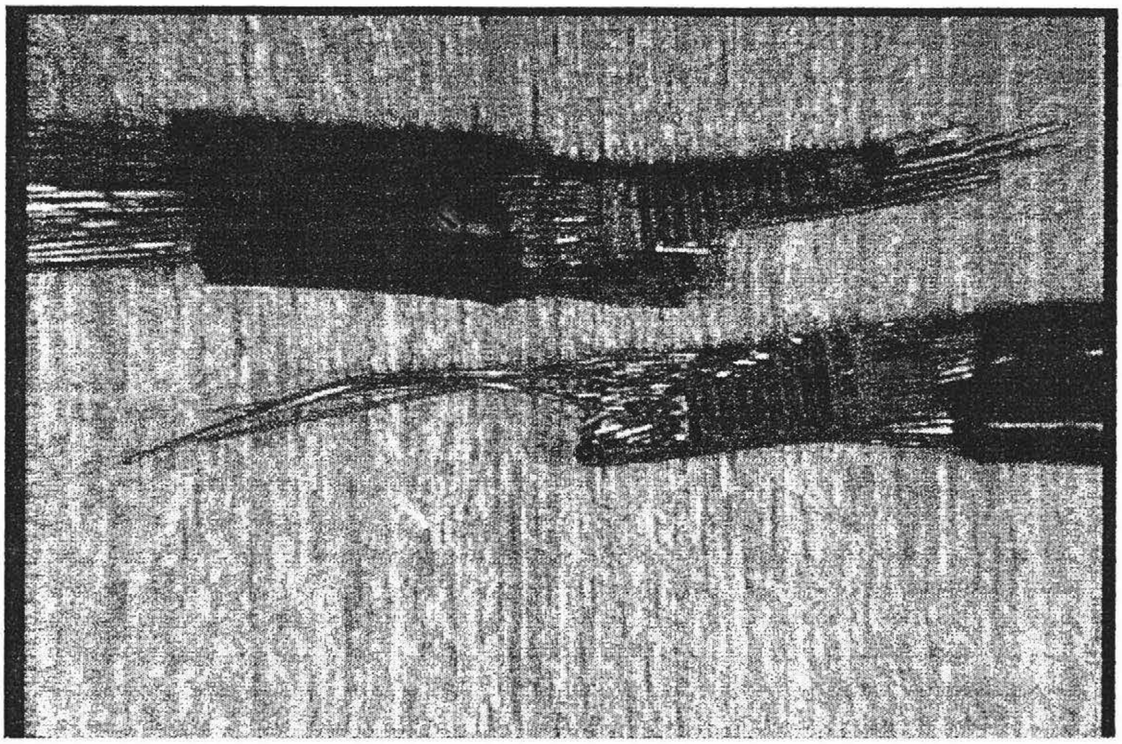


Figure 5-12, Failure of the wire strands of an ultrasonically welded splice connection, by a complete fracture through the weld (predominant in higher cross-sectional joints).

Table 5-1 summarises the points made in the fracture comparison discussion.

	Crimped splice c/s. area			**Ultrasonically welded splice c/s. area**		
Predominant failure mode	**Low**	**mediu m**	**high**	**low**	**medium**	**high**
Wire strands fracturing, away from the joint	√			√		
Fracture at the neck of the joint		√			√	
Wires pulling out from the joint			√			
Fracture of weld (shear through)						√

Table 5-1, Comparision of failure modes of ultrasonically welded connections and crimped connections

Conclusions

A comparison of the tensile strengths and electrical resistance is made. Ultrasonic connections have consistently shown better tensile and electrical resistance properties. A discussion is also made some deviations to the regular trends in the comparisons. Splice volumes have also been compared. Different types of fractures of the connections have been presented.

Chapter - 6

6. IMPLEMENTATION OF ULTRASONIC WELDING-CONSIDERATION OF SOME PRODUCTION DYNAMICS

Introduction

After having established in the previous chapters that, ultrasonic wire splicing is comparatively better in terms of the joint mechanical and electrical properties, the next logical stage is to study the economic feasibility of the ultrasonic welding. A cost benefit analysis would give a clear indication of the feasibility of the technology.

A generic model of cost benefit analysis is presented. A specific case of Alcatel New Zealand Limited is presented to explain the model. One of the main requirements of the cost benefit analysis would be to know how many of the new welding machines are required to replace the existing crimping machines. This is also required to implement the ultrasonic splicing technology in the right technical form by the industry to ripe in the desired benefits. The influence of the process capabilities of the machines and its related effects on the production dynamics were also investigated.

This chapter looks at the utilisation of a commercially available off the shelf simulation software to carry-out the above stated studies. Queuing event simulation tool (QUEST) has been used.

6.1 Simulation study

6.1.1 Objectives of the study

Objectives of this chapter are to identify and establish the changes in the production dynamics of one of the leading manufacturer of wiring harnesses in New Zealand, when ultrasonic welding machines replace the existing crimping machines. And also to develop a generic simulation model, which should be capable of simulating different combinations of ultrasonic welding machines and different batch mix of orders and produce specific results on production related performance indicators.

First, a simulation model has been designed featuring the ultrasonic welding machines. Discussion is detailed on how this model has been designed and built and what are the various technicalities involved in this design and development. Then, specific performance indicators, reflecting the production related factors were identified and solutions to these indicators were designed. Next specific commercial orders were simulated to obtain output on these performance indicators. A process model, mimicking the current manufacturing facilities with ultrasonic welding machines was made to check the data that was being processed on other models and also to give output on performance indicators to compare with ultrasonic models.

6.1.2 Selection of Queuing Event Simulation Tool (QUEST)/Features of QUEST

Queuing Event Simulation Tool is a 3D graphical discrete event simulation tool, produced by Deneb Robotics of USA. QUEST Simulation tool [16] is used to model the above production system. QUEST is an interactive, 3D simulation tool aimed at all batch process manufacturing, whatever be the product, and is capable of producing textured virtual reality walk throughs. It has the capability of producing high quality 3D graphics of geometrically and dimensionally correct models. It includes programming languages such as Simulation Control Language (SCL) and Batch Control Language (BCL) so that the users can write their own logics/routines/procedures for controlling the simulation according to the requirements.

This package was chosen for the following reasons

1. 3D graphical user interface gives a far better perception to the user and the management of the entire exercise and also it is easy to communicate with the shop floor personnel.

2. It has many built-in libraries of geometrical shapes to mimic the geometries of a wide variety of machines and other resources including human.

3. It is supplied with a library of standard logics, suitable for many common manufacturing scenarios, which could be used in many decision making situations.

4. SCL and BCL can support the simulation from both internally and externally, making it highly generic and easier for the user to customise the package.

5. Its own graphical reporting system makes it very easy to report the results very effectively.

6. Its own built in 3D design capabilities, kinematics and costing facilities make it a complete package for the serious user.

7. In addition to all the above, availability of expertise within the department of production technology, Massey University, in trouble shooting and development of the Quest package under the research umbrella of Intelligent Manufacturing Systems has

added a great strength to the utilisation of Quest.

6.2 Simulation Study Approach

Figure 6-1, shows a flowchart of the study approach. A modification to this approach was later on incorporated to check the steady state of the system.

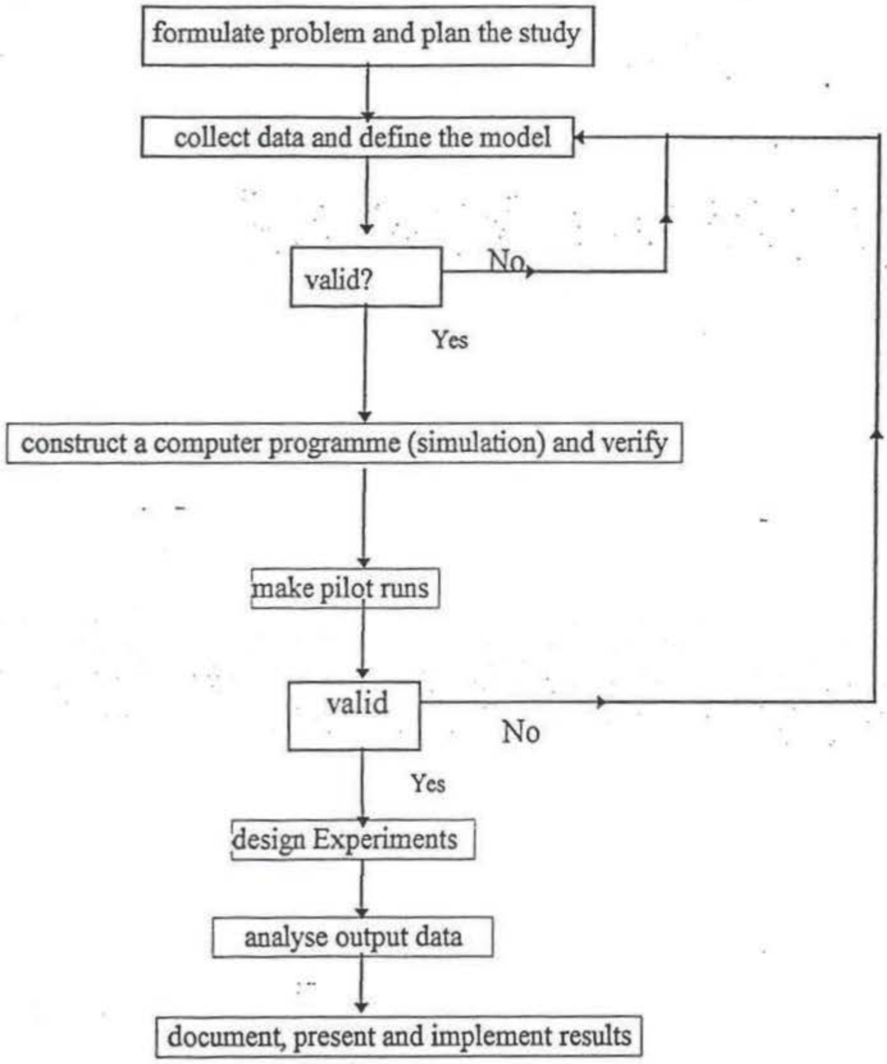


Figure 6-1, Flowchart showing the series of steps involved in the simulation study, as used by Felix.T.S.Chan

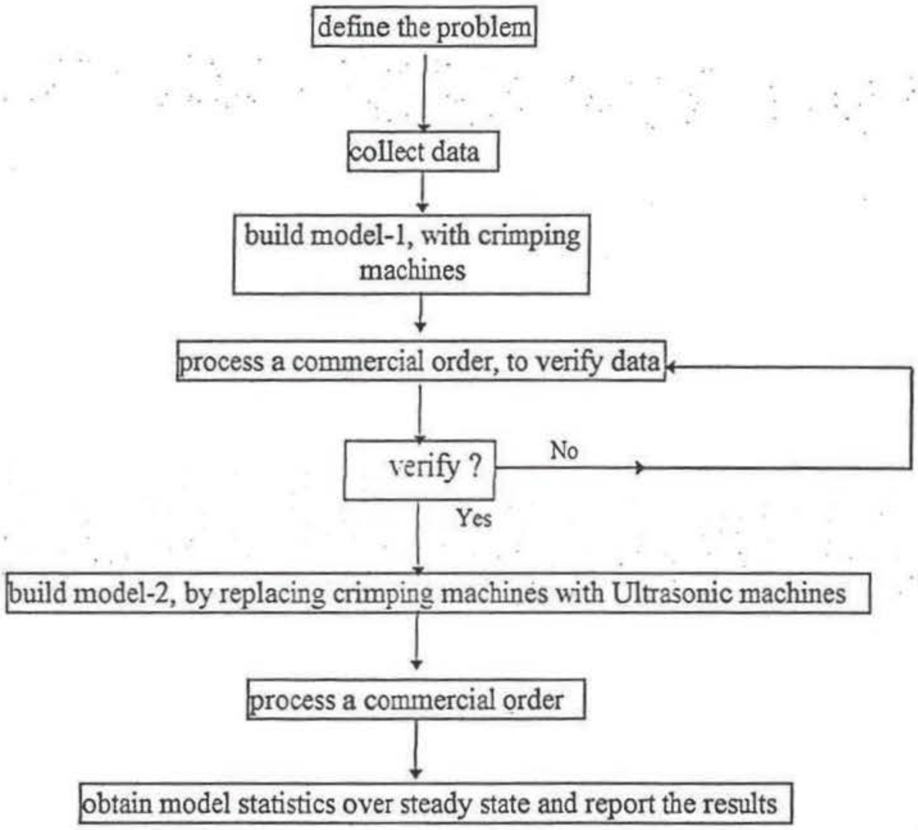


Figure 6-2, Modified simulation study approach, a two model approach

6.2.1 Experimental Procedure

A two prong approach was made as shown Figure 6-2 and discussed below

6.2.2 Problem definition

The following questions were analysed, while attempting to define the problem:

- How many of the ultrasonic machines would be required to meet the same production throughput?
- What is the throughput time in different combinations of numbers of ultrasonic welding machines?
- What is the average buffer length in all these situations?
- What is the maximum waiting time on an average for any widget before it gets processed on different machines?

Besides the above questions the different What-ifs which were answered later on were:

- What-if only one ultrasonic machine is used in place of seven crimping machines that are being currently used?
- What-if two ultrasonic welding machines are used?
- What-if the time standards supplied by the machine manufacturer are followed instead of Alcatel's own standard?
- What-if the batch mix is changed from its current form?
- What-if the automatic part transfer systems are introduced?

6.2.3 Data collection and definition of plan of action for solution

Keeping in view the specific necessities of the user and the Quest package, data was collected to develop the model in the Quest and to simulate various situations. Certain time studies were also carried out to find the data which was currently not available with Alcatel. Some of the data collected was inter arrival times of the widgets at the source, cycle times at different workcenters, travel times between workcenters, types of distribution of all these standard times, breakdown time standards etc., **Annexure-14,** shows an estimate of times used for a specific commercial order simulation.

The following equations were used in the calculation of times [refer annexure-15]

$$\text{Wrapping hours} = \lim_{\substack{c=1 to 10 \\ l=0 \text{ to } 60}} \left[\frac{1}{16874 L^{-0.67943}} + 0.00075N \right] * 1.18$$

where:

N= no. of leads/bundle

L= longest length

$$\text{Machining hours} = \lim_{3 to 20} [0.0030889 + 0.0009653x] * 1.18$$

where:

x = no. of leads spliced together

Wrapping time, splicing time and final taping time have been established by using the standard mathematical formulae developed by Alcatel. However, these formulae have been given an additional tolerance of 5%-10% depending on the complexity of the joint (length and number of wires forming the joint). This factor has been established by checking the validity of the time function formulae practically ie. time standard tests have been conducted and the results have been compared with the results obtained from the above stated formulae.

Other time has been included to accommodate travel time per Internal Joint(IJ) between the workcenters and the human factors which seem to have been not covered in the total time calculations.

Inter arrival times, sorting times, travel times and human delays have been established by conducting time studies in a pilot scale, to a limited extent. The time constraints of the project did not facilitate a thorough time study analysis of various process times. It is apparent that, the validity of the conclusions made in this chapter depend to a great extent on the exactness of the times used. However, the main thrust of the study has been at developing a generic model to simulate various similar situations that the company would come across in the future and also care has been taken to the greatest extent possible to accommodate the errors in times. The conclusions drawn from this study, if they have any discrepancy to the actual ones are more likely to be on positive side than any other effect on decision making. For example, the times that have been taken as Alcatel times have been incorporated with maximum tolerances of unlikely errors, as a result of which, even if there is any error the throughput time would be less but not more than what has been found from the simulation studies.

Ultrasonic welding cycle times have been taken from the data provided by the machine manufacturer. Annexure-16 details Stapla specification of times. Models have been built with ultrasonic welding machines and time have been varied on two different grounds;

1. Welding cycle times, feeding times and operator times relating to ultrasonic welding operation were taken from Stapla company standards [annexure-16].

2. Welding cycle time being the same, other times such as wrapping time, taping time, sorting time etc., have been found from Alcatel's in-house time standards. Excepting the splicing operation (ultrasonic welding or crimping), other operations remain the same as the ones in previous models. Annexure-17 gives an estimate of times used for ultrasonic welding models

A detailed plan was drawn to make virtual models to find answers to the questions and what-ifs posed in step-1 of the flow chart shown in Figure 6-2.

6.2.4 Verification of data

Many smaller pilot models have been built to verify the data that has been collected. Collected data has been discussed and compared with that of the existing standard data.

6.2.5 Model -1 -Current manufacturing facilities with crimping machines

Figure 6.3 shows a snapshot of the model. All the machines and the labour were given respective characteristics such as the cycle times, breakdown times, number of processes, control logics, scheduling logics, buffer logics for the buffers, route logics etc., describing the system completely.

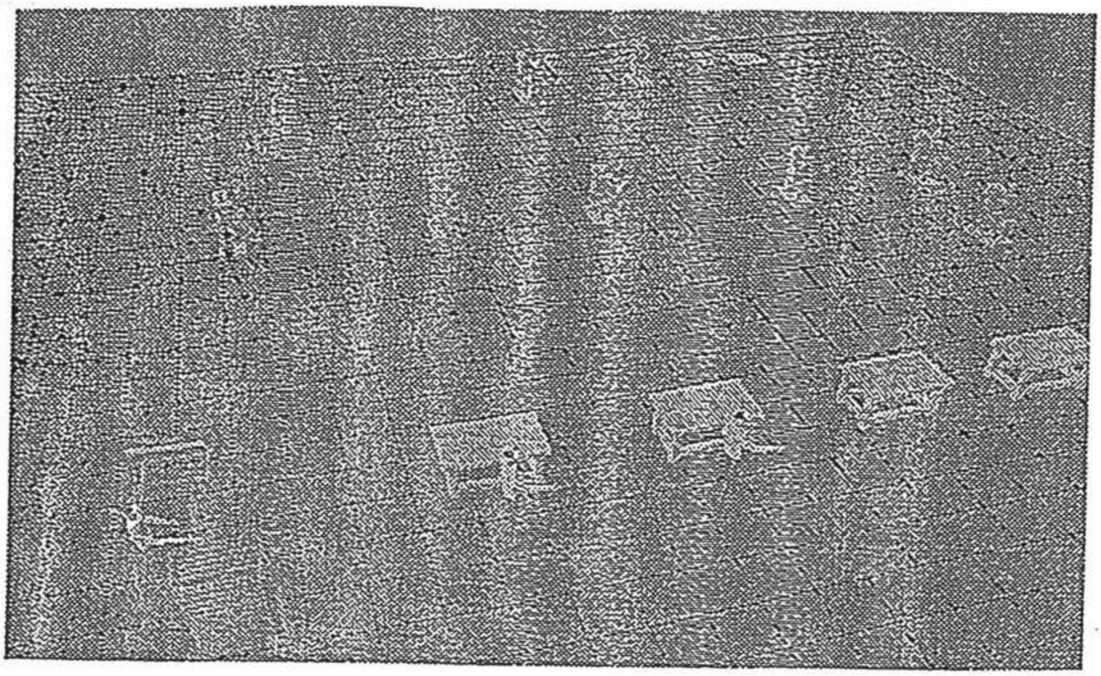


Figure 6-3, A snap of the simulation model, depicting the current manufacturing facility of Alcatel splicing center

The model shown in the Figure 6.3, is a virtual replica of the internal join manufacturing station at Alcatel(NZ)'s plant. Wires, which are cut to the size and stripped of insulation, come with their job card to the source, from then on they pass through the stages of sorting, wrapping, crimping and then finally get encapsulated, before going into the buffer to carry them to on board assembly.

6.2.6 Simulation of specific commercial order

To obtain results for the verification of the model Mitsubishi's order to Alcatel was simulated and the throughput time was measured and compared against the actual throughput time measured from the time standard sheets of Alcatel [Annexure-18].

6.2.7 Modification of the model made until the model reached a satisfactory condition of exactly mimicking the existing manufacturing facilities

The major factor was the throughput time obtained in the above step, adjustments and fine tuning the system was made until the actual throughput time and model throughput time were almost the same.

6.2.8 Model-2 -Proposed manufacturing facilities with ultrasonic welding machines

A new model duplicated from model-1 was made, ofcourse replacing the entire range of crimping machines with a different number of ultrasonic machines.

Machine connections, routing and other relevant connections were changed. All the feeder files like the inter arrival time file, cycle time file for splicing etc., were created afresh and connections were made to these files. The new process capabilities of the ultrasonic welding machines were also incorporated.

What-if questions were answered by changing the number of ultrasonic machines and finding the throughput time, average residence time and the average buffer length.

6.2.9 Simulation of specific commercial production order

After having stabilised the number of ultrasonic welding machines and other factors, a particular commercial production order was processed on both the models to see the exact difference between the two models.

6.2.10 Definition of steady state and its boundaries

Steady state boundaries were defined and results obtained over the span of steady state. Seven of the Mitsubishi orders were processed in succession and the boundaries of the steady state were defined and then the statistics were obtained over the period of the steady state.

Following figure shows, ingeneral, how the steady state of a system could be represented in a model.Machine utilisation is plotted against the time of widget travel and the steady state is obtained by the defining parameters. Mostly the span over which the machine utilisation of the system remains constant.

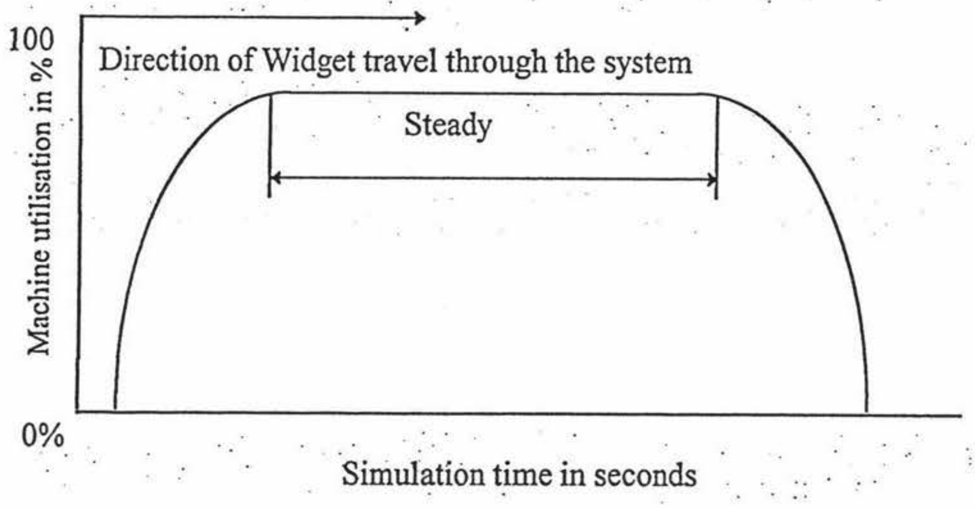


Figure 6-4, Description of the Steady state of a system

Steady State: Seven of the Mitsubishi orders were (though this number could be any thing) simulated in succession, to obtain a fair amount of continuous throughput from the system and to keep the source of the system fairly busy. From the pilot runs the time the first widget reaches the sink of the system was found out and similarly the last widget to leave the source was also found out and the span between these two states with some more tolerances at either end was taken as steady state boundaries and were eventually considered for the analysis of the statistics.

Figure 6-4 describes the steady state phenomenon. There is an initial lead-in time for system resources to come to maximum percentage utilisation and there is also a tail-end time wherein the system resources are not utilised to the maximum, with some machines becoming idle as the widgets cease to come in with other machines still processing the existing widgets. The time in between, wherein all the system resources are utilised to the maximum extent has been referred to as steady state.

6.2.11 Modification of model data

Models were altered by changing the data through SCL/ASCII file communication to answer various questions and what ifs developed earlier. The two models that were built are more or less generic ones. These are being referred to as generic ones, because they are capable of processing any commercial order/production dynamics that are specific to the model. They are not rigid to process a specific set of dynamics of demand-supply scenario. By changing the data that has been fed in to the system throughout the SCL file communication, like the exact inter arrival time of each of the widgets , standard cycle times of different work centres, process capabilities of each of the work centres etc., the model dynamics could be changed to process different commercial orders. Batch mix could also be easily incorporated by changing the corresponding feeder files. The files are easy to write with the SCL. Data in most of the cases was developed using spread sheets and was later on transferred onto SCL file suitable for Quest to understand. In this way it was easy to manipulate the data on spreadsheets.

6.2.12 Performance indicators

The following performance indicators have been selected to measure the performance of different models:

6.2.12.1 Throughput time

It is defined as the time taken on an average for the production of one widget. It was calculated from the standard function available from the Quest.

6.2.12.2 Average buffer-length

The length of the buffer, in terms of average count over the entire period of production time. This was also measured using the standard function available from the Quest package.

6.2.12.3 Average Residence time

This is defined as the time on average a widget stays in the system, excluding the times it stays at source and sink, is also calculated from the standard Quest functions.

6.2.12.4 Maximum Waiting time

The maximum time that a particular widget waits in a buffer, waiting for further processing, before any workcenter, is also calculated using the standard QUEST function.

6.3 Results

Results were downloaded onto spreadsheets and the specific tabular graphical reports were made. The in-built reporting system was not used for its slow speed and lack of compatibility with other spread sheeting and word processing software.

Following is a comprehensive report of results. Detailed output of the results are recorded in annexure-19

Model name	Throughput number of widgets	Throughput time in seconds	Avg. utilisation of splicing machines	Avg. buffer length in no. of units	Avg. Residence time in seconds	Max. wait time in seconds
crimp model	3900	76.81	5-48%	11	1.62	3.021
One ultrasonic machine (with Alcatel times)	3900	101.53	98.006%	137	12.69	25.857
two ultrasonic machines (with Alcatel times)	3900	75.56	55.931% & 72.236%	4	0.05	0.395
One ultrasonic machine (with Stapla times)	3900	75.69	64.57%	5	0.95	0.648

Table 6-1, Results of the simulation studies

Table 6-1 indicates the difference between the three models, in-terms of the performance indicators. The four models are; a) to utilise only crimping machines, b) to utilise only one ultrasonic welding machine with time standards of the machine manufacturer, c) toe utilise only one ultrasonic machine as well but the time standards are those developed by Alcatel's own experience, d) to utilise two ultrasonic welding machines and utilises times developed by Alcatel.

6.4 Discussion of results

6.4.1 Throughput time

Models were made and run by changing the number of ultrasonic welding machines and checking the model performance indicators. For example as shown in the above graph, one of the performance indicators was the throughput time. It was found from the model with crimping machines that the throughput time for processing a Mitsubishi order was

76 hrs. The throughput time obtained with one ultrasonic welding machine with the same order was 102 hr. It was 71 hr with two ultrasonic welding machines. The crimp model was using 7 crimping machines, mostly for process capability reasons. It was clear from the simulation of these models that, two ultrasonic welding machines would suffice the load requirements. Ultrasonic welding machines have a very wider process capabilities in terms of cross-sectional areas of the joints. The models built to solve this problem were very generic, now by changing the data in the SCL files that give the models data on cycle times at different workcenters, the sequence and intervals in which the material arrives, the batch mix etc., the models can process different commercial orders successfully to answer different scenarios.

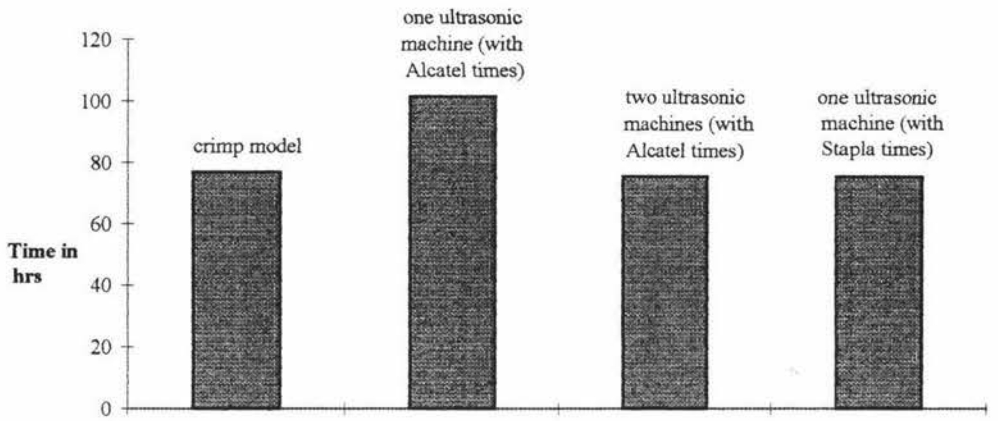


Figure 6-5, Throughput time obtained from the simulation run of a specific production order

The other factor which was studied in all the scenarios was the difference in the time standards. Time studies were conducted to find some exclusive times required for the simulation studies. Besides these times like the inter arrival times, standard times already developed by Alcatel such as the standard time for encapsulation, standard cycle time for wrapping as a function of number of leads and lengths of wires were used to define the machine characteristics and model characteristics. However, these were different to what the ultrasonic welding machine manufacturers were claiming to push their products. In order to see the difference models were run simulating the characteristics of the machine manufacturer times. The above graph shows that if the times supplied by the machine manufacturer are to be believed, then one ultrasonic welding machine would be enough to satisfy the performance indicator of throughput time.

6.4.2 Average buffer length

This was taken as the other performance indicator. The buffer length before the splicing machines is important to visualise how bottlenecks would build up before the machines. By changing the number of machines in the ultrasonic models and by changing the crimping machines with ultrasonic welding machines, the average buffer length before the splicing machines was studied. A single buffer was placed before the entire splicing center consisting of different splicing machines, like seven crimping machines or one or two ultrasonic welding machines. The despatching rule was that of first possible process, the route logic used was that of next free resource. The buffer length then reflects the behaviour of the entire splicing station as a single system.

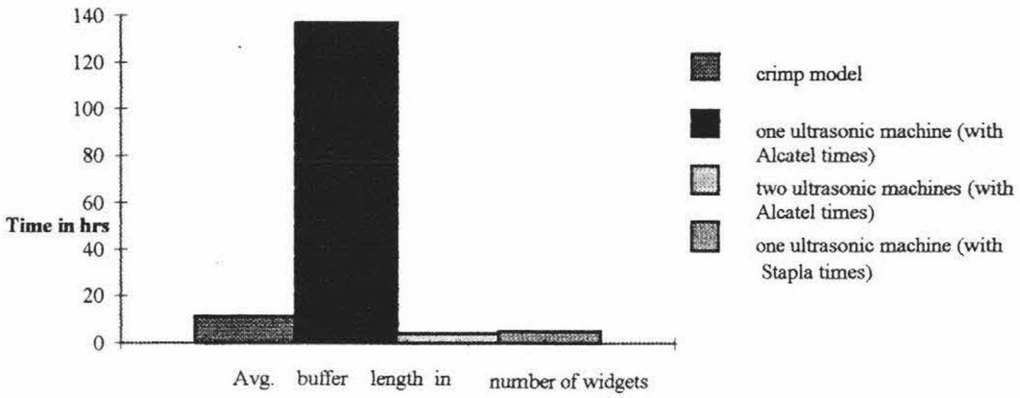


Figure 6-6 Average buffer length before a splicing machine, obtained from the simulation run of a specific production order

The results indicate that using two ultrasonic welding machines (with Alcatel times) would ease the bottle neck that otherwise develops with one ultrasonic welding machine, as shown in the Figure 6-6. One ultrasonic welding machine would not constitute a bottleneck, if ultrasonic machine manufacturer timings are followed. The average buffer length eases comparatively with ultrasonic welding machines than crimping machines, because of better process capabilities and improved cycle times.

