DESIGN AND DEVELOPMENT OF A ROBOTIC TAPE APPLICATOR

A Thesis presented in partial fulfilment of the requirements for the degree
of
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in
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Murali Guntur
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To

Saeid

my *guru*

Guruh Brahma Gurur Vishnuhu Gurur Devo Maheshwaraha
Gurur sackshat parah brahma Tasmai sri gurave namaha

Hindu mythology says
Guru is Creator (*Brahma*), Donor (*Vishnu*),
Protector (*Maheshwara*) and the ultimate person (*parah brahma*).
Hence I falicitate (*namaha*) him.

Murali

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ABSTRACT

The work described in this thesis is on the design, operation and testing of a programmable adhesive tape applicator 'EziStick'. The system demonstrates a mechatronics system comprised of mechanical, electronic and computer systems. 'EziStick' is capable of identifying any tape edge and then initialising and loading the tape over the applicator foot for successful application of tape. The tape tension monitoring system will allow continuous monitoring of the tape tension during its application. 'EziStick' is currently attached to the end of a robot arm to enhance its work envelope. The system is controlled via a low cost microcontroller and it is highly modular and transportable. 'EziStick' may be attached to the end of any robot (machines) with various degrees of freedom. In this way the cost of the system is adjusted by the complexity of the application. The experimental results showed that there is a relationship between the tape application speed and the quality of its application. Although the current prototype is designed for the application of aluminium tape, tests have indicated that other types of tape can be used in 'EziStick'.

Chapter 1

Introduction

This chapter gives a brief idea about the different changes happening in the manufacturing arena.

1.1 Introduction

In the modern manufacturing environment, manufacturing a product is no more a simple, single skilled operation. The manufacturer is faced with tremendous pressure and competition. Competition can be varied and can be from other companies in the same line or along different lines. When it comes to the international competition, the whole scenario changes on how well the industry can adapt itself to the flexibility and versatility demanded by the changing world economy. The manufacturer also has to provide an increasingly sophisticated and technologically demanding production environment. The environment should allow high volume production at competitive costs [1].

The only solution for the manufacturer if he wants to compete is to use the technique of *automatic manufacturing*. Included here are the use of robots, numerically controlled machines, computer aided design, computer aided manufacturing, computer integrated manufacturing and flexible manufacturing systems (FMS).

These new FMS and CIM systems can produce a much wider range of production variations at relatively low volumes and are also cost effective. These systems have expensive but flexible and programmable special-purpose equipment which is an added advantage over conventional high volume manufacturing systems.

The infra-structure of modern manufacturing involves several criteria. The role of manufacturing in several areas is discussed below.

1.2 Manufacturing

1.2.1 Automation in manufacturing

The FMS and CIM systems mentioned above are keys to industrial automation. They maintain high technical, quality standards and respond to the frequent changes in product design and production parameters.

Repeatability and consistency is the key concept of any *automated device*. An automated device, instrument or machine is said to be automatic when it can carry out the set of instructions (program) with the same degree of accuracy and precision over the number of times you require.

In the manufacturing environment automation is to switch the machine **ON**, and the sequence of operations are applied one after the other in a predefined manner. The only human involvement in this would be to initiate the sequence of operations by switching the machine **ON**. The sequence of operations (called programming) are applied depending on customer requirements, the machine capabilities and also on part (component) requirements. Automation depends on the flexibility and programmability of machines.

1.2.2 Automation

Automation indicates where everything is performed automatically without human involvement. Several definitions exist about automation. Automation is defined generally in the Oxford dictionary as :

'... automatic control of manufacture of product through successive stages or use of automatic equipment to save mental and manual labour '

More specifically automation is defined as [2] :

'a technology that is concerned with the use of mechanical, electronic, and computer-based systems in the operation and control of production'.

1.2.2.1 Classification of Automation

The automation technique can be dated to the early seventeenth century. The oldest concept of automation was *fixed automation.* Other automation concepts refining and extending their predecessors evolved later. Automation can be broadly classified into three types: Fixed automation, Programmable automation and Flexible automation(as shown in Figure 1.1).

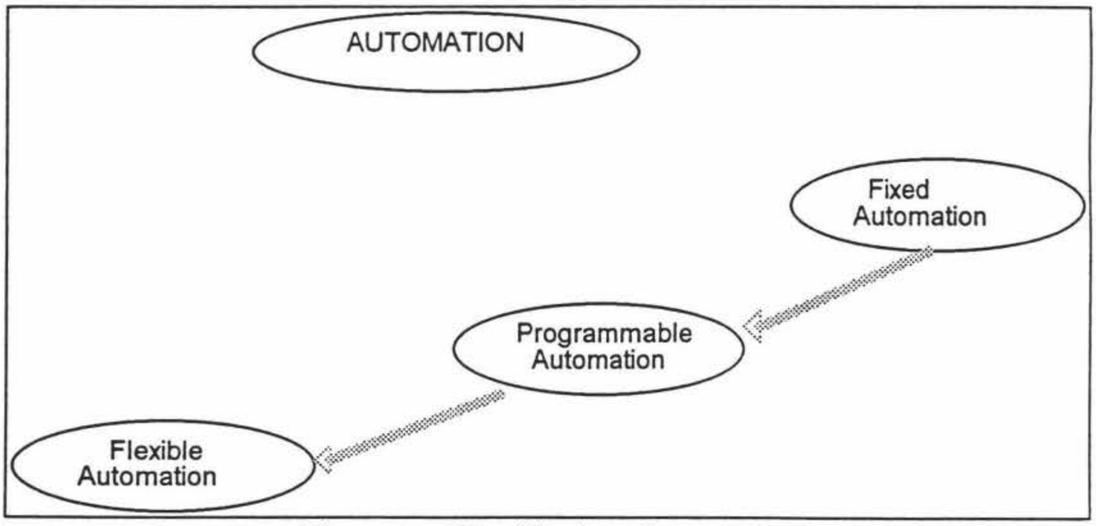

Figure 1.1: Classification of automation

As mentioned above, *fixed automation* is the oldest automation technique. Automation of simple actions is dealt by it. However, integration of these small actions into one system can make it complex.

With the advent of numerically controlled machinery & robots which are basically programmable, automation took a new turn into *programmable automation*. In this automation technique the system is mainly controlled by a program[1]. Programmable automation is hence more flexible, as any changes in the operations can be made simply by changing the program.

In programmable automation, products usually will be processed in batches, owing to the fact that it takes time for product change over and re-programming. If this change over time is reduced to zero or to minimum, then the batch size can be reduced to one. Using this theory programmable automation is logically extended into *flexible automation*. The production down time between the batches can be eliminated using this technique.

A comparison of the definitions and features of various automation techniques as described by famous authors was conducted. Table 1.1 indicates a comparison of definitions. Table 1.2 indicates a comparison of the features of various automation techniques. Figure 1.2 shows the production volume distribution among various styles of automation [3].

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[1]A Program is nothing but 'a set of coded instructions', which will be deciphered by the equipment

Automation classification	Definition
Fixed	The production systems in which the sequence of processing or assembly operations is fixed by the equipment configuration and can not be readily changed without altering the equipment.
Programmable	The system in which the equipment is designed in such a way that the sequence of production operations is controlled by a program.
Flexible	The system capable of producing various combinations and schedules of products in a continuous flow.

Table 1.1: Comparison of definitions of various automation techniques.

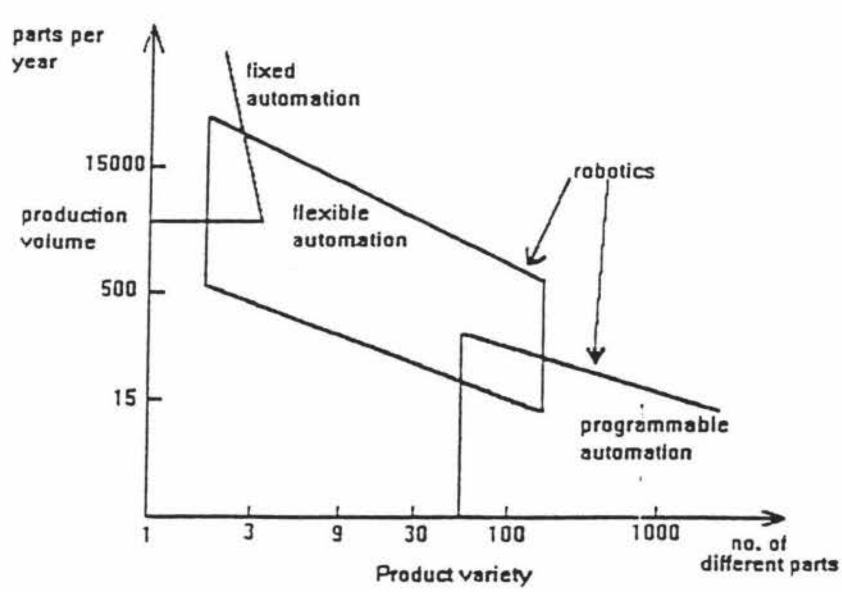


Figure 1.2: Production Volume Distribution

(Extracted from M Groover's '*Industrial robotics*')

Automation classification	Features
Fixed	i) high initial cost, due to expensive custom built or special purpose machinery. ii) high volumes of production iii) inflexibility of the system to incorporate changes without altering the set-up.
Programmable	i) less initial cost towards equipment (less than that of Fixed automation) ii) suitable for medium production volumes, production can be done in batches iii) flexible to changes in the product styles.
Flexible	i) high investment cost on custom built equipment or special purpose machines ii) flexibility to accommodate changes in the product design iii) flexibility to produce different products in continuous flow in different quantities.

Table 1.2: Comparison of features of various automation techniques.

1.2.3 Robots in manufacturing

Modern manufacturing [4] has been broken down into a number of small actions to allow flexible, productive and programmable environment. This eliminates the involvement of the skill factor from the manufacturing process. Hence, a less skilled or unskilled workforce needs to be hired.

The concept of repeatability of actions evolved into a device famously called *robot*. In high volume productions, these small actions are automated by replacing humans with robots. In the early stages of automation, robots played very important role. They are supposed to be the only tools or devices that can replace human in all menial, repetitive, tedious and unpleasant jobs in the industrial jobs.

In the long run robots are found to be cost effective than their human counterparts. Physically, robots have good edge over human beings. They are non-tiring, non-complaining *beasts* which are made to produce. They can also be programmed to different manufacturing requirements as they arise.

In most situations robots are only *single arm metal monsters* (as they are popularly imagined), that carry the working device to the manufacturing area. This working device which will always be fixed to robot arm is called '*robotic end effector*' and is the actual device that carries out the needed work. The necessary movements are provided by the robot through a program, as these robot are programmable creatures. For instance, a *deburring device* or a *grinding machine* fixed to the robot is an end effector.

1.2.4 Packaging in Manufacturing

After the product is produced it must be packed for further shipment and distribution, until it reaches it's destination, which is 'the customer'. Until that stage something should ensure the quality and integrity of the product. The package or the packaging system [5] must also ensure the safety of the product from the outside environment and vice versa. The importance of packaging side is made up of packaging materials and also packaging machinery. The increasing sophistication of packaging machines along with packaging materials combined with increasing complexity of the manufacturing system demands for an integrated design incorporating both.

Depending on the type of product and nature of activities of the industry, packaging plays a very critical role. In the soft drinks or beverage industry, container shares half the credit of it's sales. But for a mechanical part a package or container is just a wrap that keeps the product inside, safe during it's journey to the obvious customer.

1.3 Robotic end effector in packaging automation

An unavoidable and very interconnected relationship exists between the product, manufacturing environment and the package or packaging system. It varies from industry to industry and product to product and environment to environment.

This report is focusing it's use on the tertiary packaging system, where all these primary packages are put into a big case or box, and transported from one place to another place. The research work discussed in this report is a form of a robotic end effector, which works on sealing the flaps of packaging boxes / cases with an adhesive tape. This is the exact area, where this research is looking at.

The present research also involves making use of robots, and developing robotic end effectors. The emphasis is given to the end effectors rather than to the robots. Robot here is used as mere tool in implementing the concept. The concept actually is modularising the various elements of the system to the extent possible.

This report describes an end effector, called 'EziStick' that applies tape on to a surface or to the box or case in packaging, as per your requirement. This 'EziStick' is programmable and modular. This work is described in detail in later chapters.

1.4 Report Structure

Chapter 2 discusses about the literature survey and about few patents that have some similarities with the work undertaken in 'EziStick'.

Chapter 3 discusses the concepts of manufacturing.

Chapter 4 discusses about the importance of packaging in manufacturing, packaging, packaging styles, different packaging materials and different factors governing the selection of the packaging machinery.

Chapter 5 discusses about the robot, features of the robot, the 'EziStick' and the features of 'EziStick'.

Chapter 6 discusses about the various components of the 'EziStick' and explains the various functions of each component in detail.

Chapter 7 discusses the control logic of different modules of the 'EziStick'.

Chapter 8 discusses about the experiments to confirm the performance of different modules of 'EziStick' and their results.

Chapter 9 gives the conclusions of the research.

Chapter 2

Related Research

This chapter discusses the related work done elsewhere, similarities and dissimilarities of this work with 'EziStick'.

2.1 Introduction

As a part of a literature survey, related patents that have functional similarities with the present research were studied. All these patents were thoroughly studied and the functions of these devices were compared against the functions of the 'EziStick'. Several dissimilarities with 'EziStick' were found with regard to the functional aspects.

These patents are briefly discussed and their features are highlighted in the upcoming sections.

Patent1 A Canadian Patent

Name: Tape Dispensing Apparatus

Patent No.: WO-A-93 07063 (LA CORPORATION DES RUBANS ADHESIFS VIBAC DU CANADA) 15 April 1993 [6]

Patent2 A Japanese Patent

Name: Adhesive Tape Connecting Device

Patent No.: A 57098449 (HITACHI LTD.) 18 June 1982 [7]

Patent3 A German Patent

Name: Device for peeling the tape

Patent No.: EP-A-189 582 (MASCHINENFABRIK FR. NIEPMANN GMH & CO.) 6 August 1986 [8]

Patent4 A Japanese Patent

Name: Device for Automatically Stripping and Delivering fore end of a Paper roll

Patent No.: EP-A-0 189 761 (JAPAN TOBACCO INC.) 6 August 1986 [9]

Patent5 A US Patent

Name: Method for the application of lengths of tape to a surface

Patent No.: 5,192,385 (3M Limited) 9 March 1993 [10]

2.2 Patent 1: Tape Dispensing Apparatus

The 'Tape Dispensing Apparatus' described under patent1 is more a manual type as the instrument under consideration provides a structure for the tape roll and the other necessary feed rolls and cutting knife arrangements. The tape roll has to be replaced manually and the tape end has to be positioned manually onto the rollers. The tape end has to be fed to the feed rollers each time the tape roll is replaced. This apparatus is fixed in a position and the case, on which the tape is being applied, has to move under the apparatus for the tape to be applied onto it.

Figure 2.1 shows the details of the 'Tape Dispensing Apparatus'.

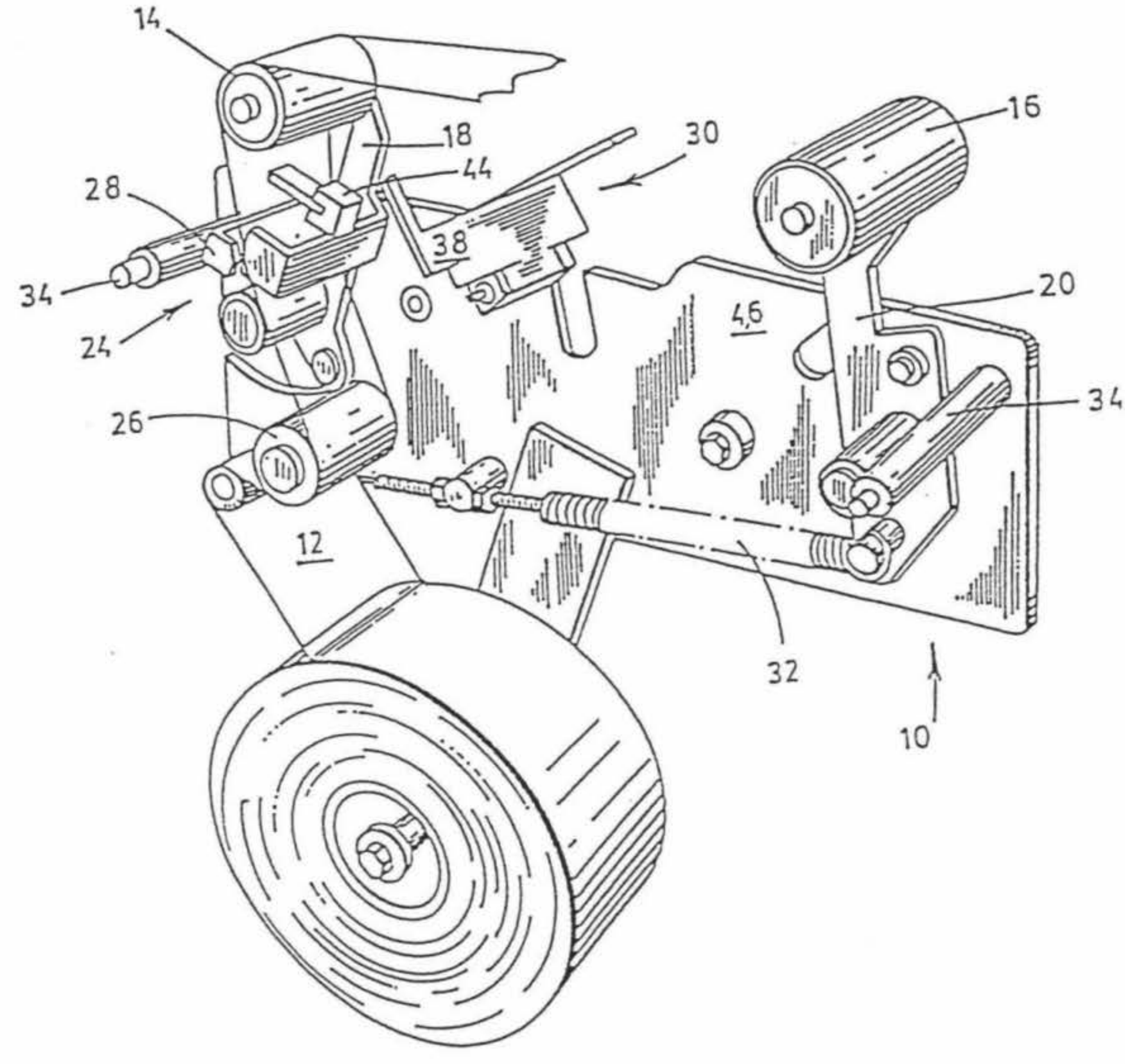


Figure 2.1: Tape dispensing apparatus

2.3 Patent 2: Adhesive Tape Connecting Device

The 'Adhesive Tape Connecting Device' described under patent2 is a device that is capable of connecting two ends of adhesive tapes automatically. At the end of one adhesive roll, the device pulls tape from the other roll and joins that end with the end of the first roll so that the process can go on without interruption. This system did not discuss tape application. The work described under the patent2, discusses a structure that has two tape rollers mounted with two mating cylinders, one concave faced and the other convex faced. The two cylinders hold and pull the tape and connect the second tape to the first tape end.

Figure 2.2 show the details of the 'Adhesive Tape Connecting Device'.

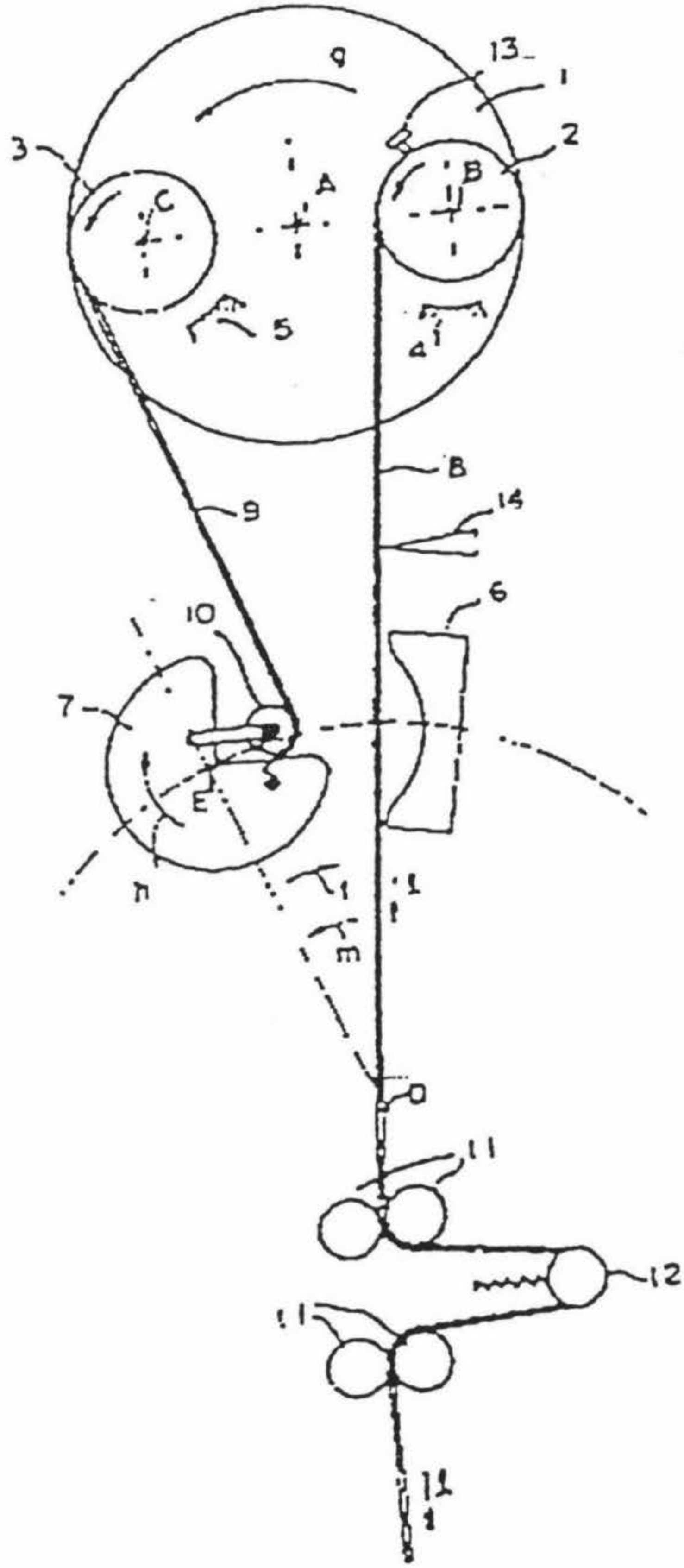


Figure 2.2: Adhesive tape connecting device

2.4 Patents 3 & 4: Automatic Tape Stripping Device

The devices described under patents 3 & 4, are similar but taken in two different countries Germany and Japan. The 'Device for automatically stripping and delivering fore end of a paper roll', described under patent4, is basically developed for a tobacco industry. This device automatically delivers the paper for cigarette manufacture as a part of the cigarette manufacturing process automation. This device is a semi automatic device. The tape loading has to be done manually. This device is not used for any tape application purpose. It only peels the paper from a paper roll and presents it to further processes like cutting and so on. It is a stationary device. The device under consideration detects the paper edge, picks up the paper fore end and presents it to the vacuum sucker roller, which rotates the paper to the next processes. The paper fore end is detected by a photo switch and the paper fore end is peeled from the paper roll by a pneumatic cylinder and a metal piece, by clamping the paper to the metal piece. Peeling of the paper fore end is performed by another pneumatic cylinder.

Figures 2.3 and 2.4 show the details of the patent 3 and patent 4.

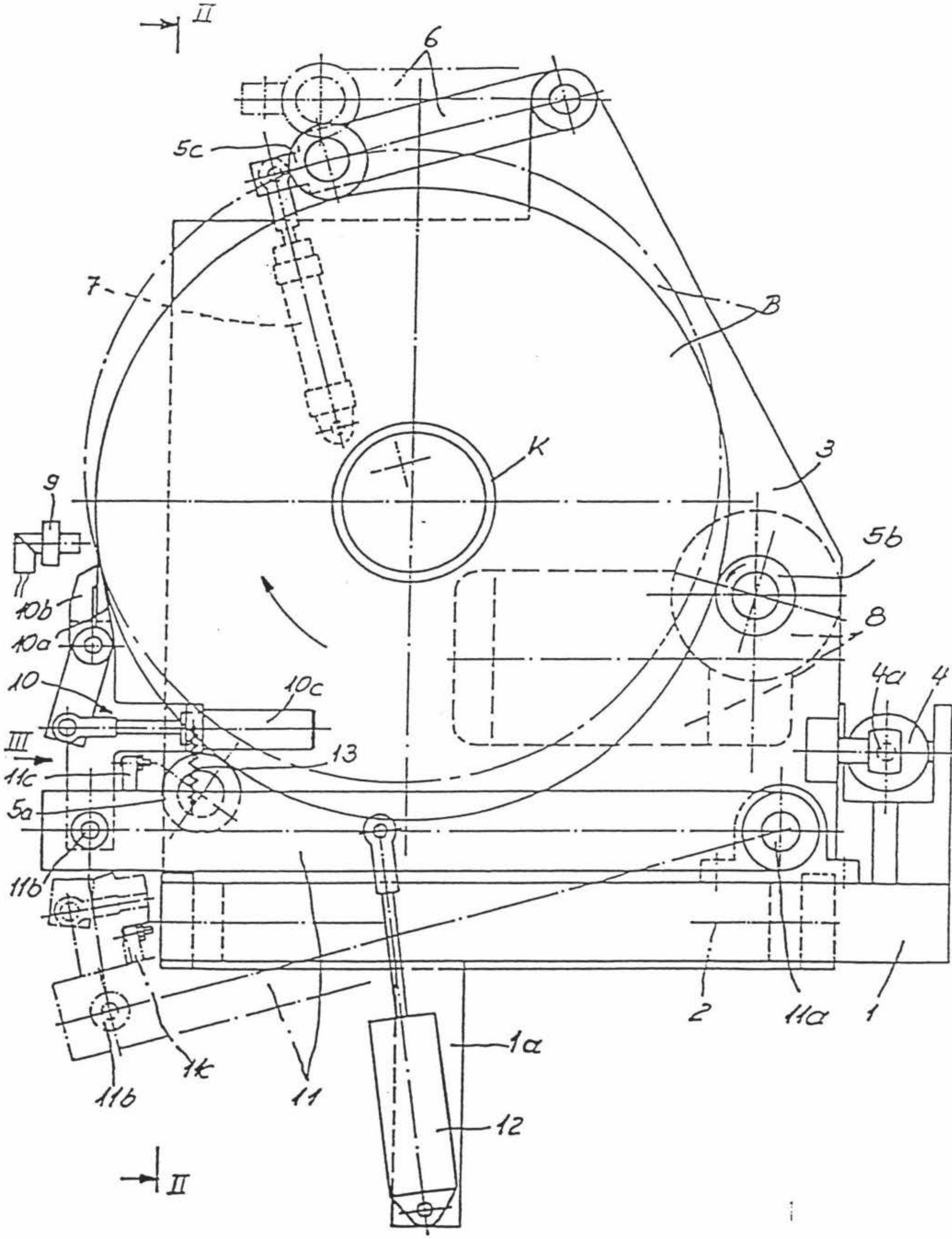


Figure 2.3: Device for peeling the tape

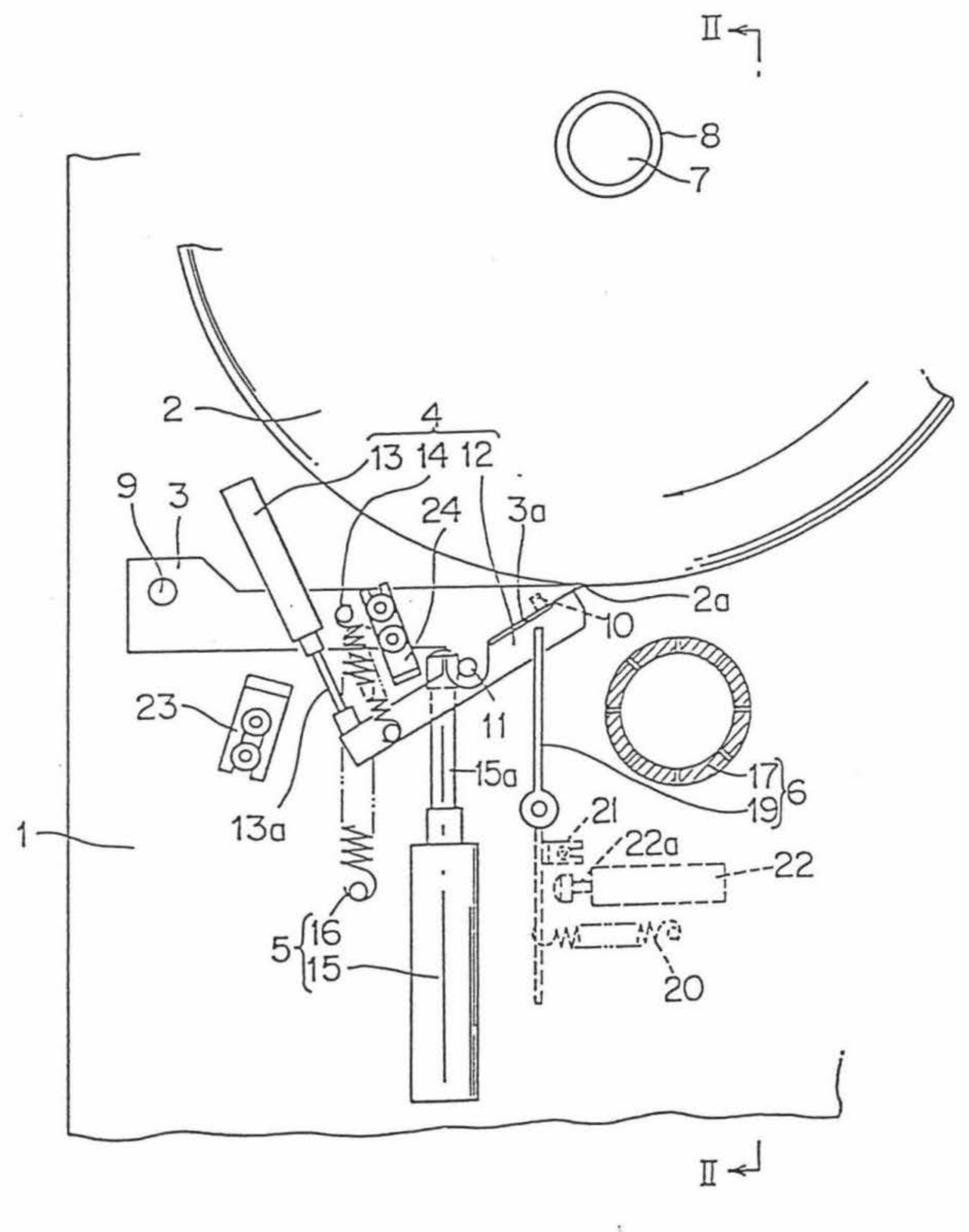


Figure 2.4: Device for automatically stripping and delivering fore end of a paper roll

2.5 Patent 5: Device for Tape Length Application

The work described under patent5, is totally focussed on the application of short lengths of tape. By the structure of the apparatus, tape roll appears to be manually loaded. The structure which is described under patent5 applies tape bits to the case corners, in 'L' bends. It applies the tape and cuts the tape as the case is moving under the device. This taping process is done on the bottom face of the case. The replacement of the empty roll and tape edge preparation are done manually.

Figure 2.5 show the details of the 'Device for tape length application'.

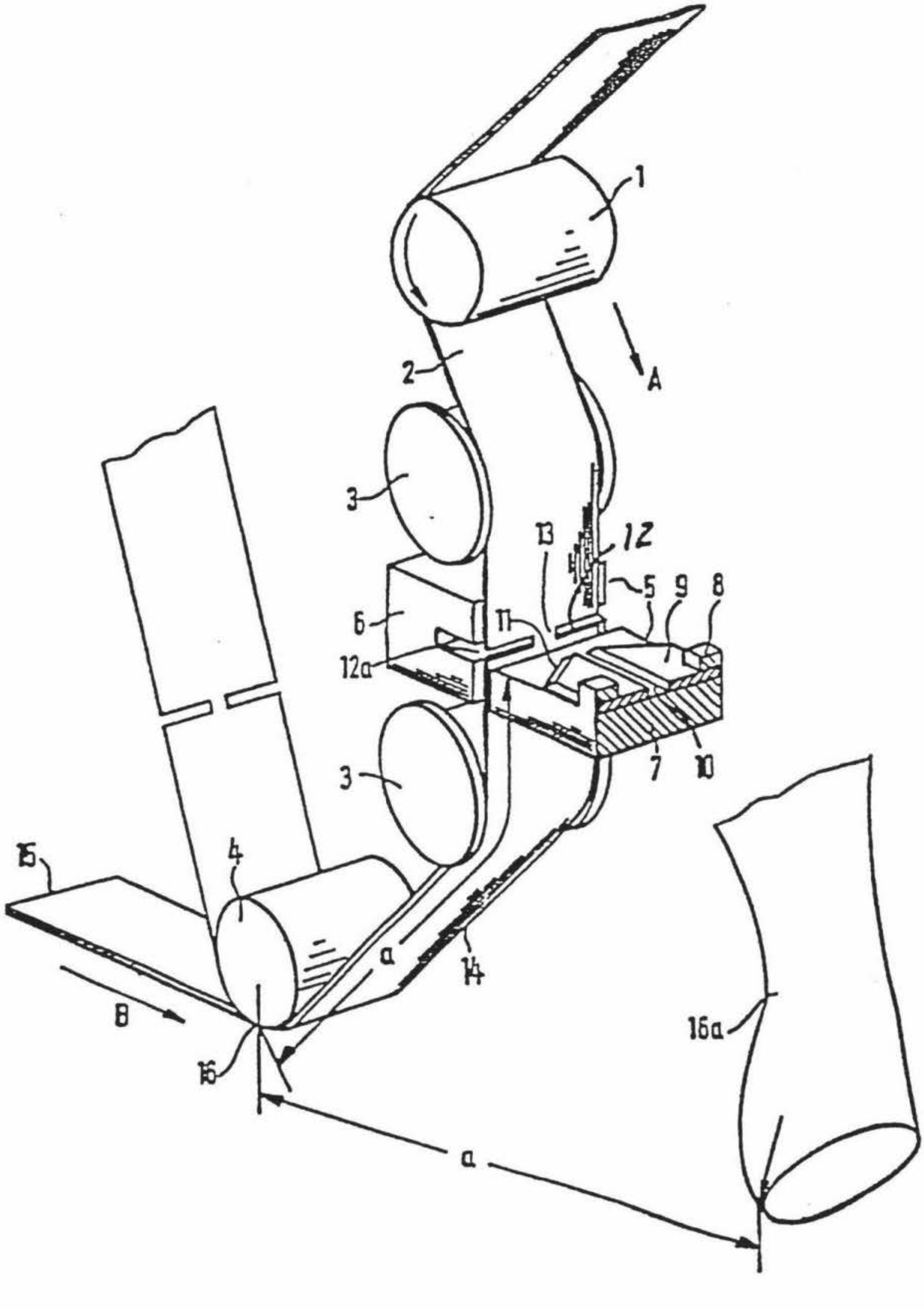


Figure 2.5: Device for tape length application

2.6 'EziStick'

2.6.1 Background

This research project was started in 1993 where a series of feasibility studies were carried out to identify the possibility of developing a robotic end effector to identify tape edges, pick up the edge and to apply it at a programmable rate and length. During the same time a series of modules were developed and tested in isolation.

At that stage a patent application was filed on the design concept and possible operation of 'EziStick' [11]. The research carried out further research on integration of the aforementioned modules and improvement of certain aspects of the unit. During the course of this research some modules had to be modified in order to ensure the smooth integration of the various elements of 'EziStick'.

2.6.2 Actions of 'EziStick'

The basic actions of the present research are detecting the tape edge, positioning the blade to peel the tape edge (on deciding the type of edge), peeling the tape edge by clamping the tape to the blade and presenting it to the applicator foot for the application. There are sensors monitoring the each action mentioned above. The tape edge is detected by optical scanners, tape surface is detected by a inductive proximity switch, the tape is clamped to the blade by a pneumatic cylinder and the tape peeling action is done by a rotation arm.

The tape edge detection is done by three diffuse scan opto sensors that are mounted across the tape roll surface. The edge is detected while the tape roll is rotating. The reason for using three sensors is that they are non-contacting. They not only detect the edge but also provide valuable information about the type of edge detected. This is possible by the control algorithm.

Depending on the information gathered by the edge sensing opto sensors, the blade will be positioned near to the leading edge to peel the tape edge properly. Another pneumatic cylinder is used to position the blade near to the tape edge. A rotation arm is used to facilitate the peeling of the tape. Inductive proximity switches are used to detect the tape surface during tape peeling.

Tape application is totally automatic with full feed-back available to the system, during the entire tape application. A tension monitoring system is incorporated in the device to read the tape tension during the tape application. This facilitates the full control of the tape application and provides valuable feedback to the system.

Another important part of the work is an applicator roller which is designed to act as an 'active roller' to accommodate slight surface unevenness and also to tape on small tubes. ‘EziStick’ will apply tape over a tube kept on a surface very successfully.

'EziStick' is a totally automated tape applicator. It is mounted on the robot. The robot assists 'EziStick' tape application and changing tape rolls. It can also be used to apply tape over cases or boxes. The robot can be programmed for different speeds depending on the requirement.

The critical features of 'EziStick' are that , this device is programmable and can apply tape to any surface (flat or curved), at a programmable speed and programmable rate. Comparing 'EziStick' with many current inventions, 'EziStick' is the only device physically moving during the actual tape application. This feature of 'EziStick' helps in sealing / taping large, bulky boxes. For example sealing / taping a box containing fridge freezer. This box would be quite big to turn around during taping operation where 'EziStick' comes in handy.

Figure 2.6 shows the details of the 'EziStick'.

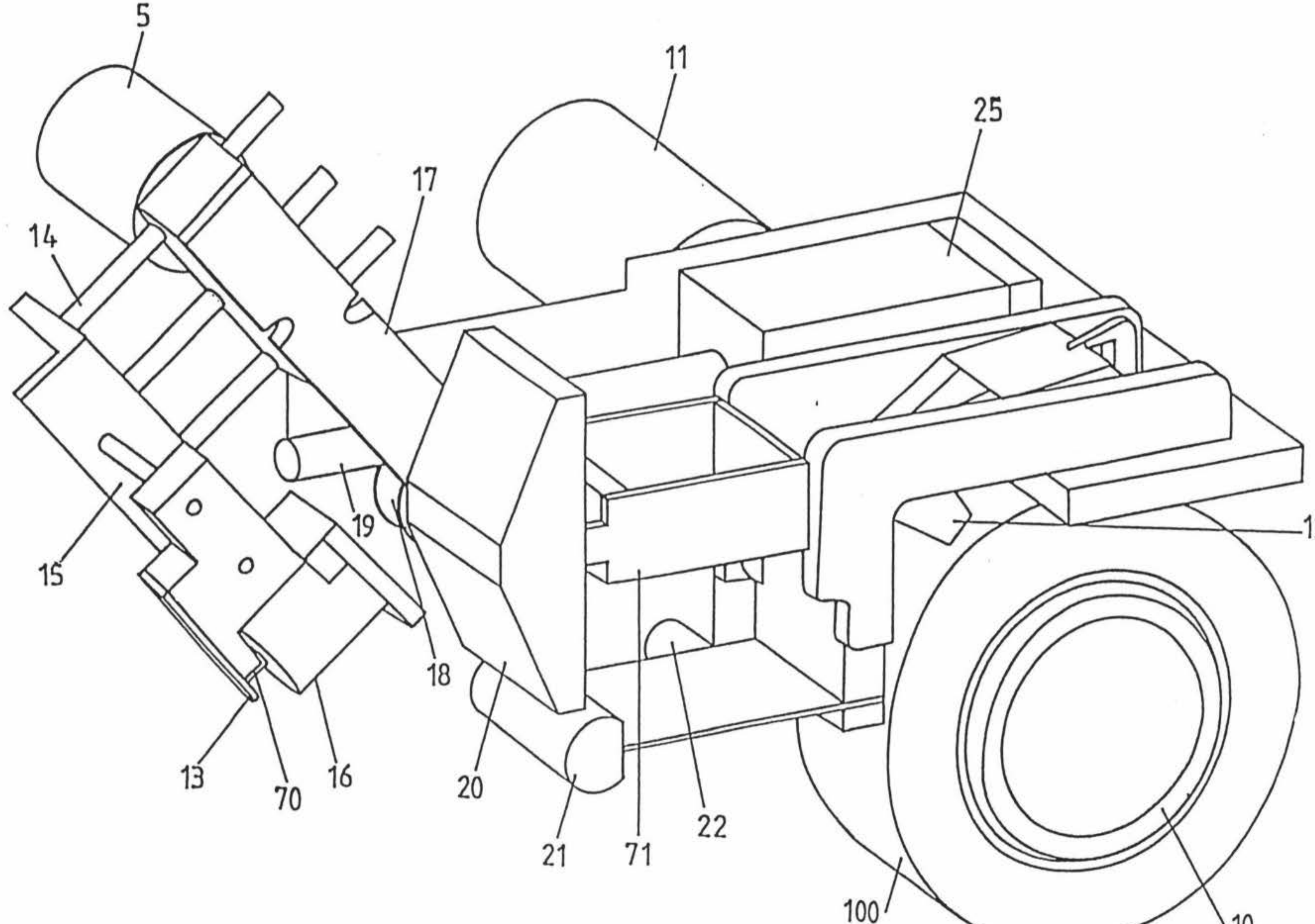


Figure 2.6: 'EziStick'

Chapter 3

Packaging

The aim of this chapter is to emphasise the importance of packaging in a manufacturing system. Packaging, packaging styles, various packaging materials and factors affecting the selection of the packaging machinery were also discussed in this chapter.

3.1 Packaging

Though application of the packaging tape is a vital part of the thesis, the presence of this chapter is only to familiarise the reader with the different ways and styles of product packaging and how important packaging has become in modern marketing strategies. Packaging in itself is a very big and deep subject. Because of space limitations, author could not discuss the packaging in detail and tried to give some packaging background to the reader

The necessity to protect and preserve the product during its transportation and shelf life, evolved into a concept called packaging. Making the products ready for transportation by packing all the final products into a protective case(e.g box) is *packaging*. The institute of packaging professionals [12] formally defined packaging as:

'The enclosure of products, items or packages in a wrap, pouch, bag, box, cup, tray, can, tube, bottle or other container form to perform one or more of the following major functions: containment for handling, transportation and use; preservation and protection of the contents for required shelf and use life and sometimes protection of the external environment from any hazards of contact with contents; identification of contents, quantity, quality and manufacturer-usually by means of printing, decoration, labelling, package shape or transparency; facilitate dispensing and use. If the device or container performs one or more of these functions, it is a package.'

Packaging can also be described in terms of functions or functionality. The increased automation of the manufacturing environment along with the sophistication of packaging machines is demanding for a total system. This system should consider the criticality of all the elements involved like packaging materials and machines.

Poor package design leads to adverse consequences like down time, lost productivity, low efficiencies and poor product quality. Hence, packaging systems design should be included into initial product and process systems design.

3.2 Functions of Packaging

Generally speaking, a package fulfils some basic functions such as containment, protection, performance and communication. Different organisations stress on different functionalities [13] of the package depending on the field they are operating in.

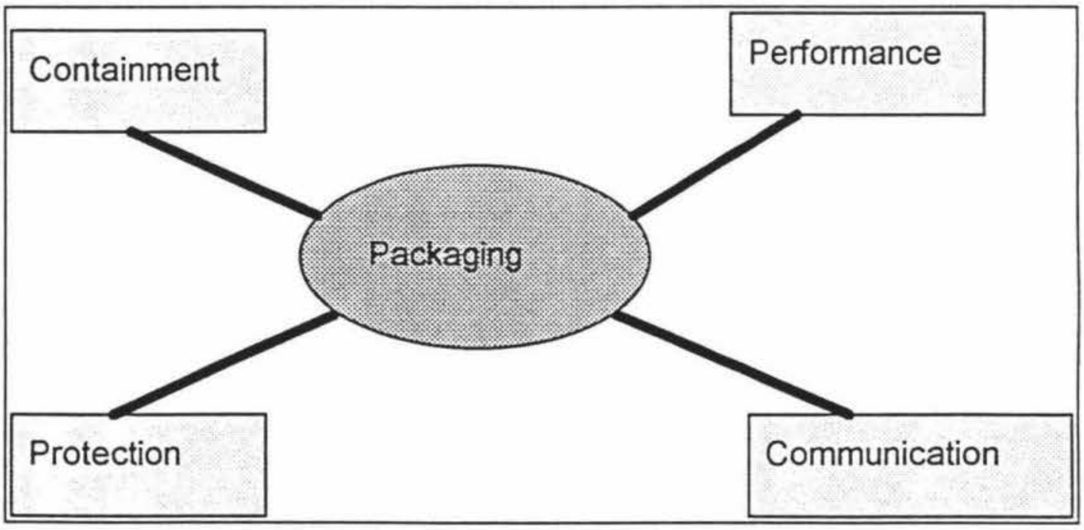


Figure 3.1: Basic functions of packaging.

Cosmetic companies focus heavily on aesthetics and easy to use aspects of the package apart from the other packaging features. Hence, performance and communication functionalities of the package is emphasised by them. Most of the consumer-oriented industries concentrate on performance, communication and protection functions of the packaging. Other industries like institutes and military organisations emphasise on protection and performance functions.

The basic functions of packaging will be discussed in the subsequent sections.

3.2.1 Containment

Containment is the function of package to embody or hold the products. Containment not only allows carrying the products that can be held by hands but also the products in the liquid form and granular form. Beverages are the best example for this type of packaging style.

3.2.2 Protection

A package has to protect the product from moisture, liquid, dirt, microorganisms, light, oxygen, losses of ingredients, flavours, fragrances, insects and other intruders (also includes intentional intrusion by human beings).

A big threat to a product is an environment which has a high range of spoilers. This can be avoided by establishing a barrier between product, environment and man.

3.2.3 Performance

Packaging performance covers all other aspects such as sanitation, unitization, dispersing and dispensing, pilferage deterrence, etc. The different aspects of performance are summarised in table 3.1.

Aspect	Use
Maintains product integrity and safety.	reduces product spoilage, minimises the loss of nutritional or functional value of the product, prevents the product from time based microbiological deterioration.
Offers easy opening, convenient devices.	provides safe and convenient use of products. e.g bottle with no-drip tops, cartons with pouring sprouts, carbonated beverages with 'finger friendly' easy opening device.
Groups products into units	allows convenience by carrying products in bulk rather than carrying the individual product
Permits packaging to users needs like small articles packed into big boxes.	minimises shop lifting by preventing thieves from pocketing things easily. e.g audio cassettes, razor blades

Table 3.1: Performance aspects of packaging .

3.2.4 Communication

At the point of sale, the package is the only communication link left between the product and consumer. Especially in the self service retail counters, when similar products are on display racks only the package can influence buyers. Hence, buyers actually purchase the package and not the product.

In these days of cut-throat competition, sales are mostly influenced by what is on a package and how attractive it is. *More attractive and communicative the package, more the sale.*

Apart from being attractive, the package should at the same time give full details of the product inside like, identity, brand, price, instructions, warnings, warranties and so on. If the product is food, cosmetic, or a pharmaceutical product, the information on the package should also contain the details of efficiency, date of manufacture, date of expiry, contra indications, contents, etc.

3.3 Levels of Packaging

The package itself may be viewed at different levels, as primary, secondary and tertiary package. At the primary level, the package will be usually handled by the customer, at secondary level the package will be handled by the retailer, at the tertiary level the package will be usually big and it is meant for shipping or distribution.

Even an individual cigarette can be called a package, because it contains and holds tobacco. But a cigarette is treated as a product and made as an individual item. A cigarette box is a primary package holding 10 individual cigarettes. The next level of packaging, a carton of cigarette packets containing 20 packets or 200 cigarettes is secondary packaging. These cartons come again in a box of 12 cartons or 24 cartons and this is the third level called tertiary packaging.

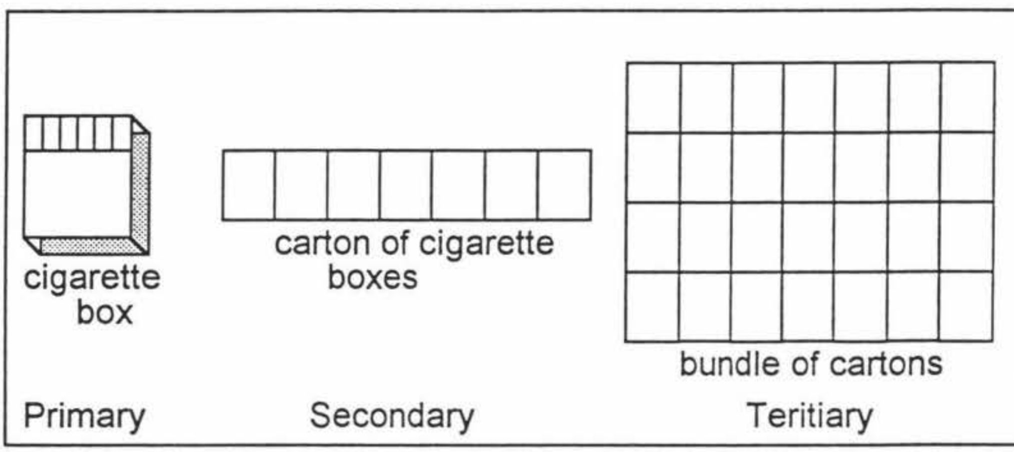


Figure 3.2: Levels of Packaging.

The above description stands for articles which are small, but things will be different for big and huge articles. If the product is large and takes good volume then the package may end up only at the second level. Here the secondary level will be it's tertiary level.

3.4 Packaging Machinery

Many types of packaging machines [14] exist in the market ranging from semi automatic to fully automatic packaging machines. There are machines which can erect the carton, fill the product and seal the carton at the rate of over 100 per minute. These are the new generation fully automatic packaging machines. The following factors should be considered before deciding the suitability of the packaging machinery in the industry. Once this information is available the type of equipment best suited for the application can be determined.

- Speed of the product to be handled in units per minute.

- Whether the product is being received intermittently or continuously.

- What is the nature of the product to be packed ? All products are different in shape, stability, compressibility, fragility, weight or position in which they must be packed.

- Are there more than one size going to be run and if so, what are the change over requirements in time ?

- In what position will the product be received? Are all products received at the machine in the same position?

- If the product is packed, what is the case load pattern?

- Is accumulation of product necessary ? How much is necessary and is the space available to accumulate ?

- What space is available for the line?

- What is the product flow through the plant ? Can the packing line coincide with this flow ?
- What will be the position of the operator or the line attendant in relation to the equipment?
- What are the labour objectives for the packaging operation ?
- What options or variations are required for the line ?
- Special manufacturing requirements to comply with company standards.
- What utilities are available in quantity ? Electricity in ampere service; air in PSIG, water in cubic feet per minute at the specified temperatures?
- Installation and maintenance are as critical as the selection of the equipment itself. Spare parts availability and maintenance of the mechanism should be considered.

Though there are many packaging machines available, the usage of tape as *carton or case sealing* medium is only considered in the present research. Another reason for selecting the tape is that glue, plastic straps, etc are not friendly to the environment.

Case sealing [15] is among the oldest industrial practices, that is used to hold products in one container. In the earlier days, glue or paper tape was used to seal cases. The new trend in case sealing is to use *pressure sensitive tape* to seal cases. The pressure sensitive tape sticks the flaps of the carton tightly and strongly without the use of any glue or water. The strength of the sealing can be increased by using a fibre reinforced pressure sensitive tape.

Versatility, convenience and consistency are the terms used to describe the pressure sensitive tapes. The usage of pressure sensitive tapes is growing in packaging industry as a case sealant means. Pressure sensitive tapes:

- are easy to use either manually or mechanically.
- offer uniform tape application under all conditions.
- offer convenience, simplicity as they are in ready to use form.
- 'hold, seal, close, open, decorate, label, bundle, enclose, protect, combine, colour code, secure, reinforce and unitize'.

3.5 Packaging shapes

The shape of the package is also a major criterion taken into consideration in the packaging industry. Packages were available in many forms mainly : boxes, folding cartons [16]. But with the recent developments in packaging, plastics are also being used as secondary and tertiary packages in shapes of drums and large size containers. Pouches and films are also part of plastics in the packaging industry.

In the present days of automation, packaging is also automated to a reasonable degree. A wide variety of machinery is available from different companies with semi-automatic and fully-automatic and random-size or fixed size as options. Whatever the machine may be, fundamentally it has to stick tape to the case or carton. The machine has to form a strong bond between tape and carton, stronger than the carton material itself. It should tear away the carton material while it is removed from the carton. This is a test one way, to make the tape application tamper-evident. The tape application speed, versatility, tape saving, ease of application and reliability of the machine are the very important criteria during the selection of the proper taping machine for the purpose.

There is a wide variety of pressure sensitive tapes available in the market, ranging from paper tapes to cloth tapes. They can be categorised into 4 major forms. They are Paper tapes (crepe tape, flatback tape), Film tapes (cellophane tape, acetate tape, polyester tape, reinforced film tape), Metal foil tapes (aluminium foil tape, lead foil tape) and Cloth tapes. Each tape has got its own area of application and they are quite convenient and popular in that area. In the present research, aluminium foil tape is being used to as the major source of tape application and applications with different tapes is also considered for analysis. This is discussed in detail in later chapters.

Another reason for using the aluminium tape for this research project is, in the initial days the project was looking at developing an automated solution for the manual tape application in the area of refrigerator manufacturing. A decade ago, the condenser tubes of fridge were positioned outside the fridge cabinet at its backside. But with the change of industrial design of refrigerator, the condenser tubes were brought inside the cabinet. This change necessitated the taping of the condenser tubes to the back panel of the fridge from inside. This is a manual operation and quite labor intensive. This project was looking at an automated solution to this manual, monotonous taping problem. And the result is 'EziStick'.

Due to the flexibility and modularity of 'EziStick', it can be used any where a taping operation has to be performed. The design features of 'EziStick' have imparted such flexibility to the system that by changing a single part, 'EziStick' can be used either for condenser tube tape application or to seal the packaging cases. The simple change of application roller facilitates this flexibility to the system.

Chapter 4

Robot - ‘EziStick’

This chapter discusses about robot, features of robot, 'EziStick' and features of 'EziStick' in detail.

4.1 The Robot

Robots are commented to be the only tools or devices that can replace humans in all menial, repetitive, tedious and unpleasant industrial jobs. The robot that is used in this research is an industrial robot from **ASEA,** IRB 6/2, and has five independent motion axes or degrees of freedom. Each of these motion axes has a separate drive system consisting of electric motor packet, gearbox or ball screw.

4.2 Robot Axes

A short description of each axes follows.

4.2.1 1st Axis - Rotational motion

Rotation of the entire mechanical robot about it's base (waist) which is anchored to the floor.

4.2.2 2nd Axis - Radial arm motion

Back and forth motion of the lower arm (and attached upper arm) about the lower arm pivot on the pillow block.

4.2.3 3rd Axis - Vertical arm motion

Up and down motion of the upper arm (and attached wrist) about the pivot point between upper and lower arms.

4.2.4 4th Axis - Wrist bend motion

Up and down motion of the wrist unit about the pivot point horizontally perpendicular to the upper arm.

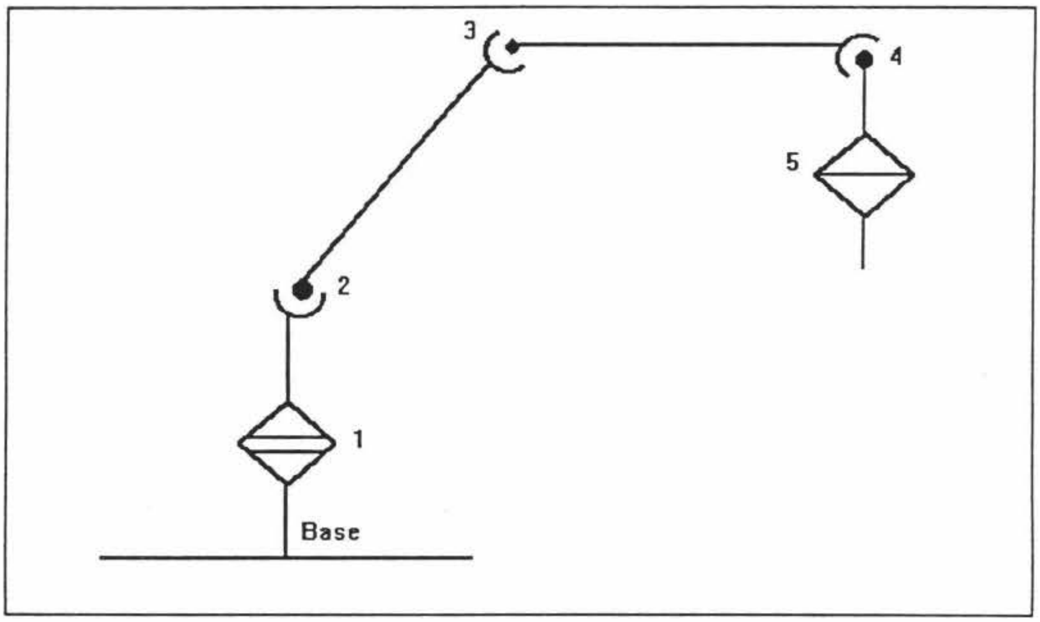


Figure 4.1: Symbolic representation of the 5 axes motions

4.2.5 5th Axis - Wrist turn motion

Rotational motion of the shaft extending outwards from the wrist bend axis.