6.4.3 Average residence times

The average residence time of any widget is the time for which a widget stays in the system, on average. It otherwise reflects the performance of the entire system ie., all the workstations like the sorting , wrapping splicing and encapsulation, all the buffers, the internal travelling and material handling etc., This is an offshoot of the throughput time of the system.

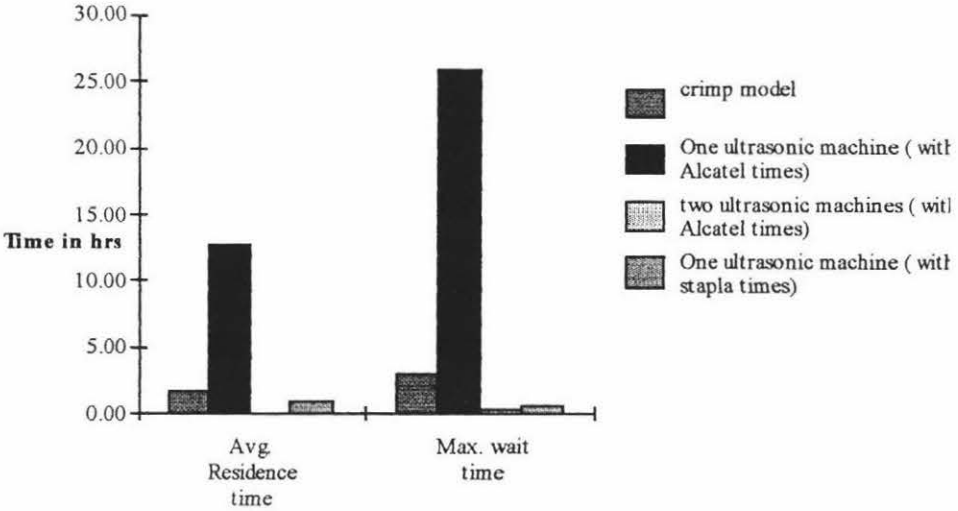


Figure 6-7 Average residence time and maximum waiting time (before the splicing station), obtained from the simulation run of a specific production order

It is evident from the Figure 6-7, the difference in average residence times between using different number of machines.

6.4.4 Maximum waiting time

Figure 6-7 indicates the maximum of all these times, measured at the buffer station before splicing. This was measured while processing the same commercial order that was used for the earlier discussions.

It is apparent from graphs in the Figure 6-7 that, if only one ultrasonic welding machine were to be used and the times supplied by machine manufacturer (here Stapla) are not to be believed ie., Alcatel times are considered then, the waiting time poses a threat. Whereas two ultrasonic machines would be ideal. On the other hand, if Stapla times are to be believed, then only one ultrasonic welding machine would suffice for all the requirements of Alcatel, if the machine is run 24 hrs a day.

6.5 Further work

The following is an overview of the work that could be taken up further

1. Further work could be done in verifying the effect of automated material handling systems, which need further development before they can be tested, using the same simulation models.

2. A lack of sound time standard statistics/data on the part of Alcatel has limited the study's results and the validity of this kind of study depends to a great extent on time standards. Further work could be taken up to re-evaluate the time standards currently followed by Alcatel by using these simulation models. Time standards could be very effectively verified using these models. By developing various statistical trends of times, the best fit times could be tested on these platforms (models developed in this project). However the times considered for the simulation runs as the time developed by Alcatel and these are actually used for their planning.

6.6 Recommendations

1. If the operator wire feed times of Stapla are considered, one ultrasonic welding machine would meet the current demands. (The demand substantiated as seven orders successively run).

2. If the operator wire feed times measured by the author practically and those already developed by Alcatel are considered then, one ultrasonic welding machine will not be sufficient , two machines are required to meet the current rate of demand.

It is suggested from the above discussion that, using two ultrasonic welding machines would be a safer option.

3. A changed batch mix, needs to be tested, for the validity of the above recommendation.

6.7 Cost benefit analysis

Cost estimations of wire splice manufacturing (internal joins) using the two techniques discussed earlier in the thesis, were made considering Alcatel's specific case. The manufacturing cost and raw material costing are made separately and these are recorded in annexure-20.The cost benefit comparison is summarised in the Table 6-2 and Figure 6-8.

	Crimping	Savings if Ultrasonically welded
Total material costs per annum	$ 62,055	$ 41,735
Total non material costs	$ 181,255	$ 10,793
Total costs at the current rate of production per annum	**$243,310**	**$ 52,528**

Table 6-2, Cost savings if the splices are made with ultrasonic welding

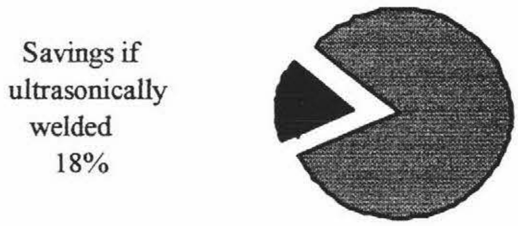


Figure 6-8, Savings on annual production of IJs by Alcatel, if ultrasonic welding machines are used in place of the existing crimping machines

It is clear from the above graphical representation that there is approximately 18% savings on the total cost of making wire splices per annum, considering the current volume of annual production at Alcatel's plant, if ultrasonic welding machines were used instead of the existing crimping machines.

The unit cost of production with crimping machines is $ 0.195048, whereas the unit cost of production with ultrasonic welding machines is $ 0.1459384. This is based on the dynamics of cost-benefit analysis described in annexure-20. Considering an annual production volume of 12,50,000/Annum, the result could be a direct saving of $50,000, on using ultrasonic welding machines alone, besides the other non monetary (ie. quality) benefits described in chapters 3,4 and 5.

Conclusions

The QUEST package has been used to answer some of the questions and what-ifs that needed to be answered to adopt Ultrasonic welding technology for wire splice manufacturing. Besides answering some key factors such as the number of ultrasonic welding machines required to meet the current production demand, some other factors like the buffer lengths if the number of ultrasonic machines changed were also made. The simulation models are custom made for Alcatel (NZ) on a generic basis and these could be used in future to process different commercial orders and also to change the batch mix. The 3D graphical user interface has given a good perception to the management to foresee the bottlenecks associated with material handling.

This chapter concludes that the utilisation of a discrete event simulation package would give the management team a good perception of the new technologies and all the possible consequences as a result of such activity. Building and implementing a pilot plant in virtual world (simulation environment) would greatly reduce the risk of unforseen problems.

Chapter - 7

7. IMPLEMENTATION OF ULTRASONIC WELDING – CONSIDERATION OF SOME AUTOMATION ASPECTS

Introduction

As discussed in the previous chapter, the success of the ultrasonic welding very much depends on the successful implementation of the right technical strategies to support the technology. The wiring harness industry is very labour intensive. Most of the operations are repetitive, involve large series time, yet there has not been significant effort towards automating the tasks. Though lot of implementation of robots has been reported for smaller sizes of harnesses [2], larger ones like the ones for the passenger cars, are still being made manually. Any research effort to bring in some means of minimising the manual repeated tasks would go a long way to increase productivity of the industry.

This chapter discusses the problems associated with the handling of wires and some of the critical methods being currently used which may seem to be redundant.

7.1 Objectives of the study

Objectives of this chapter are to :

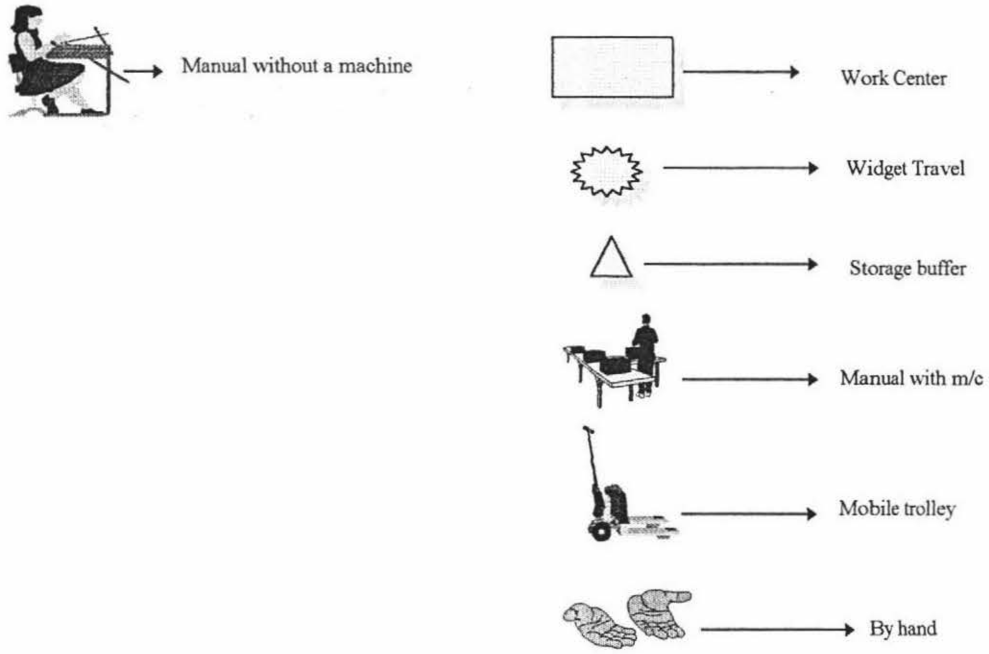
1. Present the existing system of wires handling , being used by a majority of the industry.

2. Identify problems associated within this system.

3. Suggest an alternative wire handling system with an ultimate goal of increasing the productivity ie., improvise the time of handling, minimise the cost of handling and automate certain repeated human tasks.

The current system and the proposed system have been presented in a graphical form to make understanding of the whole concept very easy.

LEGEND TO THE SYSTEM REPRESENTATION



The process representation

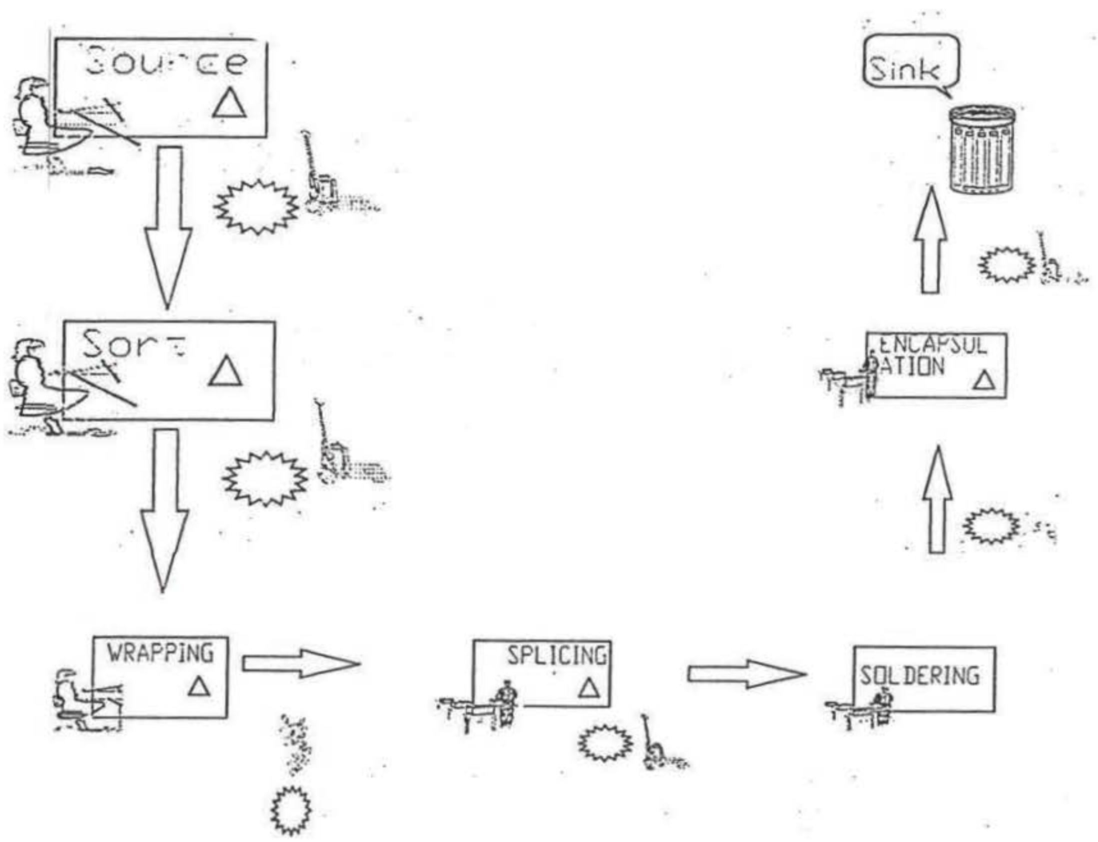


Figure 7-1, Current system of making wire splices

7.2 Operations

Annexure-21 is a tabular representation of different operations which are depicted above and their purpose. Also, it is mentioned as to why each operation is being made, the purpose of the operation.

7.3 Problems associated within the current system

1. In the first instance the wrapping operation seems to be a non value adding operation, just to facilitate better handling, orientation and support for crimping.

2. The cost involved in the tape and labour consumption in wrapping operations is considerable amounts.

3. Travelling between work centres consumes labour time, though it seems very little, it may add up to big values

4. The crimping operation might involve certain hidden unaccounted labour time in orientation of the wires, placement of wires for crimping on the machine anvil,

adjustment of ferule feed spool which all need skill of labour.

5. The cost involved in rework, which may be high if skill of the operator is low.

6. Coordination of placement of workpiece on the anvil and operation of foot lever may consume time.

All these are some of the possible draw backs of the system. Any proposed new system should be able to overcome these problems.

7.4 Proposed handling system

A semi automatic system mainly aimed at solving the above problems has been worked on. A conceptual design has been made to present the system for further criticism, refinement and development. The concept is that, the wires are held without any entanglement, on a pallet. The pallets, each of which can hold a certain number of joints, are then conveyed on a conveyor to two work stations. The first work station has the ultrasonic welding operation as its activity and the next work station encapsulates the joints. The detailed design involves the design of the following major components. These

1. Wire pallets
2. A workstation to place the wires with proper orientation on the pallets
3. An assembly line type conveyor system, with two work stations
4. First workstation is a two axis machine to feed the ultrasonic welding head to the wire pallet to weld the wires while being held on the pallet
5. A second workstation with an encapsulation machine working similar to the above two axis machine. This could be a simple tape applicator or a heat shrinker

7.5 Conceptual designs

Following are the conceptual drawings of different components.

7.5.1 Wire palletiser

The main objective of the wire palletiser is to hold the wires in proper orientation without letting the individual wire to get entangled. Two types have been designed. One is a single sided palletiser the other one is a double sided palletiser.

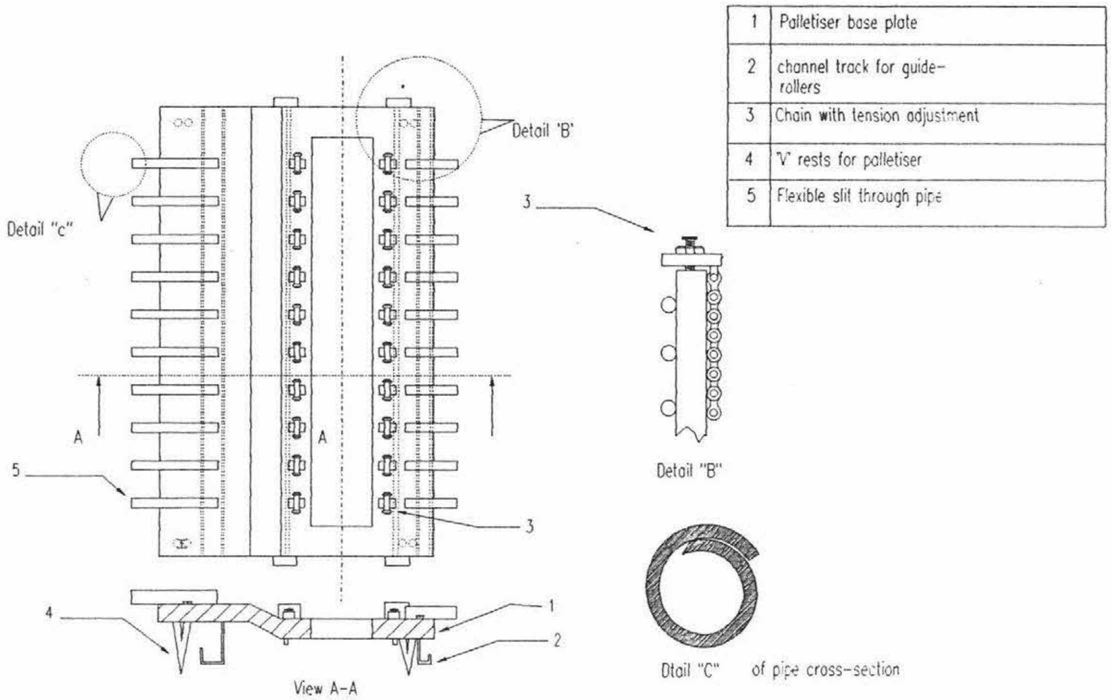


Figure 7-2, Single sided Wire palletiser

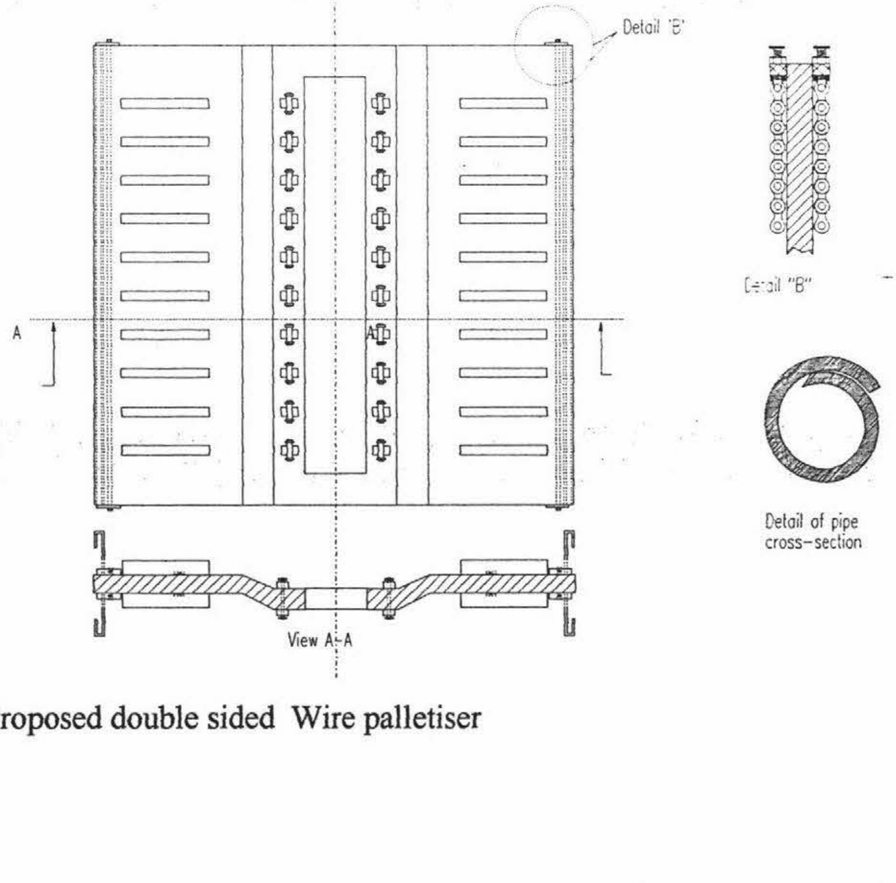


Figure 7-3, Proposed double sided Wire palletiser

The drawings explain most of the construction of the pallets. However, the following are salient points;

- Toggle clamps with compliant foam grippers, hold the wires of varied cross-sectional areas
- Slit tubes on either sides of the pallet hold the wires, not allowing them to mix-up with the wires of other joints
- There is an opening in the middle of the plate to enable the ultrasonic welding head and the encapsulation head to have access to the ends of stripped wires for operations
- The pallets have a simple chain mechanism attached to either ends with a simple tension mechanism. The chain is seated on the drive gears, which move to make the pallet move on the conveyor
- A set of angles at either ends, of the pallet hold the guide rollers to hold the pallet on to the conveyor

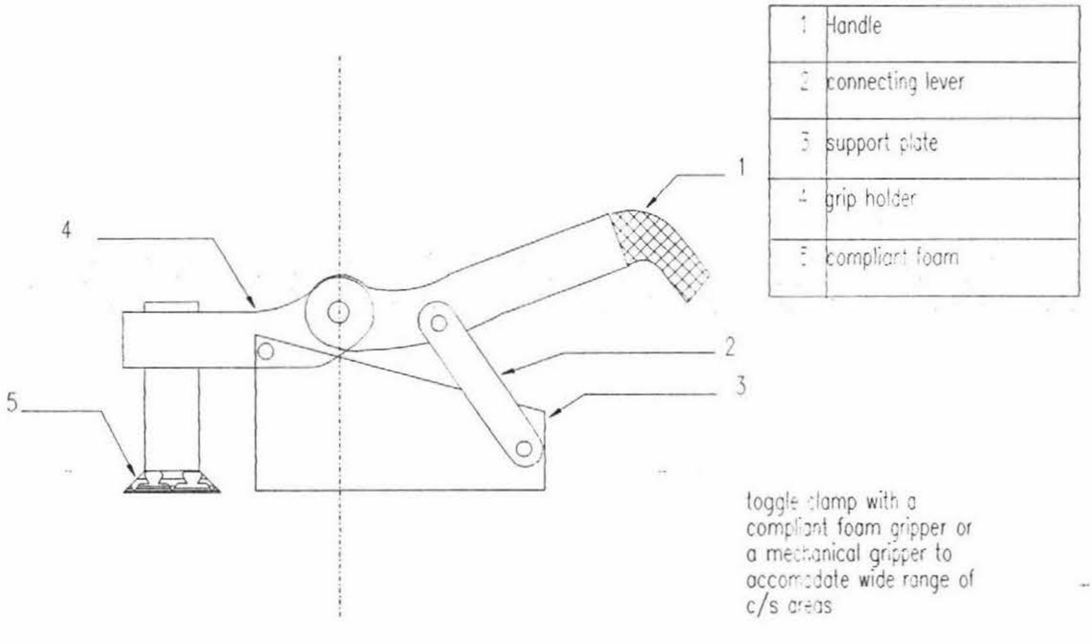
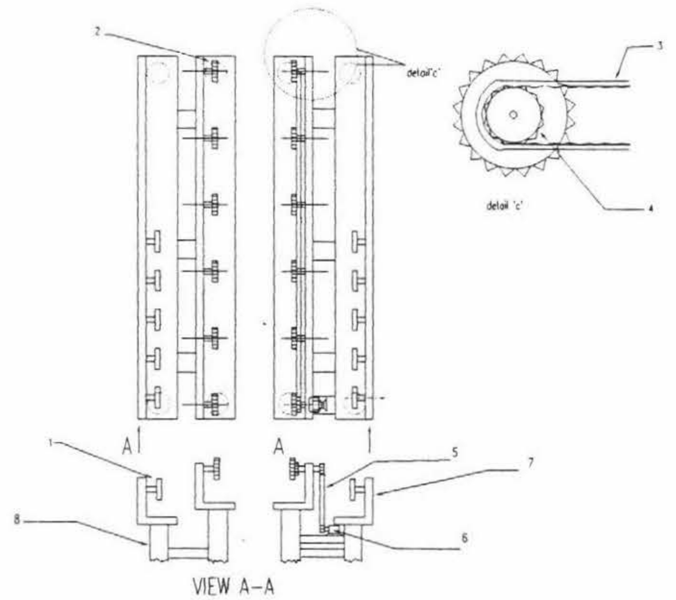


Figure 7-4 Toggle clamp with a compliant foam gripper

7.6 Conveyor for Pallet Movement



1	Guide roller bearings
2	Gear wheels for palletiser translation
3	Flexible belt to drive the gear wheels
4	Drive sprocket for belt
5	Belt drive for motor connection to drive sprocket
6	PLC controlled DC motor
7	Angle to support Guide bearings
8	Steel pipes as a support structure

Figure7-5, Conveyor for single sided wire palletiser

The proposed conveyor for the single sided pallet is shown in Figure 7-5. Its construction and operation have the following main points;

- Two sets of angles at either sides, supported on a simple structure, make the main body of the conveyor
- The extreme set of angles have guide rollers fixed onto them, the corresponding angles of the pallets lock in to these guide rollers to hold the pallet on to the conveyor, without moving upwards
- The inner set of angles on the conveyor, have drive gears fixed, on the face of these drive rollers, the chain of the pallets come and sit
- Drive rollers are connected through a belt, so that when the first drive roller is drive by another belt connected to a DC motor, drive the remaining rollers, thus making the pallet to move on the conveyor
- The DC motor can be controlled by a PLC to control the movement and sequence of different operations

7.7 Possible advantages of the proposed system

1. Many operations are avoided still meeting the requirements of the system such as wrapping, unwrapping, making bundles etc.

2. Material such as tape for wrapping is avoided

3. Operators at the splicing and taping station are not necessary.

4. There would be more control over the splicing operation, if the wire feeding to the ultrasonic welding machine is controlled automatically.

5. The rate of production would increase substantially, as number of operations and human involvement is reduced.

Conclusions

A semiautomatic wire handling approach has been proposed. It is possible to avoid some manual repetitive tasks that were identified as non value adding, like the wrapping and other preparatory operations for wire splicing. The proposed system is a conceptual presentation only. It needs further refinement and detailed designing. The automation system presented in this chapter is yet to be justified by detailed cost-benefit analysis and payback period.

Conclusions

CONCLUSIONS

The current practice of wire splicing has been technically benchmarked by quantifying the electrical resistance and tensile strengths under tension. Ultrasonic welding has been identified as a suitable alternative and superior in many aspects to crimping technology.

Ultrasonically welded samples have been developed and experiments have been carried out to quantify the electrical resistance and tensile strengths. A series of mechanical and electrical tests have been performed. Comparison of the two technologies has revealed the specific areas where the ultrasonically welded wire splices are far superior than crimped connections. Electrical resistance offered by crimped connections have proved to be more than those of ultrasonically welded connections. The tensile strengths of the ultrasonically welded splices have proved to be more than those of the crimped connections.

Logistics study, using simulation, has revealed the possibility of using a generic simulation model to assess the impact of ultrasonic welding on some of the production dynamics. It also helps the industry in finding answers to some fundamental issues relating to the implementation of the technology. Feedback has been given on many aspects of the technology implementation to the industrial sponsor of the project. The number of ultrasonic welding machines required to meet different demand dynamics have been studied and it has been concluded that, one ultrasonic welding machine could meet the existing demand but having two machines would be more reliable and would fit better in case there is any increase in the demand in the near future.

A cost-benefit analysis model has been made on ultrasonic welding machines vs crimping machines. Based on the current volume of production, at Alcatel which was taken as a case study, there is an 18% saving on the total cost of producing splice connections, if ultrasonic welding machines are used.

The concept of a wire palletiser capable of holding wires without wrangling, feeding the wires to the splicing machine and then transferring the wires to the next work centre for encapsulation, has been developed. When implemented, this could result in improving the productivity of wire splicing in the wiring harness industry.

This thesis concludes that the ultrasonic copper welding technique could be safely used for wire splicing by the New Zealand cable harness industry.

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Annexures

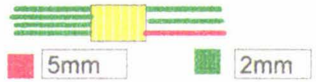
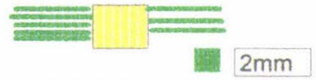
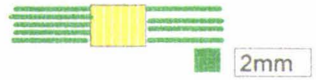
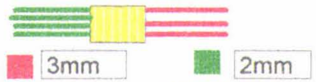
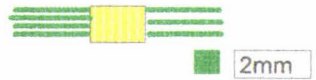
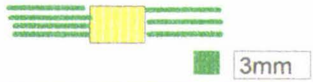
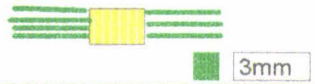
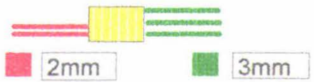
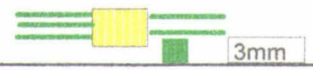
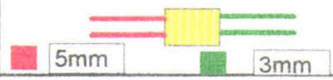
ANNEXURE-1

TABLE 3.3		
Requirements for Fusible Link Wire		
IDENTIFIER	WIRE SIZE mm^2	TENSILE FORCE
Green	0.5mm	7kg
Red	0.8mm	7kg
Black	1.25mm	12kg
Blue	2.0mm	12kg
Special note: Terminated fusible links are compulsory solder after crimping for $0.3mm^2$.		