Figure 4.1 shows a symbolic representation of the five axes motions.

The best part of using a robot is its programmability. The required movements for the "*EziStick*"(explained later in section 4.3 and chapter 5) are provided by the programmed robot. The Robot is programmed to perform various movements using it's teach pendent and are stored into it's memory. The movements that has to be performed in conjunction with the 'EziStick', are signalled through the micro controller. It is understood that there will be a time delay between signal and actual action, hence, sufficient waiting time is provided in the program between each movement to cater for the actual physical movements of 'EziStick' and robot. (When 'EziStick' gets the signal from Microcontroller, it responds to that movement signal irrespective of the other movements in progress. Hence time delay is deliberately imparted to eliminate the chance of clash between the various movements of 'EziStick').

Section 4.3 explains the robot motions in greater detail. The description of the 'EziStick' and its operational features is discussed in section 4.4. The design features of 'EziStick' are described in the next chapter along with its parts.

4.3 The Robot Motions[1]

4.3.1 1st axis motion

The *rotatory motion* [17] is the robots 1st axis motion. The rotary motion of the robot about its' waist is obtained by permitting the pedestal, which supports

[1]Much of the material in this section is quoted from the ABB Robot manual

the arm system, to rotate on a large circular bearing in the waist. The rotary movement is generated by an electric motor which rotates the pedestal via a harmonic drive gear with an extremely high reduction ratio (1:158). The drive unit for the rotary motion is mounted in the waist, within the pedestal, while the output from the reducing gear drives an intermediate plate attached to the pedestal. The angle of rotation covered by the work range is 340 degrees.

4.3.2 2nd axis motion

The 2nd axis motion of the robot is *radial arm motion* [17]. The robot performs a back and forth motion of the lower arm. The lower arm is attached and journalled by circular bearings in a pillow block which is in turn rigidly secured to the robot pedestal. The movement is generated by an electric motor attached to the end of, and driving, a long helical screw shaft. A ball nut riding on the screw transmits the rotary motion to the linear motion along the screw shaft. The ball nut is secured in a yoke attached to a lever protruding from the lower arm, and rotation of the motor thus forces the arm to move.

4.3.3 3rd axis motion

The robots 3rd axis motion is the *vertical arm motion* [17]. The robot performs an upward and downward movement of the upper arm. The upper arm is secured and journalled with circular bearings in the upper end of the lower arm. Movement is generated by an electric motor driving a ball screw assembly in the same manner as for the 2nd axis. The ball nut is secured to a yoke in one corner of a jointed parallelogram (consisting of two rods together with upper and lower arms). The movement in the parallelogram causes the upper arm to move up or down. In order to counter balance the weight of the upper arm, the robot is provided with a counter-weight attached to a guide stay at the rear of the robot. The range of the upper arm is +25 and -40 degrees about the horizontal.

4.3.4 4th axis motion

The *wrist bend motion* [17] of the robot is the 4th axis motion. It is the bending movement in the wrist of the robot which is effected by a motor unit secured to one side of the pivot centre for the lower arm. The motor is coupled to a harmonic drive gearbox which drives a pivoting disk located inside the joint. A similar disc is located inside the joint between upper and lower arms, and a third is inside the wrist. These disks are connected to one another by means of double link rods. The rotary movement on the lower pivot disc is thus transmitted via the link rods to the disc in the upper / lower arm joint and then further to the disc in the wrist. The range of the bend motion is between +90 and -90 degrees about the horizontal plane.

4.3.5 5th axis motion

The turning movement in the wrist of the robot which is effected by a motor unit is the *wrist turn motion* [17]. The 5th axis motion secured to the pivot centre of the lower arm transmits a rotary movement via harmonic drive gear box to a inside pivot disc. A similar pivot disc is located inside the joint between upper and lower arms, and yet another in the wrist. These three are connected to each other by means of double link rods which transmit the movement from one to the other. For turn motion there is also a crown wheel and pinion gear in the wrist which transfers the rotary movement of the pivot disc through 90 degrees, to a rotary movement on the tool attachment. The turning range covers +-180degrees.

4.4 'EziStick'

The present research [18] relates broadly to automated taping of objects such as packages, certain whiteware and automobile components, and cables. More specifically this research relates to applicators that can locate and lift an end from a roll of adhesive tape and apply to an object without direct human intervention at a programmed rate and length. As explained in the last paragraphs of chapter 3, the programmability and flexibility of 'EziStick' facilitates for automating the laborious process of metal tape application on the condenser tubes and also the case sealing operations. The robotic end effector which is a tape applicator [19] in packaging and also a condenser tube tape applicator is *'EziStick'*. The 'EziStick' can do any job that needs tape application.

Some automatic tape applicators used by Minnesota Mining and manufacturing company (3M) :

- Devices described in US patent 5,192,385 for dispensing variable lengths of tape.

- AU patent 307681 for applying L-clip to containers.

Starting new rolls or restarting after a break using manual processes is inefficient when compared to otherwise automated machines. The devices mentioned above suffer from the following disadvantages:

- None of them are able to lift a fresh tape end from a roll.

- The Uplifted end is maintained from a previous cutting operation or is initiated by a human operator.

- They rely on this existing end .

Handling adhesive tape requires some sensitivity in view of tape characteristics. The maximum rate of pulling a tape from a roll without breakage decreases with temperature due to an increase in binding strength of the adhesive. The tape may be scarred or torn by careless treatment, particularly when prising a fresh end from a roll using a hard blade or similar means to locate and lift an irregular edge. Machines have generally lacked sufficient sensitivity to prevent breaking or scarring in automated applicator operations.

'EziStick' may broadly be said to consist of an automatic adhesive tape applicator with the following features:

- means for holding and rotating a roll of tape

- means for locating an end edge of the tape
- means for lifting the end edge of the roll
- means for taking hold of the end and pulling tape from the roll
- means for applying the tape to an object
- means for cutting through the tape once applied to the object.

Another important aspect of 'EziStick', which no other similar device has, is a tape tension monitoring system. This system enables 'EziStick' to control the tape application within the limits of tape quality. The tape tension monitoring system essentially consists of few strain gauges in a balanced wheatstone bridge arrangement to measure the tape tension during the tape application. The intelligence of the system is improved by feeding this value to the interface through the amplifier.

4.5 Mechanical Aspects of 'EziStick'

This section deals with the mechanical details of 'EziStick'. The various parts performing 'EziStick' actions are explained later. Speaking mechanically, 'EziStick' performs the following actions :

- Holding and rotating the tape roll.
- Locating the edge of the tape.
- Lifting the tape edge from the tape role
- Taking firm hold of the tape edge and pulling the tape away from the tape roll.
- Applying the tape to the object or to the surface.
- Cutting the tape after the tape has been applied.

The first part of 'EziStick' deals with the *holding and rotating of the tape roll*. This means physically holding the tape roll for tape rotation and tape application purposes. This facility is provided by loading the tape on a mandrel which holds the tape roll during your requirements.

The second part of the system is to *locate the edge of the tape*. 'EziStick' has three diffuse scan opto sensors arranged parallel to the axis of the mandrel. These sensors detect the edge while the tape roll is rotating. The rotation of the tape roll is achieved by attaching a motor to the other end of the mandrel.

The next part of the system is to *lift the tape edge from the tape roll*. This task is accomplished through a combination of mechanical and pneumatic systems. Firstly the blade which is used to lift the tape edge has to be brought near the tape roll, close enough for lift up. This closeness is governed by a inductive proximity switch. Blade will be held stationery and the mandrel will be rotated pushing the tape edge onto the blade. Figure 4.2 explains the concept in a better way.

Taking firm hold of the tape edge and pulling the tape away from the tape roll is dealt in the next part of the system. The system is again a combination of mechanical and pneumatic systems. At the point when the tape edge is on the blade, an inductive proximity switch triggers a pneumatic cylinder to clamp the tape onto the blade surface. Then the blade along with the tape is rotated away from the tape roll. This is achieved by the rotation arm, which pivots on a shaft swinging to and away from the tape roll. (Figure 4.2)

The very purpose of this research deals with the part of the system which *applies the tape to the object or to the surface*. This is achieved using a combination of all parts of the system and the interface system. The tape is pulled over an applicator roller and the system moves 'EziStick'. This in effect applies the tape to the surface/object that is to be taped.

The last part of the system *cuts the tape after the tape has been applied.* This is achieved by using a cutting knife in combination with the pneumatic cylinder. The pneumatic cylinder has a plunger. A cutting knife is attached to the plunger. The cutting knife moves forward cutting the tape and retracts to home position. Above explanation is figuratively showed in Figure 4.3.

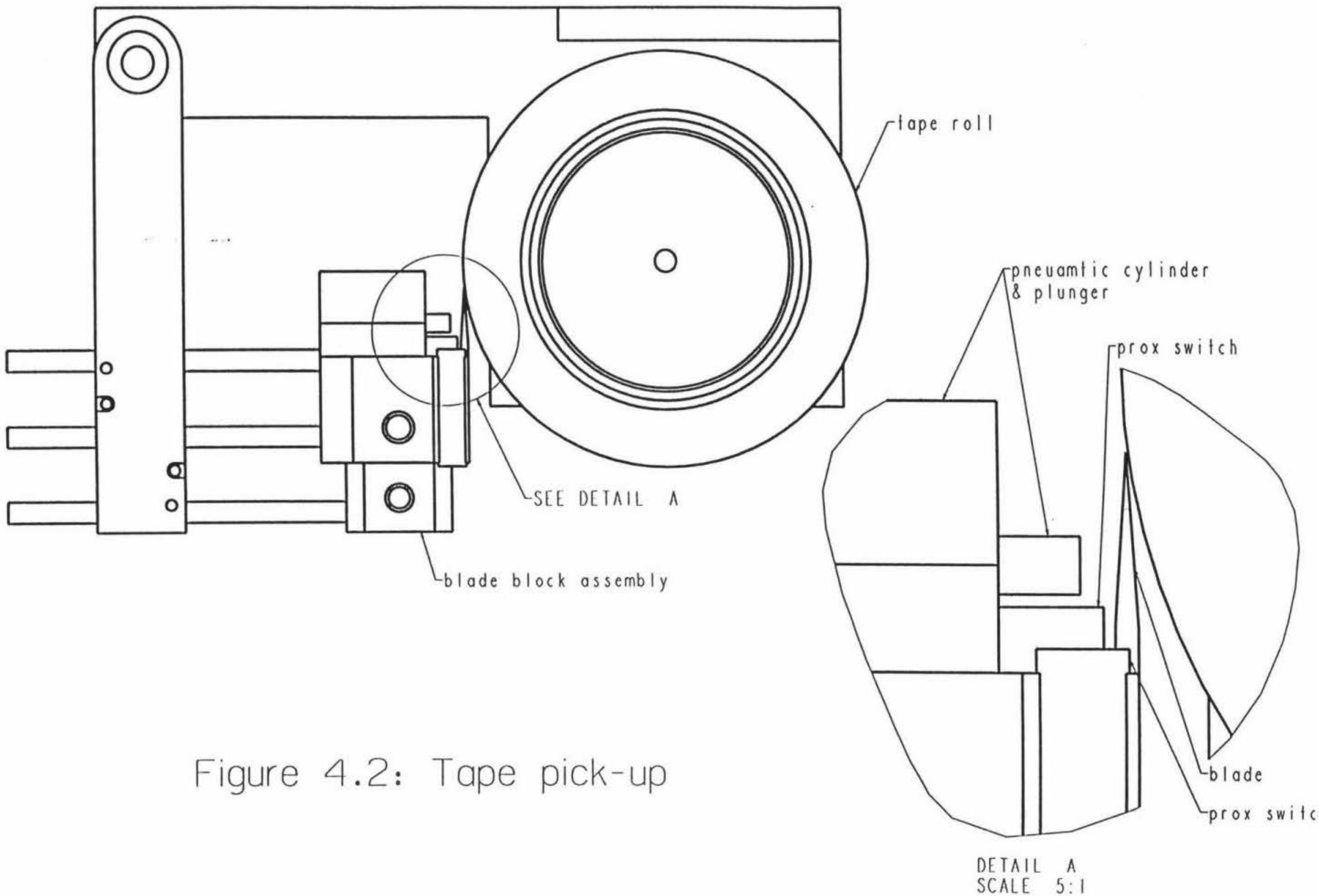


Figure 4.2: Tape pick-up

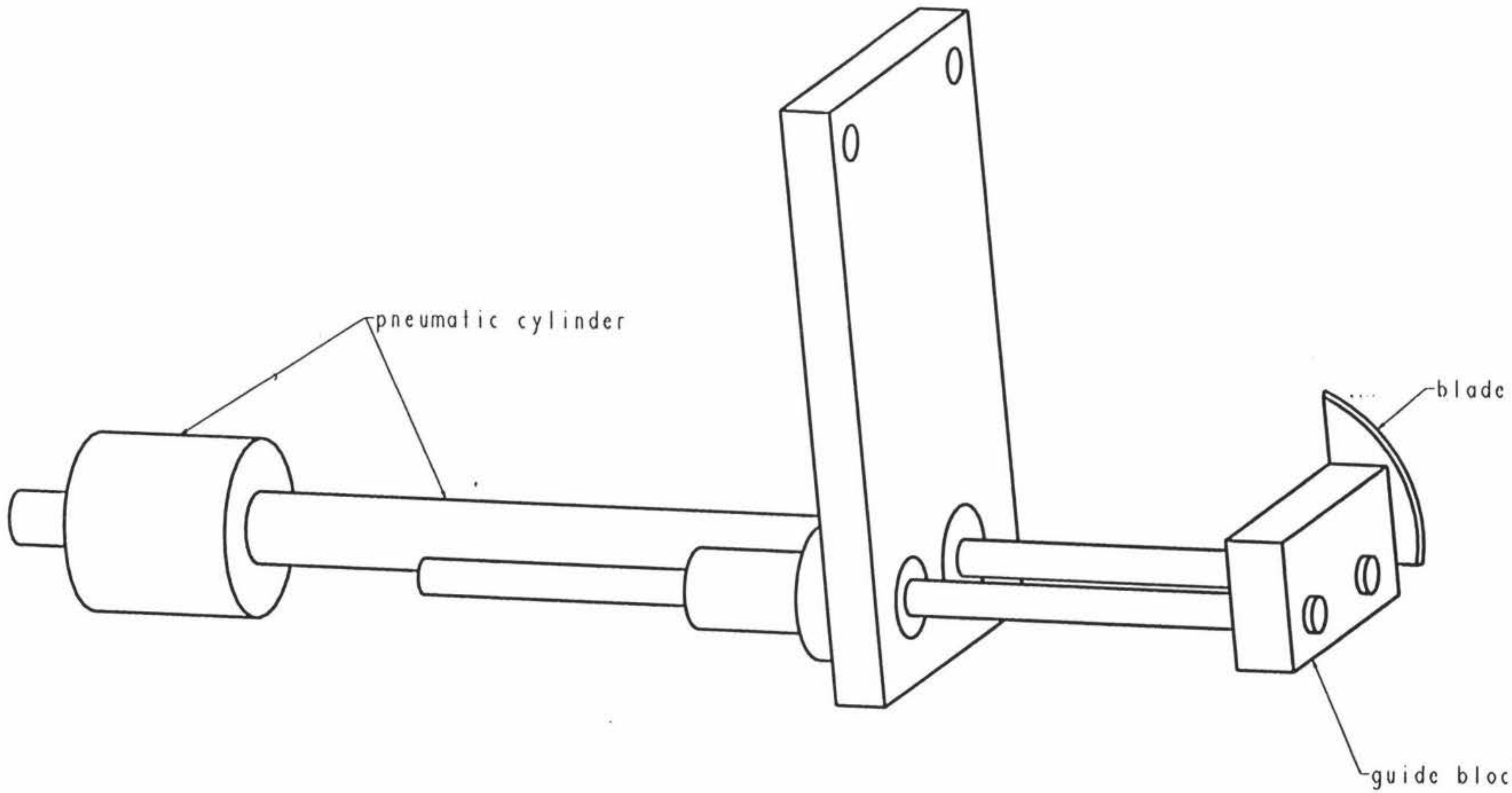


Figure 4.3: Cutting Mechanism

4.6 Functional Aspects of 'EziStick'

The different parts and different functional areas of 'EziStick' are discussed in this section. 'EziStick' is required to move / rotate internally for different movements required by the various functional aspects. For this purpose 'EziStick'. uses different motors and rams. As these motors and rams move / rotate they also carry certain parts along with them. Depending on the movement requirement the weight carried by the different individual motors and rams varies from 100 grams to 2000 grams. Generally, a standard design for the various motors and rams is required to accomplish this task. The various motors and rams which actuate an applicator device are operated by a micro controller which need not be described in detail. The applicator is also normally to be used as an 'end effector' on an otherwise general purpose robot arm or any two or three axes systems. The robot arm may be programmed to position the applicator appropriately in relation to objects on a production line.

A prototype (operates in the manner described , later) has been constructed and tested. A 12V dc motor from Radio Spares with a reduction gearbox of 130:1 is run through a specially designed Clutch Mechanism for rotation of the mandrel at about 8 rpm. A clutch was needed here to facilitate the free wheeling of the mandrel when the motor is not rotating the mandrel. The 12V dc motor rotates the mandrel and tape roll which would weigh approximately 1000 grams. Figure 4.4 shows the clutch mechanism that fits into the mandrel and mandrel motor.

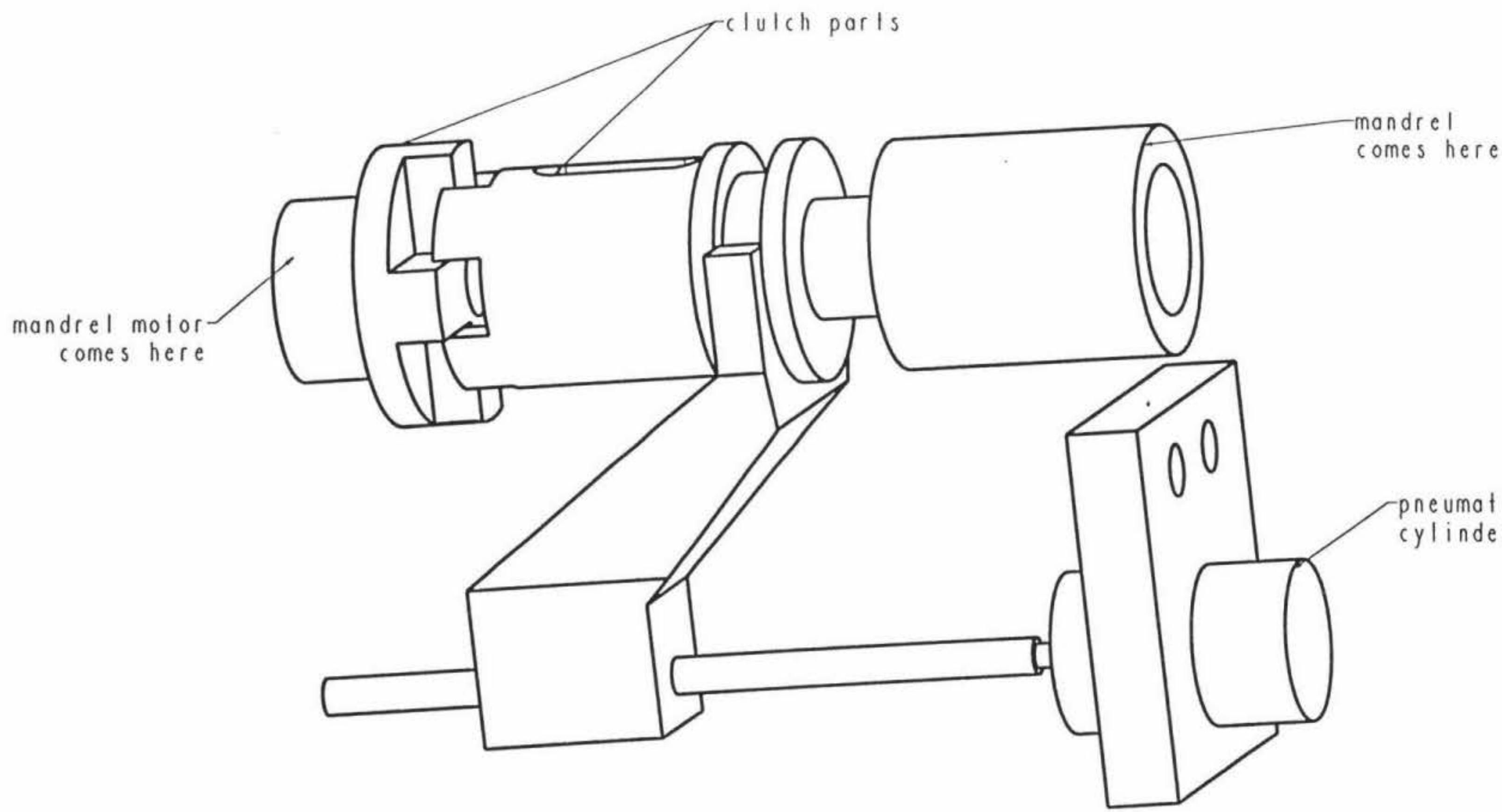


Figure 4.4: Clutch Assembly

Three standard diffuse scan opto-switch sensors [20] were used in parallel across the width of the tape to sense tape end edges. A non contacting edge detecting system was the aim , hence the use of optical sensors. High grade tool steel or spring steel blade was used in the edge lifting mechanism. High surface finish of the blade edge is recommended for the easy picking of the tape edge.

The lifting blade is positioned using a small 5V dc motor and a 16mm bore and 20mm stroke pneumatic cylinder for moving the blade across the tape surface. The motor moves the blade block assembly along with the ram. This whole assembly weighs about 400 grams. In this assembly the ram which is used to position the blade as per the tape edge, moves the blade block across the tape surface. This ram moves the blade block which weighs about 200 grams. Figure 4.5 shows the arrangement of the above said pneumatic cylinder and blade block assembly to get the desired movemets.

A 12mm bore and 5mm stroke compact cylinder was used to clamp a lifted tape end to the blade.

A 10mm bore and 80mm stroke pneumatic cylinder is used in cutting the tape after the application. A sudden force of about 4kg is required to pierce the tape at start of tape cutting. The swift movement of ram during it's forward stroke is giving sufficient force for the tape cutting initiation. Once the tape is punctured, the cut propagation is smooth and it goes with the further forward stroke of the ram. The ram moves a blade to cut the tape and that blade with the holder weighs around 50 grams.

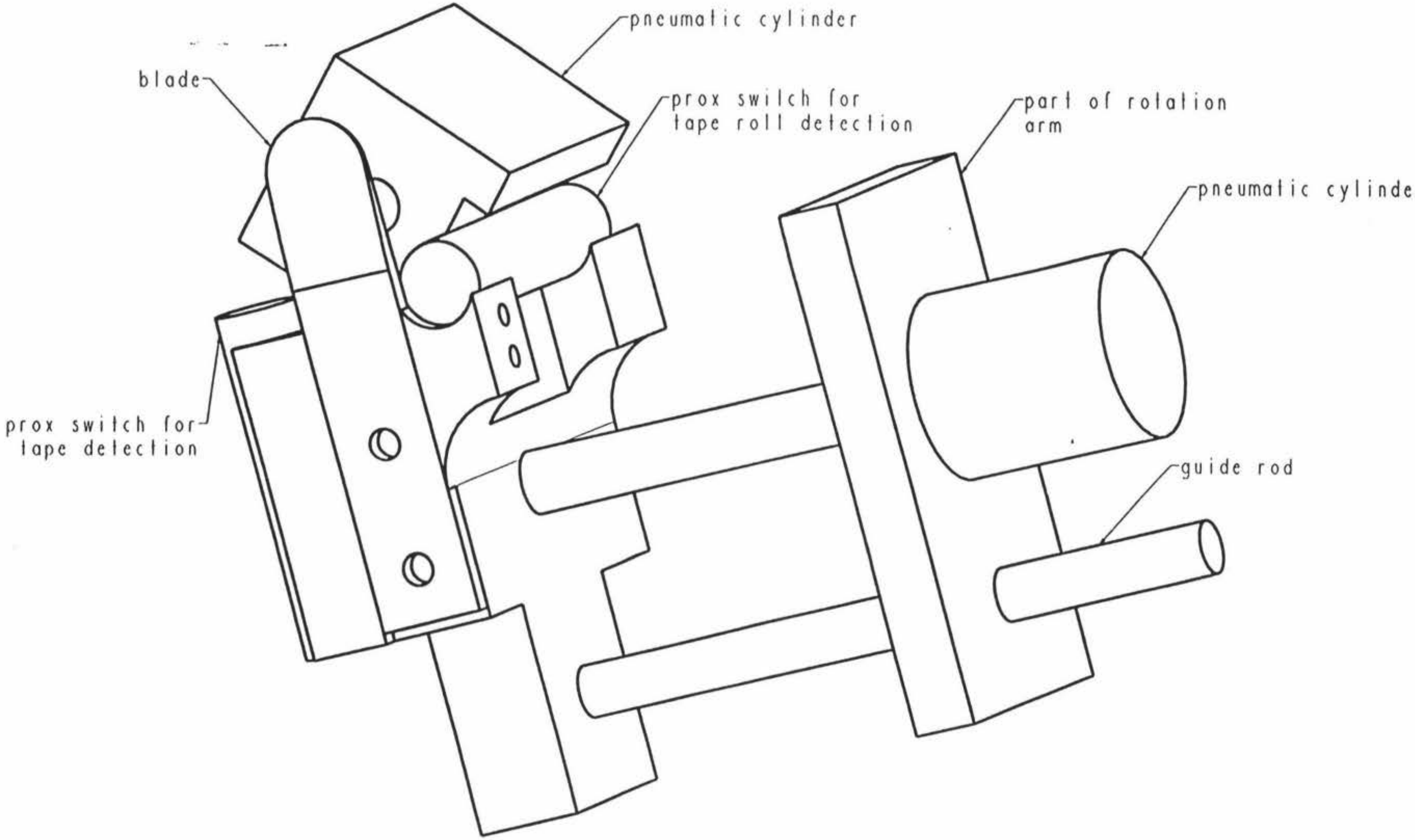


Figure 4.5: Blade Positioning Arrangement

A 32mm bore and 50mm stroke pneumatic cylinder is used for pivoting the rotation arm at about 270 degrees. This rotation is achieved by a rake and pinion arrangement which is explained in the next chapter. The ram of this cylinder is the rake and the pinion which is screwed onto the shaft rotates the whole rotation arm and blade block assembly all along the arc. This ram rotates a weight of about 1500 grams of this assembly.

A 4mm bore and 10mm stroke plug mount type pneumatic cylinder is used for roll holding mechanism. In it's forward stroke this ram balances a weight of about 700 grams (weight of the tape roll) on the mandrel. Towards this effect, the ram pushes the three fingers (explained in the next chapter) through the mandrel reliefs and balances the tape roll only during the mandrel rotation. Concept of this mechanism is shown in Figure A-10 in appendix-A.

A small pneumatic cylinder 6mm bore and 10mm stroke is used for lifting the edge sensing device away from the mandrel when it is needed to change the roll. The weight of this device is around 50 grams as the edge sensing device assembly comprises of an aluminium bracket and three opto sensors only. Figure 4.6 shows the edge sensor arrangement for tape edge detection.

Another small pneumatic cylinder of panel mounting type is used for the engagement and disengagement of the clutch.

Interfacing of the robot and 'EziStick' is done through a micro controller (SIEMENS SAB80517A) and robot controller, which controls the operation of the tape applicator as per the program sequence.

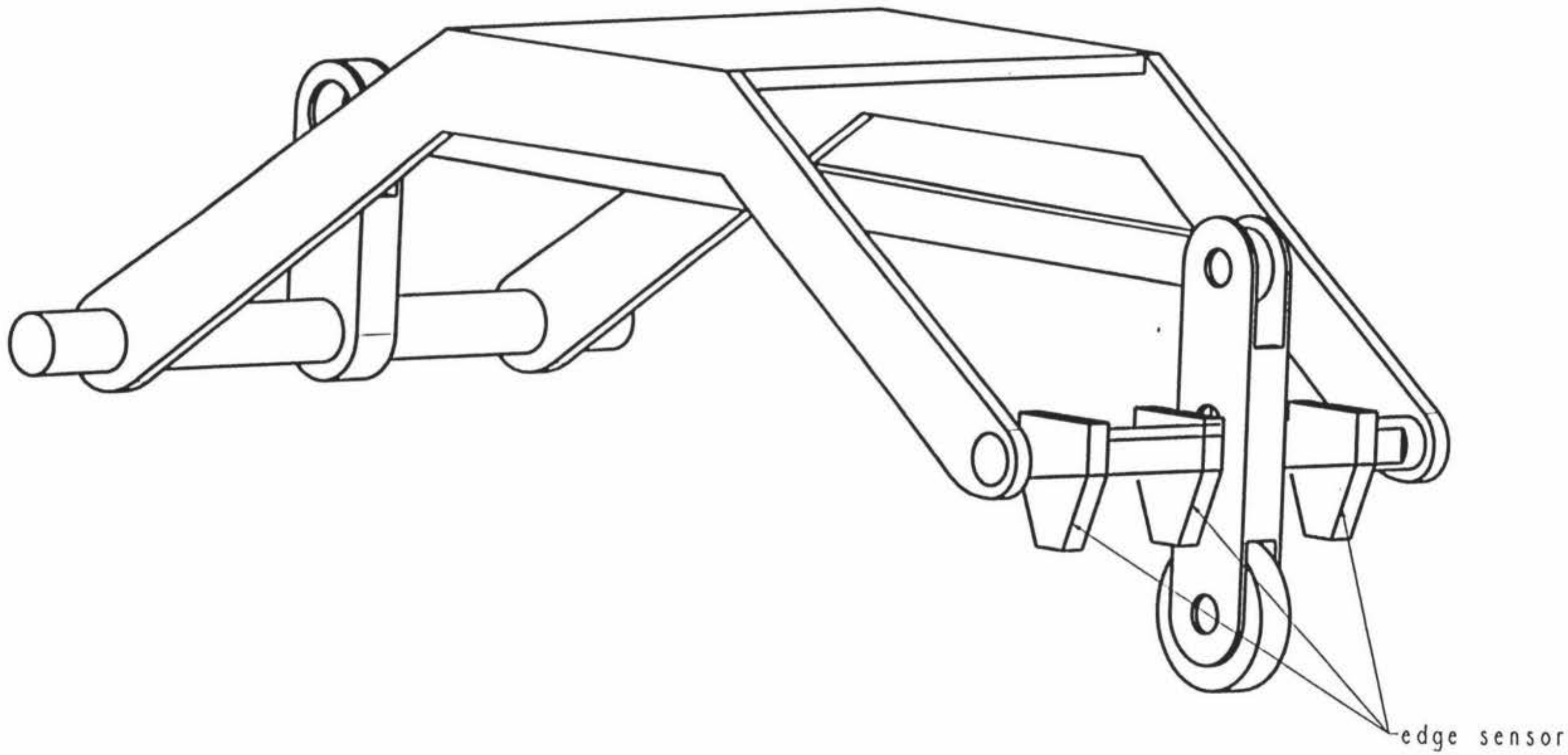


Figure 4.6: Edge Sensors Assembly

The functional aspects of the 'EziStick' are described figuratively in Appendix A. Appendix A also has an explanation of the figures. The figures discussed are:

- Figure 1 shows a prototype tape applicator device in perspective
- Figure 2 shows applicator as tape is pulled from a roll
- Figure 3 shows the applicator in position for applying tape to the object
- Figure 4 shows applicator applying tape to a flat horizontal surface
- Figure 5 shows a number of optical sensors positioned for locating a tape edge
- Figure 6 shows a blade and clamp holding a freshly lifted tape end
- Figure 7 shows a load sensor for monitoring tension in tape during testing or application to an object
- Figure 8 shows the cutting mechanism with cutter which cuts the tape after finishing one cycle of tape application
- Figure 9 shows a specially designed clutch mechanism to drive the mandrel only when required
- Figure 10 shows the roll holding mechanism over the mandrel.

Chapter 5

Components of 'EziStick'

This chapter discusses about the various components of 'EziStick' and explains their functions .

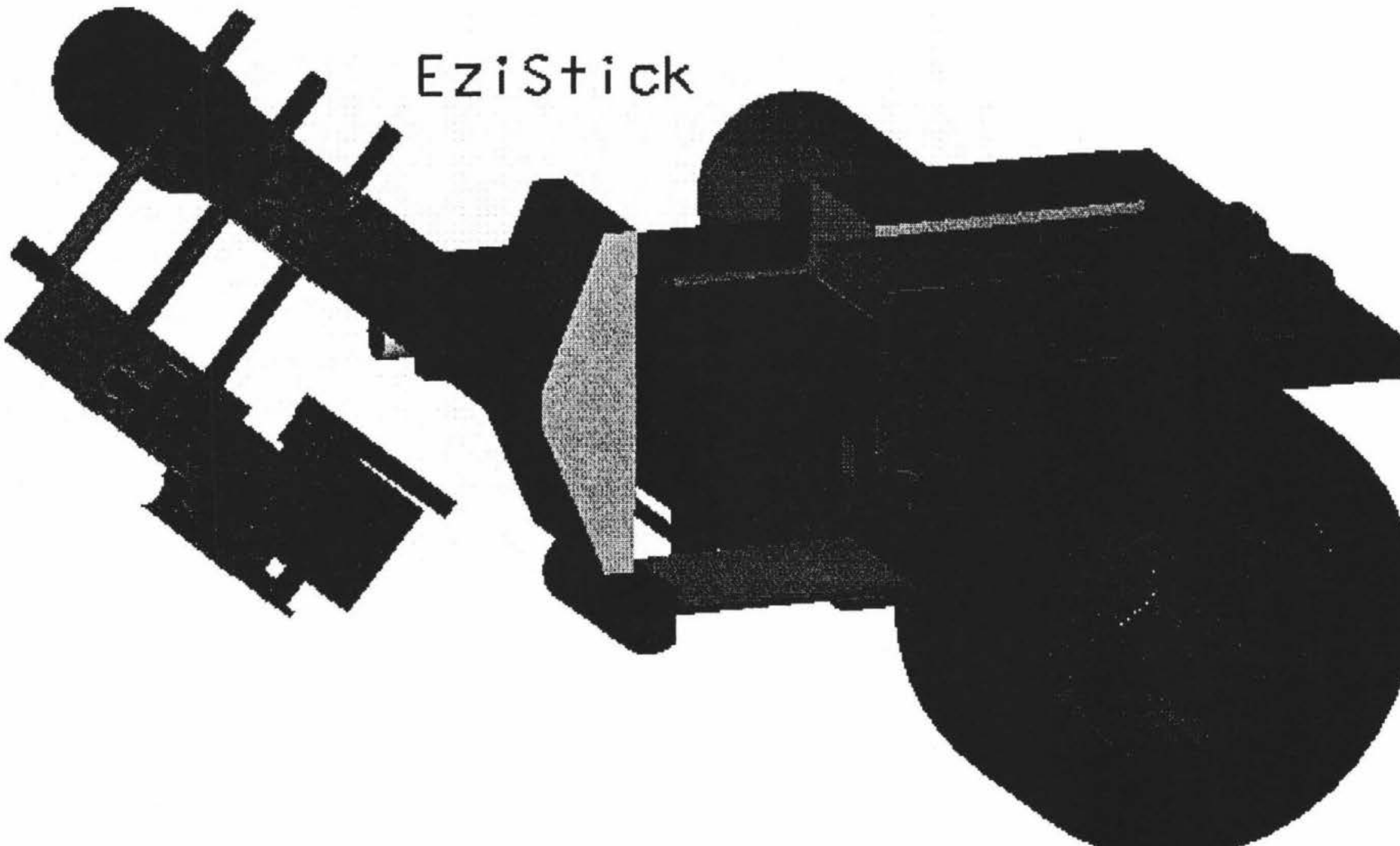


Figure 5.1: 'EziStick'

5.1 Introduction

The end effector is essentially an extension of the robotic arm, which can be modified and changed to the present application. In the present case 'EziStick' is the end effector, attached to the ASEA industrial robot arm, performing the operation of applying the metallic adhesive tape to the tubes kept on the flat surface. The end effector functions are programmable and operated through a micro controller. The computer down loads the program to the micro controller, which in turn transfers the program to the electrical / pneumatic circuitry, sequentially moving the end effector. The layout of the 'EziStick' environment is schematically shown in Figure 5.2.

The tape application which the end effector performs comprises of two activities : end effector movements and robot movements. The two movements have to be perfectly coordinated to make the tape application an effective one. The micro controller looks into this matter by the use of programming : robot programming and end effector programming .

The robot working area consists of three systems. First system is the robot itself, second system is the micro controller, electrical/pneumatic circuitry and third system is the tape roll magazine, in which 10~20 tape rolls are stocked. The second system is placed out of the robot working envelope but the third system is placed within the robot working envelope and outside the 'EziStick' working area. This is because, the robot has to reach the tape roll magazine whenever the tape roll has to be replaced.

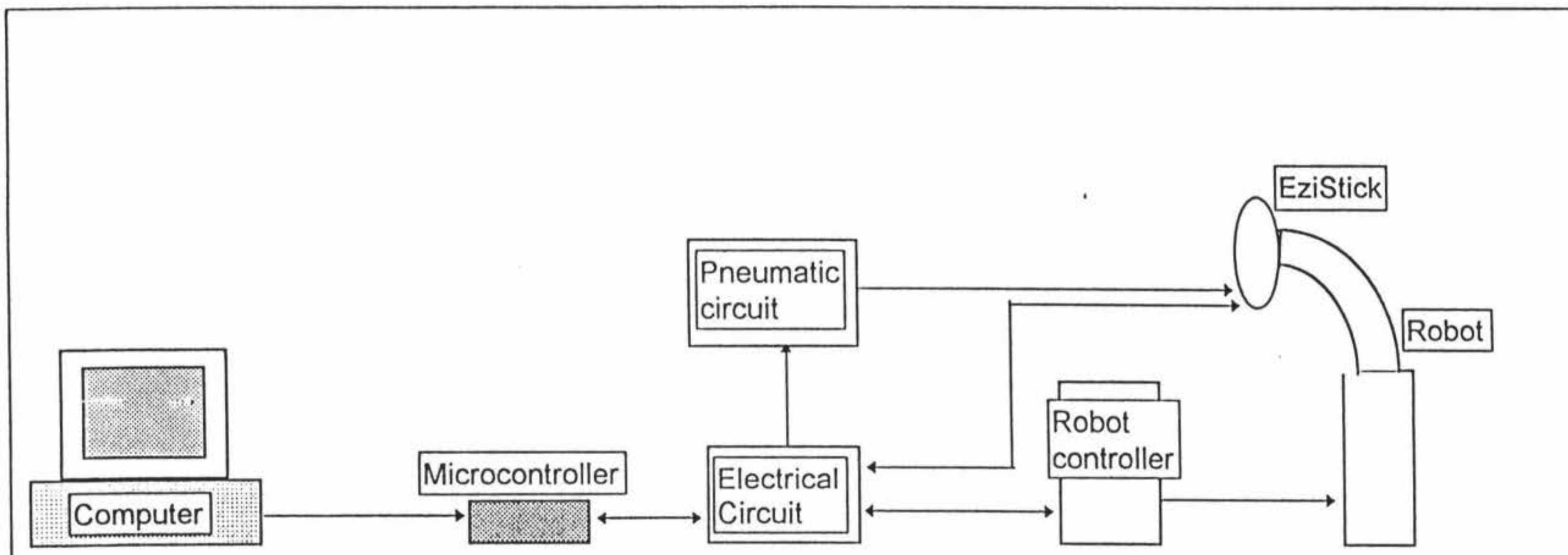


Figure 5.2 'EziStick' Layout

5.2 Tape Roll Magazine

The tape roll magazine is also a part of 'EziStick' components. But this is not essentially a part of actual 'EziStick' as it stays out of the actual system. So it is described in this section before the description of the actual components.

Different ideas of tape roll holding system were thought of. They are magazine, rotary table, gravity feeding system, sprung loaded vertical method, etc. Out of these methods a simple gravity type magazine system was selected for it's simplicity and low cost. In it's simplest form a gravity type magazine could be like as shown in figure 5.3 below.

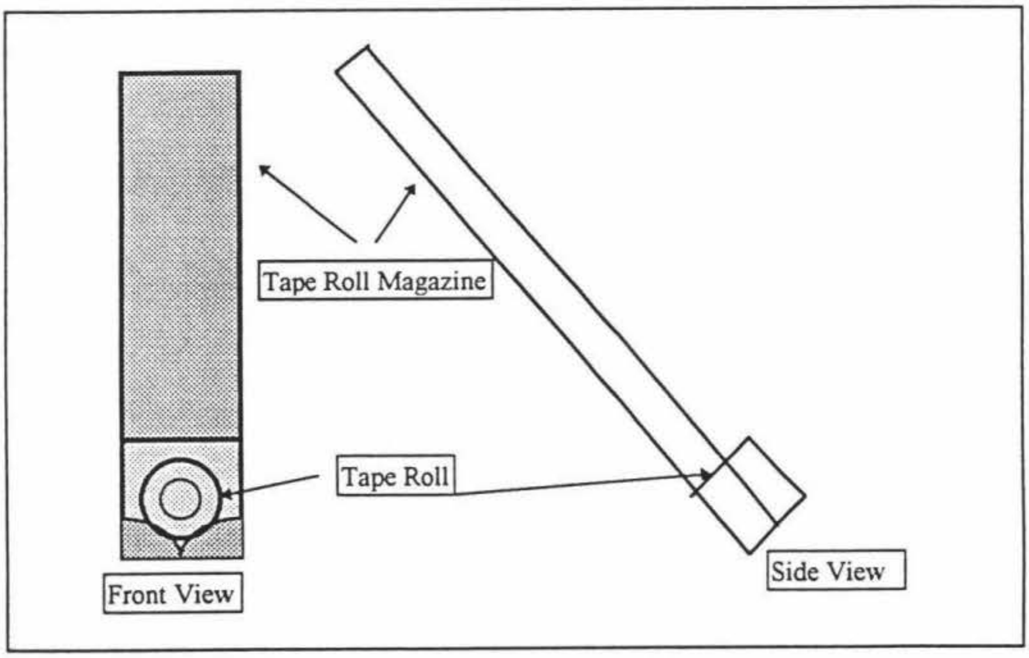


Figure 5.3: Views of Tape Roll Magazine

A tape roll magazine accommodating 10~20 tape rolls can be designed depending on the customer requirement. The concept remains same and size varies with the number of tape rolls going into the magazine. The position of the magazine has to be adjusted with respect to the actual working area so that it does not interfere with the 'EziStick' working.

5.3 Components of 'EziStick'

In order to understand the functioning of 'EziStick', the components of 'EziStick' have to be first analysed and understood. The main components of 'EziStick' are:

1. Frame
2. Rotation arm
3. Mandrel & Mandrel motor
4. Blade, Blade Holder Block & Blade motor
5. Clutch
6. Application Roller
7. Edge Sensing Mechanism
8. Tape Tension Monitoring Mechanism
9. Tape Holding Mechanism
10. Tape Cutting Mechanism

Each component is further explained in the following sub-sections.

5.4 Frame

The *frame* of 'EziStick' is made like a chassis of an automobile to accommodate all the other components of 'EziStick'. The separate components are arranged in a rigid, but light, frame. The frame also allows access for replacement of components, and the automatic loading of the tape rolls.

The frame that has been incorporated is made from aluminium plates which has been slotted and bolted together using countersunk cap screws to give a lightweight, cost effective, and a rigid structure. 'EziStick' is attached to the robot arm by means of this frame through an attachment bracket at the back side of the frame.

The weight of the frame is reduced by removing the material wherever possible. This is to keep the overall weight of the 'EziStick' less than 6kg. The frame can be made of plastic in future through injection moulding to further reduce the weight of 'EziStick'.

In Figure 5.4 the shape of frame, position of the ram and rake and pinion are shown in the best way possible.

5.5 Rotation arm

Rotation arm is like a lever that moves/rotates the entire blade and blade block assembly to the tape roll. A typical driving mechanism to radially move the

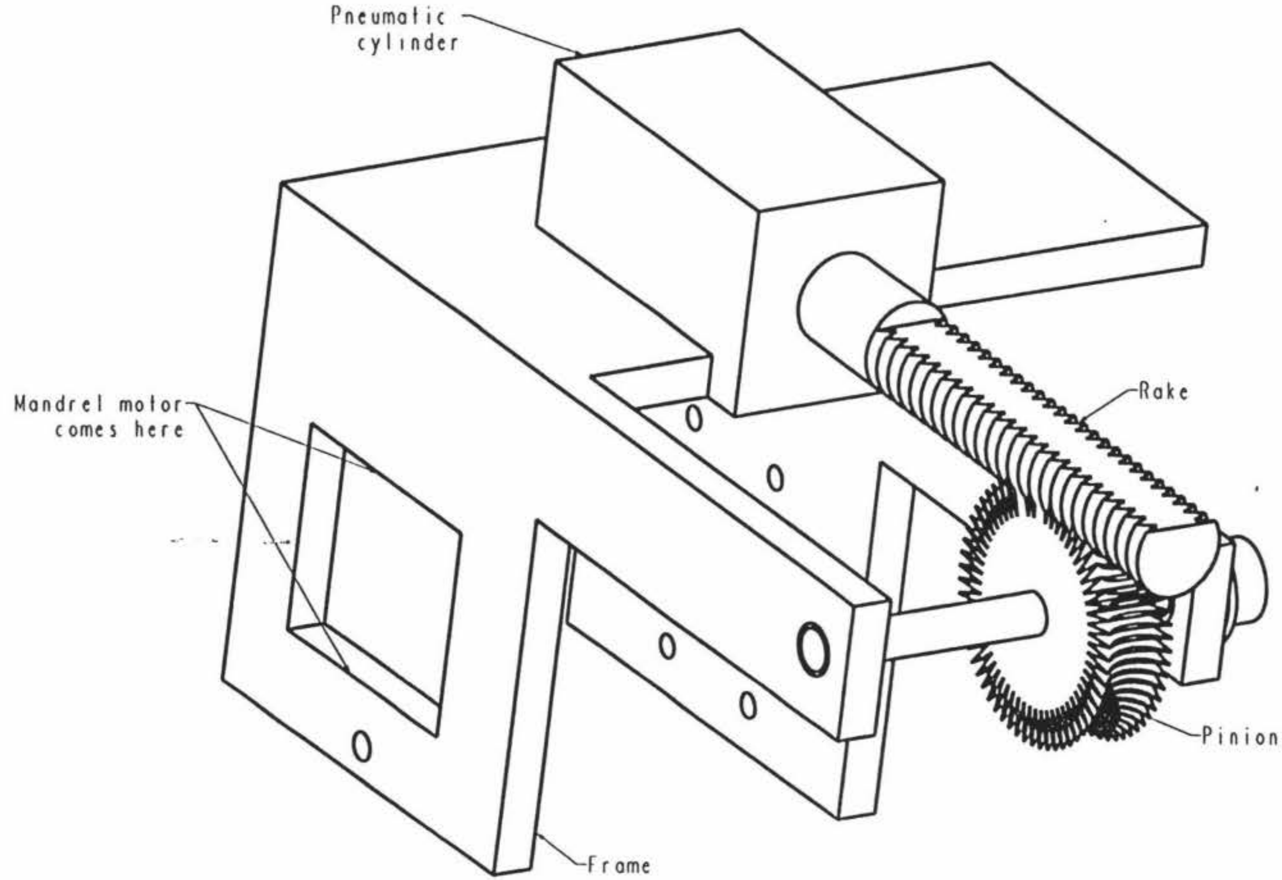


Figure 5.4: Frame Assembly

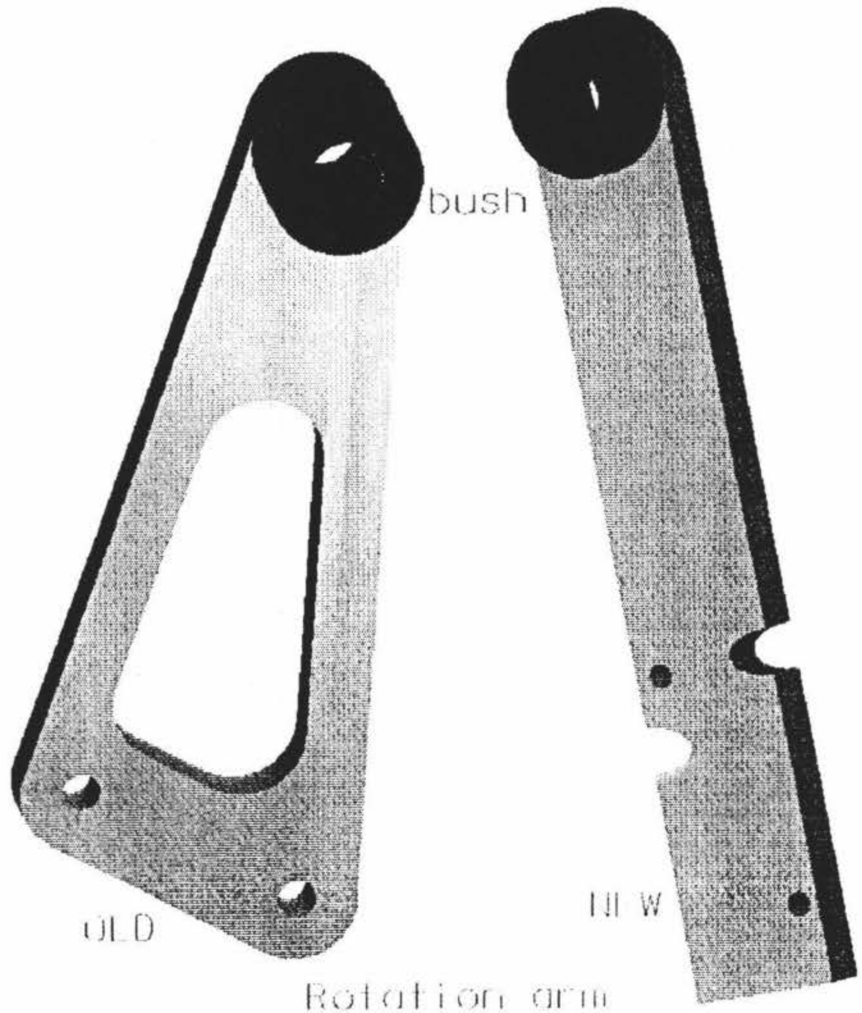
rotation arm was designed. The space and weight limitations were kept in mind during this design. And a rake and pinion drive mechanism was designed and a pneumatic cylinder was selected to provide the driving force. The ram of the cylinder is made into a rake and the pinion is fastened to the shaft on the frame. Rotation arm is also fastened to the same shaft. Hence the forward stroke of the ram drives the pinion inturn turning the rotation arm towards the tape roll and the reverse stroke of the ram pulls the rotation arm away from the tape roll.

The Rotation arm also picks the tape and pulls it away from the tape roll after the blade peels the tape. The blade block assembly is securely fastened to the rotation arm. The movement or rotation of the rotation arm is attained by means of a ram through a rake and pinion arrangement. The forward motion of rotation arm is through the forward stroke of the ram and vice versa.

The shape of the rotation arm was changed with the progress of 'EziStick'. Rotation arm's shape changed to suit and adjust to the shapes of the different rams coming onto it. As the development work went on, lighter weight of the rotation arm was emphasised. Hence the rotation arm's shape was changed to make it more light in weight. Accordingly other components coming onto rotation arm were also modified.

This rotation arm is basically a flat piece made from aluminium to give it light weight. One end of it is connected to a rake and pinion arrangement and the other end is fixed to the whole assembly of blade block.

Figure 5.5 shows and explains the changes took place in the shape of the rotation arm in a better way.



Figuren5.5: Rotation arm

5.6 Mandrel and Mandrel Motor

The basic requirement of the mandrel is to facilitate the mounting of the tape roll. The other features that go with the mandrel are:

- to clamp the roll in place so that it cannot slip either radially or transversely
- As free wheeling as possible, low friction contacts are used
- Locate the roll positively when loading
- As lightweight as possible.

To achieve these objectives, different methods for clamping the tape roll to the mandrel were tried. They are:

1. Mechanical cam working spring loaded split mandrel, to expand on the inner diameter of the roll
2. Mechanical cam working side plates to clamp on either side of the roll
3. Sizing the mandrel so that the roll is a force fit onto it.
4. Pneumatic 'air bag' which expands on the inside diameter of the roll
5. Tapered mandrel with a knurled finished.

The various options for fixing the side plates make the task of loading and unloading rolls an extremely difficult proposition. In the concept of using as few components as possible, and keeping complexity to a minimum the idea of using the tapered mandrel with knurled finished was used. This will allow for simplicity of design and will also be light weighted. The following Figure 5.6 shows the schematic arrangement of mandrel and mandrel motor.

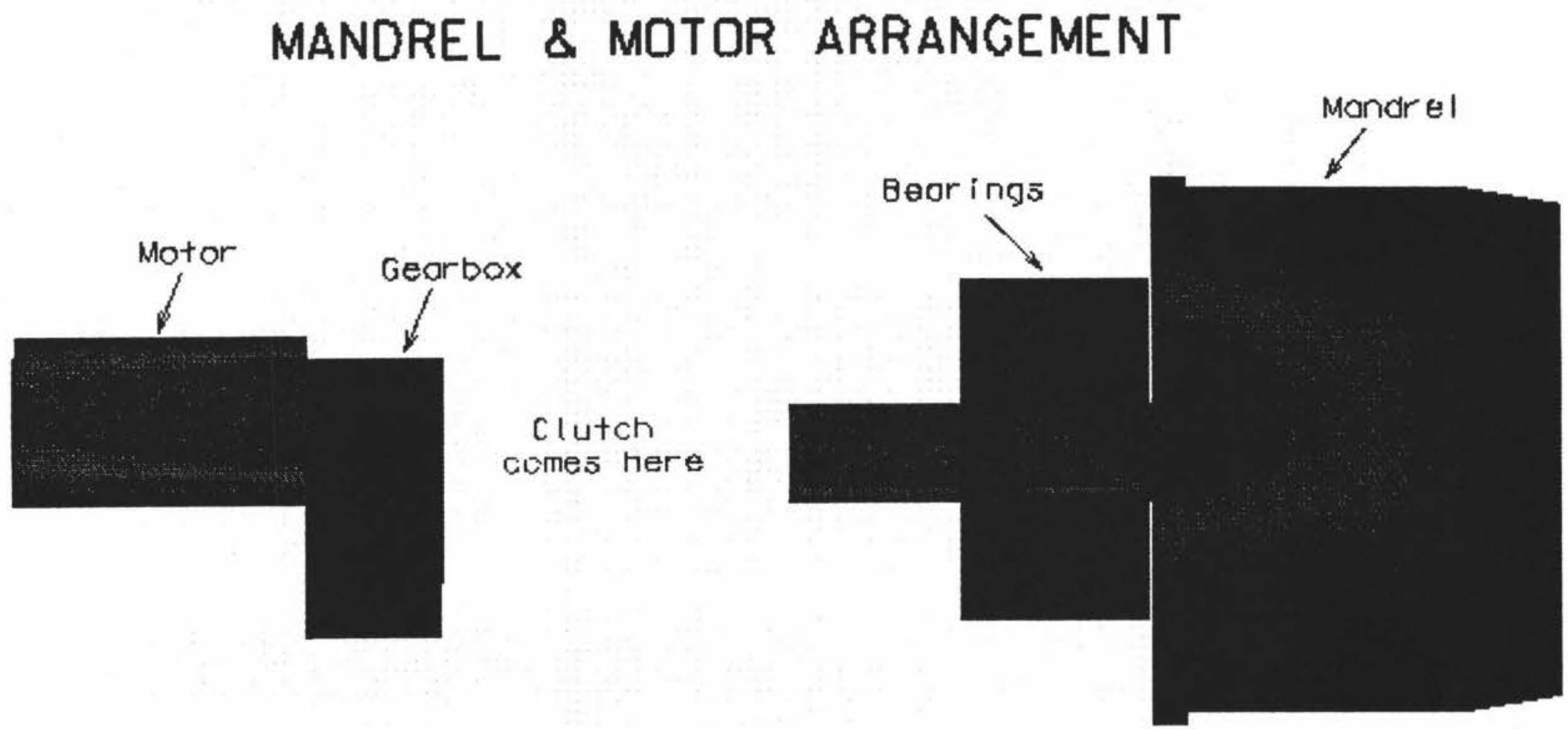


Figure 5.6: Mandrel & mandrel motor arramgment

The material selected for the mandrel manufacture is light weighted aluminium. Holes were made in the body of the mandrel to reduce the weight (wherever the functionality was not affected). To reduce the metal to metal contact between the mandrel and frame and to facilitate for the free wheeling of the mandrel, ball bearings were introduced into the frame. They are positioned in the frame around the mandrel shaft. This was an effort to reduce the frictional forces acting on the mandrel during it's rotation. Mandrel Motor should meet the following requirements of the research.

5.6.1 Tape roll rotation and Rotation Requirements

A drive system to rotate the *tape roll* must be incorporated into the design. This is necessary to rotate the roll until the edge is sensed, and also to drive the tape roll so that the edge is slipped under the blade.

To determine the rotational requirements of the mandrel an experiment was conducted. Tape roll was rotated on a dummy mandrel for edge sensing. This experiment also gave an idea of the speed of the mandrel for effective tape detection. It was observed that the edge detection is good at 5rpm. The motor torque at this speed is analysed and the following results were taken.