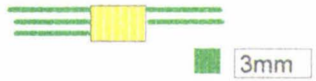
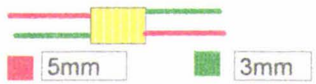
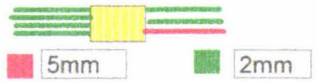
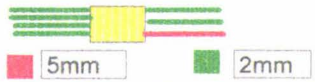
TABLE 4		
Requirements for Internal Joins		
(nominal tensile strength 250 Nm/mm^2)		
WIRE SIZE mm^2	TENSILE FORCE LIGHT GAUGE TERMINALS	TENSILE FORCE HEAVY GAUGE TERMINALS
0.3mm	7kg	7kg
0.5mm	7kg	7kg
0.85mm	9kg	13kg
2.0mm	18kg	30kg
3.0mm	18kg	45kg
5.0mm	18kg	75kg
>5.0mm	9kg/mm	15kg/mm

SUPERCEDED

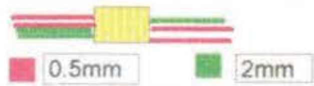
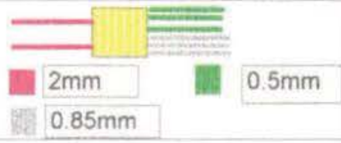
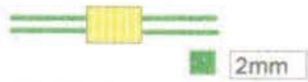
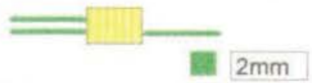
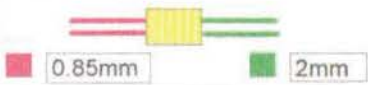
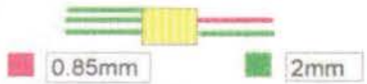
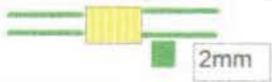
ANNEXURE-2

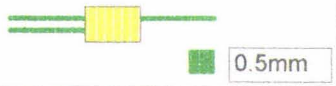
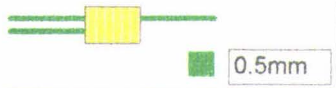
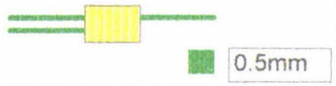
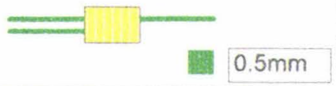
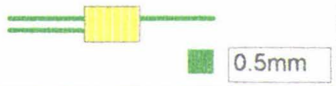
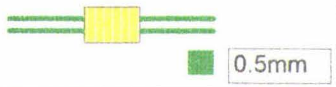
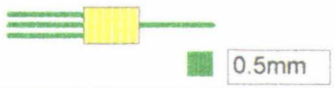
S.NO	MACHINE NO	CABLE SIZES	MACHINE SETTING	SCHEMATIC REPRESENTATION	QUANTITY	GROUP
1	20310	5mm,2mm	17.00		1	G19-E
2	20310	2mm	16.00		1	G19-C
3	20310	2mm	18.00		1	G19-D
4	20310	2mm, 3mm	18.00		1	G19-A
5	20310	2mm	14.00		1	G19-B
6	20310	3mm	24.00		1	G21-C
7	20310	3mm	15.00		1	G21-D
8	20310	3mm	18.00		1	G21-B
9	20310	2mm, 3mm	13.00		1	G21-A
10	20310	3mm	15.00		5	G1
11	20310	5mm, 3mm	16.00		5	G2

Annexure-2

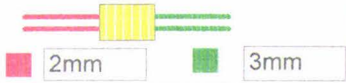
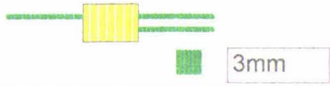
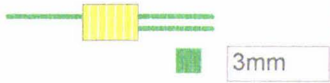
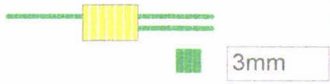
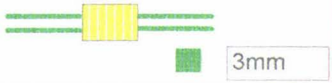
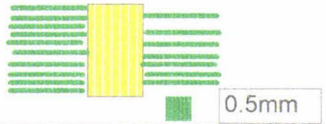
S.NO	MACHINE NO	CABLE SIZES	MACHINE SETTING	SCHEMATIC REPRESENTATION	QUANTITY
1	20312	3mm	15.00		
2	20312	3mm, 5mm	16.00		
3	20312				
4	20312				
5	20312				

Annexure-2

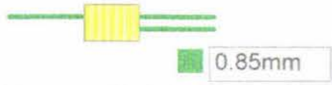
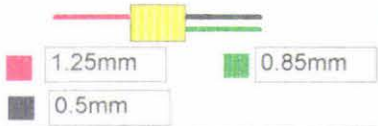
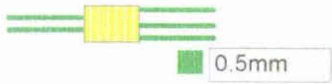
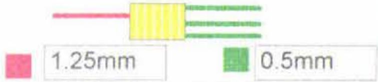
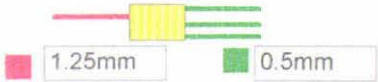
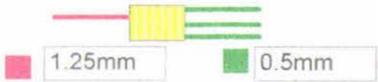
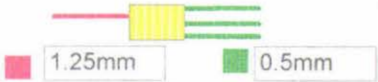
S.NO	MACHINE NO	CABLE SIZES	MACHINE SETTING	SCHEMATIC REPRESENTATION	QUANTITY	
1	20378	2mm, 0.5mm	8.00		5	G3
2	20378	2mm,0.85mm,0.5mm	8.00		5	G6
3	20378	2mm	8.00		1	G22-A
5	20378	2mm	6.00		1	G22-D
6	20378	2mm, 0.85mm	5.80		1	G22-B
7	20378	2mm, 0.85mm	8.90		1	G22-C
8	20378	2mm	8.00			

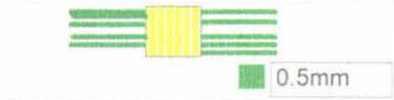
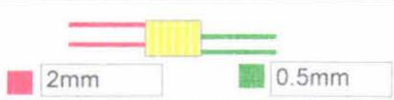
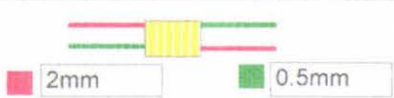
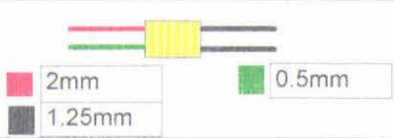
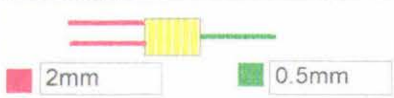
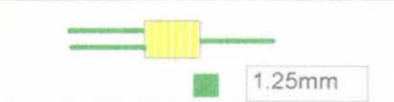
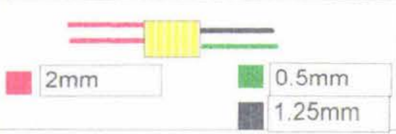
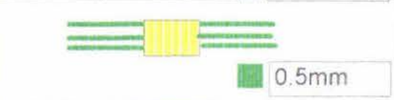
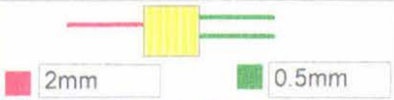
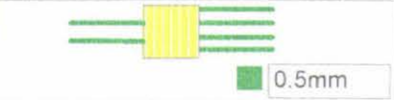
S.NO	MACHINE NO	CABLE SIZES	MACHINE SETTING	SCHEMATIC REPRESENTATION	QUANTITY	GROUP
1	20397	0.5mm	1.50		1	G23-A
2	20397	0.5mm	2.00		1	G23-B
3	20397	0.5mm	1.00		1	G23-C
4	20397	0.5mm	0.90		1	G23-D
5	20397	0.5mm	1.50		5	G17
6	20397	0.5mm	2.00		5	G16
7	20397	0.5mm	1.50		5	G9

Annexure-2

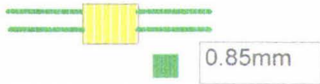
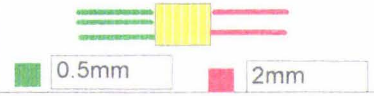
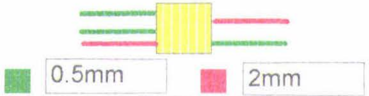
S.NO	MACHINE NO	CABLE SIZES	MACHINE SETTING	SCHEMATIC REPRESENTATION	QUANTITY	GROUP
1	20412	2mm,3mm	10.00		5	G18
2	20412	3mm	8.00		1	G20-B
3	20412	3mm	9.00		1	G20-C
4	20412	3mm	10.00		1	G20-D
5	20412	3mm	12.00		1	G20-A
6	20412	0.5mm	9 (10x8)		1	G5-3
	20412	0.5mm	9 (9x9)		1	G5-2
	20412	0.5mm	9 (9x9)		1	G5-4
	20412	0.5mm	9 (10x8)		1	G5-1

	20412	0.5mm	9 (9x9)		1	G5-5
7	20412	3mm,2mm,0.5mm	9.00		5	G12

S.NO	MACHINE NO	CABLE SIZES	MACHINE SETTING	SCHEMATIC REPRESENTATION	QUANTITY	GROUP
1	20060	0.85mm	2.55		5	G15
2	20060	0.5mm,0.85mm,1.25mm	2.60		5	G11
3	20060	0.5	2.50		5	G13
4	20060	0.5,1.25	2.75		1	G25-A
5	20060	0.5,1.25	3.00		1	G25-B
6	20060	0.5,1.25	2.30		1	G24-C
7	20060	0.5,1.25	2.55		1	G24-D

S.NO	MACHINE NO	CABLE SIZES	MACHINE SETTING	SCHEMATIC REPRESENTATION	QUANTITY	GROUP
1	20062	0.5mm,2mm	5.00		1	G7-3
2	20062	0.5mm,2mm	5.00		1	G7-2
3	20062	0.5mm,2mm	5.00		1	G7-1
4	20062	0.5mm,2mm,1.25	5.00		1	G7-4
5	20062	0.5mm,2mm	4.50		1	G24-B
6	20062	1.25mm	3.75		1	G24-A
7	20062	.5mm,2mm,1.25m	5.75		1	G24-D
8	20062	0.5mm	3.00		1	G24-C
9	20062	0.5mm,2mm	3.00		1	G8-1
10	20062	0.5mm	3.00		3	G8-3, G8-4, G8-2

Annexure-2

11	20062	0.85mm	3.40		1	G10
12	20062	2mm, 0.5mm	5.50		1	G14-2
	20062	2mm, 0.5mm	5.50		1	G14-1
	20062	2mm, 0.5mm	5.50		1	G14-3
	20062	2mm, 0.5mm	5.50		1	G14-4

ANNEXURE-3

III. MACHINE SETTINGS

1. MACHINE CROSS HEAD MOVEMENT

100 mm/min. It was decided referring to the ASTM`STANDARDS and also to the Design standards of ALCATEL, for crimp tensile testing.

2. LOAD CELL CHOSEN

100 KN. load cell was selected. This is the least available load cell, in the materials lab, giving satisfactory results.

3. CALIBRATION SETTINGS

Full scale load of 1KN and 0.5 KN were giving best results. But there seems to be good amount of noise in the plotting. If the noise becomes any constraint, 2 KN. cell shall be used. 2KN load selector was also run and was giving satisfactory results.

4. PLOTTING PAPER POLARITY

Left to right. Polarity A . This seems to be only for the sake of convenience of plot reading/ analysis.

5. PLOTTING PAPER FEED RATE

Proportionate option was selected. 2:1 feed selection is giving good plotting results. However, to quantify the various types of failure, it was decided later on, to go for a 5:1 feeding rate. It proved to be working well.

6. LENGTH OF PAPER BEING CONSUMED ON AN AVERAGE FOR ONE TEST.

200 mm of graph paper is being consumed on an average for each test. Giving a margin of 100 mm on either sides it can be concluded that it would take about 500 mm of paper.

IV. FAILURE DESCRIPTIONS

ANNEXURE-4

TEST PROCEDURE #07A

CRIMP CONTACT DEFORMATION TEST PROCEDURE FOR ELECTRICAL CONNECTORS

(From EIA Standards Proposal No. 1412, formulated under the cognizance of EIA P-5.1 Working Group on Connectors.)

Note: This TP-07A was previously published in EIA Recommended Standard RS-364 as TP-07.

1.0 TP-07A CRIMP CONTACT DEFORMATION

2.0 OBJECT

The object of this test is to detail a standard method to assess the ability of contacts to withstand the crimping operation without deformation beyond specified limits.

3.0 PREPARATION OF THE SPECIMEN

3.1 A test specimen shall consist of a contact and conductor crimped together with the specified tool.

3.2 Contacts should be checked initially to determine conformance to the applicable drawings.

4.0 TEST METHOD

4.1 Test Equipment

4.1.1 Ground precision chuck

4.1.2 Dial gauge indicator, 0.013 mm (.0005 inch) increments with a 2.4 mm (3/32 inch) diameter tip, spring loaded.

4.1.3 Stand (for holding chuck and indicator in proper position).

4.1.4 An equivalent optical gauge may be substituted for the dial indicator.

4.2 Calibration Requirements

"Run out" of the chuck shall be less than 0.013 mm (.0005 inch) when measured on a steel gauge pin (approximately 1.6 mm (1/16 inch) diameter) 13 mm (.5 inch) away from the chuck face.

4.3 Test Procedure

4.3.1 Chuck the contact in the area shown in Figure 1.

4.3.2 Position the dial indicator to the measurement points shown in Figure 1.

4.3.3 Turn the chuck through 360 degrees and record the difference between the maximum and minimum value on each measurement point; this is the TIR.

5.0 DETAILS TO BE SPECIFIED

The following detail shall be specified in the individual Specification:

(a) Wire type and size and crimping tool to be used.

(b) Maximum allowable deformation (TIR).

6.0 DOCUMENTATION

The data sheets shall contain:

(a) Title of test.

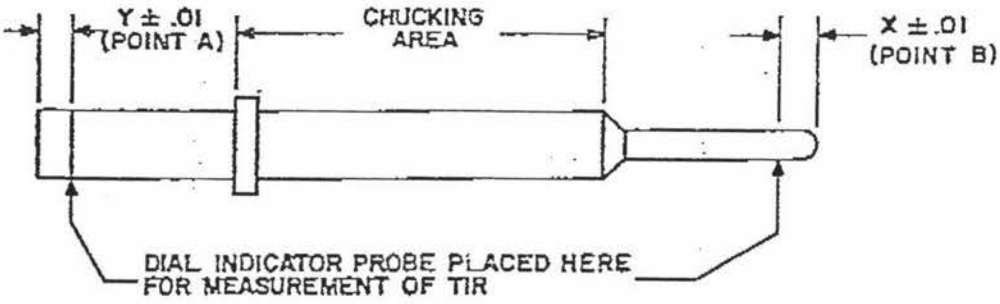
(b) Sample description including fixturing.

(c) Test equipment used.

(d) Test Procedure.

(e) Values and observations.

(f) Date of test and name of operator.



NOTE: For size 12 and larger pins, X = 1 pin diameter
Y = .05 inch

For pins smaller than size 12, X = 2 pin diameters
Y = 1/2 the distance from the rear of the wire barrel to the beginning of the crimp indent.

FIGURE 1

AXIAL CONCENTRICITY (TIR) MEASUREMENT (TYPICAL)

TEST PROCEDURE #08A

CRIMP TENSILE STRENGTH TEST PROCEDURE FOR ELECTRICAL CONNECTORS

(From EIA Standards Proposal No. 1413, formulated under the cognizance of EIA P-5.1 Working Group on Connectors.)

Note: This TP-08A was previously published in EIA Recommended Standard RS-364 as TP-08.

1.0 TP-08A CRIMP TENSILE STRENGTH

2.0 OBJECT

2.1 The object of this test procedure is to determine the tensile strength of a crimped contact to conductor joint. The values obtained give an indication of the relative strength of the joints.

3.0 PREPARATION OF THE SPECIMEN

3.1 A test specimen shall consist of an identified contact and a 5.1 cm (2 inches) minimum conductor crimped together with the specified tool. "If the contact has a wire insulation support, it shall be rendered mechanically ineffective."

4.0 TEST METHOD

4.1 Test Equipment

4.1.1 The testing device shall require the following:

(a) Clamps, jaws, or other means, that will not distort the contact in the crimp area, to hold the contact and the conductor.

(b) A mechanism to separate the holding device at a constant rate of speed 25 ± 6 mm/minimum (1 ± 1/4 inch/minimum).

(c) A gauge to register the amount of tension being exerted between the contact and conductor.

4.2 Test Procedure

4.2.1 Place crimped sample into test fixture of tensile tester.

4.2.2 Activate tensile equipment so that an axial force is exerted at a speed of 25 ± 6 mm/minimum (1 ± 1/4 inch/minimum) separating contact and conductor.

4.2.3 Record tensile data and examine sample.

4.3 Separation

4.3.1 Types of separation resulting from this test are as follows:

(a) Slip (pull out).

(b) Conductor broken in crimp area (some or all).

(c) Contact broken in crimp area (some or all).

(d) Conductor broken outside crimp area.

(e) Contact broken outside crimp area.

DETAILS TO BE SPECIFIED

5.1 The following details shall be specified in the in the individual Specification:

(a) Size and number of contact-conductor combinations required for test.

(b) Description of crimp tool to be used.

(c) Minimum tensile strength requirements.

(d) Sequence of conditioning and testing if applicable.

(e) Conditions if other than ambient.

6.0 DOCUMENTATION

6.1 Data sheets should contain:

(a) Title of test.

(b) Sample description - including fixturing.

(c) Test equipment used.

(d) Test Procedure.

(e) Values and observations.

(1) Tensile data.

(2) Types of separation.

(f) Name of operator.

(g) Date of test.

ANNEXURE-5

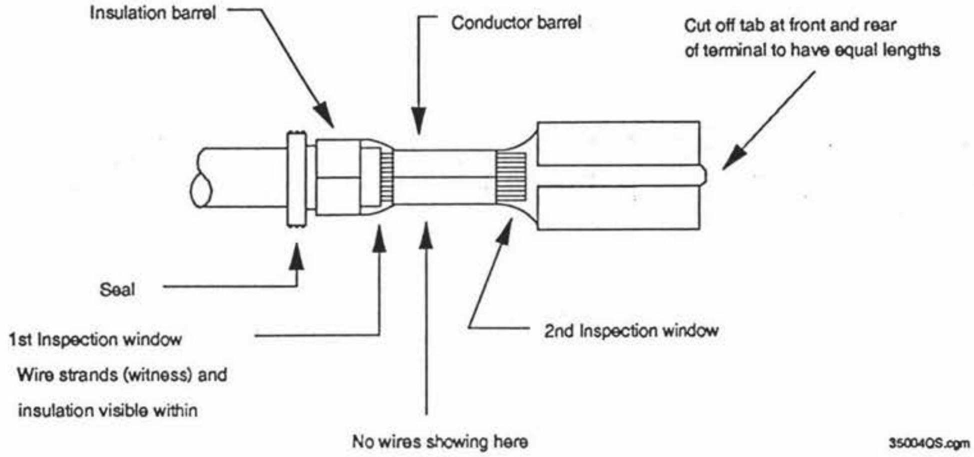


FIG: 1

4.4 Tensile Strength

4.4.1 Terminating

When requested in the Inspection Plan crimps shall pass a pull test as detailed in Tables 3.

4.4.2 Internal Joins

Internal Joins shall be pulled tested as per the specifications of Table 4.

4.5 Taping

4.5.1 Taping of Internal Joins

Internal joins shall:

a: Be completely taped using black PVC 0.12mm minimum thickness tape,

b: Overlap the join two times,

c: Have a taping overlap of 30 percent,

d: Have all ends firm and free from lifting.

Where a wire is required to have its direction reversed after taping, the tape shall overlap the internal join sufficiently so as to provide adequate strain relief.

4.5.2 Dropout

Where a dropout is not fully taped it is shall be located by spot taping.

4.6 Soldering

Where dip soldering stripped wires is required the following specifications shall apply:

a: Solder composition of 63% SN and 37% Pb,

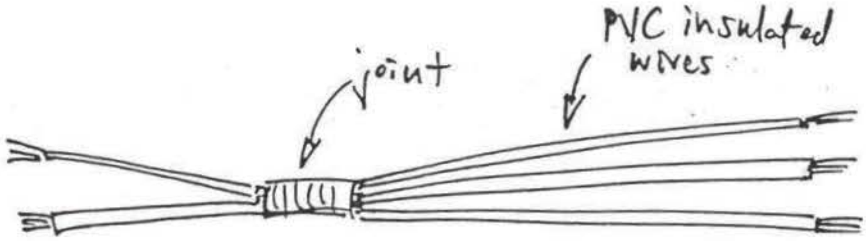
b: Non activated halide free flux,

c: Soldering temperature of $255^{o}C \pm 5^{o}C$.

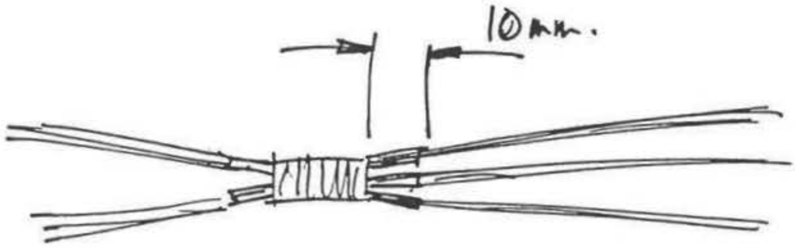
SUPERSEDED

ANNEXURE-6

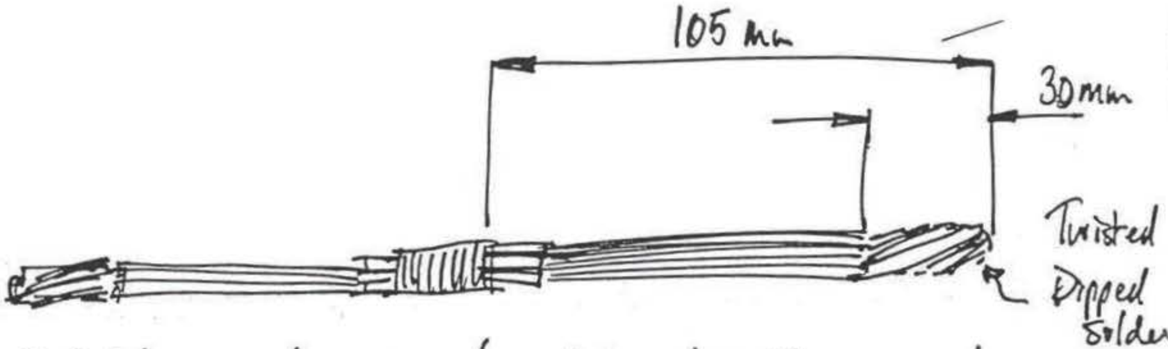
PREPERATION OF WIRE SPLICE SAMPLE FOR TENSILE TESTING :-



1/ Wire splice as recieved...



2/ Wires stripped of their PVC insulation, with small amount remainding...



3/ Wires strands brought together and twisted, subsequently dipped in flux solution, and dipped in molten solder...

Sample ready for Tensile testing.

ANNEXURE-7

Annexure-7

Failure Loads of Crimped Connections

Sample Group	Sample Number	Failure Load in N	Average Failure Load in N	Standard Deviation of Failure Load
G1	1	250.00	199.00	31.90
	2	210.00		
	3	175.00		
	4	185.00		
	5	175.00		
G2	1	255.00	242.00	62.41
	2	230.00		
	3	265.00		
	4	315.00		
	5	145.00		
G3	1	540.00	469.00	68.59
	2	520.00		
	3	365.00		
	4	450.00		
	5	470.00		
G4	1	540.00	411.00	109.22
	2	425.00		
	3	240.00		
	4	450.00		
	5	400.00		
G5	1	410.00	385.00	43.59
	2	370.00		
	3	435.00		
	4	390.00		
	5	320.00		
G6	1	430.00	411.00	106.44
	2	445.00		
	3	260.00		
	4	370.00		
	5	550.00		
G7	1	330.00	297.50	72.74
	2	190.00		
	3	320.00		
	4	350.00		

Sample Group	Sample Number	Failure Load in N	Average Failure Load in N	Standard Deviation of Failure Load
G8	1	155.00	301.25	103.07
	2	360.00		
	3	305.00		
	4	385.00		
G9	1	125.00	124.00	10.25
	2	125.00		
	3	115.00		
	4	115.00		
	5	140.00		
G10	1	310.00	310.00	0.00
G11	1	200.00	206.00	19.81
	2	225.00		
	3	220.00		
	4	210.00		
	5	175.00		
G12	1	380.00	384.00	11.40
	2	380.00		
	3	400.00		
	4	390.00		
	5	370.00		
G13	1	205.00	208.00	24.90
	2	205.00		
	3	235.00		
	4	225.00		
	5	170.00		
G14	1	270.00	302.00	38.18
	2	260.00		
	3	315.00		
	4	355.00		
	5	310.00		
G15	1	160.00	157.00	16.43
	2	180.00		
	3	160.00		

Sample Group	Sample Number	Failure Load in N	Average Failure Load in N	Standard Deviation of Failure Load
	4	150.00		
	5	135.00		
G16	1	205.00	182.00	16.81
	2	195.00		
	3	170.00		
	4	170.00		
	5	170.00		
G17	1	120.00	129.00	6.52
	2	135.00		
	3	125.00		
	4	130.00		
	5	135.00		
G18	1	335.00	388.00	39.62
	2	390.00		
	3	375.00		
	4	395.00		
	5	445.00		
G19	1	360.00	386.00	55.05
	2	360.00		
	3	330.00		
	4	410.00		
	5	470.00		
G20	1	730.00	620.00	121.38
	2	520.00		
	3	720.00		
	4	510.00		
	5			
G21	1	270.00	240.00	31.62
	2	230.00		
	3	200.00		
	4	260.00		
G22	1	460.00	330.00	92.74
	2	310.00		
	3	240.00		
	4	310.00		

Sample Group	Sample Number	Failure Load in N	Average Failure Load in N	Standard Deviation of Failure Load
G23	1	260.00	235.00	28.87
	2	210.00		
	3	260.00		
	4	210.00		
G24	1	220.00	212.50	85.88
	2	90.00		
	3	255.00		
	4	285.00		
G25	1	230.00	245.00	54.01
	2	175.00		
	3	290.00		
	4	285.00		

ANNEXURE-8

SPECIFIED TEST EQUIPMENT

Digital volt meter				
Fluke 8050A 200 mV	resolution	10 µV DC	± 0.03%	+ 2 digits
Beckman 3020 10 amp	resolution	10mA DC	± 1 %	+ 1 digit
Constant current source				
Parameters PA4303	3X30amp	@ 30 V	± 5mV p-p	± 0.5mA RMS
Tensile strength test equipment				
Alphatron	MPT-200A	0 - 90kg ± 0.1	100mm per min	
Crimp height				
Mitutoyo CHM-25DM	PN 342-411	resolution 1µm	accuracy ±µm	

DRAFT
RETURN BY

PROCESS DIAGRAM FOR CRIMP HEIGHT QUALIFICATION PROCESS
(from receipt of samples)

- OBTAIN SAMPLES and SORT
- MEASURE CRIMP HEIGHT
- FIX V/H and V/W
- 4 WIRE RESISTANCE
- STRIP VINYL
- TENSILE STRENGTH
- COMPLETE CALCULATIONS
- PRODUCE GRAPH
- DERIVE CONCLUSIONS
- COMPLETE TEST REPORT
- ENG MAN APPROVES
- COMPLETE IM & DATA ENTRY
- VERIFY
- STORE DATA & SAMPLES

FIGURE SIX

ANNEXURE-9

Annexure-9

Electrical Resistance of Crimped Splice Joints

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
G1	IV	1-2	3	1.50	0.50	0.44	0.38	5.23	16.45
		1-3	3	1.41	0.47				
		1-4	3	0.71	0.24				
		1-5	3	1.61	0.54				
		2-3	3	0.69	0.23	0.24			
		2-4	3	1.06	0.35				
		2-5	3	0.43	0.14				
		3-4	3	1.26	0.42	0.38			
		3-5	3	0.99	0.33				
		4-5	3	1.44	0.48	0.48			
	II	1-2	3	1.20	0.40	0.38	0.28	5.29	16.45
		1-3	3	1.04	0.35				
		1-4	3	0.63	0.21				
		1-5	3	1.65	0.55				
		2-3	3	0.89	0.30	0.27			
		2-4	3	1.05	0.35				
		2-5	3	0.50	0.17				
		3-4	3	0.82	0.27	0.18			
		3-5	3	0.79	0.26				
	III	1-2	3	2.36	0.79	0.60	0.46	5.30	16.45
		1-3	3	2.20	0.73				
		1-4	3	1.10	0.37				
		1-5	3	1.49	0.50				
		2-3	3	1.10	0.37	0.47			
		2-4	3	1.53	0.51				
		2-5	3	1.60	0.53				
		3-4	3	1.65	0.55	0.47			
		3-5	3	1.15	0.38				
		4-5	3	0.87	0.29	0.29			
	V	1-2	3	1.44	0.48	0.34	0.35	5.32	16.45
		1-3	3	1.28	0.43				
		1-4	3	0.56	0.19				
		1-5	3	0.82	0.27				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		2-3	3	0.85	0.28	0.34			
		2-4	3	1.12	0.37				
		2-5	3	1.05	0.35				
		3-4	3	1.33	0.44	0.37			
		3-5	3	0.91	0.30				
		4-5	3	1.08	0.36	0.36			
	I	1-2	3	1.40	0.47	0.51	0.52	5.34	16.45
		1-3	3	1.64	0.55				
		1-4	3	1.55	0.52				
		1-5	3	1.47	0.49				
		2-3	3	1.64	0.55	0.48			
		2-4	3	0.93	0.31				
		2-5	3	1.73	0.58				
		3-4	3	1.62	0.54	0.57			
		3-5	3	1.72	0.57				
		4-5	3	1.81	0.60				
G2	III	1-2	3	1.29	00.4300	00.3422	00.3409	5.04	17.04
		1-3	3	0.98	00.3267				
		1-4	5	1.35	00.2700				
		2-3	3	0.86	00.2867	00.3043			
		2-4	5	1.61	00.3220				
		3-4	5	1.88	00.3760	00.3760			
	I	1-2	3	1.18	00.3933	00.3884	00.3241	5.06	17.04
		1-3	5	1.66	00.3320				
		1-4	3	1.32	00.4400				
		2-3	5	1	00.2000	00.2400			
		2-4	3	0.84	00.2800				
		3-4	5	1.72	00.3440	00.3440			
	V	1-2	3	1.47	00.4900	00.3853	00.2838	5.07	17.04
		1-3	5	2.31	00.4620				
		1-4	5	1.02	00.2040				
		2-3	5	0.5	00.1000	00.2840			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		2-4	5	2.34	00.4680				
		3-4	5	0.91	00.1820	00.1820			
	IV	1-2	3	1.82	00.6067	00.4789	00.6491	5.09	17.04
		1-3	5	2.6	00.5200				
		1-4	5	1.55	00.3100				
		2-3	5	2.7	00.5400	00.5780			
		2-4	5	3.08	00.6160				
		3-4	5	1.91	00.3820	00.8903			
	II	1-2	3	1.29	00.4300	00.3147	00.2938	5.09	17.04
		1-3	3	0.93	00.3100				
		1-4	5	1.02	00.2040				
		2-3	3	0.55	00.1833	00.1467			
		2-4	5	0.55	00.1100				
		3-4	5	2.1	00.4200	00.4200			
G3	II	1-2	0.5	1.3	2.60	1.67	0.98	3.06	8.5288
		1-3	2	2.71	1.36				
		1-4	2	2.75	1.38				
		1-5	2	3.35	1.68				
		1-6	0.5	0.8	1.60				
		1-7	0.5	0.7	1.40				
		2-3	2	1.05	0.53	0.73			
		2-4	2	1.57	0.79				
		2-5	2	1.18	0.59				
		2-6	0.5	0.63	1.26				
		2-7	0.5	0.25	0.50				
		3-4	2	1.15	0.58	0.57			
		3-5	2	1.11	0.56				
		3-6	2	1.61	0.81				
		3-7	2	0.67	0.34				
		4-5	2	2	1.00	1.01			
		4-6	2	2.14	1.07				
		4-7	2	1.92	0.96				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		5-6	2	2.03	1.02	0.87			
		5-7	2	1.46	0.73				
		6-7	0.5	0.51	1.02	1.02			
	V	1-2	2	1.13	0.57	1.16	1.19	3.06	8.5288
		1-3	2	1.65	0.83				
		1-4	0.5	0.54	1.08				
		1-5	2	1.39	0.70				
		1-6	0.5	1.07	2.14				
		1-7	0.5	0.82	1.64				
		2-3	2	1.59	0.80	0.66			
		2-4	2	1.58	0.79				
		2-5	2	1.15	0.58				
		2-6	2	2.3	1.15				
		2-7	2		0.00				
		3-4	2	1.05	0.53	1.09			
		3-5	2	2.8	1.40				
		3-6	2	2.42	1.21				
		3-7	2	2.42	1.21				
		4-5	0.5	1.02	2.04	1.80			
		4-6	0.5	1.01	2.02				
		4-7	2	2.7	1.35				
		5-6	0.5	0.53	1.06	1.13			
		5-7	2	2.4	1.20				
		6-7	2	2.66	1.33	1.33			
	IV	1-2	2	3.01	1.51	2.06	1.53	3.08	8.5288
		1-3	0.5	1.59	3.18				
		1-4	0.5	0.33	0.66				
		1-5	2	4.18	2.09				
		1-6	2	4.05	2.03				
		1-7	0.5	1.46	2.92				
		2-3	2	2.92	1.46	1.00			
		2-4	2	2.24	1.12				
		2-5	2	1.19	0.60				
		2-6	2	1.17	0.59				
		2-7	2	2.45	1.23				
		3-4	0.5	1.29	2.58	1.94			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		3-5	2	3.44	1.72				
		3-6	2	2.94	1.47				
		3-7	0.5	1	2.00				
		4-5	2	1.42	0.71	1.55			
		4-6	2	2.61	1.31				
		4-7	0.5	1.31	2.62				
		5-6	2	1.87	0.94	1.51			
		5-7	2	4.16	2.08				
		6-7	2	2.25	1.13	1.13			
	III	1-2	0.5	0.32	0.64	1.56	1.29	3.09	8.5288
		1-3	2	1.81	0.91				
		1-4	2	3.05	1.53				
		1-5	0.5	1.29	2.58				
		1-6	0.5	1.13	2.26				
		1-7	2	2.92	1.46				
		2-3	2	2.67	1.34	1.36			
		2-4	2	1.94	0.97				
		2-5	0.5	0.74	1.48				
		2-6	0.5	0.63	1.26				
		2-7	2	3.47	1.74				
		3-4	2	3.92	1.96	1.13			
		3-5	2	1.01	0.51				
		3-6	2	2.62	1.31				
		3-7	2	1.52	0.76				
		4-5	2	2.92	1.46	1.07			
		4-6	2	2.37	1.19				
		4-7	2	1.11	0.56				
		5-6	0.5	0.92	1.84	1.69			
		5-7	2	3.09	1.55				
		6-7	2	1.85	0.93	0.93			
	I	1-2	2	1.9	0.95	0.87	0.81	3.10	8.5288
		1-3	2	1.7	0.85				
		1-4	2	2.1	1.05				
		1-5	2	1	0.50				
		1-6	2	1.53	0.77				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		1-7	2	2.16	1.08				
		2-3	0.5	0.3	0.60	0.57			
		2-4	2	0.92	0.46				
		2-5	2	1.77	0.89				
		2-6	0.5	0.18	0.36				
		2-7	0.5	0.28	0.56				
		3-4	2	1.15	0.58	0.77			
		3-5	2	1.9	0.95				
		3-6	0.5	0.4	0.80				
		3-7	0.5	0.37	0.74				
		4-5	2	1.8	0.90	0.77			
		4-6	2	1.07	0.54				
		4-7	2	1.77	0.89				
		5-6	2	1.62	0.81	1.02			
		5-7	2	2.44	1.22				
		6-7	0.5	0.43	0.86	0.86			
G4	IV	1-2	2	1.02	0.51	0.47	0.44	3.08	8.3680
		1-3	2	0.96	0.48				
		1-4	2	0.84	0.42				
		2-3	2	0.85	0.43	0.34			
		2-4	2	0.51	0.26				
		3-4	2	1.04	0.52	0.52			
	III	1-2	2	1.6	0.80	0.82	0.65	3.08	8.3680
		1-3	2	1.25	0.63				
		1-4	2	2.08	1.04				
		2-3	2	1.08	0.54	0.42			
		2-4	2	0.6	0.30				
		3-4	2	1.4	0.70	0.7			
	V	1-2	2	1.11	0.56	0.58	0.81	3.09	8.3680
		1-3	2	1.13	0.57				
		1-4	2	1.25	0.63				
		2-3	2	1.55	0.78	0.76			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		2-4	2	1.47	0.74				
		3-4	2	2.15	1.08	1.08			
	I	1-2	2	0.61	0.31	0.39	0.45	3.09	8.3680
		1-3	2	0.75	0.38				
		1-4	2	0.97	0.49				
		2-3	2	1.24	0.62	0.40			
		2-4	2	0.35	0.18				
		3-4	2	1.13	0.57	0.57			
	II	1-2	2	1.1	0.55	0.75	0.85	3.09	8.3680
		1-3	2	2.01	1.01				
		1-4	2	1.41	0.71				
		2-3	2	1.95	0.98	0.77			
		2-4	2	1.11	0.56				
		3-4	2	2.06	1.03	1.03			
G5	V	1-2	0.5	0.30	0.60	0.78	0.83	3.94	10.1376
		1-3	0.5	0.37	0.74				
		1-4	0.5	0.38	0.76				
		1-5	0.5	0.31	0.62				
		1-6	0.5	0.30	0.60				
		1-7	0.5	0.31	0.62				
		1-8	0.5	0.48	0.96				
		1-9	0.5	0.36	0.72				
		1-10	0.5	0.28	0.56				
		1-11	0.5	0.37	0.74				
		1-12	0.5	0.43	0.86				
		1-13	0.5	0.54	1.08				
		1-14	0.5	0.37	0.74				
		1-15	0.5	0.49	0.98				
		1-16	0.5	0.55	1.10				
		1-17	0.5	0.40	0.80				
		1-18	0.5	0.40	0.80				
		14-1	0.5	0.38	0.76	0.88			
		14-2	0.5	0.40	0.80				
		14-3	0.5	0.40	0.80				
		14-4	0.5	0.35	0.70				
		14-5	0.5	0.48	0.96				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		14-6	0.5	0.48	0.96				
		14-7	0.5	0.52	1.04				
		14-8	0.5	0.57	1.14				
		14-9	0.5	0.40	0.80				
		14-10	0.5	0.48	0.96				
		14-11	0.5	0.47	0.94				
		14-12	0.5	0.40	0.80				
		14-13	0.5	0.40	0.80				
		14-15							
		14-16	0.5	0.37	0.74				
		14-17	0.5	0.43	0.86				
		14-18	0.5	0.48	0.96				
	I	1-2	0.5	.24	0.48	0.75	0.75	4.00	10.1376
		1-3	0.5	.58	1.16				
		1-4	0.5	.45	0.90				
		1-5	0.5	.32	0.64				
		1-6	0.5	.41	0.82				
		1-7	0.5	.36	0.72				
		1-8	0.5	.37	0.74				
		1-9	0.5	.43	0.86				
		1-10	0.5	.34	0.68				
		1-11	0.5	.22	0.44				
		1-12	0.5	.27	0.54				
		1-13	0.5	.34	0.68				
		1-14	0.5	.32	0.64				
		1-15	0.5	.43	0.86				
		1-16	0.5	.43	0.86				
		1-17	0.5	.39	0.78				
		1-18	0.5	.45	0.90				
		11-12	0.5	.41	0.82	0.76			
		11-13	0.5	.34	0.68				
		11-14	0.5	.38	0.76				
		11-15	0.5	.5	1.00				
		11-16	0.5	.33	0.66				
		11-17	0.5	.3	0.60				
		11-18	0.5	.4	0.80				
	II	2-1	0.5	0.30	0.60	0.66	0.63	4.00	10.1376
		2-3	0.5	0.29	0.58				
		2-4	0.5	0.32	0.64				
		2-5	0.5	0.27	0.54				
		2-6	0.5	0.32	0.64				
		2-7	0.5	0.32	0.64				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		2-8	0.5	0.34	0.68				
		2-9	0.5	0.39	0.78				
		2-10	0.5	0.42	0.84				
		2-11	0.5	0.43	0.86				
		2-12	0.5	0.38	0.76				
		2-13	0.5	0.35	0.70				
		2-14	0.5	0.30	0.60				
		2-15	0.5	0.32	0.64				
		2-16	0.5	0.35	0.70				
		2-17	0.5	0.25	0.50				
		2-18	0.5	0.22	0.44				
		12-11	0.5	0.31	0.62	0.60			
		12-13	0.5	0.32	0.64				
		12-14	0.5	0.29	0.58				
		12-15	0.5	0.30	0.60				
		12-16	0.5	0.32	0.64				
		12-17	0.5	0.31	0.62				
		12-18	0.5	0.26	0.52				
	III	3-1	0.5	0.34	0.68	0.74	0.72	4.01	10.1376
		3-2	0.5	0.33	0.66				
		3-4	0.5	0.33	0.66				
		3-5	0.5	0.31	0.62				
		3-6	0.5	0.25	0.50				
		3-7	0.5	0.34	0.68				
		3-8	0.5	0.42	0.84				
		3-9	0.5	0.35	0.70				
		3-10	0.5	0.27	0.54				
		3-11	0.5	0.33	0.66				
		3-12	0.5	0.39	0.78				
		3-13	0.5	0.31	0.62				
		3-14	0.5	0.54	1.08				
		3-15	0.5	0.34	0.68				
		3-16	0.5	0.50	1.00				
		3-17	0.5	0.49	0.98				
		3-18	0.5	0.42	0.84				
		13-9	0.5	0.20	0.40	0.71			
		13-10	0.5	0.35	0.70				
		13-11	0.5	0.42	0.84				
		13-12	0.5	0.37	0.74				
		13-14	0.5	0.36	0.72				
		13-15	0.5	0.37	0.74				
		13-16	0.5	0.38	0.76				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		13-17	0.5	0.39	0.78				
		13-18	0.5	0.35	0.70				
	IV	1-2	0.5	0.40	0.80	0.88	0.79	4.00	10.1376
		1-3	0.5	0.38	0.76				
		1-4	0.5	0.60	1.20				
		1-5	0.5	0.34	0.68				
		1-6	0.5	0.39	0.78				
		1-7	0.5	0.36	0.72				
		1-8	0.5	0.59	1.18				
		1-9	0.5	0.57	1.14				
		1-10	0.5	0.41	0.82				
		1-11	0.5	0.37	0.74				
		1-12	0.5	0.46	0.92				
		1-13	0.5	0.48	0.96				
		1-14	0.5	0.42	0.84				
		1-15	0.5	0.38	0.76				
		1-16	0.5	0.42	0.84				
		1-17	0.5	0.43	0.86				
		1-18	0.5	0.51	1.02				
		15-1	0.5	0.40	0.80	0.69			
		15-2	0.5	0.32	0.64				
		15-3	0.5	0.36	0.72				
		15-4	0.5	0.35	0.70				
		15-5	0.5	0.37	0.74				
		15-6	0.5	0.45	0.90				
		15-7	0.5	0.33	0.66				
		15-8	0.5	0.39	0.78				
		15-9	0.5	0.30	0.60				
		15-10	0.5	0.36	0.72				
		15-11	0.5	0.34	0.68				
		15-12	0.5	0.26	0.52				
		15-13	0.5	0.32	0.64				
		15-14	0.5	0.34	0.68				
		15-16	0.5	0.32	0.64				
		15-17	0.5	0.31	0.62				
		15-18	0.5	0.33	0.66				
G6	II	1-2	2.00	1.52	0.76		1.32	3.08	08.5286
		1-3	2.00	1.62	0.81	0.97			
		1-4	2.00	1.60	0.80				
		1-5	2.00	2.22	1.11				
		1-6	2.00	2.00	1.00				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		1-7	2.00	1.80	0.90				
		1-8	2.00	2.43	1.22				
		2-3	2.00	2.32	1.16	0.78			
		2-4	2.00	1.35	0.68				
		2-5	2.00	1.40	0.70				
		2-6	2.00	1.16	0.58				
		2-7	2.00	0.93	0.47				
		2-8	2.00	2.16	1.08				
		3-4	0.85	0.86	1.01	1.53			
		3-5	0.5	1.02	2.04				
		3-6	0.5	0.83	1.66				
		3-7	0.85	1.16	1.36				
		3-8	0.85	1.32	1.55				
		4-5	0.85	0.91	1.07	1.31			
		4-6	0.85	1.20	1.41				
		4-7	0.85	1.10	1.29				
		4-8	0.85	1.26	1.48				
		5-6	0.5	0.85	1.70	1.61			
		5-7	0.85	1.20	1.41				
		5-8	0.85	1.47	1.73				
		6-7	0.85	0.85	1.00	1.09			
		6-8	0.85	1.00	1.18				
		7-8	0.85	0.90	1.06	1.60			
	I	1-2	2.0	3.62	1.81	0.64	1.22	3.09	08.5286
		1-3	2.0	1.00	0.50				
		1-4	2.0	0.96	0.48				
		1-5	2.0	1.64	0.82				
		1-6	2.0	1.58	0.79				
		1-7	2.0	1.30	0.65				
		1-8	2.0	1.20	0.60				
		2-3	2.0	1.39	0.70	0.78			
		2-4	2.0	2.00	1.00				
		2-5	2.0	1.08	0.54				
		2-6	2.0	1.21	0.61				
		2-7	2.0	2.12	1.06				
		2-8	2.0	1.55	0.78				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		3-4	0.85	0.87	1.02	1.15			
		3-5	0.85	1.14	1.34				
		3-6	0.85	1.02	1.20				
		3-7	0.85	1.18	1.39				
		3-8	0.85	0.66	0.78				
		4-5	0.5	0.96	1.92	1.86			
		4-6	0.5	0.81	1.62				
		4-7	0.85	1.56	1.84				
		4-8	0.5	1.03	2.06				
		5-6	0.5	0.71	1.42	1.58			
		5-7	0.85	1.52	1.79				
		5-8	0.85	1.29	1.52				
		6-7	0.85	1.15	1.35	1.36			
		6-8	0.85	1.17	1.38				
		7-8	0.85	1.02	1.20	1.20			
	III								
		1-2	2.00	0.43	0.22	0.62	1.03	3.09	08.5286
		1-3	2.00	0.85	0.43				
		1-4	2.00	1.59	0.80				
		1-5	2.00	1.13	0.57				
		1-6	2.00	1.37	0.69				
		1-7	2.00	1.44	0.72				
		1-8	2.00	1.82	0.91				
		2-3	2.00	1.17	0.59				
		2-4	2.00	1.22	0.61				
		2-5	2.00	1.25	0.63				
		2-6	2.00	1.26	0.63				
		2-7	2.00	1.45	0.73				
		2-8	2.00	1.55	0.78				
		3-4	0.85	0.38	0.45	0.82			
		3-5	0.85	0.38	0.45				
		3-6	0.85	0.52	0.61				
		3-7	0.85	1.05	1.24				
		3-8	0.85	1.15	1.35				
		4-5	2.00	1.55	0.78	0.96			
		4-6	2.00	1.98	0.99				
		4-7	2.00	1.65	0.83				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		4-8	2.00	2.48	1.24				
		5-6	2.00	1.70	0.85	1.16			
		5-7	2.00	1.82	0.91				
		5-8	2.00	3.45	1.73				
		6-7	0.5	0.35	0.70	0.93			
		6-8	0.5	0.58	1.16				
		7-8	0.5	0.85	1.70	1.70			
	IV	1-2	2.00	0.57	0.29	0.61	1.41	3.10	08.5286
		1-3	2.00	1.34	0.67				
		1-4	2.00	0.80	0.40				
		1-5	2.00	0.74	0.37				
		1-6	2.00	1.88	0.94				
		1-7	2.00	1.20	0.60				
		1-8	2.00	2.00	1.00				
		2-3	2.00	1.72	0.86	1.07			
		2-4	2.00	1.69	0.85				
		2-5	2.00	1.73	0.87				
		2-6	2.00	2.68	1.34				
		2-7	2.00	2.05	1.03				
		2-8	2.00	2.98	1.49				
		3-4	0.85	0.78	0.92	1.21			
		3-5	0.85	0.72	0.85				
		3-6	0.5	0.95	1.90				
		3-7	0.85	0.49	0.58				
		3-8	0.5	0.90	1.80				
		4-5	0.85	1.12	1.32	1.30			
		4-6	0.85	0.73	0.86				
		4-7	0.85	1.05	1.24				
		4-8	0.85	1.53	1.80				
		5-6	0.85	1.31	1.54	1.65			
		5-7	0.85	0.70	0.82				
		5-8	0.85	2.19	2.58				
		6-7	0.85	2.25	2.65	2.67			
		6-8	0.5	1.35	2.70				
		7-8	0.85	1.14	1.34	1.34			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
	V	1-2	2.00	0.78	0.39	0.85	1.19	3.13	08.5286
		1-3	2.00	2.15	1.08				
		1-4	2.00	1.28	0.64				
		1-5	2.00	1.13	0.57				
		1-6	2.00	1.68	0.84				
		1-7	2.00	3.15	1.58				
		1-8	2.00	1.66	0.83				
		2-3	2.00	2.72	1.36	0.98			
		2-4	2.00	1.09	0.55				
		2-5	2.00	1.80	0.90				
		2-6	2.00	2.06	1.03				
		2-7	2.00	2.72	1.36				
		2-8	2.00	1.42	0.71				
		3-4	0.85	0.92	1.08	1.28			
		3-5	0.85	1.16	1.36				
		3-6	0.85	1.11	1.31				
		3-7	0.85	1.14	1.34				
		3-8	0.85	1.10	1.29				
		4-5	0.85	1.00	1.18	1.41			
		4-6	0.85	1.14	1.34				
		4-7	0.5	0.75	1.50				
		4-8	0.5	0.82	1.64				
		5-6	0.85	0.68	0.80	1.32			
		5-7	0.85	1.80	2.12				
		5-8	0.85	0.89	1.05				
		6-7	0.85	1.03	1.21	1.22			
		6-8	0.85	1.04	1.22				
		7-8	0.5	0.62	1.24	1.24			
G7	II	1-2	0.50	0.31	0.62	0.58	0.54	3.48	05.3104
		1-3	2.00	1.22	0.61				
		1-4	2.00	1.04	0.52				
		2-3	2.00	1.64	0.82	0.74			
		2-4	2.00	1.31	0.66				
		3-4	2.00	0.58	0.29	0.29			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
	I	1-2	2.00	0.39	0.20	0.37	0.76	3.49	05.3104
		1-3	2.00	1.54	0.77				
		1-4	2.00	0.28	0.14				
		2-3	2.00	1.82	0.91	1.18			
		2-4	0.50	0.72	1.44				
		3-4	2.00	1.47	0.74	0.74			
	IV	1-2	1.25	0.75	0.60	0.79	0.95	3.5	05.3104
		1-3	2.00	0.71	0.36				
		1-4	1.25	1.78	1.42				
		2-3	1.25	1.71	1.37	1.04			
		2-4	1.25	0.89	0.71				
		3-4	2.00	2.01	1.01	1.01			
	III	1-2	0.50	0.58	1.16	1.12	1.62	3.54	05.6320
		1-3	0.50	0.33	0.66				
		1-4	0.50	0.41	0.82				
		1-5	0.50	0.73	1.46				
		1-6	0.50	0.61	1.22				
		1-7	0.50	0.64	1.28				
		1-8	0.50	0.57	1.14				
		1-9	0.50	0.40	0.80				
		1-10	0.50	0.78	1.56				
		2-3	0.50	0.34	0.68	1.10			
		2-4	0.50	0.75	1.50				
		2-5	0.50	0.42	0.84				
		2-6	0.50	0.73	1.46				
		2-7	0.50	0.49	0.98				
		2-8	0.50	0.58	1.16				
		2-9	0.50	0.50	1.00				
		2-10	0.50	0.57	1.14				
		3-4	0.50	0.49	0.98	1.49			
		3-5	0.50	0.48	0.96				
		3-6	0.50	0.50	1.00				
		3-7	0.50	0.42	0.84				
		3-8	0.50	0.75	1.50				
		3-9	0.50	0.96	1.92				
		3-10	0.50	1.61	3.22				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		4-5	0.50	1.09	2.18	2.00			
		4-6	0.50	0.75	1.50				
		4-7	0.50	0.40	0.80				
		4-8	0.50	1.61	3.22				
		4-9	0.50	1.22	2.44				
		4-10	0.50	0.93	1.86				
		5-6	0.50	0.72	1.44	1.94			
		5-7	0.50	0.25	0.50				
		5-8	0.50	1.55	3.10				
		5-9	0.50	0.68	1.36				
		5-10	0.50	1.66	3.32				
		6-7	0.50	0.40	0.80	1.37			
		6-8	0.50	0.62	1.24				
		6-9	0.50	1.03	2.06				
		6-10	0.50	0.69	1.38				
		7-8	0.50	0.34	0.68	0.97			
		7-9	0.50	0.48	0.96				
		7-10	0.50	0.64	1.28				
		8-9	0.50	0.42	0.84	1.47			
		8-10	0.50	1.05	2.10				
		9-10	0.50	1.57	3.14	3.14			
G8	I	1-2	2.00	0.79	0.40	0.46	0.49	3.02	03.0940
		1-3	2.00	1.03	0.52				
		2-3	0.50	0.26	0.52	0.52			
	IV	1-2	0.50	0.31	0.62	0.72	0.72	3.08	
		1-3	0.50	0.38	0.76				
		1-4	0.50	0.27	0.54				
		1-5	0.50	0.36	0.72				
		1-6	0.50	0.48	0.96				
		2-3	0.50	0.33	0.66	0.69			
		2-4	0.50	0.34	0.68				
		2-5	0.50	0.35	0.70				
		2-6	0.50	0.36	0.72				
		3-4	0.50	0.38	0.76	0.77			
		3-5	0.50	0.42	0.84				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		3-6	0.50	0.35	0.70				
		4-5	0.50	0.42	0.84	0.76			
		4-6	0.50	0.34	0.68				
		5-6	0.50	0.33	0.66	0.66			
	III	1-2	0.50	0.31	0.62	0.70	0.77	3.08	
		1-3	0.50	0.42	0.84				
		1-4	0.50	0.29	0.58				
		1-5	0.50	0.40	0.80				
		1-6	0.50	0.35	0.70				
		2-3	0.50	0.45	0.90				
		2-4	0.50	0.35	0.70				
		2-5	0.50	0.32	0.64				
		2-6	0.50	0.27	0.54				
		3-4	0.50	0.35	0.70	0.75			
		3-5	0.50	0.40	0.80				
		3-6	0.50	0.37	0.74				
		4-5	0.50	0.57	1.14	0.97			
		4-6	0.50	0.40	0.80				
		5-6	0.50	0.34	0.68	0.68			
	II	1-2	0.50	0.53	1.06	1.06	0.84	3.1	
		1-3	0.50	0.62	1.24				
		1-4	0.50	0.63	1.26				
		1-5	0.50	0.40	0.80				
		1-6	0.50	0.48	0.96				
		2-3	0.50	0.29	0.58	0.91			
		2-4	0.50	0.58	1.16				
		2-5	0.50	0.49	0.98				
		2-6	0.50	0.46	0.92				
		3-4	0.50	0.53	1.06	0.06			
		3-5	0.50	0.46	0.92				
		3-6	0.50	0.52	1.04				
		4-5	0.50	0.52	1.04	1.00			
		4-6	0.50	0.48	0.96				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		5-6	0.50	0.58	1.16	1.16			
G9	III	1-2	0.50	0.44	0.88	1.01	0.88	2.05	02.5280
		1-3	0.50	0.55	1.10				
		1-4	0.50	0.52	1.04				
		2-3	0.50	0.40	0.80	0.80			
		2-4	0.50	0.40	0.80				
		3-4	0.50	0.41	0.82	0.82			
	V	1-2	0.50	0.44	0.88	0.81	0.66	2.05	02.2528
		1-3	0.50	0.38	0.76				
		1-4	0.50	0.40	0.80				
		2-3	0.50	0.38	0.76	0.74			
		2-4	0.50	0.36	0.72				
		3-4	0.50	0.22	0.44	0.44			
	I	1-2	0.50	0.37	0.74	0.70	0.62	2.06	02.5506
		1-3	0.50	0.33	0.66				
		1-4	0.50	0.35	0.70				
		2-3	0.50	0.31	0.62	0.55			
		2-4	0.50	0.24	0.48				
		3-4	0.50	0.30	0.60	0.60			
	II	1-2	0.50	0.48	0.96	0.79	0.76	2.06	02.5506
		1-3	0.50	0.30	0.60				
		1-4	0.50	0.41	0.82				
		2-3	0.50	0.36	0.72	0.80			
		2-4	0.50	0.44	0.88				
		3-4	0.50	0.34	0.68	0.68			
	IV	1-2	0.50	0.35	0.70	0.79	0.82	2.06	02.8440
		1-3	0.50	0.37	0.74				
		1-4	0.50	0.46	0.92				
		2-3	0.50	0.45	0.90	0.87			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		2-4	0.50	0.42	0.84				
		3-4	0.50	0.40	0.80	0.80			
G10	I	1-2	0.85	2.48	2.92	2.51	1.94	3.03	03.4400
		1-3	0.85	2.30	2.71				
		1-4	0.85	1.63	1.92				
		2-3	0.85	2.40	2.82	2.09			
		2-4	0.85	1.15	1.35				
		3-4	0.85	1.03	1.21	1.21			
G11	I	1-2	1.25	0.64	0.51	1.07	1.35	2.47	02.7040
		1-3	1.25	2.04	1.63				
		2-3	0.85	1.39	1.64	1.64			
	II	1-2	1.25	2.24	1.79	1.80	1.52	2.47	02.7040
		1-3	1.25	2.25	1.80				
		2-3	0.85	1.05	1.24	1.24			
	III	1-2	1.25	0.89	0.71	1.21	1.68	2.47	02.7040
		1-3	1.25	2.14	1.71				
		2-3	0.85	1.82	2.14	2.14			
	IV	1-2	1.25	2.12	1.70	1.78	2.15	2.48	02.7040
		1-3	1.25	2.34	1.87				
		2-3	0.85	2.14	2.52	2.52			
	IV	1-2	1.25	1.72	1.38	1.61	1.49	2.48	02.7040
		1-3	1.25	2.30	1.84				
		2-3	0.85	1.16	1.36	1.36			
G12	IV	1-2	2.00	1.25	0.63	0.72	0.56	3.89	09.4728
		1-3	0.50	0.45	0.90				
		1-4	0.50	0.39	0.78				
		1-5	0.50	0.34	0.68				
		1-6	3.00	1.92	0.64				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		1-7	2.00	1.40	0.70				
		2-3	2.00	0.74	0.37	0.45			
		2-4	2.00	1.16	0.58				
		2-5	2.00	1.21	0.61				
		2-6	3.00	1.30	0.43				
		2-7	2.00	0.57	0.29				
		3-4	0.50	0.42	0.84	0.65			
		3-5	0.50	0.37	0.74				
		3-6	3.00	1.65	0.55				
		3-7	2.00	0.94	0.47				
		4-5	0.50	0.38	0.76	0.65			
		4-6	3.00	1.30	0.43				
		4-7	2.00	1.51	0.76				
		5-6	3.00	1.50	0.50	0.54			
		5-7	2.00	1.16	0.58				
		6-7	3.00	1.12	0.37	0.37			
	II	1-2	2.00	1.08	0.54	0.52	0.52	3.9	09.4728
		1-3	2.00	1.05	0.53				
		1-4	3.00	1.26	0.42				
		1-5	2.00	1.18	0.59				
		1-6	2.00	0.98	0.49				
		1-7	2.00	1.15	0.58				
		2-3	0.50	0.23	0.46	0.55			
		2-4	3.00	1.32	0.44				
		2-5	2.00	1.30	0.65				
		2-6	0.50	0.28	0.56				
		2-7	0.50	0.31	0.62				
		3-4	3.00	1.07	0.36	0.53			
		3-5	2.00	1.24	0.62				
		3-6	0.50	0.26	0.52				
		3-7	0.50	0.32	0.64				
		4-5	3.00	0.56	0.19	0.33			
		4-6	3.00	1.38	0.46				
		4-7	3.00	1.02	0.34				
		5-6	2.00	1.35	0.68	0.60			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		5-7	2.00	1.06	0.53				
		6-7	0.50	0.30	0.60	0.60			
	I	1-2	2.00	0.72	0.36	0.66	0.63	3.91	09.4728
		1-3	0.50	0.41	0.82				
		1-4	2.00	0.94	0.47				
		1-5	3.00	1.42	0.47				
		1-6	0.50	0.53	1.06				
		1-7	0.50	0.40	0.80				
		2-3	2.00	1.18	0.59	0.49			
		2-4	2.00	0.66	0.33				
		2-5	3.00	0.70	0.23				
		2-6	2.00	1.49	0.75				
		2-7	2.00	1.06	0.53				
		3-4	2.00	0.40	0.20	0.49			
		3-5	3.00	1.45	0.48				
		3-6	0.50	0.40	0.80				
		3-7	0.50	0.28	0.56				
		4-5	3.00	0.79	0.26	0.61			
		4-6	2.00	1.60	0.80				
		4-7	2.00	1.55	0.78				
		5-6	3.00	1.40	0.47	0.49			
		5-7	3.00	1.52	0.51				
		6-7	0.50	0.51	1.02	1.02			
	V								
		1-2	2.00	0.80	0.40	0.39	0.48	3.92	09.4728
		1-3	2.00	1.08	0.54				
		1-4	2.00	0.86	0.43				
		1-5	2.00	0.78	0.39				
		1-6	2.00	0.64	0.32				
		1-7	3.00	0.85	0.28				
		2-3	0.50	0.29	0.58	0.54			
		2-4	0.50	0.37	0.74				
		2-5	0.50	0.28	0.56				
		2-6	2.00	1.02	0.51				
		2-7	3.00	0.97	0.32				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		3-4	0.50	0.42	0.84	0.64			
		3-5	0.50	0.36	0.72				
		3-6	2.00	1.22	0.61				
		3-7	3.00	1.14	0.38				
		4-5	0.50	0.32	0.64	0.50			
		4-6	2.00	1.40	0.70				
		4-7	3.00	0.49	0.16				
		5-6	2.00	0.80	0.40	0.42			
		5-7	3.00	1.30	0.43				
		6-7	3.00	1.21	0.40	0.40			
	III								
		1-2	2.00	0.72	0.36	0.36	0.43	3.92	09.4728
		1-3	2.00	0.83	0.42				
		1-4	2.00	0.58	0.29				
		1-5	3.00	0.33	0.11				
		1-6	2.00	0.81	0.41				
		1-7	2.00	1.20	0.60				
		2-3	0.50	0.23	0.46	0.44			
		2-4	0.50	0.22	0.44				
		2-5	3.00	1.14	0.38				
		2-6	2.00	0.56	0.28				
		2-7	0.50	0.32	0.64				
		3-4	0.50	0.32	0.64	0.49			
		3-5	3.00	1.29	0.43				
		3-6	2.00	0.64	0.32				
		3-7	0.50	0.29	0.58				
		4-5	3.00	1.18	0.39	0.50			
		4-6	2.00	0.95	0.48				
		4-7	0.50	0.32	0.64				
		5-6	3.00	0.98	0.33	0.43			
		5-7	3.00	1.62	0.54				
		6-7	2.00	0.71	0.36	0.36			
G13	III	1-2	0.50	0.48	0.96	0.68	1.09	2.48	02.8160
		1-3	0.50	0.45	0.90				
		1-4	0.50	0.16	0.32				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		1-5	0.50	0.27	0.54				
		2-3	0.50	0.67	1.34	1.28			
		2-4	0.50	0.67	1.34				
		2-5	0.50	0.58	1.16				
		3-4	0.50	0.67	1.34	1.36			
		3-5	0.50	0.69	1.38				
		4-5	0.50	0.52	1.04	1.04			
	V	1-2	0.50	0.90	1.80	1.71	1.48	2.49	02.8160
		1-3	0.50	0.86	1.72				
		1-4	0.50	0.87	1.74				
		1-5	0.50	0.79	1.58				
		2-3	0.50	0.87	1.74	1.65			
		2-4	0.50	0.77	1.54				
		2-5	0.50	0.84	1.68				
		3-4	0.50	0.39	0.78	0.96			
		3-5	0.50	0.57	1.14				
		4-5	0.50	0.79	1.58	1.58			
	IV	1-2	0.50	0.70	1.40	1.41	1.58	2.49	02.8160
		1-3	0.50	0.64	1.28				
		1-4	0.50	0.68	1.36				
		1-5	0.50	0.79	1.58				
		2-3	0.50	0.82	1.64	1.44			
		2-4	0.50	0.62	1.24				
		2-5	0.50	0.72	1.44				
		3-4	0.50	0.82	1.64	1.81			
		3-5	0.50	0.99	1.98				
		4-5	0.50	0.84	1.68	1.68			
	II	1-2	0.50	0.92	1.84	1.44	1.11	2.49	02.8160
		1-3	0.50	0.63	1.26				
		1-4	0.50	0.72	1.44				
		1-5	0.50	0.61	1.22				
		2-3	0.50	0.59	1.18	1.09			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		2-4	0.50	0.46	0.92				
		2-5	0.50	0.59	1.18				
		3-4	0.50	0.41	0.82	1.02			
		3-5	0.50	0.61	1.22				
		4-5	0.50	0.44	0.88	0.88			
	I	1-2	0.50	0.42	0.84	0.86	0.84	2.5	02.8160
		1-3	0.50	0.41	0.82				
		1-4	0.50	0.44	0.88				
		1-5	0.50	0.44	0.88				
		2-3	0.50	0.45	0.90	0.91			
		2-4	0.50	0.42	0.84				
		2-5	0.50	0.50	1.00				
		3-4	0.50	0.49	0.98	0.91			
		3-5	0.50	0.42	0.84				
		4-5	0.50	0.35	0.70	0.70			
G14	II	1-2	2.00	0.69	0.35	0.59	03.6300	00.6803	5.6196
		1-3	2.00	1.09	0.55				
		1-4	2.00	1.22	0.61				
		1-5	2.00	1.73	0.87				
		2-3	2.00	1.12	0.56	0.60			
		2-4	2.00	0.64	0.32				
		2-5	2.00	1.84	0.92				
		3-4	0.50	0.10	0.20	0.63			
		3-5	0.50	0.53	1.06				
		4-5	0.50	0.45	0.90	0.90			
	I	1-2	2.00	0.96	0.48	0.74	03.6300	00.8851	5.6196
		1-3	2.00	1.17	0.59				
		1-4	2.00	1.62	0.81				
		1-5	2.00	2.18	1.09				
		2-3	2.00	0.89	0.45	1.20			
		2-4	0.50	0.79	1.58				
		2-5	0.50	0.79	1.58				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		3-4	2.00	0.94	0.47	0.76			
		3-5	2.00	2.09	1.05				
		4-5	0.50	0.42	0.84	0.84			
	V	1-2	2.00	0.72	0.36	0.92	03.6500	01.0894	5.6196
		1-3	2.00	3.00	1.50				
		1-4	2.00	2.22	1.11				
		1-5	2.00	1.40	0.70				
		2-3	2.00	3.01	1.51	1.18			
		2-4	2.00	2.20	1.10				
		2-5	2.00	1.87	0.94				
		3-4	0.50	0.65	1.30	1.30			
		3-5	0.50	0.65	1.30				
		4-5	0.50	0.48	0.96	0.96			
	III	1-2	2.00	2.14	1.07	0.98	03.6500	01.1515	5.907
		1-3	2.00	2.10	1.05				
		1-4	2.00	2.15	1.08				
		1-5	2.00	2.32	1.16				
		1-6	2.00	1.70	0.85				
		1-7	2.00	1.60	0.80				
		1-8	2.00	1.75	0.88				
		2-3	0.50	0.68	1.36	1.67			
		2-4	0.50	0.99	1.98				
		2-5	0.50	0.49	0.98				
		2-6	0.50	0.84	1.68				
		2-7	0.50	0.91	1.82				
		2-8	0.50	1.09	2.18				
		3-4	0.50	0.35	0.70	0.96			
		3-5	0.50	0.62	1.24				
		3-6	0.50	0.47	0.94				
		3-7	0.50	0.42	0.84				
		3-8	0.50	0.55	1.10				
		4-5	0.50	0.56	1.12	1.09			
		4-6	0.50	0.46	0.92				
		4-7	0.50	0.61	1.22				
		4-8	0.50	0.55	1.10				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		5-6	0.50	0.50	1.00	1.13			
		5-7	0.50	0.52	1.04				
		5-8	0.50	0.67	1.34				
		6-7	0.50	0.53	1.06	0.95			
		6-8	0.50	0.42	0.84				
		7-8	0.50	0.64	1.28	1.28			
	IV	1-2	2.00	2.48	1.24	1.47	03.7700	01.4134	5.9162
		1-3	0.50	0.91	1.82				
		1-4	0.50	0.82	1.64				
		1-5	2.00	2.37	1.19				
		2-3	2.00	2.98	1.49	1.22			
		2-4	2.00	2.96	1.48				
		2-5	2.00	1.35	0.68				
		3-4	0.50	1.36	2.72	1.90			
		3-5	2.00	2.17	1.09				
		4-5	2.00	2.13	1.07	1.07			
G15	I	1-2	0.85	0.42	0.49	0.45	0.42	2.46	02.5490
		1-3	0.85	0.34	0.40				
		2-3	0.85	0.34	0.40	0.40			
	IV	1-2	0.85	0.48	0.56	0.57	0.56	2.46	02.5490
		1-3	0.85	0.49	0.58				
		2-3	0.85	0.47	0.55	0.55			
	II	1-2	0.85	0.41	0.48	0.48	0.49	2.47	02.5490
		1-3	0.85	0.41	0.48				
		2-3	0.85	0.43	0.51	0.51			
	III	1-2	0.85	0.46	0.54	0.45	0.49	2.47	02.5490
		1-3	0.85	0.31	0.36				
		2-3	0.85	0.44	0.52	0.52			
	V	1-2	0.85	0.4	0.47	0.39	0.42	2.47	02.5490
		1-3	0.85	0.27	0.32				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		2-3	0.85	0.38	0.45	0.45			
G16	V	1-2	0.5	0.85	1.70	1.73	02.0500	01.2556	02.5494
		1-3	0.5	0.81	1.62				
		1-4	0.5	0.93	1.86				
		2-3	0.5	0.45	0.90	1.18			
		2-4	0.5	0.73	1.46				
		3-4	0.5	0.43	0.86	0.86			
	III	1-2	0.5	0.30	0.60	0.72	02.0500	00.6900	02.5494
		1-3	0.5	0.37	0.74				
		1-4	0.5	0.41	0.82				
		2-3	0.5	0.39	0.78	0.53			
		2-4	0.5	0.14	0.28				
		3-4	0.5	0.41	0.82	0.82			
	I	1-2	0.5	0.17	0.34	0.63	02.0600	00.6611	02.8460
		1-3	0.5	0.40	0.80				
		1-4	0.5	0.38	0.76				
		2-3	0.5	0.39	0.78	0.73			
		2-4	0.5	0.34	0.68				
		3-4	0.5	0.31	0.62	0.62			
	IV	1-2	0.5	0.45	0.90	0.91	02.0600	01.0256	02.5494
		1-3	0.5	0.49	0.98				
		1-4	0.5	0.42	0.84				
		2-3	0.5	0.78	1.56	1.15			
		2-4	0.5	0.37	0.74				
		3-4	0.5	0.51	1.02	1.02			
	II	1-2	0.5	0.29	0.58	0.76	02.0700	00.9000	02.5494
		1-3	0.5	0.53	1.06				
		1-4	0.5	0.32	0.64				
		2-3	0.5	0.30	0.60	0.84			
		2-4	0.5	0.54	1.08				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		3-4	0.5	0.55	1.10	1.10			
G17	III	1-2	0.5	0.36	0.72	0.66	0.57	2.02	01.9862
		1-3	0.5	0.3	0.60				
		2-3	0.5	0.24	0.48	0.48			
	II	1-2	0.5	0.3	0.60	0.72	0.76	2.02	01.9862
		1-3	0.5	0.42	0.84				
		2-3	0.5	0.4	0.80	0.80			
	IV	1-2	0.5	0.31	0.62	0.91	1.06	2.03	01.9862
		1-3	0.5	0.6	1.20				
		2-3	0.5	0.6	1.20	1.20			
	V	1-2	0.5	0.48	0.96	0.98	1.01	2.04	01.9862
		1-3	0.5	0.5	1.00				
		2-3	0.5	0.52	1.04	1.04			
	I	1-2	0.5	0.72	1.44	1.30	1.33	2.05	01.9862
		1-3	0.5	0.58	1.16				
		2-3	0.5	0.68	1.36	1.36			
G18	IV	1-2	3	1.20	0.40	0.42	03.9200	00.5274	10.5100
		1-3	3	1.32	0.44				
		1-4	3	1.22	0.41				
		2-3	3	1.96	0.65	0.51			
		2-4	3	1.08	0.36				
		3-4	2	1.32	0.66	0.66			
	I	1-2	3	1.17	0.39	0.38	03.9300	00.4344	10.5100
		1-3	3	1.23	0.41				
		1-4	3	1.02	0.34				
		2-3	3	1.46	0.49	0.34			
		2-4	3	0.60	0.20				
		3-4	2	1.16	0.58	0.58			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
	II	1-2	3	0.90	0.30	0.31	03.9300	00.3996	10.5100
		1-3	3	0.71	0.24				
		1-4	3	1.14	0.38				
		2-3	3	1.31	0.44	0.40			
		2-4	3	1.08	0.36				
		3-4	2	0.99	0.50	0.50			
	V								
		1-2	3	0.68	0.23	0.27	03.9400	00.4263	10.5100
		1-3	3	0.68	0.23				
		1-4	3	1.06	0.35				
		2-3	3	1.28	0.43	0.37			
		2-4	3	0.94	0.31				
		3-4	2	1.28	0.64	0.64			
	III	1-2	3	0.80	0.27	0.42	03.9500	00.4428	10.5100
		1-3	3	1.18	0.39				
		1-4	3	1.80	0.60				
		2-3	3	0.96	0.32	0.38			
		2-4	3	1.34	0.45				
		3-4	2	1.05	0.53	0.53			
G19	B	1-2	2.00	0.63	0.32	0.43	04.4900	00.5887	13.755
		1-3	2.00	1.09	0.55				
		1-4	2.00	0.72	0.36				
		1-5	2.00	0.61	0.31				
		1-6	2.00	1.04	0.52				
		1-7	2.00	1.04	0.52				
		2-3	2.00	1.02	0.51	0.47			
		2-4	2.00	1.01	0.51				
		2-5	2.00	0.59	0.30				
		2-6	2.00	1.04	0.52				
		2-7	2.00	1.07	0.54				
		3-4	2.00	1.41	0.71	0.58			
		3-5	2.00	1.10	0.55				
		3-6	2.00	1.03	0.52				
		3-7	2.00	1.06	0.53				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		4-5	2.00	1.03	0.52	0.61			
		4-6	2.00	1.22	0.61				
		4-7	2.00	1.42	0.71				
		5-6	2.00	1.04	0.52	0.58			
		5-7	2.00	1.29	0.65				
		6-7	2.00	1.26	0.63	0.63			
	C	1-2	2.00	1.26	0.63	0.46	04.7400	00.5144	15.72
		1-3	2.00	0.64	0.32				
		1-4	2.00	1.16	0.58				
		1-5	2.00	0.54	0.27				
		1-6	2.00	1.05	0.53				
		1-7	2.00	0.98	0.49				
		1-8	2.00	0.83	0.42				
		2-3	2.00	1.10	0.55	0.58			
		2-4	2.00	1.08	0.54				
		2-5	2.00	1.34	0.67				
		2-6	2.00	1.16	0.58				
		2-7	2.00	1.12	0.56				
		2-8	2.00	1.12	0.56				
		3-4	2.00	1.16	0.58	0.54			
		3-5	2.00	1.16	0.58				
		3-6	2.00	1.10	0.55				
		3-7	2.00	1.10	0.55				
		3-8	2.00	0.88	0.44				
		4-5	2.00	1.12	0.56	0.39			
		4-6	2.00	0.62	0.31				
		4-7	2.00	0.73	0.37				
		4-8	2.00	0.68	0.34				
		5-6	2.00	1.08	0.54	0.44			
		5-7	2.00	1.03	0.52				
		5-8	2.00	0.55	0.28				
		6-7	2.00	1.01	0.51	0.52			
		6-8	2.00	1.08	0.54				
		7-8	2.00	1.02	0.51	0.51			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
	A	1-2	3.00	0.70	0.23	0.20	04.8300	00.3069	17.7300
		1-3	3.00	0.63	0.21				
		1-4	3.00	0.34	0.11				
		1-5	3.00	0.50	0.17				
		1-6	3.00	0.75	0.25				
		1-7	3.00	0.72	0.24				
		2-3	3.00	0.43	0.14	0.26			
		2-4	3.00	1.09	0.36				
		2-5	3.00	1.13	0.38				
		2-6	3.00	0.72	0.24				
		2-7	3.00	0.53	0.18				
		3-4	3.00	1.20	0.40	0.31			
		3-5	3.00	1.25	0.42				
		3-6	3.00	0.84	0.28				
		3-7	3.00	0.48	0.16				
		4-5	2.00	0.48	0.24	0.28			
		4-6	2.00	0.60	0.30				
		4-7	2.00	0.58	0.29				
		5-6	2.00	0.76	0.38	0.37			
		5-7	2.00	0.73	0.37				
		6-7	2.00	0.46	0.23	0.23			
	E	1-2	2.00	0.58	0.29	0.37	04.8600	00.3830	17.019
		1-3	5.00	1.67	0.33				
		1-4	2.00	0.71	0.36				
		1-5	2.00	0.78	0.39				
		1-6	2.00	0.82	0.41				
		1-7	2.00	0.93	0.47				
		2-3	5.00	1.22	0.24	0.31			
		2-4	2.00	0.62	0.31				
		2-5	2.00	0.55	0.28				
		2-6	2.00	0.62	0.31				
		2-7	2.00	0.85	0.43				
		3-4	5.00	2.35	0.47	0.35			
		3-5	5.00	1.67	0.33				
		3-6	5.00	1.00	0.20				
		3-7	5.00	2.06	0.41				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		4-5	2.00	0.67	0.34	0.44			
		4-6	2.00	0.91	0.46				
		4-7	2.00	1.05	0.53				
		5-6	2.00	0.61	0.31	0.29			
		5-7	2.00	0.55	0.28				
		6-7	2.00	0.71	0.36	0.36			
	D	1-2	2.00	0.43	0.22	0.38	05.0100	00.3692	17.685
		1-3	2.00	0.80	0.40				
		1-4	2.00	1.05	0.53				
		1-5	2.00	0.50	0.25				
		1-6	2.00	0.70	0.35				
		1-7	2.00	0.73	0.37				
		1-8	2.00	0.82	0.41				
		1-9	2.00	1.00	0.50				
		2-3	2.00	0.73	0.37	0.34			
		2-4	2.00	0.87	0.44				
		2-5	2.00	0.64	0.32				
		2-6	2.00	0.55	0.28				
		2-7	2.00	0.44	0.22				
		2-8	2.00	0.82	0.41				
		2-9	2.00	0.69	0.35				
		3-4	2.00	0.82	0.41	0.39			
		3-5	2.00	0.87	0.44				
		3-6	2.00	1.05	0.53				
		3-7	2.00	0.95	0.48				
		3-8	2.00	0.52	0.26				
		3-9	2.00	0.51	0.26				
		4-5	2.00	0.91	0.46	0.45			
		4-6	2.00	1.13	0.57				
		4-7	2.00	0.90	0.45				
		4-8	2.00	0.81	0.41				
		4-9	2.00	0.74	0.37				
		5-6	2.00	0.55	0.28	0.35			
		5-7	2.00	0.76	0.38				
		5-8	2.00	0.69	0.35				
		5-9	2.00	0.78	0.39				
		6-7	2.00	0.75	0.38	0.37			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		6-8	2.00	0.62	0.31				
		6-9	2.00	0.87	0.44				
		7-8	2.00	0.76	0.38	0.47			
		7-9	2.00	1.10	0.55				
		8-9	2.00	0.42	0.21	0.21			
G20	B	1-2	3.00	0.30	0.10	0.11	03.9000	00.1650	9.87
		1-3	3.00	0.36	0.12				
		2-3	3.00	0.66	0.22	0.22			
	C	1-2	3.00	0.35	0.12	0.11	03.9700	00.1275	9.87
		1-3	3.00	0.28	0.09				
		2-3	3.00	0.45	0.15	0.15			
	D	1-2	3.00	0.50	0.17	0.15	04.0000	00.1717	9.87
		1-3	3.00	0.40	0.13				
		2-3	3.00	0.58	0.19	0.19			
	A	1-2	3.00	0.56	0.19	0.19	04.2200	00.2550	13.16
		1-3	3.00	0.48	0.16				
		1-4	3.00	0.70	0.23				
		2-3	3.00	0.72	0.24	0.20			
		2-4	3.00	0.49	0.16				
		3-4	3.00	1.11	0.37	0.37			
G21	A	1-2	3.00	1.01	0.34	0.46	04.490	00.470	13.8
		1-3	3.00	1.75	0.58				
		1-4	3.00	1.75	0.58				
		1-5	3.00	1.06	0.35				
		2-3	3.00	1.04	0.35	0.41			
		2-4	3.00	1.53	0.51				
		2-5	3.00	1.09	0.36				
		3-4	3.00	1.56	0.52	0.48			
		3-5	3.00	1.34	0.45				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		4-5	2.00	1.05	0.53	0.53			
	D	1-2	3.00	0.85	0.28	0.34	04.970	00.422	16.45
		1-3	3.00	1.05	0.35				
		1-4	3.00	0.58	0.19				
		1-5	3.00	1.65	0.55				
		2-3	3.00	1.08	0.36	0.43			
		2-4	3.00	1.35	0.45				
		2-5	3.00	1.45	0.48				
		3-4	3.00	1.28	0.43	0.42			
		3-5	3.00	1.25	0.42				
		4-5	3.00	1.47	0.49	0.49			
	B	1-2	3.00	0.83	0.28	0.29	05.320	00.289	19.74
		1-3	3.00	1.10	0.37				
		1-4	3.00	0.84	0.28				
		1-5	3.00	0.74	0.25				
		1-6	3.00	0.81	0.27				
		2-3	3.00	0.63	0.21	0.27			
		2-4	3.00	0.85	0.28				
		2-5	3.00	0.98	0.33				
		2-6	3.00	0.81	0.27				
		3-4	3.00	1.09	0.36	0.32			
		3-5	3.00	1.11	0.37				
		3-6	3.00	0.64	0.21				
		4-5	3.00	0.54	0.18	0.26			
		4-6	3.00	1.02	0.34				
		5-6	3.00	0.92	0.31	0.31			
	C	1-2	3.00	1.34	0.45	0.35	06.100	00.365	26.32
		1-3	3.00	1.05	0.35				
		1-4	3.00	1.18	0.39				
		1-5	3.00	0.80	0.27				
		1-6	3.00	1.02	0.34				
		1-7	3.00	0.90	0.30				
		1-8	3.00	1.04	0.35				
		2-3	3.00	0.81	0.27	0.39			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		2-4	3.00	1.11	0.37				
		2-5	3.00	1.19	0.40				
		2-6	3.00	1.45	0.48				
		2-7	3.00	1.19	0.40				
		2-8	3.00	1.27	0.42				
		3-4	3.00	0.53	0.18	0.29			
		3-5	3.00	1.30	0.43				
		3-6	3.00	0.72	0.24				
		3-7	3.00	1.11	0.37				
		3-8	3.00	0.75	0.25				
		4-5	3.00	0.92	0.31	0.26			
		4-6	3.00	0.80	0.27				
		4-7	3.00	0.70	0.23				
		4-8	3.00	0.73	0.24				
		5-6	3.00	1.34	0.45	0.37			
		5-7	3.00	0.72	0.24				
		5-8	3.00	1.30	0.43				
		6-7	3.00	0.91	0.30	0.34			
		6-8	3.00	1.14	0.38				
		7-8	3.00	1.22	0.41	0.41			
G22	B	1-2	2.00	0.50	0.25	0.39	2.80	0.64	5.6496
		1-3	2.00	1.01	0.51				
		1-4	2.00	0.82	0.41				
		2-3	2.00	1.40	0.70	0.61			
		2-4	2.00	1.03	0.52				
		3-4	0.85	0.78	0.92	0.92			
	D	1-2	2.00	0.91	0.46	0.49	2.95	0.41	5.895
		1-3	2.00	1.04	0.52				
		2-3	2.00	0.66	0.33	0.33			
	A	1-2	2.00	0.89	0.45	0.47	3.06	0.43	7.86
		1-3	2.00	0.68	0.34				
		1-4	2.00	1.22	0.61				
		2-3	2.00	0.81	0.41	0.41			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		2-4	2.00	0.82	0.41				
		3-4	2.00	0.85	0.43	0.43			
	C	1-2	2.00	1.21	0.61	0.54	3.33	0.62	8.719
		1-3	2.00	0.96	0.48				
		1-4	2.00	1.16	0.58				
		1-5	2.00	0.99	0.50				
		2-3	2.00	0.48	0.24	0.57			
		2-4	2.00	1.65	0.83				
		2-5	2.00	1.26	0.63				
		3-4	2.00	1.76	0.88	0.80			
		3-5	2.00	1.43	0.72				
		4-5	2.00	1.18	0.59	0.59			
G23	D								
		1-2	0.50	0.23	0.46	1.93	0.49	0.61	1.6896
		1-3	0.50	0.26	0.52				
		2-3	0.50	0.36	0.72		0.72		
	C								
		1-2	0.50	0.23	0.46	1.96	0.58	0.58	1.6896
		1-3	0.50	0.35	0.70				
		2-3	0.50	0.29	0.58		0.58		
	A								
		1-2	0.50	0.15	0.30	2.03	0.44	0.54	1.6896
		1-3	0.50	0.29	0.58				
		2-3	0.50	0.32	0.64		0.64		
	B								
		1-2	0.50	0.43	0.86	2.13	1.12	1.01	1.6896
		1-3	0.50	0.69	1.38				
		2-3	0.50	0.45	0.90		0.90		
G24	C	1-2	0.50	0.49	0.98	1.06	2.99	0.74	3.3792
		1-3	0.50	0.41	0.82				
		1-4	0.50	0.50	1.00				
		1-5	0.50	0.56	1.12				
		1-6	0.50	0.69	1.38				