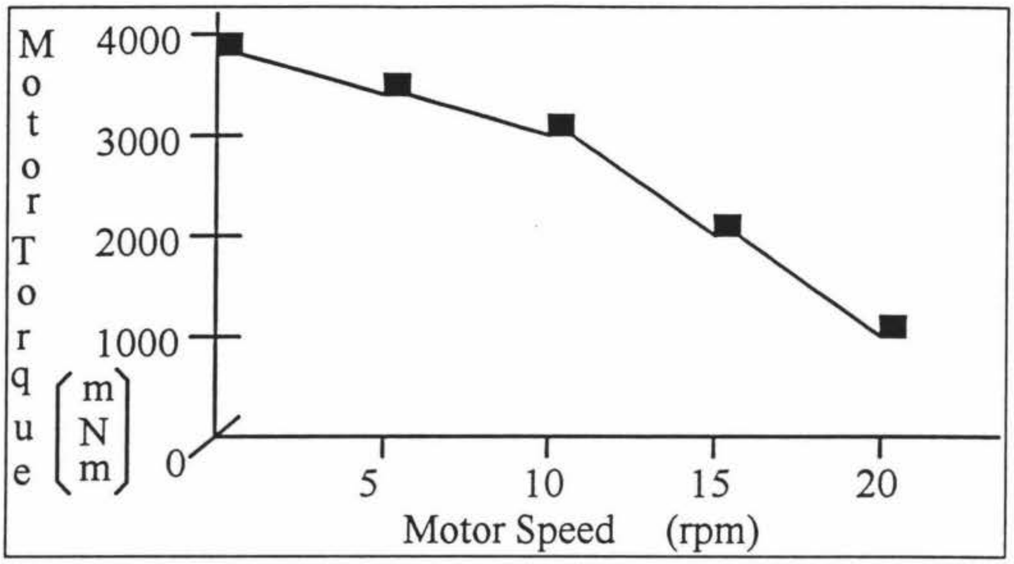


Figure 5.7 Motor and Gear box Torque rating.

The *rotation requirements* are :

1) Output torque requirement : 3300 mNm

2) This torque is at 5rpm

3)Minimum Rotation 365^{0}

4) Accuracy +/-2^{0}

5) Weight <1 kg.

6) System power off to allow the roll to be rotated by pulling of tape edge.

Several systems were considered for use, namely servo-motor systems, rotary pneumatic actuators, and Stepper motors. The various systems and their disadvantages are summarised in the Table 5.1.

Name	Disadvantages
Servo motors	heavy in weight. Because of the closed loop system, and associated control gear this option is too expensive and large
Rotary Pneumatic Actuators	Accurate positioning of the roll is not easily achieved, repeatability of positioning is difficult, and the actuators on offer, that are inside the weight restrictions, do not rotate more than 270 degrees
Stepper Motors	Stepper motors needed to drive the roll within the specified torque and speed are too heavy

Table 5.1 : Comparison of various systems.

The drive unit could only take a light weight gripper(no more than 2 kg). Hence, the stepper motors were used in a different fashion for the following reasons:

- Though the servo motors had the necessary torque, speed, rotational accuracy and directional control, they suffered from their heavy weight.
- The identified actuators in rotatory pneumatic requirements did not meet the requirements.
- The stepper motor characteristics could be used in different ways.
- The use of such smaller stepper motors combined with a reduction gear box means that the required torque and speed can be achieved for under 1 kg weight.
- Rotation is unlimited , direction is easily reversed, and the accuracy is as good as +/-0.2° (1.8o Stepper & 8.5:1 Gear box).
- The system can be programmed for various acceleration/Torque settings.

However, a major disadvantage which makes it unfeasible is the power off characteristics. This makes the force required to pull the tape too high.

Solution : Finally a 12 V DC motor/gear box 20 rpm (Radio Spares unit, Stock no . 320-607) was chosen. The gear box gives a reduction of 130:1. The clutch unit allows for free wheeling and drive from the motor/gearbox in both the directions. The slow speed of the Mandrel motor is very important for the edge sensing arrangement. Figure 5.7 shows the arrangement Clutch and Mandrel motor for the required speed of mandrel.

From the Figure 5.7, the unit has a stall torque of 4000 mNm, and an operating torque of 3500 mNm at 5 RPM. This unit exceeds that required operating torque and is lighter than allowed . The clutch imparts the ability to 'free wheel' when tape initiation has succeeded.

5.7 Blade, Blade Holder Block and Blade Motor

The *blade* is as simple as possible to cut down on cost and to make it easy to replicate. The material selected is high grade tool steel to enable a fine edge to be obtained. The blade holder has a channel milled across its length for the easy positioning of the blade and for the inductive proximity switches to be placed. The blade could be coated with Teflon coating, similar to that used in frying pans, on its working surfaces to give a less friction surface which to slide upon. The design thus obtained has the following characteristics:

- Sharp thin rounded edge to slip under the tape end
- Solid section approx. 10 mm back from the edge for clamping area
- Tool steel grade to resist wear and have high strength characteristics.
- Non stick surface to assist in slipping under tape edge and to resist the build up of adhesive.
- Be of modular design so that blades can be replaced easily and cheaply.

In order to have some rigidity to the blade arrangement, as well as to house the necessary inductive proximity switches and pneumatic pistons that clamp the tape to the blade a *blade holder block* is used. *Blade holder block* connects the blade to a block. The following characteristics are needed in the block

- light weighted and rigid.
- to move linearly across the face of the tape.
- to connect to a pneumatic air line
- geometrically shaped to fit around the tape edge.

The present block has all the above mentioned characteristics. This has been achieved by :

- Specifying aluminium as the material.
- Mounting the block on a SMC pneumatic cylinder to give the needed moment.
- Having simple pneumatic nipples with flexible piping can be connected to.
- Having a shaped profile to hang the tape role hence minimising the bulk without minimising the rigidity.
- Have room for the positioning of the inductive proximity switches.

The block has been designed to fit two inductive proximity switches, one to sense when the blade has come into contact with the tape role, and the other to detect when a sufficient amount of tape has passed over the blade. The clamping mechanism has used a compact cylinder with a tongue type attachment to allow for the clamping of the tape against the blade. The blade and Blade block holder require accurate positioning as the blade should be positioned touching to the tape surface. This requires accurate movements of the *blade motors* and rams involved. The required movements are :

- Linear movement parallel to the tape surface.
- Linear movement towards and away from the tape centre
- Rotary movement of the whole blade assembly to allow easier tape presentation to the application roller

All three movements have been accomplished via pneumatic actuators.

The linear movement parallel to the tape surface has been accomplished by a pneumatic cylinder , thus minimising the space in the design. This movement has no great forces demanded from it as it is only a positioning task although the precision of the unit is important due to accuracy needed for the blade positioning.

Linear movement towards and away from the tape centre was carried out initially by a dual rod cylinder. This moved the blade holder towards the tape surface until it had feed back from the inductive proximity switch which told when the blade had contact with the tape, therefore allowing the blade holder to be locked into position. A dual rod cylinder was selected to stop any rotation of the slides and to maintain stiffness. Later this dual rod cylinder was replaced with a small dc motor, as the motor gave more control over the positioning of the blade. The motor drives the blade block through a gear block with two guides supporting the blade block movements all the time. This also provides economic and space efficient driving system for blade manoeuvring. The motor is powered through a relay and is actuated by a signal from the micro controller. The movement of the blade block is accomplished by means of a gear and lead screw arrangement, that drives the blade block towards and away from the tape roll surface. This allows for more control over the positioning of the blade near the tape surface.

Radial movement of the above mentioned arrangement (shown in Figures 5.8 and 5.9) has been carried out by SMC pneumatic cylinder. The pneumatic cylinder is bolted to the frame of the end effector and rotates the rotation arm which in turn rotates the whole blade block holder assembly. The rotation is provided by a rake and pinion arrangement, rake is fixed to the plunger of the pneumatic cylinder and the pinion to the shaft connecting the rotation arm and the frame.

In Figures 5.8 and 5.9 the different components of the blade block assembly are shown. The assembly of these components was also shown to the extent possible in these two figures.

In Figure 5.10 the assembly of the blade block to the rotation arm was shown. To emphasise the progress of the research, the previous version of this assembly was also shown.

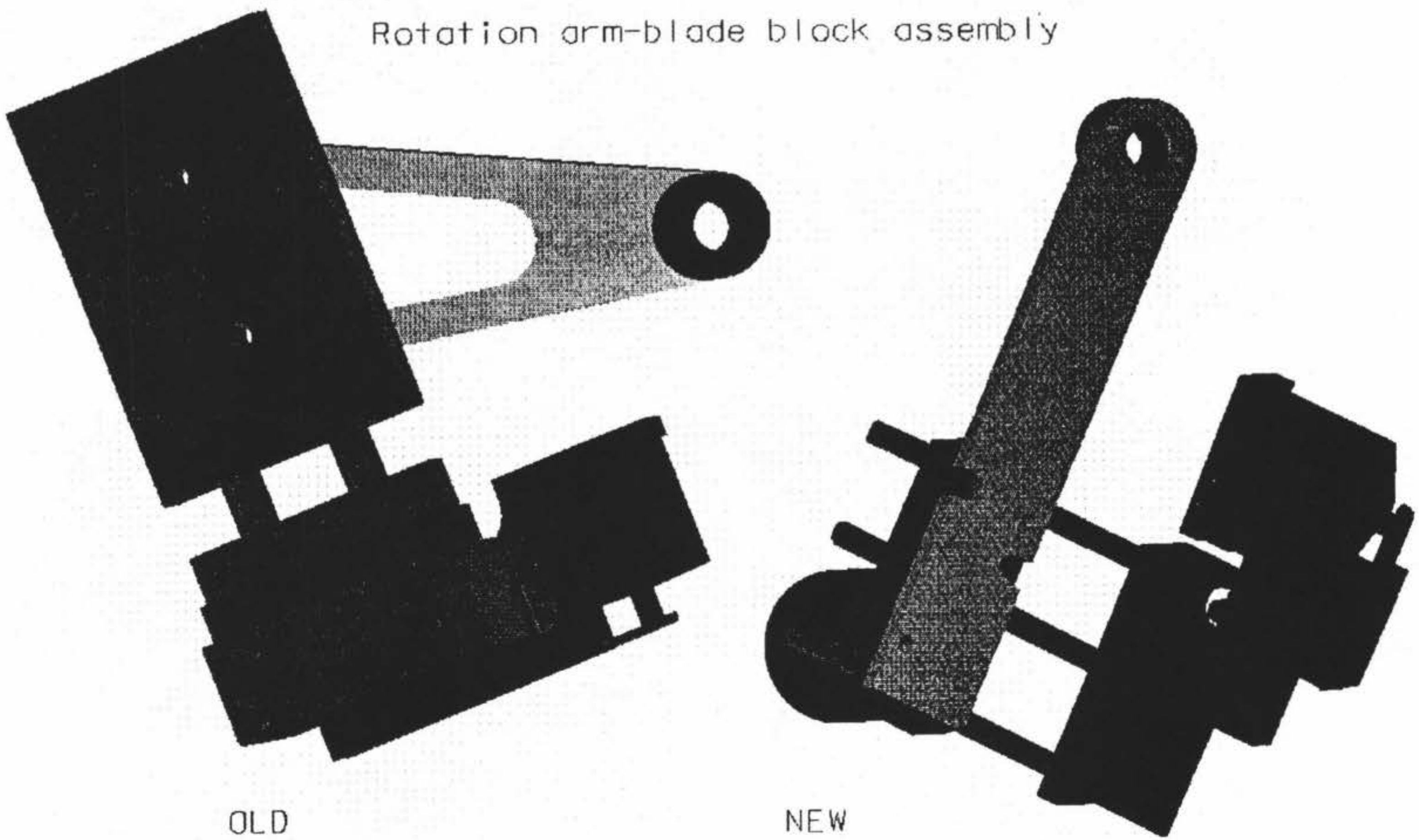


Figure 5.8: Blade motor & blade block assembly

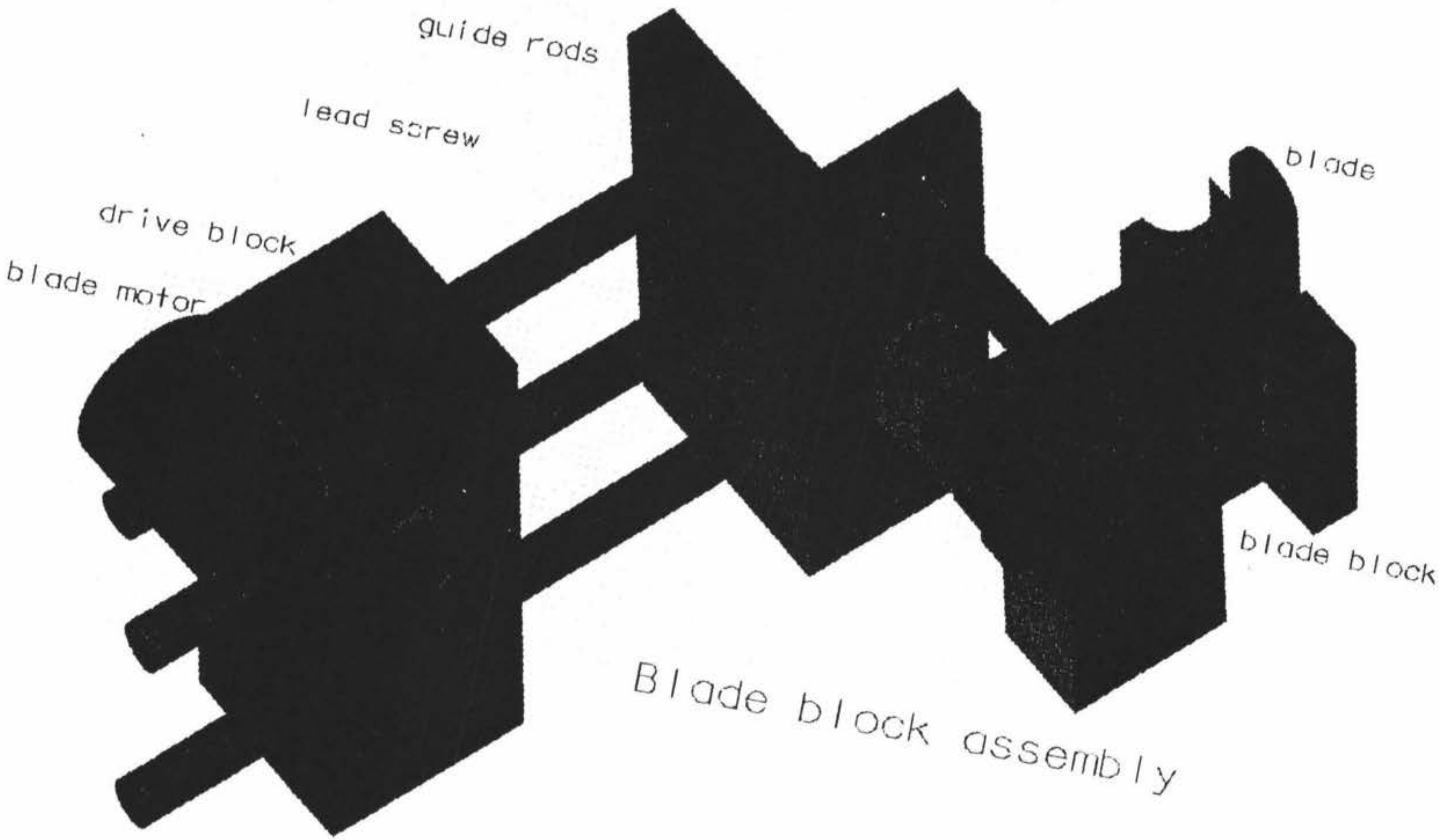


Figure 5.9: Blade block

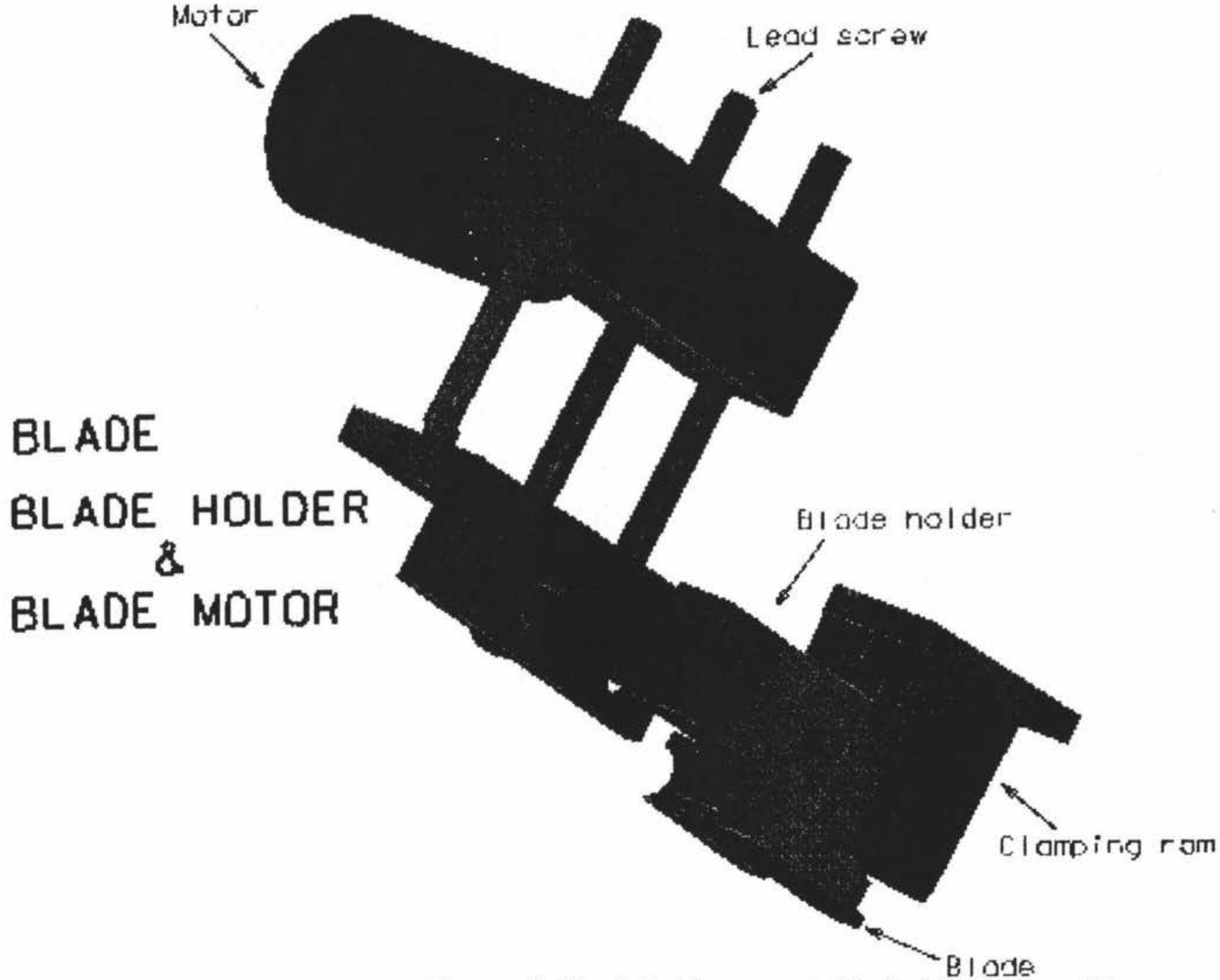


Figure 5.10: Rotation arm & blade block assembly

5.8 Clutch

The *Clutch* facilitates the engagement and disengagement of the mandrel from the mandrel motor. The clutch facilities were achieved in the earlier days of research through Massport Pull Start Clutch Mechanism. The Massport pull start clutch unit is unidirectional and allows for free wheeling in one direction i.e., clockwise direction and drive from the motor/gearbox in the other direction i.e., counter clockwise direction. The output shaft is keyed to the mandrel unit.

As the research proceeded a need for a bi-directional clutch was noticed. This requirement lead to the development of a specially designed clutch which will allow the mandrel to rotate in both directions. The new clutch is also designed to be of light weight. The basic engagement and disengagement of clutch with the mandrel is accomplished by a ram which engages the mandrel with its forward stroke and disengages it with its backward stroke. The return stroke is also supplemented by a spring to make the disengagement perfect.

Most of the components used in the clutch manufacture were Teflon plastic. The components of the clutch are shown in Figure 5.11. Figure 5.11 also shows the assembly of the clutch components.

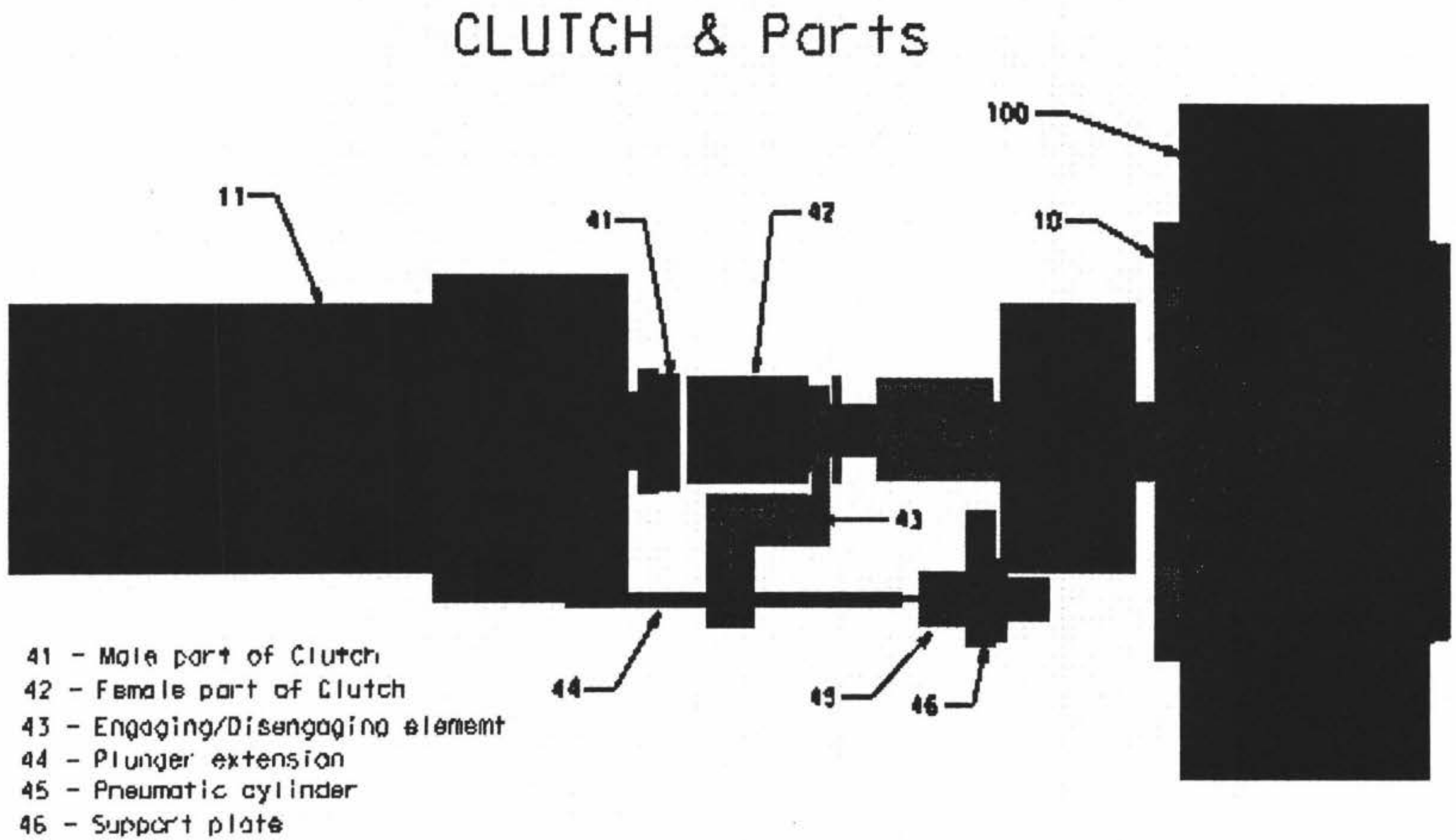


Figure 5.11: Clutch

5.9 Application Roller

Guiding the tape to the correct application point and applying good pressure on the tape during tape application is done by an *Application roller*. Different application rollers were experimented. Table 5.2 is a summary of the different application rollers, their features, advantages and disadvantages offered by them. An application roller should essentially have the following features:

- Protect surface of work piece from damage
- Impart some pressure to apply the tape evenly over the whole surface of the application roller.

Figure 5.12 shows the applicator roller in it's assembly perspective.
Figure 5.13 shows the active roller in it's assembly perspective.

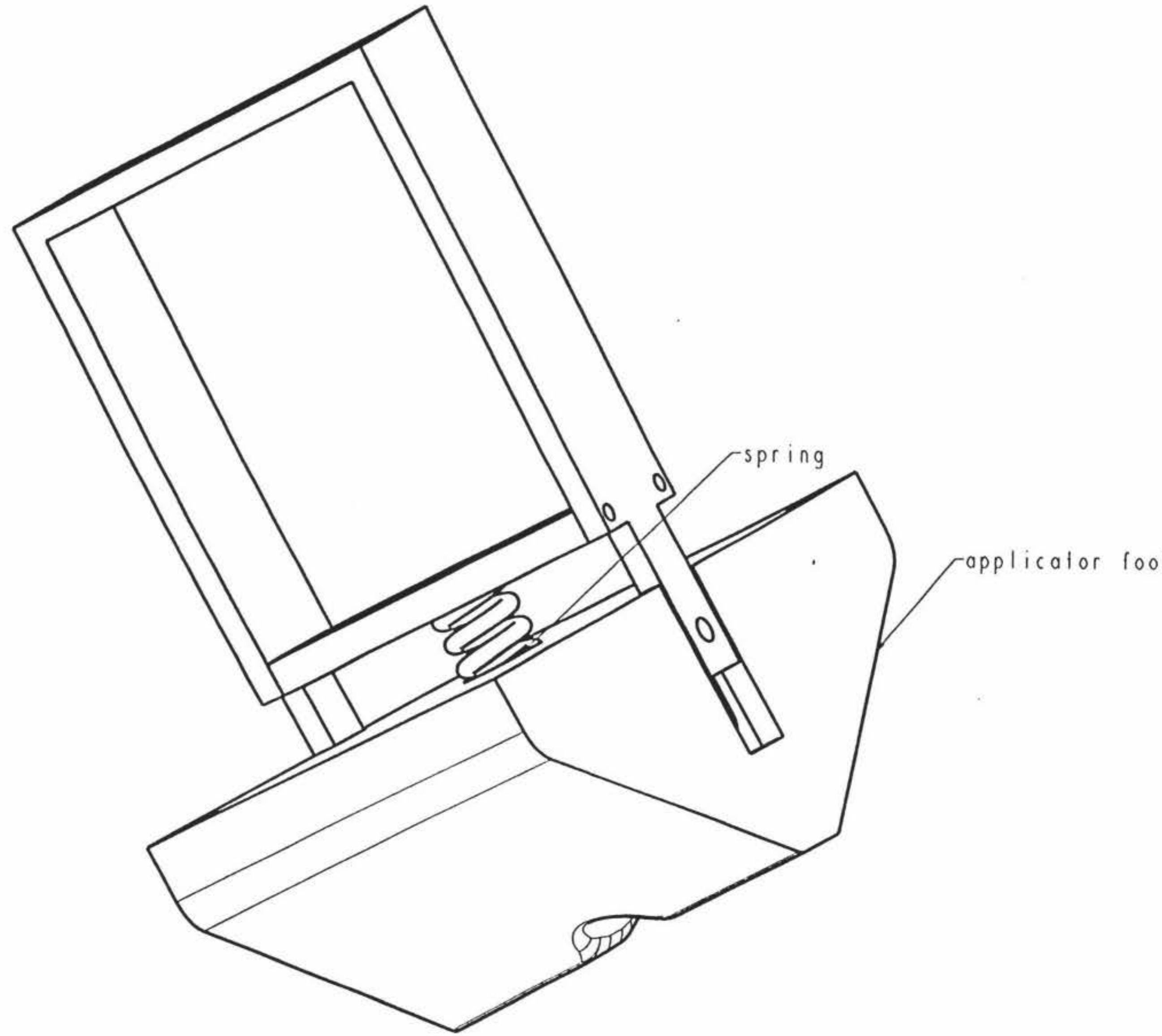


Figure 5.12: Applicator Foot Assembly

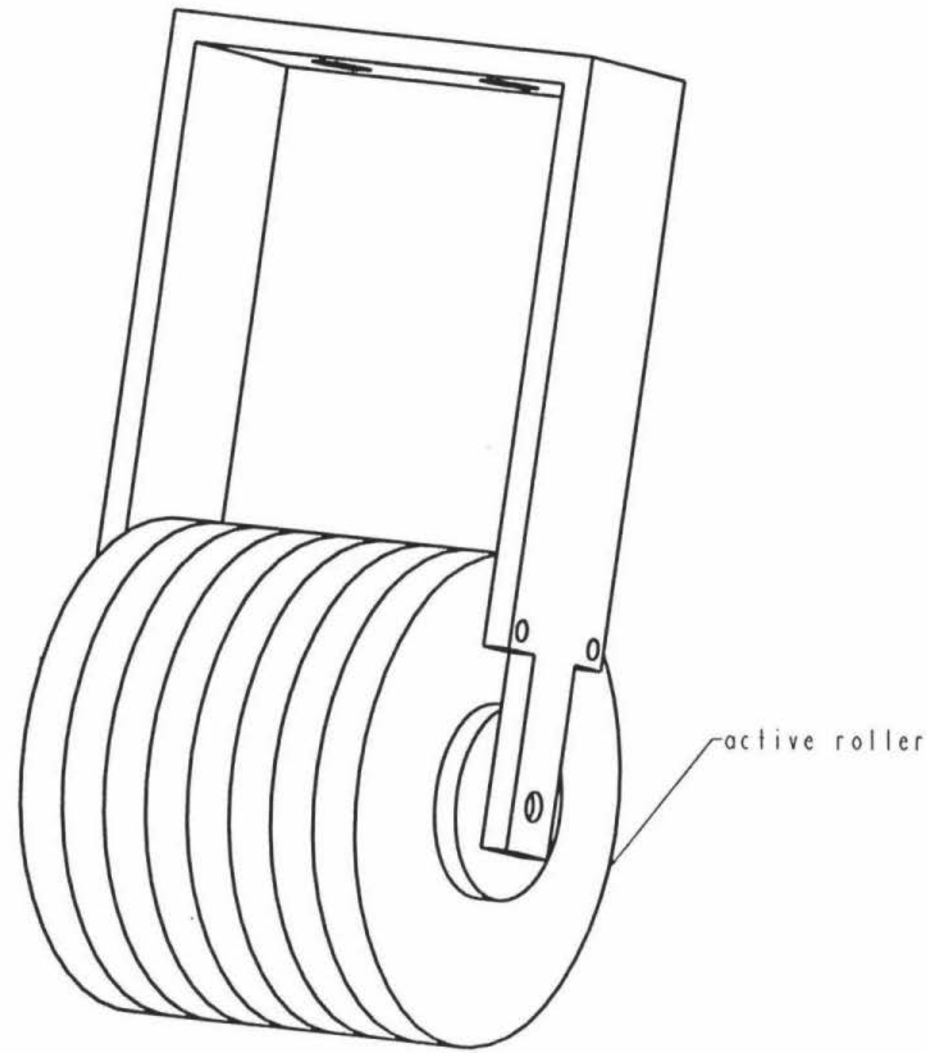


Figure 5.13: Active Roller Assembly

Shape	Feature	advantages / *disadvantages*[1]
cylindrical	groove corresponding to the tube diameter machined along the diameter of the cylinder.	*rips the tape during tape application.*
rectangular	1.similar relief for the tube as the previous one. 2.lateral relief to accommodate the pressure variations.	applies the tape in the same way as a human. *1.only point contact while applying the tape.* *2.changes the colour of the tape during tape application due to excessive stretching*
rectangular	1.All features of the second applicator roller. 2.Double in size . 3.Primary and secondary relieves for the tape.	gives proper surface contact pressure to the tape during tape application.