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
		2-3	0.50	0.29	0.58	0.72			
		2-4	0.50	0.48	0.96				
		2-5	0.50	0.32	0.64				
		2-6	0.50	0.35	0.70				
		3-4	0.50	0.43	0.86	0.70			
		3-5	0.50	0.31	0.62				
		3-6	0.50	0.31	0.62				
		4-5	0.50	0.38	0.76	0.72			
		4-6	0.50	0.34	0.68				
		5-6	0.50	0.24	0.48	0.48			
	A								
		1-2	1.25	0.45	0.36	0.36	3.12	0.40	3.861
		1-3	1.25	0.45	0.36				
		2-3	1.25	0.55	0.44	0.44			
	B	1-2	2.00	0.75	0.38	0.47	3.3	0.34	4.493
		1-3	2.00	1.14	0.57				
		2-3	2.00	0.42	0.21	0.21			
	D	1-2	1.25	1.35	1.08	1.10	3.59	0.56	5.7802
		1-3	2.00	2.05	1.03				
		1-4	2.00	2.39	1.20				
		2-3	2.00	0.69	0.35	0.30			
		2-4	2.00	0.52	0.26				
		3-4	2.00	0.56	0.28	0.28			
G25	D	1-2	1.25	1.15	0.92	1.05	2.45	1.28	3.654
		1-3	1.25	1.50	1.20				
		1-4	1.25	1.28	1.02				
		2-3	0.5	0.82	1.64	1.48			
		2-4	0.5	0.66	1.32				
		3-4	0.5	0.65	1.30	1.30			

Sample Group	Sample Number	Setup	Current (amps)	Voltage Drop in mv DC	Resistance in micro ohms	Average individual resistance in micro ohms	Average Resistance in micro ohms	Average Height in mm	Total C/S Area of the joint in sq.mm
	C	1-2	1.25	0.82	0.66	0.87	2.51	0.92	3.654
		1-3	1.25	1.60	1.28				
		1-4	1.25	0.84	0.67				
		2-3	0.5	0.53	1.06	0.86			
		2-4	0.5	0.33	0.66				
		3-4	0.5	0.52	1.04	1.04			
	B	1-2	1.25	0.70	0.56	0.51	2.6	0.65	3.654
		1-3	1.25	0.55	0.44				
		1-4	1.25	0.67	0.54				
		2-3	0.5	0.16	0.32	0.67			
		2-4	0.5	0.51	1.02				
		3-4	0.5	0.39	0.78	0.78			
	A	1-2	1.25	1.25	1.00	1.09	2.65	1.19	3.654
		1-3	1.25	1.32	1.06				
		1-4	1.25	1.50	1.20				
		2-3	0.5	0.78	1.56	1.28			
		2-4	0.5	0.50	1.00				
		3-4	0.5	0.60	1.20	1.20			

ANNEXURE-10

Designation: F 458 – 84

Standard Practice for Nondestructive Pull Testing of Wire Bonds[1]

This standard is issued under the fixed designation F 458; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

[S]cope

[1.]1 This practice covers nondestructive testing of indi[vidu]al wire bonds made by either ultrasonic, thermal com[pres]sion or thermosonic techniques. The test is destructive to [un]acceptable wire bonds but is designed to avoid damage to [acce]ptable wire bonds.

[N]OTE 1—Common usage at the present time considers the term [wir]e bond" to include the entire interconnection: both welds and the [interv]ening wire span.

[1].2 The practice covers wire bonds made with small-[dia]meter (from 0.0007 to 0.003-in. (18 to 76-μm)) wire of [the t]ype used in integrated circuits and hybrid microcircuits.

[1].3 This practice can be used only when the loop height of [the] wire bond is large enough to allow a suitable hook for [pull]ing to be placed under the wire.

[1].4 While the procedure is applicable to wire of any [com]position and metallurgical state, criteria are given only [for] gold and aluminum wire.

[1].5 A destructive pull test is used on wire bonds of the [sam]e type and geometry to provide the basis for the [dete]rmination of the nondestructive pulling force to be used [in t]his practice. This may only be used if the sample standard [dev]iation, s, of the pulling forces required to destroy at least [...] of the same wire bonds tested by the destructive pull-test [met]hod is less than or equal to 0.25 of the sample average, $\bar{x}$. [If s] $> 0.25\ \bar{x}$, this practice may not be used.

[N]OTE 2—If $s > 0.25\ \bar{x}$, some aspect of the bonding process is out of [contr]ol. Following corrective action, the destructive pull-test measure[men]ts should be repeated to determine if the $s \leq 0.25\ \bar{x}$ criterion is met.

[1].6 The nondestructive wire-bond pull test is to be per[for]med before any other treatment or screening following [bo]nding and at the same point in processing as the accom[pan]ying destructive test. Preferably, this is done immediately [aft]er bonding.

[1].7 The procedure does not ensure against wire-bond [fail]ure modes induced after the test has been performed.

[1].8 *This standard may involve hazardous materials, oper[ati]ons, and equipment. This standard does not purport to [ad]dress all of the safety problems associated with its use. It is [the] responsibility of whoever uses this standard to consult and [est]ablish appropriate safety and health practices and deter[mi]ne the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

F 219 Methods of Testing Fine Round and Flat Wire for Electron Devices and Lamps[2]

F 459 Test Methods for Measuring Pull Strength of Microelectronic Wire Bonds[2]

3. Summary of Practice

3.1 The use of nondestructive wire-bond pull tests is predicated on data obtained from destructive pull tests on typical samples selected from a lot. The maximum safe nondestructive pull-force levels are determined as a function of the metallurgical properties of the wire and from the calculated mean ($\bar{x}$) and standard deviation (s) of the destructive pull-test data determined in accordance with Methods F 459.

3.2 The maximum safe nondestructive bond-pull force is then applied as a screen for individual wire bonds to identify all bonds with pull strength below the predetermined level of acceptability.

4. Significance and Use

4.1 The nondestructive wire-bond pull test provides a screen for evaluating wire-bond quality and is capable of detecting weak or nonadherent bonds.

4.2 The test is not destructive to acceptable wire bonds.

4.3 This practice provides a procedure for identifying a bonding situation that requires corrective action.

4.4 The purpose of this practice is to identify wire bonds that may fail during subsequent screening procedures or field operation.

4.5 The procedure is to be applied after bonding and before any further treatment.

5. Interferences

5.1 As the force levels of the nondestructive wire-bond pull test depend upon the correct, consistent application of the destructive wire-bond pull test, the same interferences apply as given in Methods F 459.

6. Apparatus

6.1 The apparatus used for the procedure is identical to that used in Methods F 459 except that the lifting mechanism shall have the capability of stressing the wire bond up to a predetermined level. As this predetermined level may change in accordance with the results of a successive series of tests using Methods F 459, as well as to accommodate

[1] This practice is under the jurisdiction of ASTM Committee F-1 on Electronics [and] is the direct responsibility of Subcommittee F01.07 on Interconnection [Bo]nding.

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[2] *Annual Book of ASTM Standards*, Vol 10.04.

TABLE 1 Recommended Maximum Safe Nondestructive Pull Force for Aluminum and Gold Wire

NOTE—$s > 0.25\ \bar{x}$ is inapplicable

Wire		Relation Between $\bar{x}$ and s on the Wire-Bond Pull Test	Recommended Maximum Safe NDP Force
Composition	Elongation, %		
Aluminum	<5	$0.15\bar{x} < s \leq 0.25\bar{x}$	$0.9\ (\bar{x} - 3s)$
Aluminum	<5	$s \leq 0.15\bar{x}$	$0.9\ (\bar{x} - 4s)$
Aluminum	5 to 20	$s \leq 0.25\bar{x}$	$(\bar{x} - 3s)/2$
Aluminum	>20	$s \leq 0.25\bar{x}$	$(\bar{x} - 3s)/3$
Gold	all	$0.15\bar{x} < s \leq 0.25\bar{x}$	$0.7\ (\bar{x} - 3s)$
Gold	all	$s \leq 0.15\bar{x}$	$0.7\ (\bar{x} - 4s)$

changes in wire composition and metallurgy, the lifting mechanism must be capable of applying an adjustable maximum force.

7. Sampling

7.1 As the test is nondestructive, it may be used as a 100 % production line screen so that sampling is not required.

7.2 The test may be used as a lot acceptance test with the sampling scheme agreed to by the participating parties.

8. Calibration and Standardization

8.1 Calibrate the nondestructive stressing device in the same manner as is used in calibrating the destructive wire-bond pull-test apparatus as specified in Methods F 459.

8.2 Carry out the destructive wire-bond pull test in accordance with either Method A or B of Methods F 459, whichever is appropriate to the particular wire bond being tested. Use a rate of force application within the range from 1 to 30 gf/s (10 to 290 mN/s) inclusive. Record the force required to break the wire bond, as well as identifying the wire bond, the device, and whether Method A or B was used.

8.2.1 For noncontinuous use of a particular bonding machine, apply either Method A or Method B (whichever is appropriate) of Methods F 459 to a minimum sample of at least 25 of the same wire bonds once the bonding machine has been turned on, thermally stabilized, and tuned (if the machine is not self-tuning).

8.2.2 For continuous use of a particular bonding machine, apply either Method A or B (whichever is appropriate) of Methods F 459 to a sample of approximately 0.1 % (at least 25 bonds) of the particular wire bond under study after every 2-h period of bonding.

8.3 Given a set of n observed values of the destructive wire-bond pull strength $\{x_i\}$, $i = 1, \ldots, n$, calculate the mean, $\bar{x}$, and the standard deviation, s, of the destructive wire-bond pull test in accordance with the following:

8.3.1 Calculate the average wire-bond pull strength, $\bar{x}$, as follows:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

8.3.2 Calculate the standard deviation for the sample, s, by either of the following:

$$s = \left\{ \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2 \right\}^{1/2},$$

or (equivalently)

$$s = \left\{ \frac{1}{n-1} \left[\sum_{i=1}^{n} x_i^2 - n\,\bar{x}^2 \right] \right\}^{1/2}$$

8.4 Using Table 1, select the wire composition and elongation (obtainable from the wire manufacturer), and the relation between $\bar{x}$ and s appropriate to the wire bond to be tested and determine the recommended maximum safe nondestructive pull (NDP) force from the corresponding entry in the last column.

9. Procedure

9.1 Mount the specimen to be tested and set the lifting mechanism to apply the maximum force level determined in 8.4.

9.2 Carefully place the hook under the center of the wire-bond loop, as in the previously performed destructive wire-bond pull test.

9.3 Set the rate of force application at the same as that used in the destructive test.

9.4 Actuate the lifting mechanism to stress the wire bond.

9.5 Observe whether the bond breaks.

9.5.1 If the bond breaks, record the identification of the bond and the device containing the bond.

9.5.2 If the bond does not break, accept it as satisfactory.

9.6 Repeat 9.1 through 9.5 for all bonds to be tested.

9.7 Record the total number of wire bonds that fail when subjected to the predetermined stress.

9.8 Record the number of devices that failed the test.

10. Report

10.1 The report shall include the following:

10.1.1 Name of the person performing the test,

10.1.2 Date of the test,

10.1.3 Identification of the microelectronic specimen,

10.1.4 Identification of the specific wire bond tested,

10.1.5 Identification of wire by spool and lot,

10.1.6 Identification of bonding machine,

10.1.7 Mean and standard deviation of the destructive wire-bond pull test, as well as the total number of wire bonds so tested,

10.1.8 Wire elongation, and

10.1.9 Percentage of wire bonds that failed upon application of the predetermined safe maximum NDP force.

NOTE 3—Information pertaining to the failure modes observed during the nondestructive test may be useful in failure analysis studies.

ANNEXURE-11

Annexure-11

Fialure Loads of Ultrasonically Welded Splice Joints

Sample Group	Sample Number	Failure Load in N	Average Failure Load in N	Standard Deviation of Failure Loads
G1	1	1350	1377.00	63.206012
	2	1365		
	3	1480		
	4	1380		
	5	1310		
G2	1	1080	1322.00	144.98276
	2	1340		
	3	1400		
	4	1330		
	5	1460		
G3	1	760	728.00	35.637059
	2	760		
	3	740		
	4	690		
	5	690		
G4	1	860	849.00	60.456596
	2	760		
	3	820		
	4	900		
	5	905		
G5	1	680	748.00	88.994382
	2	800		
	3	880		
	4	680		
	5	700		
G6	1	630	780.00	94.074439
	2	890		
	3	800		
	4	780		
	5	800		
G7	1	480	445.00	140.83087
	2	240		
	3	560		
	4	500		

Sample Group	Sample Number	Failure Load in N	Average Failure Load in N	Standard Deviation of Failure Loads
G8	1	225	238.75	32.24257
	2	260		
	3	270		
	4	200		
G9	1	130	137.00	4.472136
	2	135		
	3	140		
	4	140		
	5	140		
G10	1	350	350	0
G11	1	165	227.00	47.249339
	2	250		
	3	240		
	4	195		
	5	285		
G12	1	740	732.00	35.637059
	2	670		
	3	740		
	4	750		
	5	760		
G13	1	220	242.00	25.641763
	2	215		
	3	240		
	4	275		
	5	260		
G14	1	600	481.25	115.20814
	2	385		
	3	380		
	4	560		
	5			
G15	1	320	220.00	56.013391
	2	195		
	3	200		
	4	195		
	5	190		

Sample Group	Sample Number	Failure Load in N	Average Failure Load in N	Standard Deviation of Failure Loads
G16	1	200	162.00	37.516663
	2	205		
	3	130		
	4	145		
	5	130		
G17	1	120	107.00	17.888544
	2	110		
	3	125		
	4	100		
	5	80		
G18	1	860	822.00	52.630789
	2	770		
	3	870		
	4	850		
	5	760		
G19	1	1400	1319.00	153.63919
	2	1395		
	3	1440		
	4	1300		
	5	1060		
G20	1	1100	790.00	208.00641
	2	670		
	3	670		
	4	720		
	5			
G21	1	850	1671.25	552.24353
	2	1960		
	3	1850		
	4	2025		
G22	1	890	537.50	272.93162
	2	250		
	3	590		
	4	420		
G23	1	135	133.75	2.5
	2	130		
	3	135		
	4	135		

Sample Group	Sample Number	Failure Load in N	Average Failure Load in N	Standard Deviation of Failure Loads
G24	1	240	242.50	108.97247
	2	120		
	3	225		
	4	385		
G25	1	215	232.50	13.228757
	2	245		
	3	230		
	4	240		

ANNEXURE-12

Annexure-12

Electrical Resistance of Ultrasonically Welded SpliceJoints

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
G1	1	1-2	3	0.14	0.0467	0.0375	0.0397917	0.034194
		1-3	3	0.15	0.0500			
		1-4	3	0.09	0.0300			
		1-5	3	0.07	0.0233			
		2-3	3	0.15	0.0500	0.05		
		2-4	3	0.15	0.0500			
		2-5	3	0.15	0.0500			
		3-4	3	0.14	0.0467	0.038333		
		3-5	3	0.09	0.0300			
		4-5	3	0.10	0.0333	0.033333		
	2	1-2	3	0.07	0.0233	0.036667	0.0333333	
		1-3	3	0.10	0.0333			
		1-4	3	0.14	0.0467			
		1-5	3	0.13	0.0433			
		2-3	3	0.09	0.0300	0.03		
		2-4	3	0.10	0.0333			
		2-5	3	0.08	0.0267			
		3-4	3	0.08	0.0267	0.026667		
		3-5	3	0.08	0.0267			
		4-5	3	0.12	0.0400	0.04		
	3	1-2	3	0.11	0.0367	0.041667	0.0365278	
		1-3	3	0.13	0.0433			
		1-4	3	0.11	0.0367			
		1-5	3	0.15	0.0500			
		2-3	3	0.08	0.0267	0.037778		
		2-4	3	0.13	0.0433			
		2-5	3	0.13	0.0433			
		3-4	3	0.07	0.0233	0.033333		
		3-5	3	0.13	0.0433			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		4-5	3	0.10	0.0333	0.033333		
	4	1-2	3	0.11	0.0367	0.0325	0.0274306	
		1-3	3	0.11	0.0367			
		1-4	3	0.08	0.0267			
		1-5	3	0.09	0.0300			
		2-3	3	0.12	0.0400	0.038889		
		2-4	3	0.13	0.0433			
		2-5	3	0.10	0.0333			
		3-4	3	0.07	0.0233	0.021667		
		3-5	3	0.06	0.0200			
		4-5	3	0.05	0.0167	0.016667		
	5	1-2	3	0.13	0.0433	0.045	0.0338889	
		1-3	3	0.14	0.0467			
		1-4	3	0.13	0.0433			
		1-5	3	0.14	0.0467			
		2-3	3	0.16	0.0533	0.042222		
		2-4	3	0.11	0.0367			
		2-5	3	0.11	0.0367			
		3-4	3	0.05	0.0167	0.021667		
		3-5	3	0.08	0.0267			
		4-5	3	0.08	0.0267	0.026667		
G2	1	1-2	3	0.05	0.0167	0.022222	0.0160741	0.022044
		1-3	5	0.12	0.0240			
		1-4	5	0.13	0.0260			
		2-3	5	0.06	0.0120	0.016		
		2-4	5	0.10	0.0200			
		3-4	5	0.05	0.0100	0.01		
	2	1-2	3	0.05	0.0167	0.021556	0.0181852	
		1-3	5	0.11	0.0220			
		1-4	5	0.13	0.0260			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		2-3	5	0.12	0.0240	0.023		
		2-4	5	0.11	0.0220			
		3-4	5	0.05	0.0100	0.01		
	3	1-2	3	0.05	0.0167	0.022222	0.0250741	
		1-3	5	0.13	0.0260			
		1-4	5	0.12	0.0240			
		2-3	5	0.18	0.0360	0.029		
		2-4	5	0.11	0.0220			
		3-4	5	0.12	0.0240	0.024		
	4	1-2	3	0.07	0.0233	0.029111	0.0277037	
		1-3	5	0.16	0.0320			
		1-4	5	0.16	0.0320			
		2-3	5	0.18	0.0360	0.032		
		2-4	5	0.14	0.0280			
		3-4	5	0.11	0.0220	0.022		
	5	1-2	3	0.11	0.0367	0.027556	0.0231852	
		1-3	5	0.13	0.0260			
		1-4	5	0.10	0.0200			
		2-3	5	0.18	0.0360	0.028		
		2-4	5	0.10	0.0200			
		3-4	5	0.07	0.0140	0.014		
G3	1	1-2	2	0.17	0.0850	0.060833	0.0720556	0.095706
		1-3	2	0.15	0.0750			
		1-4	2	0.14	0.0700			
		1-5	2	0.07	0.0350			
		1-6	2	0.11	0.0550			
		1-7	2	0.09	0.0450			
		2-3	0.5	0.04	0.0800	0.084		
		2-4	2	0.18	0.0900			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		2-5	2	0.10	0.0500			
		2-6	0.5	0.05	0.1000			
		2-7	0.5	0.05	0.1000			
		3-4	2	0.19	0.0950	0.1		
		3-5	2	0.09	0.0450			
		3-6	0.5	0.08	0.1600			
		3-7	0.5	0.05	0.1000			
		4-5	2	0.10	0.0500	0.045		
		4-6	2	0.07	0.0350			
		4-7	2	0.10	0.0500			
		5-6	2	0.11	0.0550	0.0425		
		5-7	2	0.06	0.0300			
		6-7	0.5	0.05	0.1000	0.1		
	2	1-2	2	0.06	0.0300	0.043	0.049625	
		1-3	2	0.11	0.0550			
		1-4	2	0.09	0.0450			
		1-5	2	0.05	0.0250			
		1-6	2	0.05	0.0250			
		1-7	2	0.13	0.0650			
		2-3	0.5	0.05	0.1000	0.066		
		2-4	2	0.09	0.0450			
		2-5	2	0.09	0.0450			
		2-6	0.5	0.03	0.0600			
		2-7	0.5	0.04	0.0800			
		3-4	2	0.20	0.1000	0.09875		
		3-5	2	0.07	0.0350			
		3-6	0.5	0.06	0.1200			
		3-7	0.5	0.07	0.1400			
		4-5	2	0.05	0.0250	0.04		
		4-6	2	0.04	0.0200			
		4-7	2	0.15	0.0750			
		5-6	2	0.01	0.0050	0.03		
		5-7	2	0.11	0.0550			
		6-7	0.5	0.01	0.0200	0.02		

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
	3	1-2	2	0.11	0.0550	0.054167	0.074875	
		1-3	2	0.04	0.0200			
		1-4	2	0.10	0.0500			
		1-5	2	0.12	0.0600			
		1-6	2	0.10	0.0500			
		1-7	2	0.18	0.0900			
		2-3	0.5	0.02	0.0400	0.078		
		2-4	2	0.07	0.0350			
		2-5	2	0.07	0.0350			
		2-6	0.5	0.05	0.1000			
		2-7	0.5	0.09	0.1800			
		3-4	2	0.07	0.0350	0.05625		
		3-5	2	0.10	0.0500			
		3-6	0.5	0.03	0.0600			
		3-7	0.5	0.04	0.0800			
		4-5	2	0.02	0.0100	0.018333		
		4-6	2	0.06	0.0300			
		4-7	2	0.03	0.0150			
		5-6	2	0.20	0.1000	0.0625		
		5-7	2	0.05	0.0250			
		6-7	0.5	0.09	0.1800	0.18		
	4	1-2	2	0.20	0.1000	0.0975	0.1373056	
		1-3	2	0.19	0.0950			
		1-4	2	0.12	0.0600			
		1-5	2	0.13	0.0650			
		1-6	2	0.25	0.1250			
		1-7	2	0.28	0.1400			
		2-3	0.5	0.11	0.2200	0.183		
		2-4	2	0.28	0.1400			
		2-5	2	0.27	0.1350			
		2-6	0.5	0.12	0.2400			
		2-7	0.5	0.09	0.1800			
		3-4	2	0.28	0.1400	0.1825		
		3-5	2	0.22	0.1100			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		3-6	0.5	0.12	0.2400			
		3-7	0.5	0.12	0.2400			
		4-5	2	0.05	0.0250	0.078333		
		4-6	2	0.18	0.0900			
		4-7	2	0.24	0.1200			
		5-6	2	0.16	0.0800	0.1025		
		5-7	2	0.25	0.1250			
		6-7	0.5	0.09	0.1800	0.18		
	5	1-2	2	0.22	0.1100	0.095833	0.1446667	
		1-3	2	0.22	0.1100			
		1-4	2	0.14	0.0700			
		1-5	2	0.08	0.0400			
		1-6	2	0.21	0.1050			
		1-7	2	0.28	0.1400			
		2-3	0.5	0.11	0.2200	0.183		
		2-4	2	0.20	0.1000			
		2-5	2	0.23	0.1150			
		2-6	0.5	0.13	0.2600			
		2-7	0.5	0.11	0.2200			
		3-4	2	0.28	0.1400	0.2025		
		3-5	2	0.22	0.1100			
		3-6	0.5	0.14	0.2800			
		3-7	0.5	0.14	0.2800			
		4-5	2	0.08	0.0400	0.076667		
		4-6	2	0.19	0.0950			
		4-7	2	0.19	0.0950			
		5-6	2	0.22	0.1100	0.11		
		5-7	2	0.22	0.1100			
		6-7	0.5	0.10	0.2000	0.2		
G4	1	1-2	2	0.08	0.0400	0.05	0.0475	0.047889
		1-3	2	0.11	0.0550			
		1-4	2	0.11	0.0550			
		2-3	2	0.10	0.0500	0.0525		

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		2-4	2	0.11	0.0550			
		3-4	2	0.08	0.0400	0.04		
	2	1-2	2	0.08	0.0400	0.053333	0.0502778	
		1-3	2	0.12	0.0600			
		1-4	2	0.12	0.0600			
		2-3	2	0.12	0.0600	0.0575		
		2-4	2	0.11	0.0550			
		3-4	2	0.08	0.0400	0.04		
	3	1-2	2	0.08	0.0400	0.05	0.0483333	
		1-3	2	0.11	0.0550			
		1-4	2	0.11	0.0550			
		2-3	2	0.11	0.0550	0.055		
		2-4	2	0.11	0.0550			
		3-4	2	0.08	0.0400	0.04		
	4	1-2	2	0.10	0.0500	0.051667	0.0472222	
		1-3	2	0.10	0.0500			
		1-4	2	0.11	0.0550			
		2-3	2	0.11	0.0550	0.055		
		2-4	2	0.11	0.0550			
		3-4	2	0.07	0.0350	0.035		
	5	1-2	2	0.09	0.0450	0.048333	0.0461111	
		1-3	2	0.10	0.0500			
		1-4	2	0.10	0.0500			
		2-3	2	0.10	0.0500	0.055		
		2-4	2	0.12	0.0600			
		3-4	2	0.07	0.0350	0.035		
G5	1	1-2	0.5	0.18	0.36	0.3235	0.302201	0.243658

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		1-3	0.5	0.17	0.34			
		1-4	0.5	0.17	0.34			
		1-5	0.5	0.19	0.38			
		1-6	0.5	0.18	0.36			
		1-7	0.5	0.18	0.36			
		1-8	0.5	0.15	0.30			
		1-9	0.5	0.16	0.32			
		1-10	0.5	0.17	0.34			
		1-11	0.5	0.14	0.28			
		1-12	0.5	0.15	0.30			
		1-13	0.5	0.14	0.28			
		1-14	0.5	0.14	0.28			
		1-15	0.5	0.16	0.32			
		1-16	0.5	0.14	0.28			
		1-17	0.5	0.16	0.32			
		1-18	0.5	0.17	0.34			
		5-6	0.5	0.19	0.38	0.3538		
		5-7	0.5	0.16	0.32			
		5-8	0.5	0.19	0.38			
		5-9	0.5	0.18	0.36			
		5-10	0.5	0.16	0.32			
		5-11	0.5	0.16	0.32			
		5-12	0.5	0.19	0.38			
		5-13	0.5	0.17	0.34			
		5-14	0.5	0.17	0.34			
		5-15	0.5	0.18	0.36			
		5-16	0.5	0.19	0.38			
		5-17	0.5	0.19	0.38			
		5-18	0.5	0.17	0.34			
		11-12	0.5	0.11	0.22	0.2314		
		11-13	0.5	0.10	0.20			
		11-14	0.5	0.10	0.20			
		11-15	0.5	0.12	0.24			
		11-16	0.5	0.13	0.26			
		11-17	0.5	0.12	0.24			
		11-18	0.5	0.13	0.26			
		15-16	0.5	0.15	0.30	0.3000		
		15-17	0.5	0.16	0.32			
		15-18	0.5	0.14	0.28			
	2	1-2	0.5	0.12	0.24	0.2412	0.2337255	

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistanc e in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		1-3	0.5	0.11	0.22			
		1-4	0.5	0.12	0.24			
		1-5	0.5	0.12	0.24			
		1-6	0.5	0.11	0.22			
		1-7	0.5	0.12	0.24			
		1-8	0.5	0.09	0.18			
		1-9	0.5	0.10	0.20			
		1-10	0.5	0.13	0.26			
		1-11	0.5	0.13	0.26			
		1-12	0.5	0.14	0.28			
		1-13	0.5	0.13	0.26			
		1-14	0.5	0.13	0.26			
		1-15	0.5	0.13	0.26			
		1-16	0.5	0.14	0.28			
		1-17	0.5	0.11	0.22			
		1-18	0.5	0.12	0.24			
		10-11	0.5	0.15	0.30	0.2400		
		10-12	0.5	0.13	0.26			
		10-13	0.5	0.11	0.22			
		10-14	0.5	0.10	0.20			
		10-15	0.5	0.10	0.20			
		10-16	0.5	0.11	0.22			
		10-17	0.5	0.13	0.26			
		10-18	0.5	0.13	0.26			
		15-16	0.5	0.10	0.20	0.2200		
		15-17	0.5	0.10	0.20			
		15-18	0.5	0.13	0.26			
	3	1-2	0.5	0.05	0.10	0.1835	0.2315178	
		1-3	0.5	0.07	0.14			
		1-4	0.5	0.06	0.12			
		1-5	0.5	0.07	0.14			
		1-6	0.5	0.07	0.14			
		1-7	0.5	0.07	0.14			
		1-8	0.5	0.09	0.18			
		1-9	0.5	0.09	0.18			
		1-10	0.5	0.06	0.12			
		1-11	0.5	0.13	0.26			
		1-12	0.5	0.15	0.30			
		1-13	0.5	0.13	0.26			
		1-14	0.5	0.09	0.18			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		1-15	0.5	0.13	0.26			
		1-16	0.5	0.1	0.20			
		1-17	0.5	0.08	0.16			
		1-18	0.5	0.12	0.24			
		5-6	0.5	0.08	0.16	0.2231		
		5-7	0.5	0.05	0.10			
		5-8	0.5	0.04	0.08			
		5-9	0.5	0.13	0.26			
		5-10	0.5	0.13	0.26			
		5-11	0.5	0.13	0.26			
		5-12	0.5	0.08	0.16			
		5-13	0.5	0.16	0.32			
		5-14	0.5	0.11	0.22			
		5-15	0.5	0.11	0.22			
		5-16	0.5	0.14	0.28			
		5-17	0.5	0.15	0.30			
		5-18	0.5	0.14	0.28			
		11-12	0.5	0.13	0.26	0.2629		
		11-13	0.5	0.15	0.30			
		11-14	0.5	0.11	0.22			
		11-15	0.5	0.14	0.28			
		11-16	0.5	0.13	0.26			
		11-17	0.5	0.13	0.26			
		11-18	0.5	0.13	0.26			
		15-16	0.5	0.14	0.28	0.2667		
		15-17	0.5	0.13	0.26			
		15-18	0.5	0.13	0.26			
	4	1-2	0.5	0.12	0.24	0.2313		
		1-3	0.5	0.10	0.20			
		1-4	0.5	0.10	0.20			
		1-5	0.5	0.13	0.26			
		1-6	0.5	0.13	0.26			
		1-7	0.5	0.13	0.26			
		1-8	0.5	0.07	0.14			
		1-9	0.5	0.13	0.26			
		1-10	0.5	0.12	0.24			
		1-11	0.5	0.06	0.12			
		1-12	0.5	0.14	0.28			
		1-13	0.5	0.12	0.24			
		1-14	0.5	0.12	0.24			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		1-15	0.5	0.12	0.24			
		1-16	0.5	0.15	0.30			
		1-17	0.5	0.11	0.22			
		1-18	0.5		0.00			
		5-6	0.5	0.13	0.26	0.2733		
		5-7	0.5	0.14	0.28			
		5-8	0.5	0.16	0.32			
		5-9	0.5	0.14	0.28			
		5-10	0.5	0.13	0.26			
		5-11	0.5	0.13	0.26			
		5-12	0.5	0.14	0.28			
		5-13	0.5	0.15	0.30			
		5-14	0.5	0.12	0.24			
		5-15	0.5	0.13	0.26			
		5-16	0.5	0.15	0.30			
		5-17	0.5	0.12	0.24			
		5-18	0.5					
		10-11	0.5	0.12	0.24	0.2314		
		10-12	0.5	0.1	0.20			
		10-13	0.5	0.12	0.24			
		10-14	0.5	0.1	0.20			
		10-15	0.5	0.13	0.26			
		10-16	0.5	0.11	0.22			
		10-17	0.5	0.13	0.26			
		14-15	0.5	0.08	0.16	0.1800		
		14-16	0.5	0.08	0.16			
		14-17	0.5	0.11	0.22			
	5	1-2	0.5	0.13	0.26	0.2482	0.2071895	
		1-3	0.5	0.14	0.28			
		1-4	0.5	0.10	0.20			
		1-5	0.5	0.13	0.26			
		1-6	0.5	0.16	0.32			
		1-7	0.5	0.12	0.24			
		1-8	0.5	0.14	0.28			
		1-9	0.5	0.13	0.26			
		1-10	0.5	0.15	0.30			
		1-11	0.5	0.07	0.14			
		1-12	0.5	0.10	0.20			
		1-13	0.5	0.13	0.26			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistanc e in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		1-14	0.5	0.09	0.18			
		1-15	0.5	0.15	0.30			
		1-16	0.5	0.11	0.22			
		1-17	0.5	0.13	0.26			
		1-18	0.5	0.13	0.26			
		10-11	0.5	0.12	0.24	0.2200		
		10-12	0.5	0.11	0.22			
		10-13	0.5	0.11	0.22			
		10-14	0.5	0.12	0.24			
		10-15	0.5	0.08	0.16			
		10-16	0.5	0.10	0.20			
		10-17	0.5	0.13	0.26			
		10-18	0.5	0.11	0.22			
		15-16	0.5	0.08	0.16	0.1533		
		15-17	0.5	0.08	0.16			
		15-18	0.5	0.07	0.14			
G6	1	1-2	2	0.12	0.0600	0.080714	0.1381982	0.120605
		1-3	2	0.19	0.0950			
		1-4	2	0.17	0.0850			
		1-5	2	0.16	0.0800			
		1-6	2	0.16	0.0800			
		1-7	2	0.14	0.0700			
		1-8	2	0.19	0.0950			
		2-3	2	0.11	0.0550	0.0775		
		2-4	2	0.18	0.0900			
		2-5	2	0.14	0.0700			
		2-6	2	0.14	0.0700			
		2-7	2	0.16	0.0800			
		2-8	2	0.20	0.1000			
		3-4	0.5	0.10	0.2000	0.158353		
		3-5	0.5	0.09	0.1800			
		3-6	0.85	0.08	0.0941			
		3-7	0.85	0.12	0.1412			
		3-8	0.85	0.15	0.1765			
		4-5	0.5	0.09	0.1800	0.180294		
		4-6	0.85	0.18	0.2118			
		4-7	0.85	0.14	0.1647			
		4-8	0.85	0.14	0.1647			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		5-6	0.85	0.11	0.1294	0.160784		
		5-7	0.85	0.14	0.1647			
		5-8	0.85	0.16	0.1882			
		6-7	0.85	0.13	0.1529	0.152941		
		6-8	0.85	0.13	0.1529			
	2	1-2	2	0.10	0.0500	0.077857	0.110267	
		1-3	2	0.18	0.0900			
		1-4	2	0.16	0.0800			
		1-5	2	0.16	0.0800			
		1-6	2	0.15	0.0750			
		1-7	2	0.18	0.0900			
		1-8	2	0.16	0.0800			
		2-3	2	0.16	0.0800	0.071667		
		2-4	2	0.20	0.1000			
		2-5	2	0.13	0.0650			
		2-6	2	0.10	0.0500			
		2-7	2	0.13	0.0650			
		2-8	2	0.14	0.0700			
		3-4	0.5	0.07	0.1400	0.121882		
		3-5	0.5	0.07	0.1400			
		3-6	0.85	0.09	0.1059			
		3-7	0.85	0.07	0.0824			
		3-8	0.85	0.12	0.1412			
		4-5	0.5	0.10	0.2000	0.135294		
		4-6	0.85	0.09	0.1059			
		4-7	0.85	0.09	0.1059			
		4-8	0.85	0.11	0.1294			
		5-6	0.85	0.11	0.1294	0.12549		
		5-7	0.85	0.12	0.1412			
		5-8	0.85	0.09	0.1059			
		6-7	0.85	0.10	0.1176	0.129412		
		6-8	0.85	0.12	0.1412			
	3	1-2	2	0.05	0.0250	0.071429	0.1196401	
		1-3	2	0.19	0.0950			
		1-4	2	0.17	0.0850			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		1-5	2	0.16	0.0800			
		1-6	2	0.11	0.0550			
		1-7	2	0.15	0.0750			
		1-8	2	0.17	0.0850			
		2-3	2	0.26	0.1300	0.081		
		2-4	2	0.16	0.0800			
		2-5	2	0.16	0.0800			
		2-6	2	0.12	0.0600			
		2-7	2	0.11	0.0550			
		2-8	2	0.10				
		3-4	0.5	0.09	0.1800	0.158353		
		3-5	0.5	0.10	0.2000			
		3-6	0.85	0.11	0.1294			
		3-7	0.85	0.11	0.1294			
		3-8	0.85	0.13	0.1529			
		4-5	0.5	0.12	0.2400	0.16		
		4-6	0.85	0.11	0.1294			
		4-7	0.85	0.13	0.1529			
		4-8	0.85	0.10	0.1176			
		5-6	0.85	0.10	0.1176	0.141176		
		5-7	0.85	0.16	0.1882			
		5-8	0.85	0.10	0.1176			
		6-7	0.85	0.11	0.1294	0.105882		
		6-8	0.85	0.07	0.0824			
	4	1-2	2	0.11	0.0550	0.073571	0.0987927	
		1-3	2	0.19	0.0950			
		1-4	2	0.13	0.0650			
		1-5	2	0.17	0.0850			
		1-6	2	0.15	0.0750			
		1-7	2	0.10	0.0500			
		1-8	2	0.18	0.0900			
		2-3	2	0.28	0.1400	0.083333		
		2-4	2	0.16	0.0800			
		2-5	2	0.16	0.0800			
		2-6	2	0.14	0.0700			
		2-7	2	0.13	0.0650			
		2-8	2	0.13	0.0650			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		3-4	0.5	0.09	0.1800	0.165412		
		3-5	0.5	0.10	0.2000			
		3-6	0.85	0.09	0.1059			
		3-7	0.85	0.17	0.2000			
		3-8	0.85	0.12	0.1412			
		4-5	0.5	0.08	0.1600	0.125294		
		4-6	0.85	0.05	0.0588			
		4-7	0.85	0.11	0.1294			
		4-8	0.85	0.13	0.1529			
		5-6	0.85	0.12	0.1412	0.129412		
		5-7	0.85	0.10	0.1176			
		5-8	0.85	0.11	0.1294			
		6-7	0.85	0.05	0.0588	0.082353		
		6-8	0.85	0.09	0.1059			
	5	1-2	2	0.17	0.0850	0.095	0.1257892	
		1-3	2	0.27	0.1350			
		1-4	2	0.22	0.1100			
		1-5	2	0.23	0.1150			
		1-6	2	0.10	0.0500			
		1-7	2	0.18	0.0900			
		1-8	2	0.16	0.0800			
		2-3	2	0.11	0.0550	0.0775		
		2-4	2	0.15	0.0750			
		2-5	2	0.15	0.0750			
		2-6	2	0.17	0.0850			
		2-7	2	0.21	0.1050			
		2-8	2	0.14	0.0700			
		3-4	0.5	0.08	0.1600	0.167529		
		3-5	0.5	0.08	0.1600			
		3-6	0.85	0.16	0.1882			
		3-7	0.85	0.13	0.1529			
		3-8	0.85	0.15	0.1765			
		4-5	0.5	0.10	0.2000	0.155882		
		4-6	0.85	0.16	0.1882			
		4-7	0.85	0.12	0.1412			
		4-8	0.85	0.08	0.0941			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		5-6	0.85	0.13	0.1529	0.141176		
		5-7	0.85	0.12	0.1412			
		5-8	0.85	0.11	0.1294			
		6-7	0.85	0.12	0.1412	0.117647		
		6-8	0.85	0.08	0.0941			
G7	1	1-2	2	0.05	0.0250	0.041667	0.0480556	0.101261
		1-3	2	0.10	0.0500			
		1-4	2	0.10	0.0500			
		2-3	0.5	0.05	0.1000	0.0675		
		2-4	2	0.07	0.0350			
		3-4	2	0.07	0.0350	0.035		
	2	1-2	2	0.04	0.0200	0.076667	0.1230556	
		1-3	2	0.21	0.1050			
		1-4	2	0.21	0.1050			
		2-3	0.5	0.21	0.4200	0.2525		
		2-4	2	0.17	0.0850			
		3-4	2	0.08	0.0400	0.04		
	3	1-2	0.5	0.09	0.1800	0.142222	0.1407111	
		1-3	0.5	0.08	0.1600			
		1-4	0.5	0.10	0.2000			
		1-5	0.5	0.05	0.1000			
		1-6	0.5	0.09	0.1800			
		1-7	0.5	0.07	0.1400			
		1-8	0.5	0.06	0.1200			
		1-9	0.5	0.05	0.1000			
		1-10	0.5	0.05	0.1000			
		2-3	0.5	0.09	0.1800	0.165		
		2-4	0.5	0.10	0.2000			
		2-5	0.5	0.09	0.1800			
		2-6	0.5	0.10	0.2000			
		2-7	0.5	0.05	0.1000			
		2-8	0.5	0.06	0.1200			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		2-9	0.5	0.08	0.1600			
		2-10	0.5	0.09	0.1800			
		5-6	0.5	0.10	0.2000	0.188		
		5-7	0.5	0.10	0.2000			
		5-8	0.5	0.08	0.1600			
		5-9	0.5	0.09	0.1800			
		5-10	0.5	0.10	0.2000			
		7-8	0.5	0.09	0.1800	0.153333		
		7-9	0.5	0.09	0.1800			
		7-10	0.5	0.05	0.1000			
		8-9	0.5	0.05	0.1000	0.1		
		9-10	0.5	0.06	0.1200	0.12		
	4	1-2	2	0.16	0.0800	0.071667	0.0932222	
		1-3	2	0.16	0.0800			
		1-4	2	0.11	0.0550			
		2-3	1.25	0.11	0.0880	0.12		
		2-4	1.25	0.19	0.1520			
		3-4	1.25	0.11	0.0880	0.088		
G8	1	1-2	2	0.13	0.0650	0.10	0.15	0.17
		1-3	2	0.27	0.1350			
		2-3	0.5	0.08	0.1600	0.16		
	2	1-2	0.5	0.07	0.1400	0.18	0.19	
		1-3	0.5	0.12	0.2400			
		1-4	0.5	0.08	0.1600			
		1-5	0.5	0.07	0.1400			
		1-6	0.5	0.10	0.2000			
		2-3	0.5	0.09	0.1800	0.18		
		2-4	0.5	0.10	0.2000			
		2-5	0.5	0.06	0.1200			
		2-6	0.5	0.11	0.2200			
		3-4	0.5	0.12	0.2400	0.20		