Table 5.2 Characteristics of tape applicators.

Material specified for the Applicator roller is usually grey PVC. However, depending on the requirements any similar material can also be used. An application roller has two degrees of freedom and is supported by a rigid frame. This frame is spring loaded and allows for variations in the work surface by keeping a constant pressure on the work surface.

[1]The string in italics indicates the disadvantages.

5.10 Edge Sensing Mechanism

To position the blade appropriately and to pick-up the tape edge an *edge sensor* is used. The edge sensors detect the edge of the tape on the roll. The edge is usually a straight edge, a left to right sloping edge or a right to left sloping edge. In each of these cases the position of the blade across the tape roll will be different. Three edge sensors are used to detect an edge on a rotating tape roll. Until, all the three sensors register an edge the shape of the edge and the blade positioning are not analysed.

The present system of edge detection has three reflective opto switches aiming at the tape roll from a predetermined distance. The reflective opto switch comprises of an infra-red light emitting diode with a silicon photo transistor in a rugged package. The sensor responds to the emitted radiation from the infra-red source only when a reflective object is within the view field of the sensor. In combination with the comparator circuit, each sensor gives an independent output when an edge is detected. These outputs will be analysed to determine the type of edge and accordingly the blade position will be determined. Three main points are required in sensor support and layout :

1. Maintain sensing distance of between 8 and 9 mm
2. Keep the three sensors correctly separated
3. Should allow sensors withdrawal at the time of a roll change

The actuators should withdraw the sensors once edge detection is done. However, this means keeping the sensors in contact with tape surface until an edge is detected. This poses a problem as sensors will interfere with the next tape roll loading

To overcome this a linear actuator is used to move the sensors towards the tape surface. The sensors are sprung loaded to a distance of 21mm to allow for the difference between a full roll and an empty roll. This system will allow for the linear actuator to have only two positions: **in & out** and still give easy access for a full tape roll to be loaded.

The sensors are kept aligned towards the centre of the tape. This was achieved by the use of a forked bracket that will have small roller bearings fitted to the ends

Figure 5.14 shows the edge sensors arrangement on the tape roll. Mandrel motor, clutch and mandrel arrangement is also seen in this figure.

5.11 Tape Tension Monitoring System

The use of the strain gauges enables the accurate measurement of the force acting on the tape, while it is being pulled from the tape roll. The information gained can then be used to accurately determine the maximum speed of the tape application. This gives a feedback to the controller and enables it to prevent the tape from ripping. To have an accurate measurement of load the right positioning of the load measurement system is needed.

The design of the end effector was changed due to the angle needed by the load measurement device. The calculations required for the design [21] are shown in

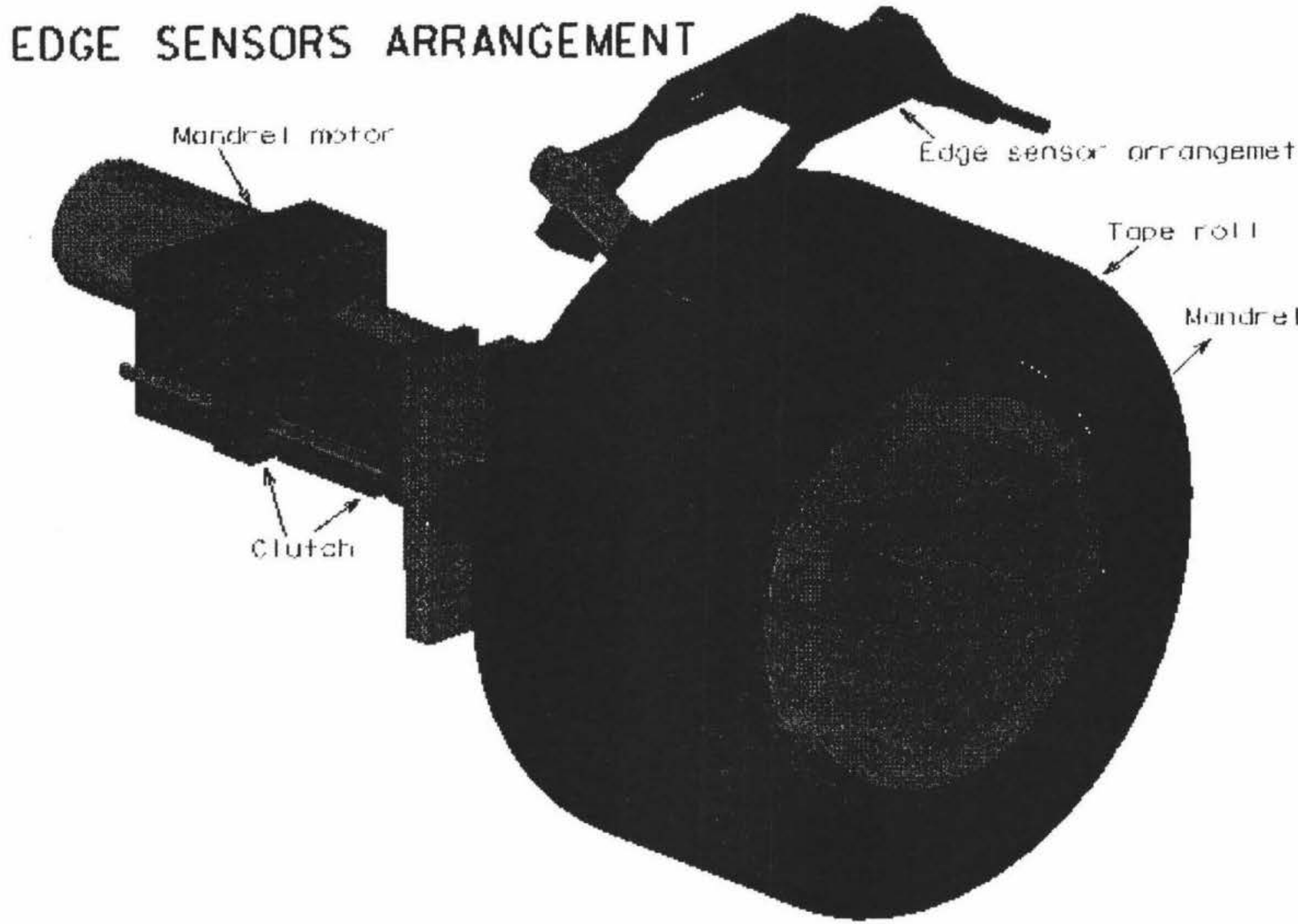


Figure 5.14: Edge sensor arrangement

appendix B. The tape is removed normally from the tape roll and pulled near 90° (as possible) . This gives the same pulling force on the load measurement device as pulling the tape from the tape roll. Figure 5.15 shows the tape tension monitoring arrangement.

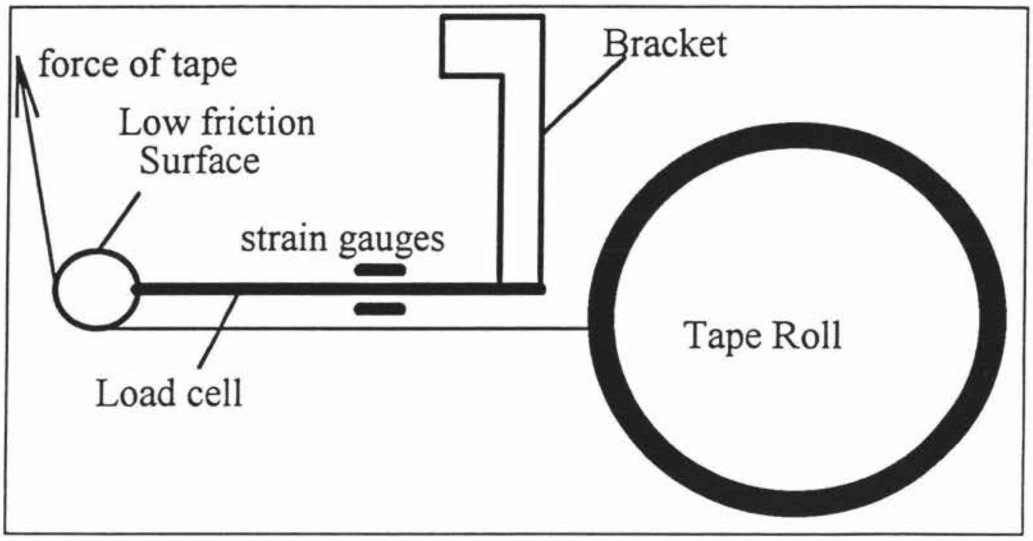


Figure 5.15: Tape Tension Monitoring Arrangement

Figure 5.16 shows the same arrangement shown in Figure 5.16 in different prospective. The same figure also shows the applicator roller with it's holder.

5.12 Tape Roll Holding Mechanism

The function of the mandrel is to hold the tape roll during the stay of the tape roll on the mandrel. But at the same time it has to release the roll when the roll is finished. This allows the robot to go and pick up a new roll from the tape roll magazine. This facility is attributed to 'EziStick' by an arrangement which will fulfil the above requirements for the mandrel.

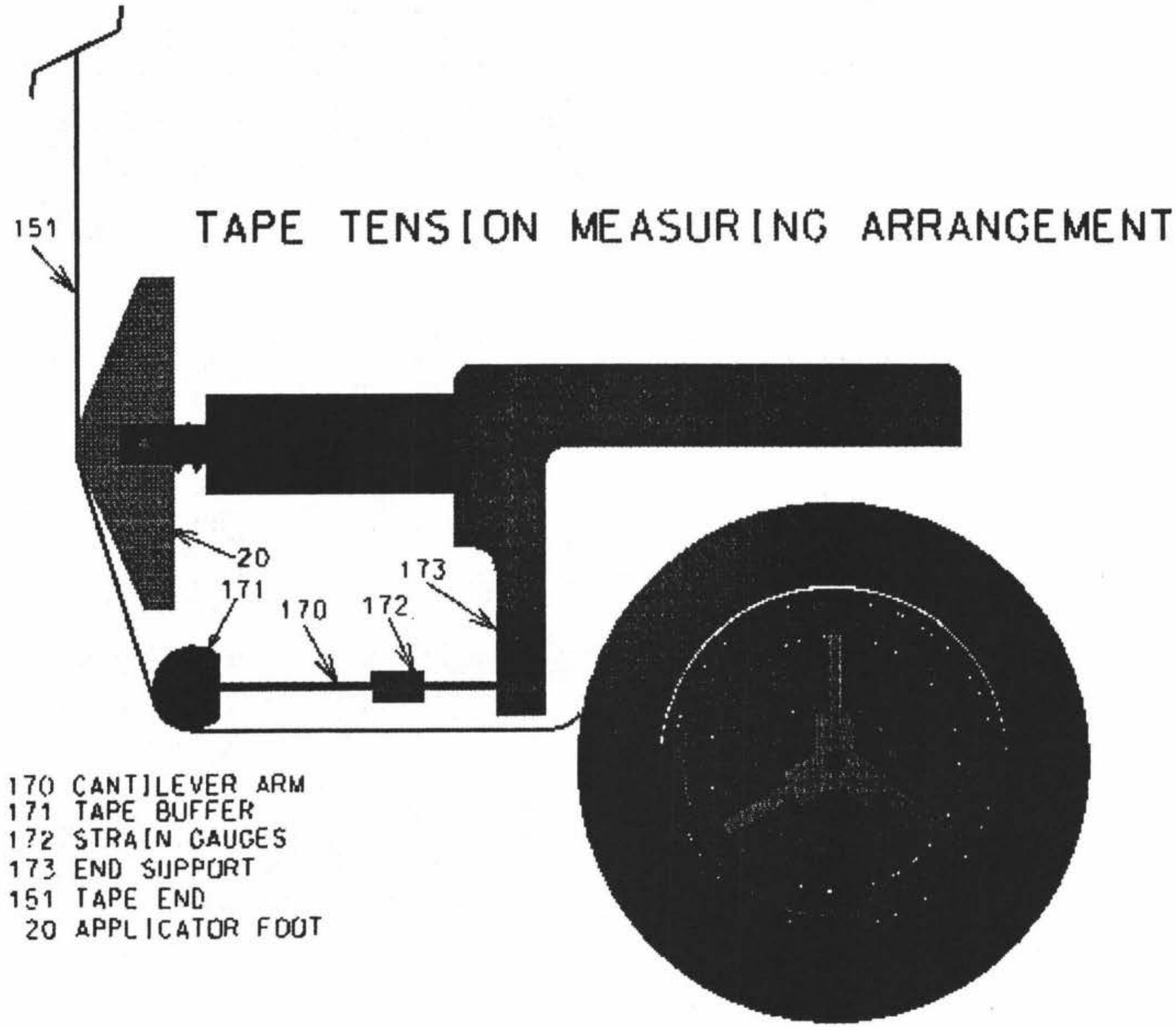
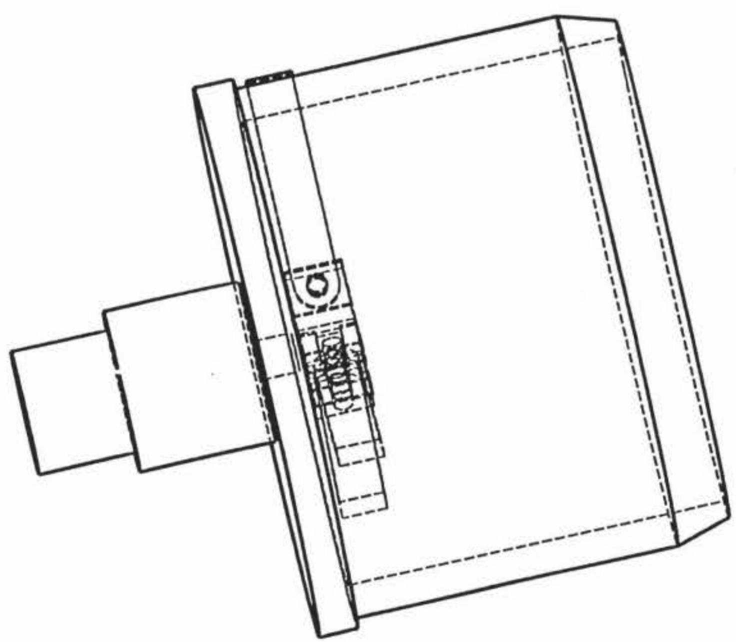
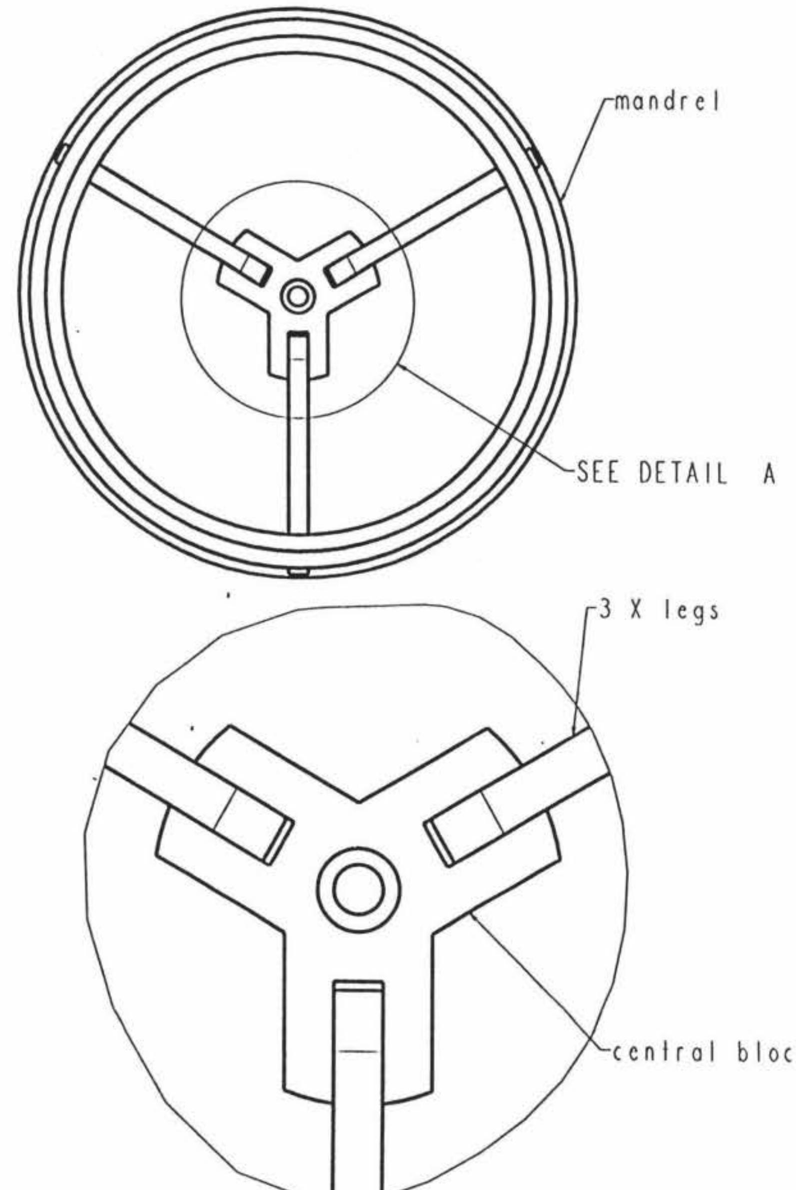


Figure 5.16: Tape tension monitoring arrangement



Roll Holding Mechanism



DETAIL A
SCALE 5:1

Research in the past, advocated the use of a mandrel to tightly hold the tape roll by pure friction. The tape roll was snugly fit on the mandrel by having the outer diameter of the mandrel slightly more than the inner diameter of the tape roll.

As the research advanced, it was also required to have a system which can provide the easy release of the tape roll when required. This necessity led to the development of a small mechanism which does the holding and releasing of the tape roll when needed. This system basically consists of three loosely held legs one end of which is in contact with the tape roll through the relief holes in the mandrel and the other ends are connected to a centre piece.

Figure 5.17 shows the above arrangement to the extent possible. But the ram which actuates the actions could not be shown in the figure. The ram is hidden behind the centre piece.

The centre piece and the three legs of the tape roll holding mechanism are made of aluminium so that the system can be light in weight. The holding and releasing of the tape roll is achieved by a small ram fixed in the centre of the mandrel. The ram operates on

- pushing the centrepiece forward
- pushing the three legs outward
- pressing into the tape roll
- holding it tightly above the mandrel.

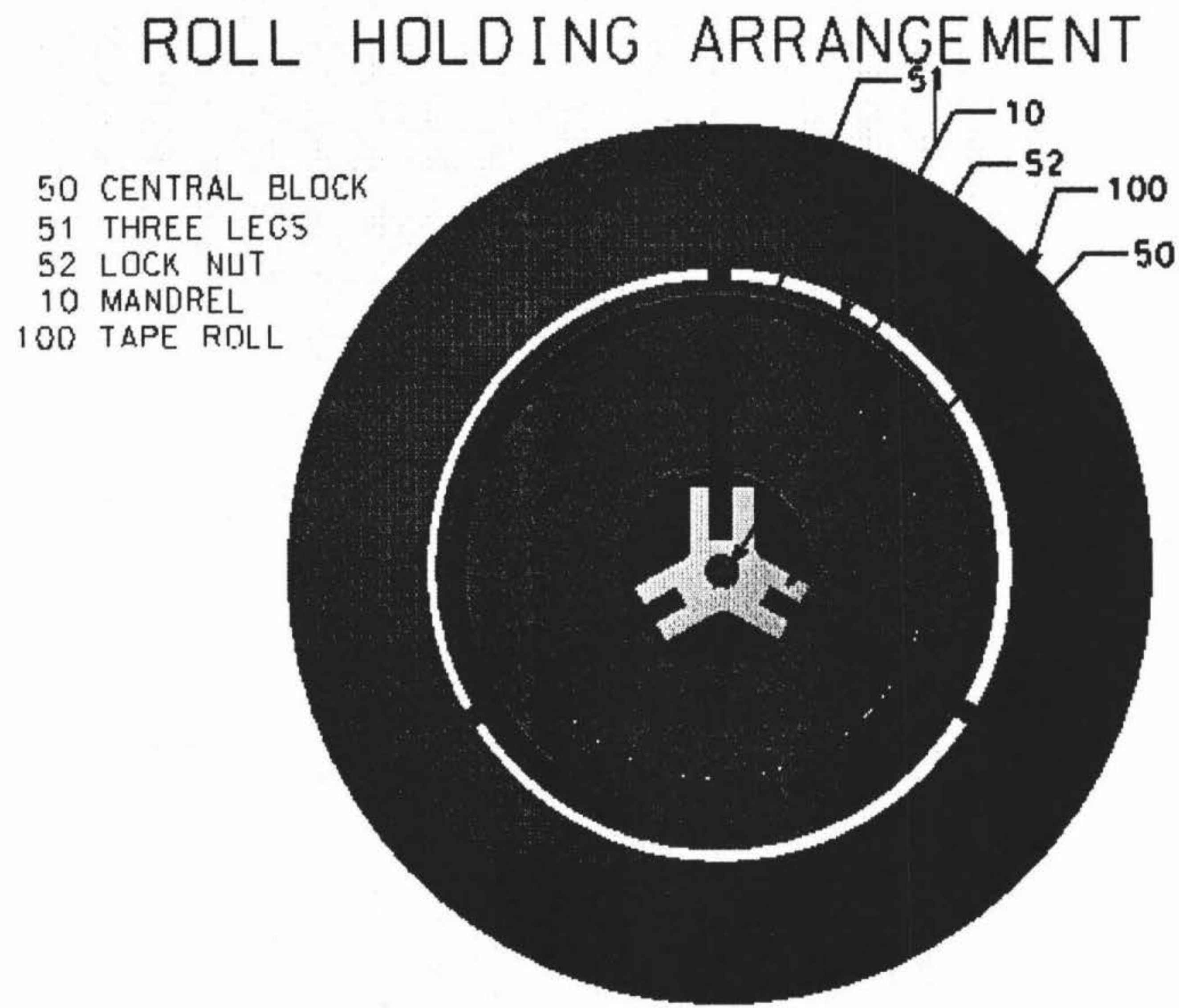


Figure 5.17: Roll holding mechanism

The backward motion of the ram, pulls back the centrepiece, in turn pulling the three legs back, releasing the tape roll. The back and forth movements of the ram are controlled by the micro controller program. In this way a used tape roll can be released for a new tape roll and the new tape roll can be held securely.

5.13 Tape Cutting Mechanism

The cut-off knife is required to pierce the tape at a time when a tape application has been completed. The tape cutting mechanism should :

- Successfully puncture tape across the tape width.
- Cut the tape after the application roller.
- Place the knife so that it will not interfere with the initiation knife, or movement system.

The system is designed to consist of a ram and a knife. (similar to a scalpel knife fixed to the ram stroke). The whole system is fixed to a frame. The forward motion of the ram drives the knife forward (cuts the tape) and the backward motion of the ram pulls it back. The frame mentioned above is positioned above the tape tension monitoring system to allow the tape to be cut as close as possible to the tape roll.

The assembly and arrangement of the tape cutting mechanism is shown in Figure 5.18. The different components going into this system are also shown in the Figure 5.19.