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		3-5	0.5	0.07	0.1400			
		3-6	0.5	0.11	0.2200			
		4-5	0.5	0.08	0.1600	0.18		
		4-6	0.5	0.10	0.2000			
		5-6	0.5	0.10	0.2000	0.20		
	3	1-2	0.5	0.12	0.2400	0.17	0.16	
		1-3	0.5	0.07	0.1400			
		1-4	0.5	0.08	0.1600			
		1-5	0.5	0.07	0.1400			
		1-6	0.5	0.09	0.1800			
		2-3	0.5	0.10	0.2000	0.21		
		2-4	0.5	0.10	0.2000			
		2-5	0.5	0.10	0.2000			
		2-6	0.5	0.11	0.2200			
		3-4	0.5	0.08	0.1600	0.17		
		3-5	0.5	0.06	0.1200			
		3-6	0.5	0.11	0.2200			
		4-5	0.5	0.07	0.1400	0.12		
		4-6	0.5	0.05	0.1000			
		5-6	0.5	0.08	0.1600	0.16		
	4	1-2	0.5	0.10	0.2000	0.16	0.16	
		1-3	0.5	0.08	0.1600			
		1-4	0.5	0.08	0.1600			
		1-5	0.5	0.08	0.1600			
		1-6	0.5	0.07	0.1400			
		2-3	0.5	0.09	0.1800	0.16		
		2-4	0.5	0.04	0.0800			
		2-5	0.5	0.08	0.1600			
		2-6	0.5	0.10	0.2000			
		3-4	0.5	0.07	0.1400	0.18		
		3-5	0.5	0.10	0.2000			
		3-6	0.5	0.10	0.2000			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		4-5	0.5	0.06	0.1200	0.13		
		4-6	0.5	0.07	0.1400			
		5-6	0.5	0.09	0.1800	0.18		
G9	1	1-2	0.5	0.13	0.2600	0.20	0.20	0.16
		1-3	0.5	0.08	0.1600			
		1-4	0.5	0.09	0.1800			
		2-3	0.5	0.11	0.2200	0.22		
		2-4	0.5	0.10	0.2000			
		3-4	0.5	0.09	0.1800	0.18		
	2	1-2	0.5	0.09	0.1800	0.13	0.12	
		1-3	0.5	0.05	0.1000			
		1-4	0.5	0.05	0.1000			
		2-3	0.5	0.07	0.1400	0.14		
		2-4	0.5	0.07	0.1400			
		3-4	0.5	0.05	0.1000	0.10		
	3	1-2	0.5	0.10	0.2000	0.19	0.16	
		1-3	0.5	0.10	0.2000			
		1-4	0.5	0.08	0.1600			
		2-3	0.5	0.08	0.1600	0.16		
		2-4	0.5	0.08	0.1600			
		3-4	0.5	0.06	0.1200	0.12		
	4	1-2	0.5	0.08	0.1600	0.17	0.15	
		1-3	0.5	0.05	0.1000			
		1-4	0.5	0.13	0.2600			
		2-3	0.5	0.08	0.1600	0.16		
		2-4	0.5	0.08	0.1600			
		3-4	0.5	0.06	0.1200	0.12		

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
	5	1-2	0.5	0.10	0.1033	0.09		
		1-3	0.5	0.13				
		1-4	0.5	0.08				
		2-3	0.5	0.09	0.0850			
		2-4	0.5	0.08				
		3-4	0.5	0.09	0.0900			
G10		1-2	0.85	0.06	0.0967	0.13	0.13	
		1-3	0.85	0.13				
		1-4	0.85	0.10				
		2-3	0.85	0.15	0.1450			
		2-4	0.85	0.14				
		3-4	0.85	0.14	0.1400			
G11	1	1-2	1.25	0.16	0.1280	0.12	0.12	0.13
		1-3	1.25	0.13	0.1040			
		2-3	0.85	0.10	0.1176	0.12		
	2	1-2	1.25	0.13	0.1040	0.14	0.16	
		1-3	1.25	0.22	0.1760			
		2-3	0.85	0.16	0.1882	0.19		
	3	1-2	1.25	0.09	0.0720	0.09	0.10	
		1-3	1.25	0.14	0.1120			
		2-3	0.85	0.09	0.1059	0.11		
	4	1-2	1.25	0.12	0.0960	0.12	0.14	
		1-3	1.25	0.19	0.1520			
		2-3	0.85	0.13	0.1529	0.15		

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
	5	1-2	1.25	0.21	0.1680	0.15	0.15	
		1-3	1.25	0.17	0.1360			
		2-3	0.85	0.12	0.1412	0.14		
G12	1	1-2	0.5	0.11	0.2200	0.190278	0.1147407	0.122343
		1-3	2	0.26	0.1300			
		1-4	3	0.44	0.1467			
		1-5	0.5	0.12	0.2400			
		1-6	2	0.29	0.1450			
		1-7	0.5	0.13	0.2600			
		2-3	2	0.09	0.0450	0.124		
		2-4	3	0.33	0.1100			
		2-5	0.5	0.09	0.1800			
		2-6	2	0.21	0.1050			
		2-7	0.5	0.09	0.1800			
		3-4	3	0.15	0.0500	0.061667		
		3-5	2	0.15	0.0750			
		3-6	2	0.12	0.0600			
		3-7	2	0.29	0.1450			
		4-5	3	0.16	0.0533	0.08		
		4-6	3	0.16	0.0533			
		4-7	3	0.40	0.1333			
		5-6	2	0.13	0.0650	0.1325		
		5-7	0.5	0.10	0.2000			
		6-7	2	0.20	0.1000	0.1		
	2	1-2	0.5	0.09	0.1800	0.139444	0.1298981	
		1-3	2	0.13	0.0650			
		1-4	3	0.35	0.1167			
		1-5	0.5	0.08	0.1600			
		1-6	2	0.23	0.1150			
		1-7	0.5	0.10	0.2000			
					#DIV/0!			
		2-3	2	0.26	0.1300	0.156333		
		2-4	3	0.38	0.1267			
		2-5	0.5	0.11	0.2200			
		2-6	2	0.17	0.0850			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		2-7	0.5	0.11	0.2200			
		3-4	3	0.11	0.0367	0.067222		
		3-5	2	0.25	0.1250			
		3-6	2	0.08	0.0400			
		3-7	2	0.20	0.1000			
		4-5	3	0.32	0.1067	0.088889		
		4-6	3	0.14	0.0467			
		4-7	3	0.34	0.1133			
		5-6	2	0.29	0.1450	0.2025		
		5-7	0.5	0.13	0.2600			
					#DIV/0!			
		6-7	2	0.25	0.1250	0.125		
	3	1-2	0.5	0.13	0.2600	0.179722	0.1328704	
		1-3	2	0.17	0.0850			
		1-4	3	0.46	0.1533			
		1-5	0.5	0.06	0.1200			
		1-6	2	0.36	0.1800			
		1-7	0.5	0.14	0.2800			
		2-3	2	0.30	0.1500	0.198333		
		2-4	3	0.47	0.1567			
		2-5	0.5	0.09	0.1800			
		2-6	2	0.41	0.2050			
		2-7	0.5	0.15	0.3000			
		3-4	3	0.19	0.0633	0.059444		
		3-5	2	0.11	0.0550			
		3-6	2	0.12	0.0600			
		3-7	2	0.30	0.1500			
		4-5	3	0.22	0.0733	0.092222		
		4-6	3	0.17	0.0567			
		4-7	3	0.44	0.1467			
		5-6	2	0.15	0.0750	0.1375		
		5-7	0.5	0.10	0.2000			
		6-7	2	0.26	0.1300	0.13		

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
	4	1-2	0.5	0.11	0.2200	0.183889	0.1100463	
		1-3	2	0.28	0.1400			
		1-4	3	0.34	0.1133			
		1-5	0.5	0.13	0.2600			
		1-6	2	0.26	0.1300			
		1-7	0.5	0.12	0.2400			
		2-3	2	0.26	0.1300	0.145		
		2-4	3	0.27	0.0900			
		2-5	0.5	0.12	0.2400			
		2-6	2	0.25	0.1250			
		2-7	0.5	0.07	0.1400			
		3-4	3	0.10	0.0333	0.081111		
		3-5	2	0.31	0.1550			
		3-6	2	0.11	0.0550			
		3-7	2	0.29	0.1450			
		4-5	3	0.41	0.1367	0.077778		
		4-6	3	0.17	0.0567			
		4-7	3	0.12	0.0400			
		5-6	2	0.11	0.0550	0.1075		
		5-7	0.5	0.08	0.1600			
		6-7	2	0.13	0.0650	0.065		
	5	1-2	0.5	0.13	0.2600	0.198056	0.1241574	
		1-3	2	0.26	0.1300			
		1-4	3	0.43	0.1433			
		1-5	0.5	0.13	0.2600			
		1-6	2	0.31	0.1550			
		1-7	0.5	0.12	0.2400			
		2-3	2	0.29	0.1450	0.144667		
		2-4	3	0.31	0.1033			
		2-5	0.5	0.09	0.1800			
		2-6	2	0.27	0.1350			
		2-7	0.5	0.08	0.1600			
		3-4	3	0.13	0.0433	0.062778		
		3-5	2	0.20	0.1000			
		3-6	2	0.09	0.0450			
		3-7	2	0.24	0.1200			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		4-5	3	0.33	0.1100	0.094444		
		4-6	3	0.12	0.0400			
		4-7	3	0.40	0.1333			
		5-6	2	0.12	0.0600	0.13		
		5-7	0.5	0.10	0.2000			
		6-7	2	0.23	0.1150	0.115		
G13	1	1-2	0.5	0.08	0.1600	0.245	0.2670833	0.238
		1-3	0.5	0.14	0.2800			
		1-4	0.5	0.13	0.2600			
		1-5	0.5	0.14	0.2800			
		2-3	0.5	0.14	0.2800	0.273333		
		2-4	0.5	0.14	0.2800			
		2-5	0.5	0.13	0.2600			
		3-4	0.5	0.14	0.2800	0.29		
		3-5	0.5	0.15	0.3000			
		4-5	0.5	0.13	0.2600	0.26		
	2	1-2	0.5	0.05	0.1000	0.195	0.2379167	
		1-3	0.5	0.11	0.2200			
		1-4	0.5	0.12	0.2400			
		1-5	0.5	0.11	0.2200			
		2-3	0.5	0.11	0.2200	0.246667		
		2-4	0.5	0.13	0.2600			
		2-5	0.5	0.13	0.2600			
		3-4	0.5	0.10	0.2000	0.23		
		3-5	0.5	0.13	0.2600			
		4-5	0.5	0.14	0.2800	0.28		
	3	1-2	0.5	0.09	0.1800	0.24	0.2441667	
		1-3	0.5	0.13	0.2600			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		1-4	0.5	0.14	0.2800			
		1-5	0.5	0.12	0.2400			
		2-3	0.5	0.07	0.1400	0.166667		
		2-4	0.5	0.09	0.1800			
		2-5	0.5	0.09	0.1800			
		3-4	0.5	0.08	0.1600	0.23		
		3-5	0.5	0.15	0.3000			
		4-5	0.5	0.17	0.3400	0.34		
	4	1-2	0.5	0.09	0.1800	0.24	0.1908333	
		1-3	0.5	0.14	0.2800			
		1-4	0.5	0.10	0.2000			
		1-5	0.5	0.15	0.3000			
		2-3	0.5	0.12	0.2400	0.193333		
		2-4	0.5	0.06	0.1200			
		2-5	0.5	0.11	0.2200			
		3-4	0.5	0.06	0.1200	0.17		
		3-5	0.5	0.11	0.2200			
		4-5	0.5	0.08	0.1600	0.16		
	5	1-2	0.5	0.11	0.2200	0.25	0.25	
		1-3	0.5	0.15	0.3000			
		1-4	0.5	0.11	0.2200			
		1-5	0.5	0.13	0.2600			
		2-3	0.5	0.15	0.3000	0.24		
		2-4	0.5	0.11	0.2200			
		2-5	0.5	0.10	0.2000			
		3-4	0.5	0.12	0.2400	0.25		
		3-5	0.5	0.13	0.2600			
		4-5	0.5	0.13	0.2600	0.26		

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
G14	1	1-2	0.5	0.05	0.1000	0.135	0.1464583	0.18763
		1-3	2	0.18	0.0900			
		1-4	2	0.22	0.1100			
		1-5	0.5	0.12	0.2400			
		2-3	2	0.20	0.1000	0.173333		
		2-4	2	0.28	0.1400			
		2-5	0.5	0.14	0.2800			
		3-4	2	0.15	0.0750	0.1175		
		3-5	2	0.32	0.1600			
		4-5	2	0.32	0.1600	0.16		
	2	1-2	0.5	0.13	0.2600	0.33375	0.2365625	
		1-3	2	0.09	0.0450			
		1-4	2	0.38	0.1900			
		1-5	0.5	0.42	0.8400			
		2-3	2	0.13	0.0650	0.365		
		2-4	2	0.38	0.1900			
		2-5	0.5	0.42	0.8400			
		3-4	2	0.41	0.2050	0.1925		
		3-5	2	0.36	0.1800			
		4-5	2	0.11	0.0550	0.055		
	3	1-2	0.5	0.15	0.3000	0.32125	0.2198958	
		1-3	2	0.10	0.0500			
		1-4	2	0.35	0.1750			
		1-5	0.5	0.38	0.7600			
		2-3	2	0.13	0.0650	0.333333		
		2-4	2	0.35	0.1750			
		2-5	0.5	0.38	0.7600			
		3-4	2	0.32	0.1600	0.165		
		3-5	2	0.34	0.1700			
		4-5	2	0.12	0.0600	0.06		

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
	4	1-2	0.5	0.30	0.6000	0.24625	0.1476042	
		1-3	2	0.29	0.1450			
		1-4	2	0.08	0.0400			
		1-5	0.5	0.10	0.2000			
		2-3	2	0.14	0.0700	0.201667		
		2-4	2	0.27	0.1350			
		2-5	0.5	0.20	0.4000			
		3-4	2	0.26	0.1300	0.1075		
		3-5	2	0.17	0.0850			
		4-5	2	0.07	0.0350	0.035		
G15	1	1-2	0.85	0.16	0.1882	0.170588	0.1735294	0.161765
		1-3	0.85	0.13	0.1529			
		2-3	0.85	0.15	0.1765	0.176471		
	2	1-2	0.85	0.15	0.1765	0.194118	0.1852941	
		1-3	0.85	0.18	0.2118			
		2-3	0.85	0.15	0.1765	0.176471		
	3	1-2	0.85	0.13	0.1529	0.176471	0.1588235	
		1-3	0.85	0.17	0.2000			
		2-3	0.85	0.12	0.1412	0.141176		
	4	1-2	0.85	0.16	0.1882	0.194118	0.1676471	
		1-3	0.85	0.17	0.2000			
		2-3	0.85	0.12	0.1412	0.141176		
	5	1-2	0.85	0.08	0.0941	0.129412	0.1235294	
		1-3	0.85	0.14	0.1647			
		2-3	0.85	0.10	0.1176	0.117647		

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
G16	1	1-2	0.5	0.11	0.2200	0.253333	0.2611111	0.247778
		1-3	0.5	0.12	0.2400			
		1-4	0.5	0.15	0.3000			
		2-3	0.5	0.16	0.3200	0.31		
		2-4	0.5	0.15	0.3000			
		3-4	0.5	0.11	0.2200	0.22		
	2	1-2	0.5	0.11	0.2200	0.266667	0.2255556	
		1-3	0.5	0.14	0.2800			
		1-4	0.5	0.15	0.3000			
		2-3	0.5	0.13	0.2600	0.27		
		2-4	0.5	0.14	0.2800			
		3-4	0.5	0.07	0.1400	0.14		
	3	1-2	0.5	0.11	0.2200	0.28	0.2733333	
		1-3	0.5	0.15	0.3000			
		1-4	0.5	0.16	0.3200			
		2-3	0.5	0.15	0.3000	0.32		
		2-4	0.5	0.17	0.3400			
		3-4	0.5	0.11	0.2200	0.22		
	4	1-2	0.5	0.07	0.1400	0.2	0.24	
		1-3	0.5	0.15	0.3000			
		1-4	0.5	0.08	0.1600			
		2-3	0.5	0.15	0.3000	0.28		
		2-4	0.5	0.13	0.2600			
		3-4	0.5	0.12	0.2400	0.24		
	5	1-2	0.5	0.10	0.2000	0.266667	0.2388889	
		1-3	0.5	0.14	0.2800			
		1-4	0.5	0.16	0.3200			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		2-3	0.5	0.13	0.2600	0.25		
		2-4	0.5	0.12	0.2400			
		3-4	0.5	0.10	0.2000	0.2		
G17	1	1-2	0.5	0.08	0.1600	0.22	0.25	0.252
		1-3	0.5	0.14	0.2800			
		2-3	0.5	0.14	0.2800	0.28		
	2	1-2	0.5	0.09	0.1800	0.23	0.245	
		1-3	0.5	0.14	0.2800			
		2-3	0.5	0.13	0.2600	0.26		
	3	1-2	0.5	0.08	0.1600	0.22	0.24	
		1-3	0.5	0.14	0.2800			
		2-3	0.5	0.13	0.2600	0.26		
	4	1-2	0.5	0.08	0.1600	0.21	0.255	
		1-3	0.5	0.13	0.2600			
		2-3	0.5	0.15	0.3000	0.3		
	5	1-2	0.5	0.09	0.1800	0.22	0.27	
		1-3	0.5	0.13	0.2600			
		2-3	0.5	0.16	0.3200	0.32		
G18	1	1-2	2	0.14	0.0700	0.058889	0.0468519	0.040889
		1-3	3	0.17	0.0567			
		1-4	3	0.15	0.0500			
		2-3	3	0.17	0.0567	0.055		
		2-4	3	0.16	0.0533			
		3-4	3	0.08	0.0267	0.026667		

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
	2	1-2	2	0.10	0.0500	0.047778	0.0375926	
		1-3	3	0.15	0.0500			
		1-4	3	0.13	0.0433			
		2-3	3	0.14	0.0467	0.041667		
		2-4	3	0.11	0.0367			
		3-4	3	0.07	0.0233	0.023333		
	3	1-2	2	0.10	0.0500	0.047778	0.032037	
		1-3	3	0.13	0.0433			
		1-4	3	0.15	0.0500			
		2-3	3	0.09	0.0300	0.031667		
		2-4	3	0.10	0.0333			
		3-4	3	0.05	0.0167	0.016667		
	4	1-2	2	0.08	0.0400	0.046667	0.0455556	
		1-3	3	0.16	0.0533			
		1-4	3	0.14	0.0467			
		2-3	3	0.17	0.0567	0.056667		
		2-4	3	0.17	0.0567			
		3-4	3	0.10	0.0333	0.033333		
	5	1-2	2	0.11	0.0550	0.053889	0.0424074	
		1-3	3	0.17	0.0567			
		1-4	3	0.15	0.0500			
		2-3	3	0.15	0.0500	0.046667		
		2-4	3	0.13	0.0433			
		3-4	3	0.08	0.0267	0.026667		
G19	A	1-2	3	0.06	0.0200	0.030556	0.0589444	0.111324
		1-3	3	0.04	0.0133			
		1-4	3	0.05	0.0167			
		1-5	3	0.12	0.0400			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		1-6	3	0.13	0.0433			
		1-7	3	0.15	0.0500			
		2-3	3	0.11	0.0367	0.046667		
		2-4	3	0.12	0.0400			
		2-5	3	0.16	0.0533			
		2-6	3	0.14	0.0467			
		2-7	3	0.17	0.0567			
		3-4	3	0.05	0.0167	0.036667		
		3-5	3	0.15	0.0500			
		3-6	3	0.11	0.0367			
		3-7	3	0.13	0.0433			
		4-5	3	0.16	0.0533	0.05		
		4-6	3	0.14	0.0467			
		4-7	3	0.15	0.0500			
		5-6	2	0.18	0.0900	0.0875		
		5-7	2	0.17	0.0850			
		6-7	2	0.16	0.0800	0.08		
	B	1-2	2	0.14	0.0700	1.1375	0.2811333	
		1-3	2	0.14	0.0700			
		1-4	2	0.11	0.0550			
		1-5	2	13.00	6.5000			
		1-6	2	0.14	0.0700			
		1-7	2	0.12	0.0600			
		2-3	2	0.16	0.0800	0.074		
		2-4	2	0.12	0.0600			
		2-5	2	0.16	0.0800			
		2-6	2	0.15	0.0750			
		2-7	2	0.15	0.0750			
		3-4	2	0.10	0.0500	0.0625		
		3-5	2	0.10	0.0500			
		3-6	2	0.16	0.0800			
		3-7	2	0.14	0.0700			
		4-5	2	0.11	0.0550	0.061667		
		4-6	2	0.12	0.0600			
		4-7	2	0.14	0.0700			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		5-6	2	0.14	0.0700	0.0675		
		5-7	2	0.13	0.0650			
		6-7	2	0.13	0.0650	0.065		
	C	1-2	2	0.14	0.0700	0.075714	0.0641854	
		1-3	2	0.14	0.0700			
		1-4	2	0.14	0.0700			
		1-5	2	0.16	0.0800			
		1-6	2	0.15	0.0750			
		1-7	2	0.17	0.0850			
		1-8	2	0.16	0.0800			
		2-3	2	0.10	0.0500	0.064167		
		2-4	2	0.13	0.0650			
		2-5	2	0.13	0.0650			
		2-6	2	0.14	0.0700			
		2-7	2	0.13	0.0650			
		2-8	2	0.14	0.0700			
		3-4	2	0.12	0.0600	0.069		
		3-5	2	0.15	0.0750			
		3-6	2	0.14	0.0700			
		3-7	2	0.14	0.0700			
		3-8	2	0.14	0.0700			
		4-5	2	0.10	0.0500	0.06125		
		4-6	2	0.12	0.0600			
		4-7	2	0.13	0.0650			
		4-8	2	0.14	0.0700			
		5-6	2	0.13	0.0650	0.066667		
		5-7	2	0.13	0.0650			
		5-8	2	0.14	0.0700			
		6-7	2	0.10	0.0500	0.0575		
		6-8	2	0.13	0.0650			
		7-8	2	0.11	0.0550	0.055		
	D	1-2	2	0.15	0.0750	0.068125	0.0639799	
		1-3	2	0.13	0.0650			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		1-4	2	0.12	0.0600			
		1-5	2	0.17	0.0850			
		1-6	2	0.14	0.0700			
		1-7	2	0.12	0.0600			
		1-8	2	0.13	0.0650			
		1-9	2	0.13	0.0650			
		2-3	2	0.13	0.0650	0.060714		
		2-4	2	0.10	0.0500			
		2-5	2	0.17	0.0850			
		2-6	2	0.11	0.0550			
		2-7	2	0.10	0.0500			
		2-8	2	0.11	0.0550			
		2-9	2	0.13	0.0650			
		3-4	2	0.12	0.0600	0.061667		
		3-5	2	0.11	0.0550			
		3-6	2	0.14	0.0700			
		3-7	2	0.11	0.0550			
		3-8	2	0.13	0.0650			
		3-9	2	0.13	0.0650			
		4-5	2	0.09	0.0450	0.068		
		4-6	2	0.16	0.0800			
		4-7	2	0.13	0.0650			
		4-8	2	0.14	0.0700			
		4-9	2	0.16	0.0800			
		5-6	2	0.15	0.0750	0.065		
		5-7	2	0.14	0.0700			
		5-8	2	0.10	0.0500			
		5-9	2	0.13	0.0650			
		6-7	2	0.08	0.0400	0.063333		
		6-8	2	0.14	0.0700			
		6-9	2	0.16	0.0800			
		7-8	2	0.13	0.0650	0.065		
		7-9	2	0.13	0.0650			
		8-9	2	0.12	0.0600	0.06		
	E	1-2	2	0.12	0.0600	0.075833	0.088375	
		1-3	2	0.13	0.0650			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		1-4	2	0.13	0.0650			
		1-5	2	0.13	0.0650			
		1-6	2	0.13	0.0650			
		1-7	2	0.27	0.1350			
		2-3	2	0.11	0.0550	0.074		
		2-4	2	0.11	0.0550			
		2-5	2	0.14	0.0700			
		2-6	2	0.12	0.0600			
		2-7	2	0.26	0.1300			
		3-4	2	0.13	0.0650	0.08375		
		3-5	2	0.11	0.0550			
		3-6	2	0.14	0.0700			
		3-7	2	0.29	0.1450			
		4-5	2	0.13	0.0650	0.086667		
		4-6	2	0.13	0.0650			
		4-7	2	0.26	0.1300			
		5-6	2	0.12	0.0600	0.1		
		5-7	2	0.28	0.1400			
		6-7	2	0.22	0.1100	0.11		
G20	A	1-2	3	0.06	0.0200	0.035556	0.0340741	0.033102
		1-3	3	0.13	0.0433			
		1-4	3	0.13	0.0433			
		2-3	3	0.09	0.0300	0.033333		
		2-4	3	0.11	0.0367			
		3-4	3	0.10	0.0333	0.033333		
	B	1-2	3	0.05	0.0167	0.025	0.0308333	
		1-3	3	0.10	0.0333			
		2-3	3	0.11	0.0367	0.036667		
	C	1-2	3	0.06	0.0200	0.028333	0.0308333	
		1-3	3	0.11	0.0367			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		2-3	3	0.10	0.0333	0.033333		
	D	1-2	3	0.05	0.0167	0.03	0.0366667	
		1-3	3	0.13	0.0433			
		2-3	3	0.13	0.0433	0.043333		
G21	A	1-2	2	0.12	0.0600	0.055	0.0573611	0.038811
		1-3	3	0.14	0.0467			
		1-4	3	0.14	0.0467			
		1-5	3	0.20	0.0667			
		2-3	3	0.20	0.0667	0.067778		
		2-4	3	0.21	0.0700			
		2-5	3	0.20	0.0667			
		3-4	3	0.15	0.0500	0.05		
		3-5	3	0.15	0.0500			
		4-5	3	0.17	0.0567	0.056667		
	B	1-2	3	0.05	0.0167	0.020556	0.0283148	
		1-3	3	0.07	0.0233			
		1-4	3	0.05	0.0167			
		1-5	3	0.05	0.0167			
		1-6	3	0.07	0.0233			
		1-7	3	0.08	0.0267			
		2-3	3	0.11	0.0367	0.036		
		2-4	3	0.10	0.0333			
		2-5	3	0.11	0.0367			
		2-6	3	0.13	0.0433			
		2-7	3	0.09	0.0300			
		3-4	3	0.11	0.0367	0.035		
		3-5	3	0.12	0.0400			
		3-6	3	0.11	0.0367			
		3-7	3	0.08	0.0267			
		4-5	3	0.10	0.0333	0.023333		
		4-6	3	0.06	0.0200			
		4-7	3	0.05	0.0167			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		5-6	3	0.09	0.0300	0.031667		
		5-7	3	0.10	0.0333			
		6-7	3	0.07	0.0233	0.023333		
	C	1-2	3	0.11	0.0367	0.030556	0.0365667	
		1-3	3	0.11	0.0367			
		1-4	3	0.10	0.0333			
		1-5	3	0.07	0.0233			
		1-6	3	0.05	0.0167			
		1-7	3	0.11	0.0367			
		2-3	3	0.10	0.0333	0.038667		
		2-4	3	0.11	0.0367			
		2-5	3	0.12	0.0400			
		2-6	3	0.12	0.0400			
		2-7	3	0.13	0.0433			
		3-4	3	0.05	0.0167	0.024167		
		3-5	3	0.08	0.0267			
		3-6	3	0.05	0.0167			
		3-7	3	0.11	0.0367			
		4-5	3	0.12	0.0400	0.04		
		4-6	3	0.11	0.0367			
		4-7	3	0.13	0.0433			
		5-6	3	0.15	0.0500	0.046667		
		5-7	3	0.13	0.0433			
		6-7	3	0.10	0.0333	0.033333		
	D	1-2	3	0.09	0.0300	0.033333	0.033	
		1-3	3	0.10	0.0333			
		1-4	3	0.11	0.0367			
		1-5	3	0.13	0.0433			
		1-6	3	0.06	0.0200			
		1-7	3	0.11	0.0367			
		2-3	3	0.05	0.0167	0.024667		
		2-4	3	0.04	0.0133			
		2-5	3	0.10	0.0333			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		2-6	3	0.10	0.0333			
		2-7	3	0.08	0.0267			
		3-4	3	0.04	0.0133	0.03		
		3-5	3	0.11	0.0367			
		3-6	3	0.08	0.0267			
		3-7	3	0.13	0.0433			
		4-5	3	0.10	0.0333	0.023333		
		4-6	3	0.05	0.0167			
		4-7	3	0.06	0.0200			
		5-6	3	0.14	0.0467	0.046667		
		5-7	3	0.14	0.0467			
		6-7	3	0.12	0.0400	0.04		
G22	A	1-2	2	0.14	0.0700	0.065	0.0616667	0.068359
		1-3	2	0.12	0.0600			
		1-4	2	0.13	0.0650			
		2-3	2	0.14	0.0700	0.06		
		2-4	2	0.10	0.0500			
		3-4	2	0.12	0.0600	0.06		
	B	1-2	2	0.11	0.0550	0.08	0.0791667	
		1-3	2	0.18	0.0900			
		1-4	2	0.19	0.0950			
		2-3	2	0.20	0.1000	0.0975		
		2-4	2	0.19	0.0950			
		3-4	2	0.12	0.0600	0.06		
	C	1-2	2	0.06	0.0300	0.05375	0.0638542	
		1-3	2	0.07	0.0350			
		1-4	2	0.16	0.0800			
		1-5	2	0.14	0.0700			
		2-3	2	0.11	0.0550	0.066667		
		2-4	2	0.16	0.0800			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		2-5	2	0.13	0.0650			
		3-4	2	0.16	0.0800	0.07		
		3-5	2	0.12	0.0600			
		4-5	2	0.13	0.0650	0.065		
	D	1-2	2	0.11	0.0550	0.0625	0.06875	
		1-3	2	0.14	0.0700			
		2-3	2	0.15	0.0750	0.075		
G23	A	1-2	0.5	0.08	0.1600	0.2	0.23	0.2225
		1-3	0.5	0.12	0.2400			
		2-3	0.5	0.13	0.2600	0.26		
	B	1-2	0.5	0.10	0.2000	0.18	0.17	
		1-3	0.5	0.08	0.1600			
		2-3	0.5	0.08	0.1600	0.16		
	C	1-2	0.5	0.08	0.1600	0.22	0.24	
		1-3	0.5	0.14	0.2800			
		2-3	0.5	0.13	0.2600	0.26		
	D	1-2	0.5	0.10	0.2000	0.26	0.25	
		1-3	0.5	0.16	0.3200			
		2-3	0.5	0.12	0.2400	0.24		
G24	A	1-2	1.25	0.12	0.0960	0.1	0.106	0.133931
		1-3	1.25	0.13	0.1040			
		2-3	1.25	0.14	0.1120	0.112		
	B	1-2	2	0.11	0.0550	0.1	0.1225	
		1-3	2	0.29	0.1450			
		2-3	2	0.29	0.1450	0.145		

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
	C	1-2	0.5	0.11	0.2200	0.22	0.2103333	
		1-3	0.5	0.10	0.2000			
		1-4	0.5	0.11	0.2200			
		1-5	0.5	0.12	0.2400			
		1-6	0.5	0.11	0.2200			
		2-3	0.5	0.10	0.2000	0.215		
		2-4	0.5	0.11	0.2200			
		2-5	0.5	0.11	0.2200			
		2-6	0.5	0.11	0.2200			
		3-4	0.5	0.14	0.2800	0.246667		
		3-5	0.5	0.13	0.2600			
		3-6	0.5	0.10	0.2000			
		4-5	0.5	0.07	0.1400	0.17		
		4-6	0.5	0.10	0.2000			
		5-6	0.5	0.10	0.2000	0.2		
	D	1-2	2	0.11	0.0550	0.081667	0.0968889	
		1-3	2	0.17	0.0850			
		1-4	2	0.21	0.1050			
		2-3	2	0.17	0.0850	0.105		
		2-4	2	0.25	0.1250			
		3-4	1.25	0.13	0.1040	0.104		
G25	A	1-2	1.25	0.29	0.2320	0.213333	0.2444444	0.2285
		1-3	1.25	0.23	0.1840			
		1-4	1.25	0.28	0.2240			
		2-3	0.5	0.13	0.2600	0.26		
		2-4	0.5	0.13	0.2600			
		3-4	0.5	0.13	0.2600	0.26		
	B	1-2	1.25	0.15	0.1200	0.162667	0.2042222	
		1-3	1.25	0.23	0.1840			
		1-4	1.25	0.23	0.1840			
		2-3	0.5	0.11	0.2200	0.23		
		2-4	0.5	0.12	0.2400			

Group	Sample number	Setup	Current (amps)	Voltage drop in mv DC	Resistance in micro ohms	Average individual resistance of each set up	Average resistance of each sample	Total Sample Average micro ohms
		3-4	0.5	0.11	0.2200	0.22		
	C	1-2	1.25	0.23	0.1840	0.165333	0.1917778	
		1-3	1.25	0.19	0.1520			
		1-4	1.25	0.20	0.1600			
		2-3	0.5	0.11	0.2200	0.21		
		2-4	0.5	0.10	0.2000			
		3-4	0.5	0.10	0.2000	0.2		
	D	1-2	1.25	0.21	0.1680	0.210667	0.2735556	
		1-3	1.25	0.29	0.2320			
		1-4	1.25	0.29	0.2320			
		2-3	0.5	0.13	0.2600	0.29		
		2-4	0.5	0.16	0.3200			
		3-4	0.5	0.16	0.3200	0.32		

ANNEXURE-13

Annexure-13

Splice volumes of crimped and ultrasonically welded joints

Group name	Ultrasonically welded samples					Crimped splice samples				
	Height in mm	Length in mm	Width in mm	Volume in cu.mm	Unit volume in cu.mm	Height in mm	Length in mm	Width in mm	Volume in cu.mm	Unit volume in cu.mm
G1	3.680	11.186	5.298	218.0894	20.21444	5.296	8.578	9.506	313.859	30.190
G2	3.606	11.646	5.470	229.7153	27.74231	5.288	8.492	9.512	336.865	42.629
G3	2.324	10.000	4.366	101.4658	29.79655	3.112	5.538	7.000	135.870	55.750
G4	2.430	10.124	4.174	102.6859	32.09883	3.116	5.340	6.930	131.675	79.510
G5	2.906	9.810	4.204	119.847	34.09545	4.074	6.914	9.778	168.017	52.114
G6	2.418	10.804	4.166	108.8329	37.00717	3.120	5.314	7.070	140.430	85.678
G7	2.113	10.655	3.113	70.05829	42.11388	3.503	5.590	6.650	116.156	74.623
G8	1.818	6.228	6.443	72.91932	70.05829	3.070	4.775	6.000	123.170	116.156
G9	1.338	2.046	10.134	27.74231	72.91932	2.056	3.232	6.452	42.629	123.170
G10	1.710	2.350	10.480	42.11388	87.52579	3.030	4.740	5.980	74.623	104.444
G11	1.616	2.056	10.262	34.09545	101.4658	2.470	3.780	4.190	52.114	135.870
G12	2.878	4.436	11.246	143.5755	102.6859	2.474	3.750	4.192	123.421	131.675
G13	1.688	2.084	10.520	37.00717	108.8329	3.908	6.698	9.750	85.678	140.430
G14	2.087	3.370	12.447	87.52579	119.847	2.490	3.736	4.174	104.444	168.017
G15	1.480	2.038	10.642	32.09883	143.5755	3.666	4.830	5.838	79.510	123.421
G16	1.318	2.050	11.028	29.79655	147.4401	2.466	3.710	4.184	55.750	110.634
G17	1.378	1.432	10.244	20.21444	218.0894	2.058	3.204	6.228	30.190	313.859
G18	2.708	4.746	11.472	147.4401	229.7153	2.032	3.212	5.818	110.634	336.865

ANNEXURE-14

Annexure-14

Time estimates for simulation models using crimping machines

IJ NO.	MITSUBISHI ORD. QTY	SORT-TIME/IJ secs	WRAPPING TIME/IJ secs	SPLICING TIME/IJ secs	FINAL TAPE TIME/IJ secs	OTHER TIME/IJ secs	TOTAL TIME/IJ secs	TOTAL ord qty TIME- secs
20397								
9001	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9003	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9004	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9007	60	2.00	29.203	13.56	08.35	5.00	58.12	3487.05
9008	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9009	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9011	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9014	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9015								
9016	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9017	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9019	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9020	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9030	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9032	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9036	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9039	30	2.00	39.208	21.54	08.35	5.00	76.10	2283.06
9040	30	0.00	00.000	00.00	00.00	0.00	00.00	00.00
9043	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9047	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9049	60	2.00	29.203	13.56	08.35	5.00	58.12	3487.05
9061	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9064	60	2.00	33.206	15.54	08.35	5.00	64.10	3845.87
9066	60	2.00	33.206	15.54	08.35	5.00	64.10	3845.87
9068	60	2.00	29.203	13.56	08.35	5.00	58.12	3487.05
9070	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9096	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9097	30	2.00	29.203	13.56	08.35	5.00	58.12	1743.52
9098	30	2.00	29.203	13.56	08.35	5.00	58.12	1743.52
9099	30	2.00	29.203	13.56	08.35	5.00	58.12	1743.52
9100	30	2.00	29.203	13.56	08.35	5.00	58.12	1743.52
9101	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9102	30	2.00	39.208	21.54	08.35	5.00	76.10	2283.06
II								
9024	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
20060								
9002	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9005	60	0.00	00.000	00.00	00.00	0.00	00.00	00.00
9051	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9054	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9060	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56

IJ NO.	MITSUBISHI ORD. QTY	SORT-TIME/IJ secs	WRAPPING TIME/IJ secs	SPLICING TIME/IJ secs	FINAL TAPE TIME/IJ secs	OTHER TIME/IJ secs	TOTAL TIME/IJ secs	TOTAL ord qty TIME- secs
9062	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9065	60	2.00	33.206	15.54	08.35	5.00	64.10	3845.87
9069	60	2.00	29.203	13.56	08.35	5.00	58.12	3487.05
9074	120	2.00	29.203	13.56	08.35	5.00	58.12	6974.10
20062								
9006	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9010	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9012	60	2.00	39.208	21.54	08.35	5.00	76.10	4566.12
9013	60	2.00	39.208	21.54	08.35	5.00	76.10	4566.12
9018	60	2.00	29.203	13.56	08.35	5.00	58.12	3487.05
9021	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9022	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9023	60	2.00	29.203	13.56	08.35	5.00	58.12	3487.05
9031	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9035	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9041	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9045	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9046	60	2.00	29.203	13.56	08.35	5.00	58.12	3487.05
9052	60	2.00	29.203	13.56	08.35	5.00	58.12	3487.05
9055	60	2.00	29.203	13.56	08.35	5.00	58.12	3487.05
9056	60	2.00	29.203	13.56	08.35	5.00	58.12	3487.05
9057	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9058	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9059	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
9071	120	2.00	29.203	13.56	08.35	5.00	58.12	6974.10
9072	120	2.00	29.203	13.56	08.35	5.00	58.12	6974.10
9073	120	2.00	29.203	13.56	08.35	5.00	58.12	6974.10
9080	120	2.00	25.452	11.54	08.35	5.00	52.34	6281.11
9092	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9093	30	2.00	25.452	11.54	08.35	5.00	52.34	1570.28
9095	30	2.00	33.206	15.54	08.35	5.00	64.10	1922.93
20378								
9087	60	2.00	25.452	11.54	08.35	5.00	52.34	3140.56
II								
9042	30	2.00	39.208	21.54	08.35	5.00	76.10	2283.06
9048	60	2.00	33.206	15.54	08.35	5.00	64.10	3845.87
20412								
9038	30	2.00	39.208	21.54	08.35	5.00	76.10	2283.06
9053	60	2.00	29.203	13.56	08.35	5.00	58.12	3487.05
9056	60	0.00	00.000	00.00	00.00	0.00	00.00	00.00
9094	30	2.00	33.206	15.54	08.35	5.00	64.10	1922.93
II								
9050	60	2.00	33.206	15.54	08.35	5.00	64.10	3845.87
20310								
9033	30	2.00	39.208	21.54	08.35	5.00	76.10	2283.06

ANNEXURE-15

COSTING DATA BASED ON CURRENT PRODUCTION DYNAMICS

IJ Machine Costs

Replace Blades	7 machines@$300/year/machine
Power Output	7 machines@1.128kW@10.82cents/kWh
M/c Cleaning	7 machines@5 min/week/machine
M/c Maintenance	4 hours/month total
M/c Breakdowns	10 min/day total
M/c Rental	$5480 pa

Set-up costs/Additional labour costs

Marshalling costs	40 hours/week (team leader)@$11.05/hour
Set-ups	205changes/year@2 min/reel change
Inspection Time	1 hour/day
Pull-testing	6 machines@3-4 min/hour

Inventory related costs

Wrapping tape used	$1600
Taping tape used	$18000
IJ terms used	$35000
Taping tape inv. value	$720
IJ Term Value	$5500
Material Handling	205 reels/year@5 min/reel = $150 pa approx
Stock Adjustments	340 adjustments@1 min/adjustment = $55 pa approx
MRP Ordering/Storage Cost	negligible = $5 pa approx
Freight Charges	205 reels/year@$5/reel

Process Time costs

Wrapping hours $= \lim_{\substack{C=1 to 10 \\ L=0 to 600}} \left[\frac{1}{16874L^{-0.67943}} + 0.00075N\right] * 1.18$

where N=no.leads/bundle L=longest length

Machining hours $= \lim_{3 to 20} [0.0030889 + 0.0009653x] * 1.18$

where x=no. leads spliced together

Final taping hours	0.00232 hours/IJ
Waterproof taping hours	0.00650 hours/IJ

Current weekly IJ requirement (based on 85% efficiency of above standards)

Wrapping	118 hours/week (see Process time costs)
IJ Machining	143 hours/week
Taping	53 hours/week (see Process time costs)
Waterproof Taping	2 hours/week
Soldering Time	3 hours/week

ANNEXURE-16

SUBA ENGINEERING PTY. LTD. (A.C.N. 002 549 144)
6/150 CANTERBURY ROAD, BANKSTOWN NSW 2200. AUSTRALIA · PHONE (02) 790 0900 · FAX (02) 708 3040

SUBA ENGINEERING

Bankstown, 26 August, 1996 - GK/ms

ALCATEL (N.Z.) LTD
02 SEP 1996
RECEIVED

Alcatel New Zealand
Attn: Mr Graeme Wild
Industrial Engineering Manager
P.O. Box 480
MASTERTON
NEW ZEALAND

STAPLA ULTRASONIC WELDING

Dear Mr Wild

With regards to the Stapla project we are pleased to advise as follows.

CYCLE TIME

The cycle time for each weld is consisting of handling the wires and inserting the wires between the tools and the cycle time of the machine.

The handling time depends on the skillness of the operator and on the number of wires to be handled.

The cycle time of the machine is approx. 0,5 to 1,0 sec. including the actual weld time which is between 0,2 to 0.6 sec.

In general it is estimated that the operator requires 2 to 5 seconds for handling plus 2 seconds for the machine cycle and deposit of the welded parts.

POWER CONSUMPTION

The energy consumption is extremely low. The machine is operated with 220/110 Volt and requires power only during the actual welding time which is between approx. 0,2 to 0,6 seconds.
During this very short weld time of as per fax.

NOISE FACTOR

The process operates with a frequency of 20 kHz which is not audible. In additions however there are other frequencies produced which are audible similar to the noise of a honey-bee.

The machines do not require any noise protection.

SUBA 149525

SUBA ENGINEERING

ALCATEL (N.Z.) LTD
0 2 SEP 1996
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MACHINE MAINTENANCE

The maintenance of the equipment is:

- Outside cleaning,
- Little grease on 2 moving elements,
- No additional maintenance required.

The life time of the sonotrode/tooling very much depends on the quality of copper and the size of the splices to be welded.
In general the life time of the tool is between 150.000 and 500.000 welds. Thereafter the surface of the tooling can be re-worked and used again.

IN SUMMARY

After careful evaluation, Stapla recommend the Octopus range, either standard or with stepper motor tool width adjustment.

Both machines are operated with the STAPLA controller allowing to memorise all wire splice configurations and machine settings thereto (except tool width with OCTOPUS Standard, which is set manually).
Each splice is re-called by simply selecting a 3-digit reference number.
At any later stage the Controller may by up-graded in order to weld in sequences, i.e. pre-set splice configurations can be welded within a repeatable sequence.

Please find Stapla's 2 quotations enclosed and please do not hesitate to contact us for any further questions.

Yours sincerely

SUBA ENGINEERING PTY LTD

Gareth King
Area Manager OS

per

Heinz Zimmermann
Marketing Director

Enclosures: 2 x Quotations from Stapla

ANNEXURE-17

ANNEXURE-18

Annexure-17, 18

Time estimates for simulation models using ultrasonic welding machines

IJ NO.	MITSUBISHI ORD. QTY	SORT-TIME/IJ secs	WRAPPING TIME/IJ secs	SPLICING TIME/IJ secs	FINAL TAPE TIME/IJ secs	OTHER TIME/IJ secs	TOTAL TIME/IJ secs	TOTAL ord qty TIME- secs
20397								
9001	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9003	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9004	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9007	60	2.00	29.203	11.87	08.35	5.00	56.42	3385.34
9008	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9009	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9011	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9014	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9015								
9016	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9017	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9019	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9020	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9030	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9032	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9036	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9039	30	2.00	39.208	21.54	08.35	5.00	76.10	2283.06
9040	30	0.00	00.000	00.00	00.00	0.00	00.00	00.00
9043	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9047	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9049	60	2.00	29.203	11.87	08.35	5.00	56.42	3385.34
9061	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9064	60	2.00	33.206	15.54	08.35	5.00	64.10	3845.87
9066	60	2.00	33.206	15.54	08.35	5.00	64.10	3845.87
9068	60	2.00	29.203	11.87	08.35	5.00	56.42	3385.34
9070	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9096	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9097	30	2.00	29.203	11.87	08.35	5.00	56.42	1692.67
9098	30	2.00	29.203	11.87	08.35	5.00	56.42	1692.67
9099	30	2.00	29.203	11.87	08.35	5.00	56.42	1692.67
9100	30	2.00	29.203	11.87	08.35	5.00	56.42	1692.67
9101	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9102	30	2.00	39.208	21.54	08.35	5.00	76.10	2283.06
II								
9024	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
20060								
9002	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9005	60	0.00	00.000	00.00	00.00	0.00	00.00	00.00
9051	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9054	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9060	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9062	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9065	60	2.00	33.206	15.54	08.35	5.00	64.10	3845.87

IJ NO.	MITSUBISHI ORD. QTY	SORT-TIME/IJ secs	WRAPPING TIME/IJ secs	SPLICING TIME/IJ secs	FINAL TAPE TIME/IJ secs	OTHER TIME/IJ secs	TOTAL TIME/IJ secs	TOTAL ord qty TIME- secs
9069	60	2.00	29.203	11.87	08.35	5.00	56.42	3385.34
9074	120	2.00	29.203	11.87	08.35	5.00	56.42	6770.69
20062								
9006	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9010	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9012	60	2.00	39.208	21.54	08.35	5.00	76.10	4566.12
9013	60	2.00	39.208	21.54	08.35	5.00	76.10	4566.12
9018	60	2.00	29.203	11.87	08.35	5.00	56.42	3385.34
9021	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9022	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9023	60	2.00	29.203	11.87	08.35	5.00	56.42	3385.34
9031	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9035	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9041	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9045	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9046	60	2.00	29.203	11.87	08.35	5.00	56.42	3385.34
9052	60	2.00	29.203	11.87	08.35	5.00	56.42	3385.34
9055	60	2.00	29.203	11.87	08.35	5.00	56.42	3385.34
9056	60	2.00	29.203	11.87	08.35	5.00	56.42	3385.34
9057	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9058	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9059	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
9071	120	2.00	29.203	11.87	08.35	5.00	56.42	6770.69
9072	120	2.00	29.203	11.87	08.35	5.00	56.42	6770.69
9073	120	2.00	29.203	11.87	08.35	5.00	56.42	6770.69
9080	120	2.00	25.452	11.87	08.35	5.00	52.67	6320.54
9092	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9093	30	2.00	25.452	11.87	08.35	5.00	52.67	1580.14
9095	30	2.00	33.206	15.54	08.35	5.00	64.10	1922.93
20378								
9087	60	2.00	25.452	11.87	08.35	5.00	52.67	3160.27
II								
9042	30	2.00	39.208	21.54	08.35	5.00	76.10	2283.06
9048	60	2.00	33.206	15.54	08.35	5.00	64.10	3845.87
20412								
9038	30	2.00	39.208	21.54	08.35	5.00	76.10	2283.06
9053	60	2.00	29.203	11.87	08.35	5.00	56.42	3385.34
9056	60	0.00	00.000	00.00	00.00	0.00	00.00	00.00
9094	30	2.00	33.206	11.87	08.35	5.00	60.43	1812.77
II								
9050	60	2.00	33.206	11.87	08.35	5.00	60.43	3625.53
20310								
9033	30	2.00	39.208	21.54	08.35	5.00	76.10	2283.06

3900

ANNEXURE-19

QUEST SUMMARY REPORT

Model : MITBAK.MDL
User : UNKNOWN
Date : Wednesday 11 September 1996
Time : 12:47 PM

Simulation Time : 76.81
Warmup Time : 0.00
Statistics Collection Time : 76.81

Time Units : hr

SOURCE

Name	No. of Entries	Repair Time
Source_1	539	0.000

SINK

Name	Processed Widgets	Repair Time
Sink_1	427	0.000

BUFFER

Name	Max. Buffer length	Avg. Buffer length	Avg. Residence	Max. Wait Time	Min. Wait Time
bufr_tape	2	0.393	0.056	0.181	0.000
bufr_20397	9	1.621	0.541	1.708	0.000
bufr_20060	6	0.783	0.955	2.733	0.000
bufr_20062	11	3.011	1.224	3.021	0.000
bufr_20378	1	0.002	0.006	0.129	0.000
bufr_wrap	467	226.572	32.286	65.274	0.000
bufr_20412	1	0.021	0.056	0.226	0.000
bufr_sort	529	33.854	4.824	9.429	0.000
bufr_20310	1	0.000	0.000	0.000	0.000

WORKCELL

Name	Avg. Utilization	Busy Time	Idle Time	Block Time	No. of Products	Avg. Residence
sorting	11.744 %	9.020	67.786	0.000	539	0.000
wrapping_1	96.653 %	74.235	1.570	0.000	175	0.000
wrapping_2	96.653 %	74.235	1.570	0.000	175	0.000
wrapping_3	96.101 %	73.811	1.995	0.000	174	0.000
crimp_20397	47.049 %	36.136	39.669	0.000	230	0.000
crimp_20060	37.096 %	28.492	47.314	0.000	63	0.000
crimp_20062	57.274 %	43.990	31.816	0.000	189	0.000
crimp_20378	5.966 %	4.582	71.223	0.000	21	0.000
taping_1	45.436 %	34.897	40.908	0.000	427	0.000
taping_2	12.293 %	9.442	66.364	0.000	0	0.000
crimp_20412	7.237 %	5.558	70.247	0.000	28	0.000

crimp_20310	1.636 %	1.257	74.549	0.000	7	0.000
wrapping_4	5.044 %	3.874	71.931	0.000	14	0.000

-------------------------- End of QUEST Summary Report -----------------------

QUEST SUMMARY REPORT

Model : USW.MDL
User : UNKNOWN
Date : Wednesday 11 September 1996
Time : 12:26 PM

Simulation Time : 101.53
Warmup Time : 0.00
Statistics Collection Time : 101.53

Time Units : hr

SOURCE

Name	No. of Entries	Repair Time
Source_1	539	0.000

SINK

Name	Processed Widgets	Repair Time
Sink_1	538	0.000

BUFFER

Name	Max. Buffer length	Avg. Buffer length	Avg. Residence	Max. Wait Time	Min. Wait Time
bufr_tape	1	0.000	0.000	0.000	0.000
bufr_usw	137	67.286	12.698	25.857	0.000
bufr_wrap	467	171.366	32.279	65.106	0.000
bufr_sort	529	25.642	4.830	9.596	0.000
Buffer_1	1	0.000	0.000	0.000	0.000

WORKCELL

Name	Avg. Utilization	Busy Time	Idle Time	Block Time	No. of Products	Avg. Residence
sorting	9.048 %	9.187	92.341	0.000	539	0.000
wrapping_1	73.118 %	74.235	25.793	0.000	175	0.000
wrapping_2	73.118 %	74.235	25.793	0.000	175	0.000
wrapping_3	72.700 %	73.811	26.217	0.000	174	0.000
octopus_std	98.006 %	99.504	0.524	0.000	538	0.000
taping_1	41.921 %	42.561	57.467	0.000	518	0.000
taping_2	1.587 %	1.611	98.417	0.000	20	0.000
wrapping_4	3.816 %	3.874	96.154	0.000	14	0.000

---------------------------- End of QUEST Summary Report ------------------------

QUEST SUMMARY REPORT

Model : USW2.MDL
User : UNKNOWN
Date : Wednesday 11 September 1996
Time : 1:25 PM

Simulation Time : 75.56
Warmup Time : 0.00
Statistics Collection Time : 75.56

Time Units : hr

SOURCE

Name	No. of Entries	Repair Time
Source_1	539	0.000

SINK

Name	Processed Widgets	Repair Time
Sink_1	538	0.000

BUFFER

Name	Max. Buffer length	Avg. Buffer length	Avg. Residence	Max. Wait Time	Min. Wait Time
bufr_tape	1	0.001	0.000	0.075	0.000
bufr_usw	4	0.317	0.045	0.395	0.000
bufr_wrap	467	229.975	32.237	65.272	0.000
bufr_sort	529	34.415	4.824	9.429	0.000
Buffer_1	1	0.000	0.000	0.000	0.000

WORKCELL

Name	Avg. Utilization	Busy Time	Idle Time	Block Time	No. of Products	Avg. Residence
sorting	11.938 %	9.020	66.536	0.000	539	0.000
wrapping_1	98.252 %	74.235	0.320	0.000	175	0.000
wrapping_2	99.375 %	75.084	0.472	0.000	177	0.000
wrapping_3	97.691 %	73.811	0.745	0.000	174	0.000
octopus_std	72.236 %	54.578	19.977	0.000	306	0.000
taping_1	40.728 %	30.772	44.783	0.000	382	0.000
taping_2	16.632 %	12.567	62.989	0.000	156	0.000
wrapping_4	4.395 %	3.321	71.235	0.000	12	0.000
Workcell_1	55.931 %	42.259	33.297	0.000	232	0.000

------------------------- End of QUEST Summary Report -----------------------

QUEST SUMMARY REPORT

Model : USWR.MDL
User : UNKNOWN
Date : Wednesday 11 September 1996
Time : 12:07 PM

Simulation Time : 75.69
Warmup Time : 0.00
Statistics Collection Time : 75.69

Time Units : hr

SOURCE

Name	No. of Entries	Repair Time
Source_1	539	0.000

SINK

Name	Processed Widgets	Repair Time
Sink_1	538	0.000

BUFFER

Name	Max. Buffer length	Avg. Buffer length	Avg. Residence	Max. Wait Time	Min. Wait Time
bufr_tape	2	0.125	0.018	0.182	0.000
bufr_usw	5	0.949	0.133	0.648	0.000
bufr_wrap	408	202.184	28.394	57.076	0.000
bufr_sort	532	62.203	8.735	17.643	0.000
Buffer_1	1	0.000	0.000	0.000	0.000

WORKCELL

Name	Avg. Utilization	Busy Time	Idle Time	Block Time	No. of Products	Avg. Residence
sorting	12.577 %	9.520	66.174	0.000	539	0.000
wrapping_1	98.072 %	74.235	0.459	0.000	175	0.000
wrapping_2	98.072 %	74.235	0.459	0.000	175	0.000
wrapping_3	97.512 %	73.811	0.884	0.000	174	0.000
octopus_std	64.572 %	48.878	25.657	0.000	538	0.000
taping_1	47.083 %	35.639	39.056	0.000	430	0.000
taping_2	11.494 %	8.700	65.994	0.000	108	0.000
wrapping_4	5.118 %	3.874	70.820	0.000	14	0.000

--------------------------- End of QUEST Summary Report ---------------------------

ANNEXURE-20

Annexure-20

Cost estimate of crimped splices

S.no	Location (w/c)	Material	Labour hrs	Machine hrs	Others	Type of cost	Unit cost	Total cost
I	Raw material store							
1		Ferule				Dir. material		$ 35,000
2		solder				Dir. material		$ 500
3		wires	not being considered					
4		Ferule				frieght		$ 1,025
5		solder				frieght		
6		ferule				storage/Mrp cost		$ 5
7		ferule				stock adjustments		$ 55
8		ferule				material handling		$ 150
9		taping tape				dir. material cost		$ 18,000
10		wrapping tape				dir. material cost		$ 1,600
11		IJ term				inv. value***		$ 5,500

S.no	Location (w/c)	Material	Labour hrs	Machine hrs	Others	Type of cost	Unit cost	Total cost
4			4hrs/month x 11months		maintenance		9/hr	$ 396
5			10min/day total		breakdowns			$ 360
S.no	**Location (w/c)**	**Material**	**Labour hrs**	**machine hrs**	**others**	**Type of cost**	**unit cost**	**total cost**
6				7 crimping m/cs		m/c rental		$ 5,650
			143 hrs/week x 49 weeks	7 crimping m/cs		dir. labour (operator)	9/hr	$ 63,063
7			205 changes @2min/change		setups		9/hr	$ 62
8			1hr/day		inspection		9/hr	$ 2,205
9			6 m/cs @ 3-4min/hr		pull-testing		9/hr	$ 7,056
V	**Soldering**							
			3hrs/week x 49weeks pa			dir. labour (operator)	9/hr	$ 1,323
VI	**Final Taping**							

S.no	Location (w/c)	Material	Labour hrs	Machine hrs	Others	Type of cost	Unit cost	Total cost
		Taping tape				inv. value***		$ 720
						Total costs pa		**$ 62,555**
II	**In buffer**							
1			40hrs/week x 49weeks/pa			marshalling (team leader)	$ 11	$ 21,658
III	**Wrapping**							
1			118hrs/week x 49weeks pa			dir. labour (operator)	$ 9	$ 52,038
1					replace blades		7m/cs@ $300/year/m/c	$ 2,100
2				143 hrs/week x 49pa	power		12.2cents/hr/ m.c	$ 837
3			5min/ m.c / week x 7m/cs		cleaning		9/hr	$ 252

S.no	Location (w/c)	Material	Labour hrs	Machine hrs	Others	Type of cost	Unit cost	Total cost
10		wrapping tape				dir. material cost		$ 1,600
		Taping tape				inv. value***		$ 720
						Total costs pa		**$ 20,320**
II	**In buffer**							
1			40hrs/week x 49weeks/pa			marshalling (team leader)	$ 11	$ 21,658
III	**Wrapping**							
1			118hrs/week x 49weeks pa			dir. labour (operator)	$ 9	$ 52,038
IV	**Ultrasonic welding**							
	surface rework of sonotrode tooling							
2				143 hrs/week x 49pa	power		12.2cents/hr/ m.c	$ 837

S.no	Location (w/c)	Material	Labour hrs	Machine hrs	Others	Type of cost	Unit cost	Total cost
					rental		**	
			53hrs/week x 49 pa			dir. labour (operator)	9/hr	$ 23,373
			3hrs/week x 49 pa		water proof taping	dir. labour (operator)	9/hr	$ 882
					Total cost pa			**$ 181,255**

Manufacturing Burden cost		106.87/sq. m
	Total cost pa	$ 243,810
	Unit cost of Production	0.195048

Cost estimate of ultrasonically welded splices

I	Raw material store							
3		wires	not being considered					
9		taping tape				dir. material cost		$ 18,000

S.no	Location (w/c)	Material	Labour hrs	Machine hrs	Others	Type of cost	Unit cost	Total cost
3			5min/ m.c / week x 7m/cs		cleaning		9/hr	$ 252
4			4hrs/month x 11months		maintenance			
5			10min/day total		breakdowns			
S.no	**Location (w/c)**	**Material**	**Labour hrs**	**machine hrs**	**others**	**Type of cost**	**unit cost**	**total cost**
6				1 usw m/cs		depriciat ion		
			143 hrs/week x 49 weeks	7 crimping m/cs		dir. labour (operator)	9/hr	$ 63,063
7			205 changes @2min/chang e		setups			
8			1hr/day		inspection			
9			6 m/cs @ 3-4min/hr		pull-testing			
V	**Soldering**							
VI	**Final Taping**							
					rental			

S.no	Location (w/c)	Material	Labour hrs	Machine hrs	Others	Type of cost	Unit cost	Total cost
			53hrs/week x 49 pa			dir. labour (operator)	9/hr	$ 23,373
			3hrs/week x 49 pa		water proof taping	dir. labour (operator)	9/hr	$ 882
					Total cost pa			**$ 162,103**

Manufacturing Burden cost 106.87/sq. m

Total cost pa $ 182,423

Unit cost of Production 0.145938

ANNEXURE-21

Time estimates of the various operations in the current system of splicing wires.

Sequence No.	Work station	Operation	Operation Purpose
1	Source	placement	input for the centre
2	sort	travel	to bring wires from source to sorting stn.
3	sort	sorting	to sort wires for further dispatch to wrapping stn.
4	sort	travel	to take the wires to different wrapping stn.
5	wrapping	pick up inbin	to pick up wire bundles for wrapping
6	wrapping	job card	to note work progress
7	wrapping	unwrap bundle	remove the tape that is wrapped around the bundle
8	wrapping	loop & wrap individual sets	to loop and wrap to 1. ease the handling in further processing 2. Avoid wrangling of wires 3. support the wire splices properly without falling over at the timeof splicing

Sequence No.	Work station	Operation	Operation Purpose
9	wrapping	wrap the bundle	to collect the wires of same set together ie., with left and right orientations
10	wrapping	job card	to note work progress
11	wrapping	place outbin	to facilitate further travelling of work pieces
12	wrapping	travel	to take the workpieces to crimping machines
13	splicing	job card	to note work progress
14	splicing	unwrap bundle	facilitate further crimping of individual sets of wires
15	splicing	orientation	keep individual sets of wires to the left and right to form the proper IJ
16	splicing	pick l&r	pick up left set and right set if each joint
17	splicing	place on anvil	placement of left and right sets on the anvil for crimping
18	splicing	foot lever	to facilitate the movement of ram to apply ferule
19	splicing	replace IJ	

20	splicing	wrap bundle	wrap the lot together for further operations
21	splicing	jobcard	to note work progress
22	splicing	out bin	to facilitate further travelling of lot to taping stn.
23	splicing	travel	travelling of work piece lots to taping stn.
24	Taping	jobcard	to note work progress
25	Taping	unwrap	unwrap the lot for individual pick up and tape
26	Taping	tape	encapsulate on taping machine
27	Taping	jobcard	to note work progress
28	Taping	outbin	ready for travel to assembly board