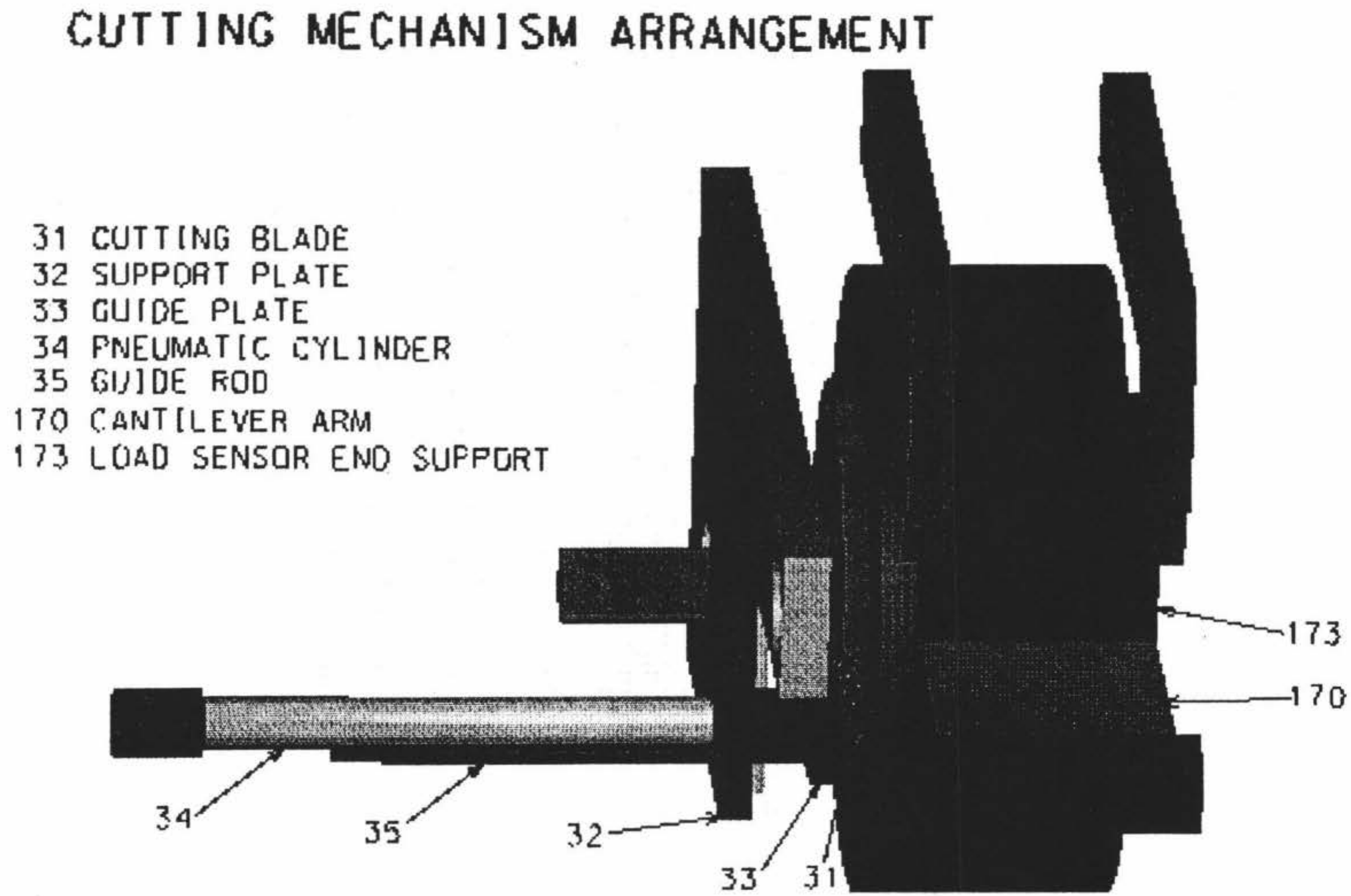


Figure 5.18: Tape cutting mechanism

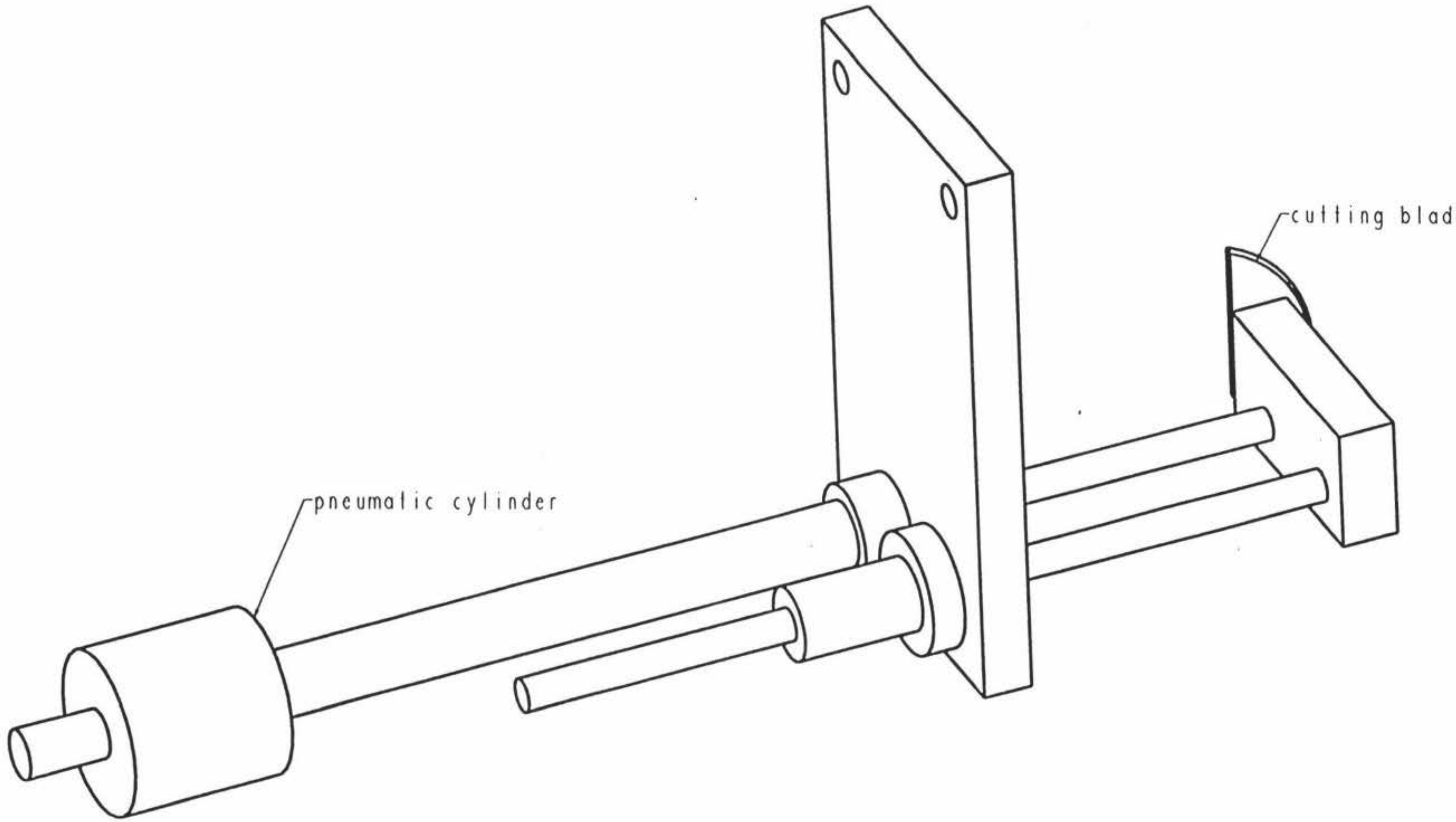


Figure 5.19: Cutting Mechanism - Closure View

Figure 5.19 is the closure view of the tape cutting mechanism. Tape cutter and it's driving ram are clearly shown in this figure.

5.14 Working of 'EziStick'

The working of the 'EziStick' starts with the loading of a new tape roll. This is achieved by the robot which moves the EziStick to the tape roll magazine and pushes the mandrel into the tape roll. A check to see whether the tape roll has been properly loaded or not is done by micro switch. The micro switch clicks and sends the signal to micro controller informing it about the load.

To facilitate the loading of the tape roll the edge sensor bracket is pushed away from the tape roll. This is done by using a small pneumatic cylinder, which pushes the edge sensor bracket away in it's forward stroke, while the tape roll is being loaded and leaves the edge sensor bracket against the tape roll in it's backward stroke (after the tape roll has been loaded). The normal position of the edge sensors is always against the tape roll as their presence is only to detect the starting edge of the tape.

Once the tape roll is loaded onto the mandrel the mandrel motor starts rotating the mandrel and tape roll. Following this action the starting edge of the tape roll are presented to the optical sensors which are always positioned at right angle to the tape surface. This enables the edge to be detected by the edge sensors.

The sensors work on the principle of receiving the light ray back. One side of the sensor sends the light beam and the other side receives the light beam reflected off the tape surface. If it does not receive the reflected light beam back, the sensors assume that the edge has passed, and the signal is sent to the micro controller, saying that the edge is detected. Once an edge detection signal is received, the micro controller stops the mandrel motor. Otherwise, the mandrel motor will go on rotating the mandrel even though the edge is detected.

As the mandrel motor stops, rotation arm is brought into action. It swings down towards the tape roll. The swing of the rotation arm is controlled so that it stops at a certain distance from the tape roll. This allows the blade motor to run forward and drive the blade to the tape surface. As the blade reaches the tape surface, the blade motor stops, halting the blade from further advancement. This is made possible with the help of an inductive proximity switch which senses the tape metal surface from 2mm distance and sends the signal to the micro controller to stop the blade motor. The blade motor stops in time not ramming the blade into the tape roll. The proximity switch is adjusted to stop the blade motor at the point blade touching the tape roll.

As the blade motor stops the mandrel motor starts rotating the mandrel and the tape roll. When the blade is stopped touching the tape surface the rotation of the mandrel drives the tape edge onto the blade face. As soon as a certain amount of tape is pushed onto the blade surface, the mandrel motor stops, halting the mandrel. The presence of tape on the blade is determined by another proximity switch, which is positioned by the side of the blade. When sufficient amount of tape is loaded onto the blade, the proximity switch detects the tape and sends a signal to the micro controller, asking it to stop the mandrel motor. The signal from the proximity switch also triggers another action from the micro controller and activates pneumatic cylinder, clamps the tape between the blade face and the plunger of the pneumatic cylinder.

The radial movement of the rotation arm is accomplished by the rake and pinion arrangement from the frame. The rake is attached to the pneumatic cylinder (fixed to the frame) and the pinion to the steel shaft. This connects the frame and the rotation arm. The motion of rotation arm moving towards the tape roll is by the forward stroke of the pneumatic cylinder and the rotation arm moving away from the tape roll is by the backward stroke of the pneumatic cylinder.

As the tape is clamped between the blade and plunger, the rotation arm is swung away, peeling the tape from the tape roll. The rotation arm also pulls the tape, over the strain gauge bridge and the applicator foot during its back travel. The stain gauge bridge is for monitoring the load during the application of the tape and it also sends the signals to micro controller continuously for corrective actions (in case the tape tension exceeds the working range of the tape tension). The application roller is the device that helps in applying the tape over the tubes to the surface. It has a relief to accommodate tube while the tape is being applied. This is also spring loaded to take care of the pressure needed for the tape application.

Now the tape is ready to be applied. The actions took place so far, are in the end effector controlled by the micro controller. Once the tape is on the applicator foot it is the turn of the robot to act and move to apply the tape over the tubes. The movements of the robot are programmed separately, but the signals for the robot movement are governed through the micro controller. The plunger releases the tape end allowing the robot to apply the tape.

Once a certain length of the tape or a programmed length of the tape has been applied the tape has to be cut. The next sequence can then be started. The cutting of the tape is done by a separate mechanism consisting of a pneumatic cylinder which runs across the cutter tape and to cuts the tape. The cutter that is cutting the tape is a sort of scalpel blade, attached to the end of the pneumatic cylinder plunger. After the cutting, the robot applies the remaining length of the tape and moves back to it's normal position. Then the mandrel motor rotates in the reverse direction rolling back the loose tape to the tape roll.

This entire operations are performed in a cycle and the cycles can be repeated depending on the number of tubes to be taped.

5.15 Electrical and Pneumatic Circuitry

The following drawings show the details of the electrical and pneumatic circuits of 'EziStick'. It also explains the changes made from the old circuits to the new circuits. In few areas the changes were very necessary to work with the function of 'EziStick'.

In the early stages of this research, few variable power supplies to provide the power to various electrical parts of 'EziStick' were used. As the research proceeded few power supply kits were assembled into a single unit to give the power to all the electrical parts of the circuits. This option suffered from the micro controller failing to provide enough current to drive the mandrel motor and the blade motor. So it was needed to isolate the motors from the micro controller circuit and operate them separately. The **ON** and **OFF** signal from the micro controller was obtained by incorporating transistors in the circuit and isolating the whole motor driving system from the power supply.

As discussed before optical sensors are being used for the edge detection. Several other means to do the edge detection were tried. They are discussed below.

A microphone was used to detect the tape edge by differentiating the noise signal. In effect the edge signal was perfect but the microphone is also picking the ambient noise. This is resulting in fake edges and so of no use.

Another attempt was to use the Bi-Morph vibration element for the edge detection. This element has two probes and it works by the voltage difference generated between the two probes. Edge will create a larger voltage difference between the two probes of the element. To get the edge signal this probes should always be in contact with the tape surface. As the tape has adhesive on one side, the probes are getting stuck to the tape roll on its reverse turning. Thus getting bent and sending wrong signals. Hence this element was also discarded for edge detection.

Inductive proximity switches were used to detect the tape surface during tape pick up and to sense the presence of the tape on the blade during the tape clamping. The switches used are distance sensitive and the first one is of 5mm range and the second one is of 2mm range. When the tape comes within the operating range of the proximity switches a signal is sent to micro controller and the system works accordingly. (Refer to Figure 4.8 for better understanding of proximity switch positioning).

Tape loading and blade motor home position signals are obtained by using micro limit switches. The output from these is obtained when their lever is pressed to actuate the switch. Electro-pneumatic solenoids are used to move the pistons of the air cylinders used in the circuits. All these solenoids are actuated through the relays by the micro controller.

The electrical circuitry is shown in the following figures.

Figure 5.20 shows the total electrical and pneumatic layout of the circuitry.

Figure 5.21 shows the connections going to and from the microcontroller. All the connections are numbered according to the boards they are being connected to.

Figure 5.22 shows the input and output connections to the robot controller.

Figure 5.23 shows the motor driving circuit and the driving circuit for the pneumatic solenoids.

Figure 5.24 shows the relay circuit for the limit switches and input/output to the robot controller.

Figure 5.25 shows the details of the plug connections going to the 'EziStick'.

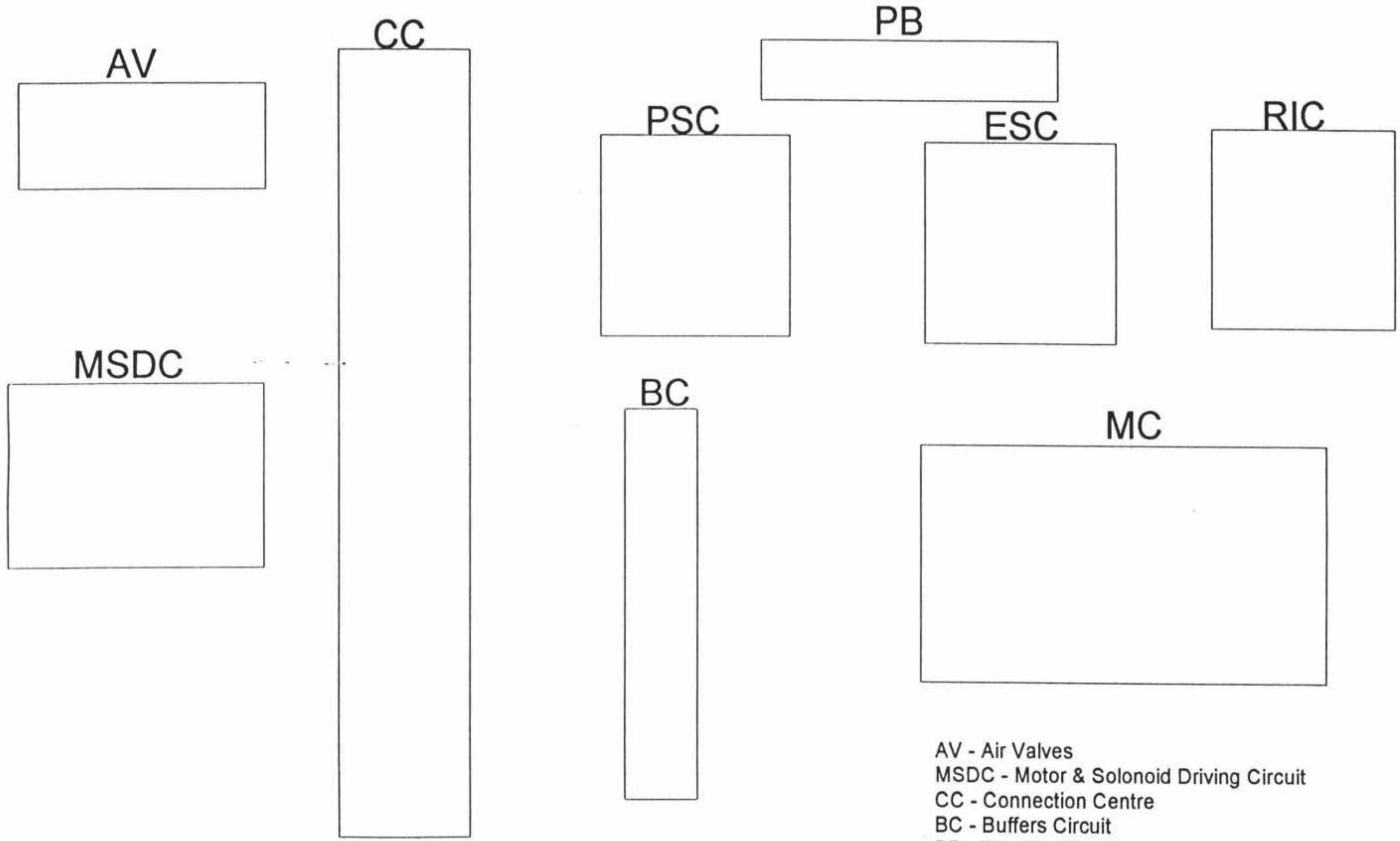


Figure 5.20: Electrical & pneumatic circuit outlay

AV - Air Valves
MSDC - Motor & Solonoid Driving Circuit
CC - Connection Centre
BC - Buffers Circuit
PB - Plug Board
PSC - Proximity Switch Circuit
ESC - Edge Sensing Circuit
RIC - Robot Interfacing Circuit
MC - Micro Controller

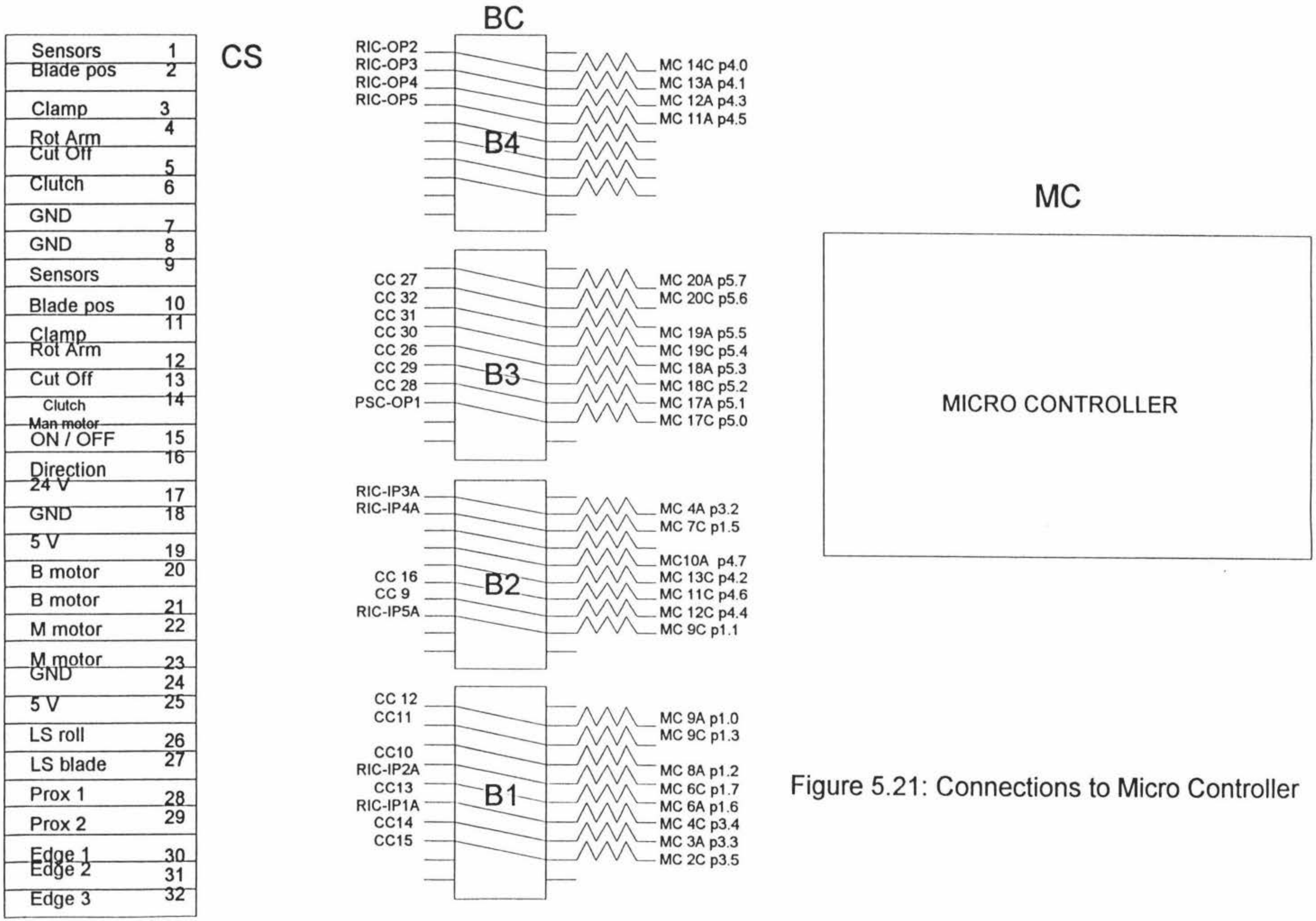
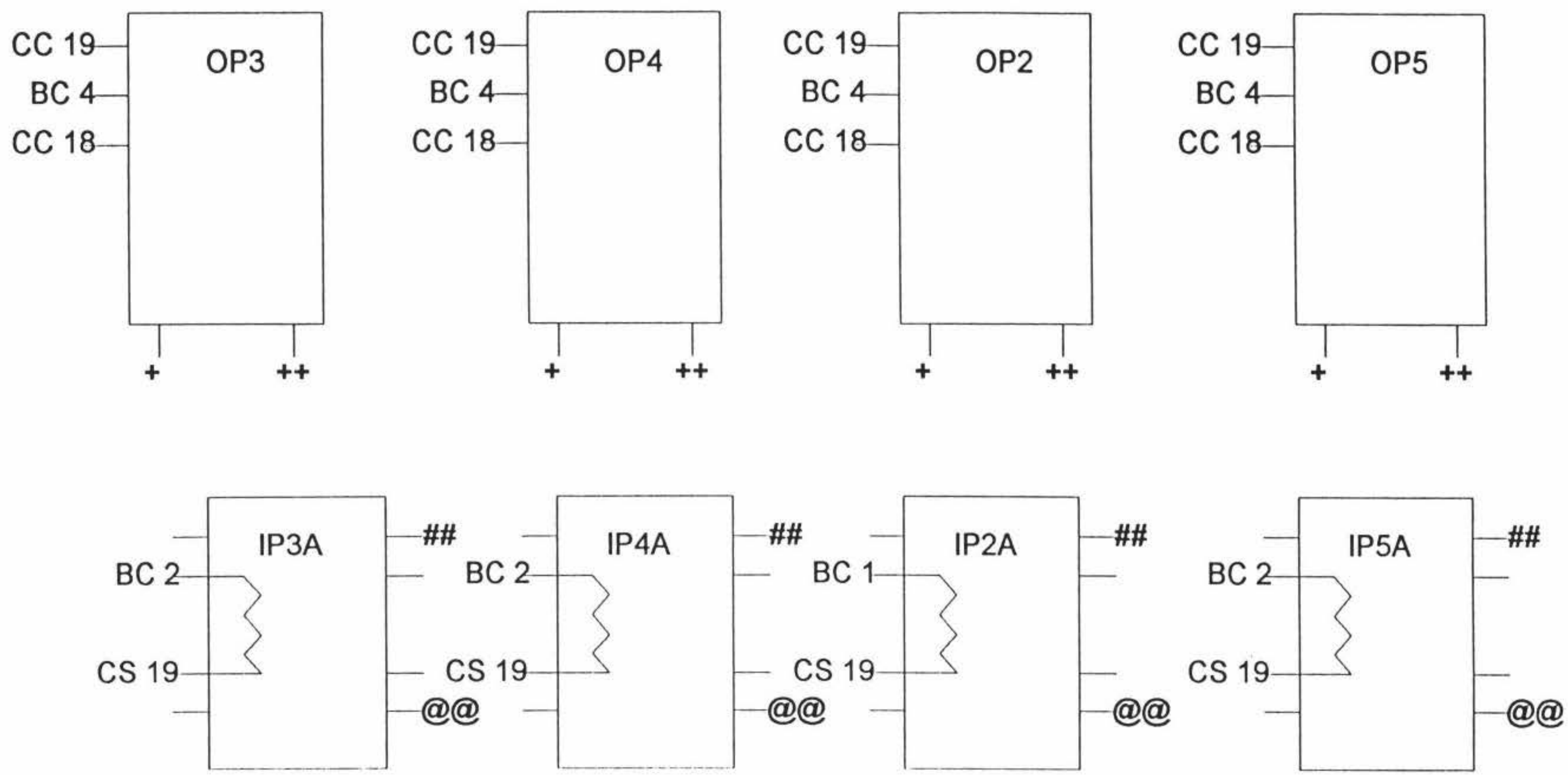


Figure 5.21: Connections to Micro Controller



+ - 0 v from Robot Controller
++ - Output from Robot Controller
- 24 v from Robot Controller
@@ - Input to Robot Controller
*** CC, BC represent respective circuit boards for the connections

Figure 5.22: I/O Connections from Robot Interfacing Circuit (RIC

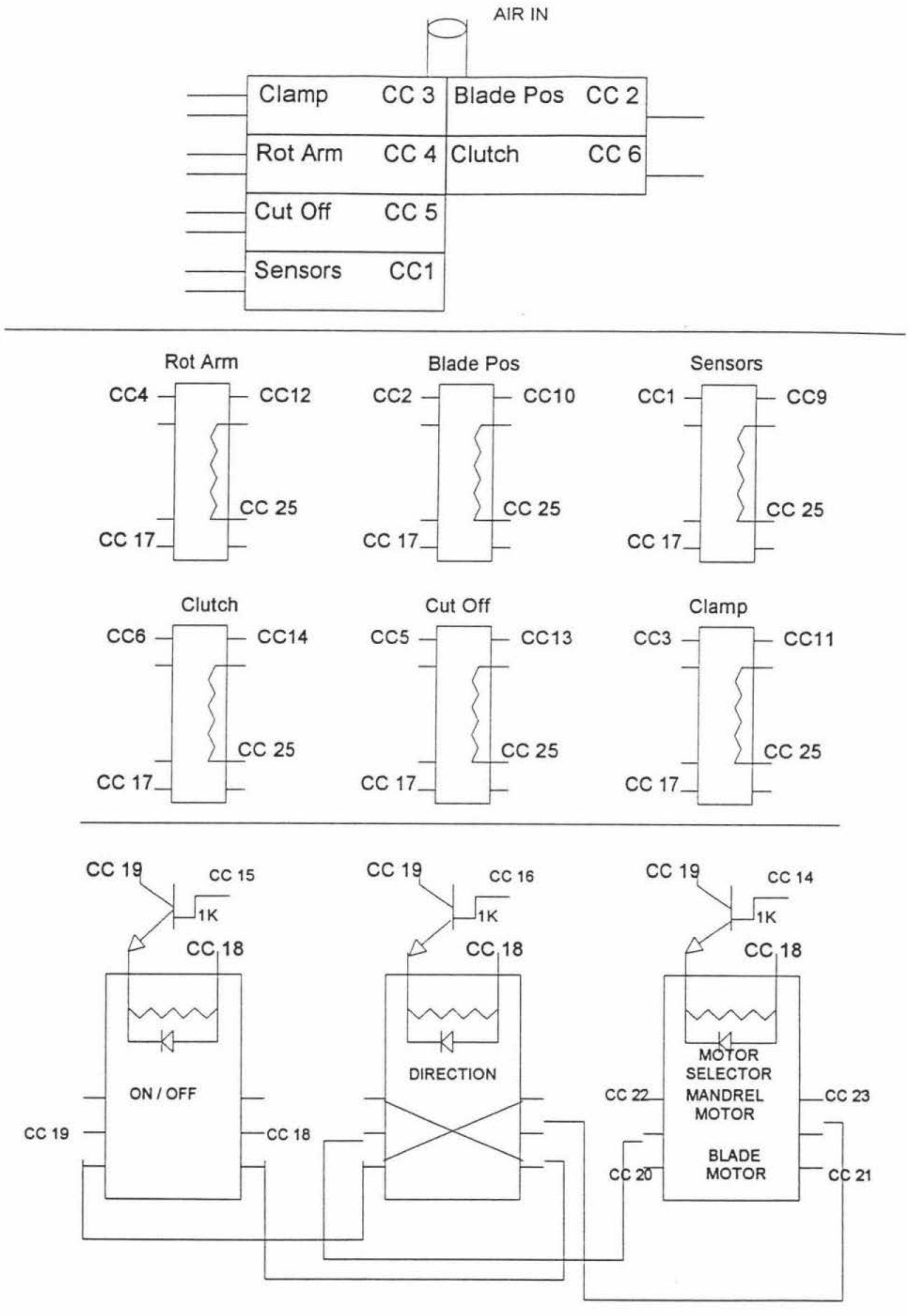


Figure 5.23: Motors & Solonoids Circuit

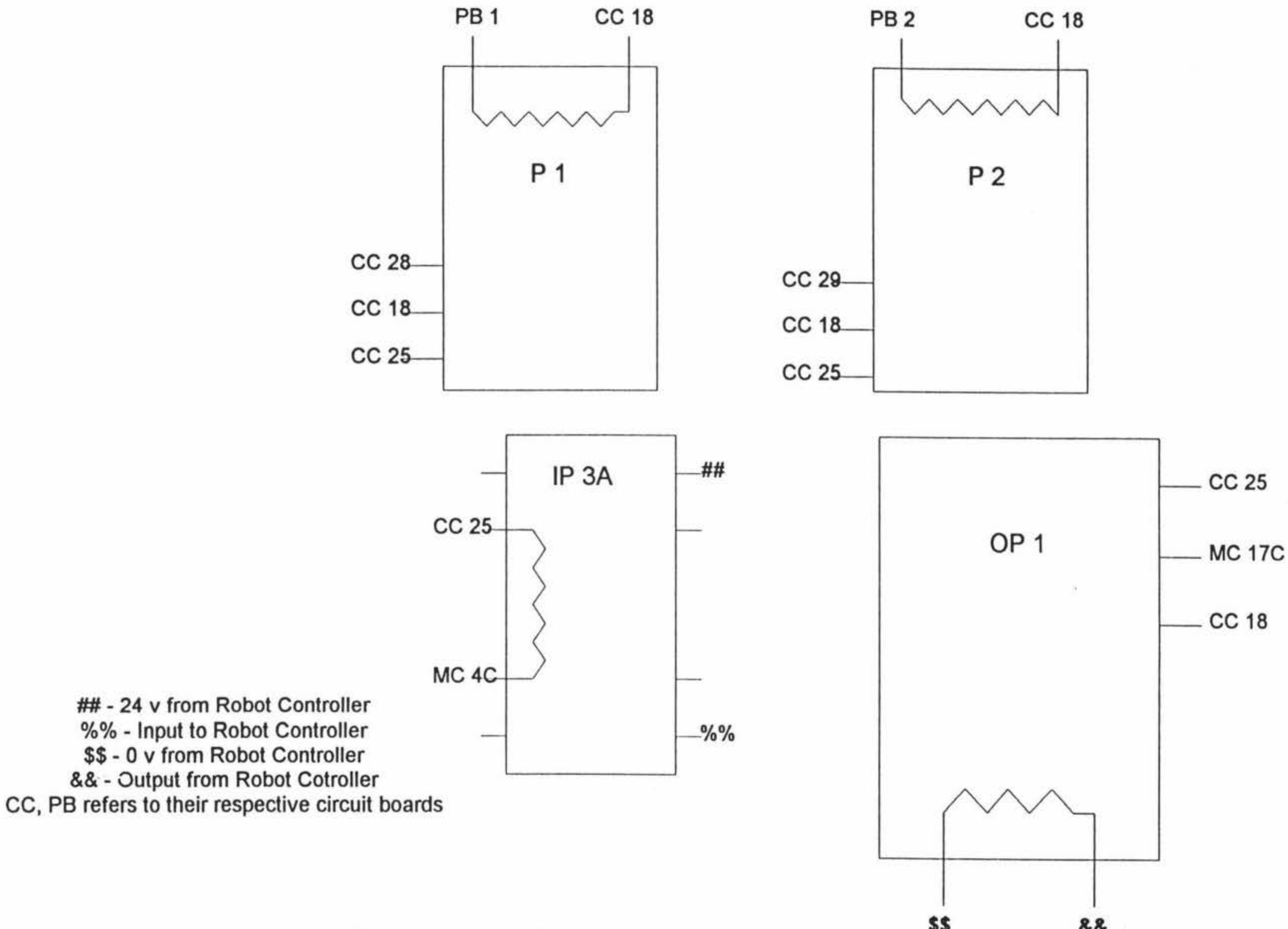
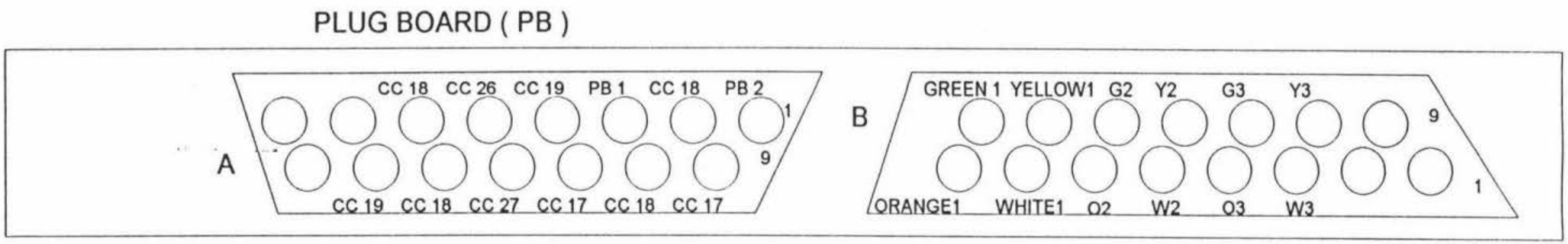


Figure 5.24: Relay Details of Proximity Switch Circuit (PSC



1,2,3 refer connections to edge sensors 1,2,3.

Figure 5.25: Plug Board Layout

Chapter 6

Modules of 'EziStick'

This chapter discusses about the different modules of 'EziStick' and the logic behind each module

6.1 Introduction

Robot and 'EziStick' are programmable. This chapter aims at giving an outlook on the control programs. The whole concept is divided into five different modules. They are :

1. 'EziStick' Module
2. Edge Sensing Module
3. Blade Positioning Module
4. Tape Pick up Module
5. Tape Tension Module

'EziStick' module is the overall sequence of all other modules. It gives the sequence of all other modules. The idea of calling the whole sequence of modules a module is to emphasise the modularity of the project. The whole module can be repeated any number of times as per the requirements.

The various modules are summarised in Table 6.1. The following sections explain each module in greater depth. The flow charts for the different modules of 'EziStick' are in appendix C. The control programs of the 'EziStick' and the Robot are in the appendix D.

Module	Occurrence	Action
'EziStick' Module	-	The main module of 'EziStick'. Puts all the other modules in sequence.
Edge Sensing Module	First Module	senses the tape edge
Blade Positioning Module	Follows edge sensing module	Positions and monitors the blade with respect to the type of tape edge.
Tape Picking Module	Follows blade positioning module	Moves the rotation arm and picks up the tape
Tape Tension Monitoring Module	Follows tape picking module	Measures and monitors the tape tension continuously.

Table 6.1 Modules of 'EziStick'.

6.2 Edge Sensing Program Logic

The basic concept of the edge sensing lies on the performance of the sensors. At the present time, Diffuse-scan Optical sensors are being used. The sensors contain an infra red transmitter and a receiver. Each sensor is attached to a timer and the timer triggers to counting as soon as the sensor detects the edge. If the reflected light does not come back then an edge is assumed even though the reflection is from an edge, a bad surface , a bump, a blemish or something else. In order to avoid this three sensors are placed across the width of the tape and are used for effective feed back about the edge as well as the type of edge. Hence, all three timers should have readings for detecting an edge. Till all the sensors detect an edge, the micro controller will not register it. The sequence of steps involved for detecting an edge are :

1. Light is sent by the transmitter.
2. The light goes and hits the tape surface and is reflected back.
3. If the reflected light misses the receiver an edge is detected.
4. If it is an edge, a note is made in the timers attached to the sensors. (From the timer values the type of edge and the blade position can be calculated).

Depending on the timer values the slope of the edge can be calculated and this information helps in positioning the blade to the mm accuracy. The following calculations show how that can be done.

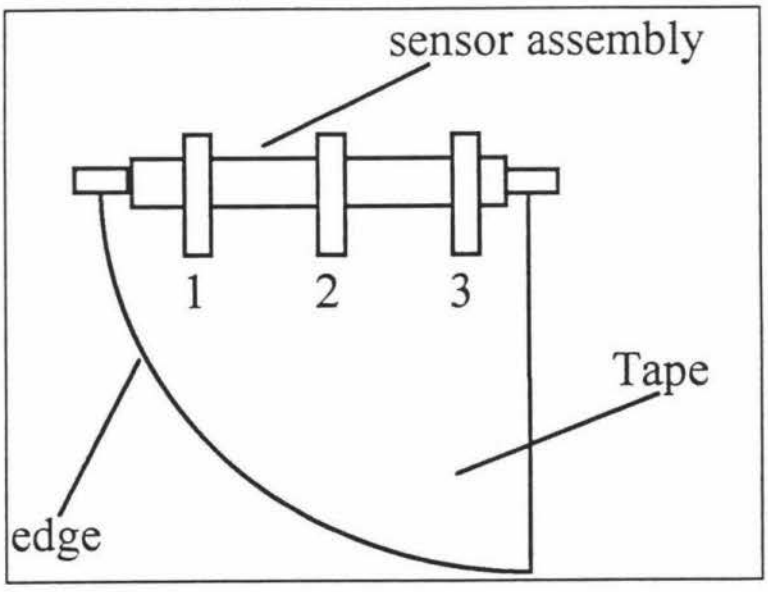
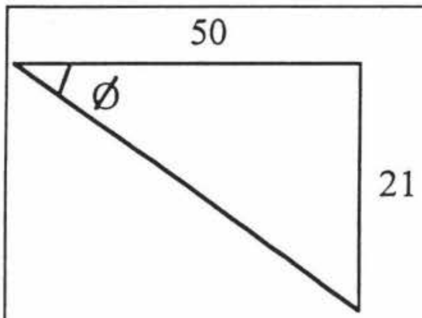


Figure 6.1: edge and sensors

For example, if the edge is as shown in Figure 6.1, and the tape roll is rotating, an edge will be detected. As the edge is not straight, there will be three different timer times. Let Timer1 corresponds to sensor1, Timer2 corresponds to sensor2 and Timer3 corresponds to sensor3.

For instance let the readings in the three timers be 1,15 and 22 respectively. Let the tape width be 50 mm. The values gives a triangle with 50mm as base and 21 timer units as side. The calculations involved in the angle of the tape edge are shown in figure 6.2



$$\tan \varnothing = \frac{\text{OPPOSITE SIDE}}{\text{ADJACENT SIDE}}$$

$$= (21*2.43)/50$$

$$= 1.0206$$

$$\varnothing = \tan^{-1}(1.0206)$$

$$= 45.58^{o}$$

Figure 6.2: Edge angle calculations.

Timer units to 'mm' conversion:

A small experiment to figure out the timer units for one revolution of mandrel was conducted. The results are as below:

Timer units for one revolution of mandrel = 158.2

Circumference of tape roll = 385 mm

Hence, for each timer unit mandrel travels a distance of

385/158.2 = 2.43mm

So to get the real value of timer units in 'mm' every timer unit should be multiplied by a factor of 2.43)

A timing technique to eliminate blemish from being recognised as a real edge is also programmed. The timing technique follows the following sequence of steps.

1. Fix a selected number. (We have assumed that any bad, long edge would not be more than 1/4 of tape roll circumference. That gives a timer value of 40.)
2. Start the timer loop in sensors.
3. Compare all the timers for timercount = selected number.
4. If one of the timers reach the selected value

    check for the value in the other two timers.

    If no value in the other two timers

        "Fake Edge" is detected.

    else

        "True edge" is detected.

5. If no value in the timers "No edge" is detected.

6.3 Blade Positioning Logic

'EziStick' is making use of a double acting pneumatic cylinder for blade positioning purpose.

By design, this cylinder has only 2 positions home position and extended position. Hence there are only 2 positions for the blade to pick up the tape.

The Blade positioning module follows the edge sensing module. The whole logic of blade positioning module depends on the three timer values Timer1, Timer2 and Timer3 respectively. The blade positioning logic works on the differences of the timer values. For the pneumatic cylinder to be at home position Timer1 should be more than the Timer2 and Timer3.

If Timer1>Timer2 and Timer1>Timer3 Then
Blade Position=Home position or Retracted position.

The next position of the pneumatic cylinder is it's extended position. For the pneumatic cylinder to be in it's extended position, the Timer3 should be more than Timer2 and Timer1.

If Timer3>Timer2 and Timer3>Timer1 Then
Blade Position=Extended position.

In any case if Timer2 is more than Timer1 and Timer3 or all the timer values are equal to each other, then the pneumatic cylinder will be at home position only

If Timer2>Timer1 and Timer2>Timer3 or Timer1=Timer2=Timer3
Then Blade Position=Home or Retracted position.

6.4 Tape Picking Logic

Synchronisation of the electro-pneumatic systems is the tape picking module. Once the blade is positioned in accordance with the edge type, rotation arm moves the whole blade block towards the tape roll. At this stage, blade motor starts and drives the blade towards the tape roll, until the proximity switch behind the blade senses the tape surface. On sensing the tape surface, the blade motor positions the blade.

At this point mandrel motor starts rotating and pushes the tape onto the blade. Mandrel motor stops the mandrel as soon as there is sufficient tape on the blade for clamping. This is determined by another proximity switch fixed to the clamping cylinder.

Once there is sufficient tape on the blade, clamping cylinder clamps the tape between it's plunger and the blade, and rotation arm swings away from the tape roll pulling the tape along with it. Blade motor reverses at this stage leaving the tape ready for the application. As said before this module is a co-ordination between different items of 'EziStick'.

6.5 Tape Tension Monitoring System

Tape tension monitoring depends on the readings from the strain gauge amplifier. The readings are dynamically obtained and fed to the micro controller. Depending on the values the micro controller decides what action has to be taken at that particular tape tension value.

The tape which is mounted on the mandrel will allow for free removal of tape. The tape coming out of tape roll will go over the bridge, onto the work surface. Four strain gauges are fixed onto the bridge and they are balanced in a wheatstone bridge arrangement. The output of this balanced strain arrangement is the output value for tape tension. The pull on the tape during application will cause tension on the tape which inturn bends the bridge slightly in proportion to the pull force. This bending of the bridge creates an imbalance in the balanced wheatstone bridge arrangement of the strain gauges. This imbalance is calibrated in terms of volts which will be fed to the amplifier to make the tape tension value suitable to the requirement. These values will be fed continuously all along the tape application and the micro controller will take the control measures depending upon the tape tension values.

Certain actions need to be taken by the micro controller at certain ranges of tape tension. The actions should restore the tape application. Hence, experiments were done to obtain the initial values of strain. This enables a comparison of the tape tension range against the known load.

Tape tensions were recorded in the following manner. The three measurement points: strain gauge reading 1 (sgr1), strain gauge reading 2 (sgr2), and strain gauge reading 3 (sgr3) were taken into consideration while the tape was being applied. As the tape application is dynamic in nature the values will keep changing. The tape tension values pass through the line from the first point to the last point. Any action by the micro controller is initiated only after calculating the difference between the first, second and last measurement values.

It is assumed that as the tape application starts the tape tension also starts increasing. While calibrating the strain gauge amplifier the working range of tape tension during normal application was established. The tape tension should be usually lying in the normal application range (1.1 to 1.7 volts). During this application, if the tape tension lies below or above the working tape tension range, the micro controller assumes it as a fault and starts taking measures to rectify the situation. The way the tape tension is monitored is shown in Figure 6.4.

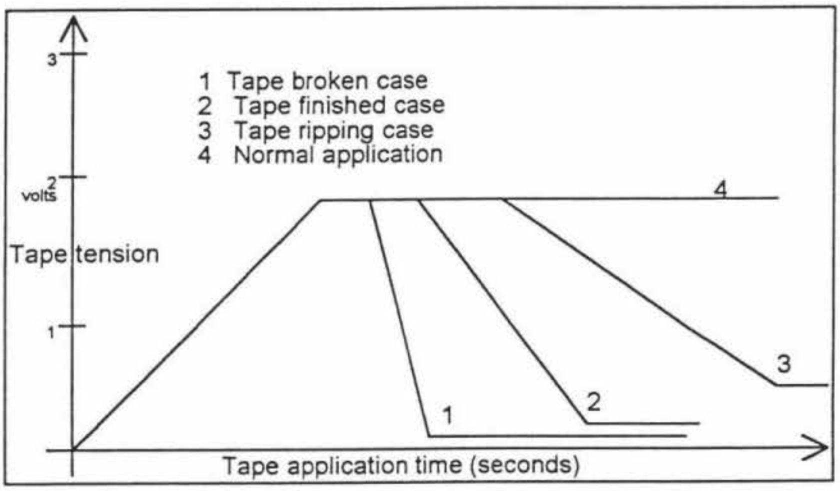


Figure 6.4 : Tape tension monitoring cases

The micro controller performs different actions for each case. Three different cases were envisaged so far.

1. Tape Broken Case
2. Tape Finished Case
3. Tape Ripping Case.

And the fourth case is of course normal application, where the application is perfect and the tape tension would be with in the working range.

6.5.1 Casel. Tape Broken:

Figure 6.5 shows a graph comparing the tape tension against tape application. During the tape application if the tape suddenly breaks, the tape tension value drops suddenly. The slope in Figure 6.5 is rather straight indicating an abruptness of the incident.

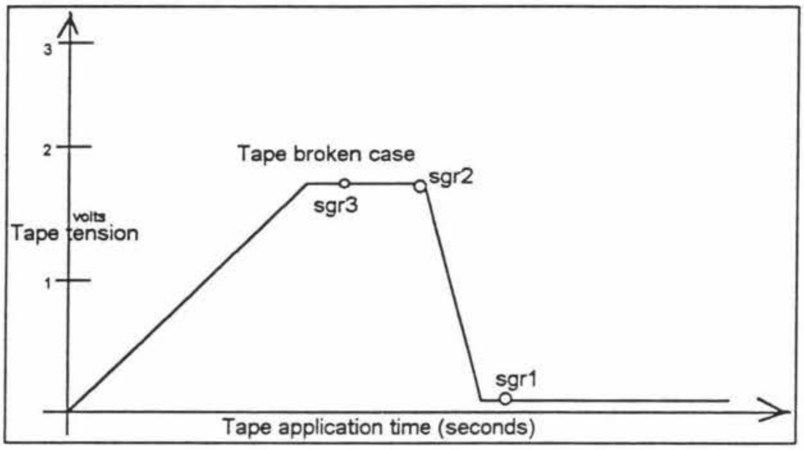


Figure 6.5 : Tape Broken Case.

If a steep slope is observed and the difference between sgr1 and sgr2 is more, difference between sgr2 and sgr3 is zero, then the micro controller assumes the steepness of the slope for the tape broken case. If sgr2-sgr3=0 and sgr2-sgr1>=1 Volt, a tape broken case is indicated. The micro controller then, signals the robot to stop the tape application. After the tape application is stopped, micro controller restarts the whole sequence again from the edge detection to the tape application.

6.5.2 Case2. Tape finished:

If the slope of the tape tension line is more than that of tape broken case, then it is a tape finished case(as shown in Figure 6.6). Tape starts peeling paper roll after the tape is finished hence, the slope is slightly more.

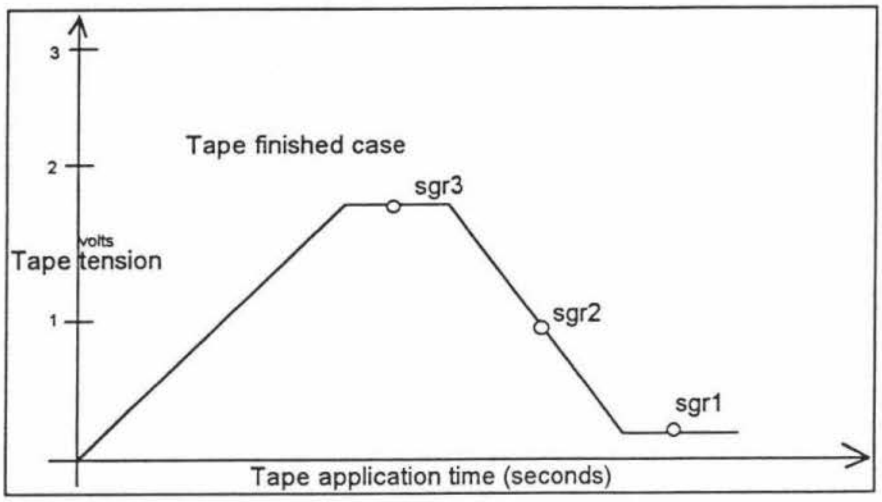


Figure 6.6: Tape Finished Case

If sgr3-sgr2=0.5 and sgr2-sgr1=0.5, then it is the tape finished case. In this case the micro controller stops the robot from the tape application and moves it to fetch a new roll from the tape roll magazine. The whole sequence of 'EziStick' operations are re-started.

6.5.3 Case3. Tape Ripping:

If the slope of the tape tension line is high and more than the previous two slope lines (Tape finished case and tape broken case), then it is a tape ripping case. The robot will still be applying only half the width or quarter the width of tape. This drops the tape tension value considerably. The micro controller picks up this value change and starts taking corrective actions.

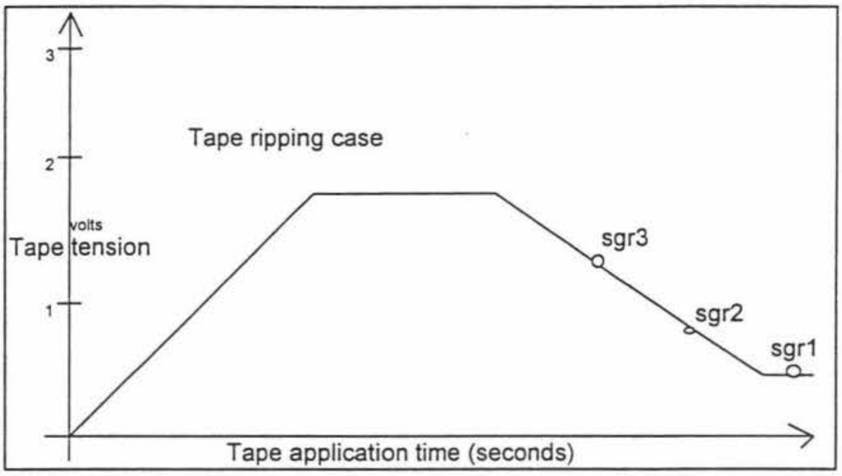


Figure 6.7: Tape Ripping Case

If sgr3-sgr2=<0.5 and sgr2-sgr1=<0.5, then it is the tape ripping case. The first action would be to stop the robot and cut the tape. Following it, the tape roll is discarded and a new roll is picked . The robot will start applying the tape after the edge sensing and tape pick up operations are finished.

Apart from the above discussed tape cases, there is one more case. The case refers to the situation, where the tape tension value increases rapidly above the working range of tape tension value (as in Figure 6. 8). If the tape tension value increases above 2 volts, the micro controller assumes an interruption to the tape roll rotation, and stops the tape application.

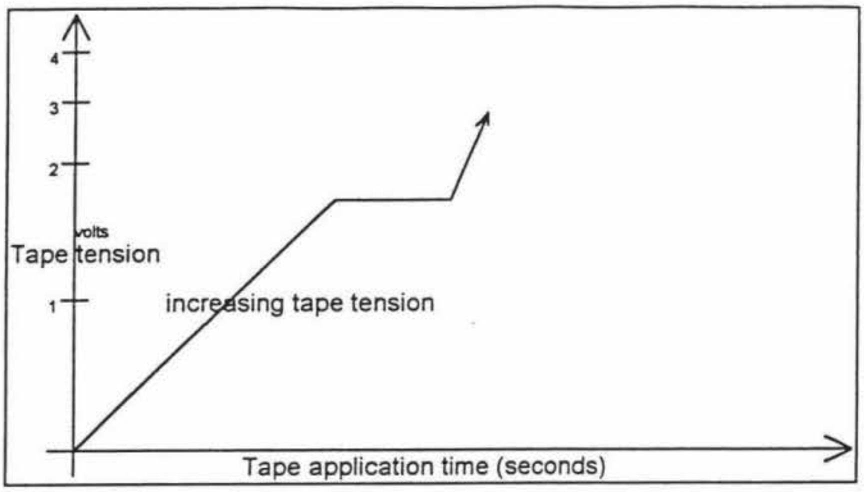


Figure 6.8: Tape Tension Increasing Case

If the sgr>2 volts, the micro controller assumes that the tape roll is stuck or tape application speed is too much. So it first sends a signal to robot to slow down by some factor. This loop goes on until the tape tension comes down to normal working tape tension range. Meanwhile, the micro controller will continuously monitor the changes in the tape tension. If the tape tension does not reduce even after slowing down the robot, then the micro controller stops the robot from further tape application.

Chapter 7

Experiments & Results

This chapter discusses the experiments conducted during the design and development of 'EziStick' and results obtained from the experiments.

7.1 Introduction

The operations of the 'EziStick' were divided into modules. Each module was individually developed keeping the project objectives in mind. Their results were not only analysed individually, but also on how much they affect the whole project. As already discussed in the previous chapters the major modules of the module 'EziStick' are :

Edge sensing module,
Blade positioning module,
Tape picking module,
Tape tension monitoring module.

The main operation of 'EziStick' is itself modularised, consisting of these 4 modules. Hence, experiments[22] were conducted on these 4 modules and the results were used to develop the 'EziStick' module. The following sections deal with the experiments conducted on different modules.

7.2 Experiments with 'edge sensing module'

Experimentation and observation were carried out on the photo-sensors which are used for edge detection on 'EziStick'. This work was to determine if, edge sensors are capable of determining any sort of edge. Edges that never occur in the industrial working environment now, are quite possible to appear in the future. The future of edge sensing should therefore be kept in mind.

Two types of sensors were experimented: reflective opto switches and miniature reflective opto switches. Technical details of the sensors are available in appendix-E. (Radio Spares data sheet 4276)

7.2.1 Discussion

The human eye, with over ten thousand sensing elements has a hard job of detecting this edge, let alone a sensing arrangement with three elements! In the experiments carried on edge sensing in this project three types of edges were tested.

- Edge of a brand new roll.
- Edge produced by the cutter on 'EziStick'
- Edge that can result from a possible tearing or breaking of the tape during application.

No information exists on the third type of edges. A roller was therefore used to press down the edge of the tape. The edge produced by this roller is very flat, with little to distinguish the edge from the tape. The difference between the top layer and the next can be at a minimum of 50 microns, depending upon the tape. The three categories of edge types can now be grouped into one category.

The sensors being used are designed to detect a reflective object on a non-reflective background. In the present context, they are used to detect a non-reflective object (the edge, strictly speaking still a reflective object, except it deflects the light) on a reflective background (the tape). The circuits given in the data sheets should therefore be changed accordingly. However, this circuit is dependent on the sensors and what they detect.

A new roll's edge is raised and is easily detectable. An edge cut by the cutter on 'EziStick' and slightly pressed down by the roller on the edge sensors. The sensing proximity switch is raised and is easily detectable. This leaves the third type of edge, a ripped edge. It is assumed that the tape ripping point will be between the peeling point of the tape and the application surface. This means that there will be a free end hanging loose, just as in the cut edge case. This loose end could be rolled back under the edge sensor's roller. The tape roll can be rotated forward and the edge detectors start operating on that.

7.2.2 Experiment One

Aim: Taking three different edge types and running the program to see if an edge is detected.

Procedure

1. The first edge type was a pressed down edge. This edge was run past the edge sensors ten times.

Ten times the edge was not detected.

2. The second edge type was the edge of a new roll. This edge was run past the edge sensors ten times.

Ten times the edge was detected. Sensor one (the outside sensor) had the same value (5) each time. Sensor two (the middle sensor) had the same value (4) each time. Sensor three (the inside sensor) had the same value (1) each time. These values are counter values from the program which depend upon the number of instructions in the counter loop. For each value the highest value was given by the sensor which first detected the edge and the lowest (the value of which is always one) by the last sensor to detect the edge. All three sensors can have the same value (one) or two can have the same value.

3. The third edge type was a pressed down edge that was lifted and roughened until all three sensors registered it. (The roughening is a function of the lifting). The tape was lifted about 2mm and the edge was run past the edge sensors ten times.

The edge was detected ten times. The values were 2,3,1 for sensors one, two and three respectively.

Conclusions

From these results it can be seen that a practical lifted or new edge is consistently detected, but the flat edge which is artificially produced is never detected.

7.2.3 Experiment Two

Aim: With the present arrangement of blade and proximity switch, if the edge is lifted (if it is lifted too high) it might get stuck to the proximity switch. This will pose a problem in blade clamping of the tape edge. The aim of the experiment was to determine if this was a problem, and if so, how much of a problem.

Procedure

1. A raised edge was produced and duly detected.

2. Experiments were conducted to see if false edges could be eliminated in the software. When the program was run, the 'fake edge elimination' algorithm eliminated the fake edges satisfactorily. But again, this algorithm is also dependent on the abilities of the sensors. With the new fake edge elimination algorithm, a true edge is always detected, although it may be after two or three revolutions.

3. The same sort of experiments were conducted using another type of sensors (miniature sensors) with in the same set-up. The results were in the similar lines as the previous sensors. The new miniature sensors are not only sensitive to pressed down edge, but are also more sensitive to every other bump and blemish on the tape (fake edges). They are also more difficult to mount and are much more sensitive to distance (maximum distance from tape about 5mm). However, they are not so sensitive to angle. Apart from size, which is not really a consideration on the prototype, they do not offer any advantage.

Observations during these experiments indicated that the operating characteristics of one of the sensors (sensor one) was slightly different than the other two.

4. A comparator circuit was designed where this was taken into account . This did not seem to make any big difference in detecting a pressed down edge. This could be due to the difference found in the interior of the sensor. To line it up properly the exterior angle must hence be changed.

Conclusions

The comparator circuit functions well. As the control software acts on the information given to it by the comparator circuit, the control software also functions well. The algorithm logic of the control software seems to be sound and will react to the edge shape.

The present sensors in the present arrangement will not detect a pressed down edge. Slightly different opto sensors were tried with no effect. The present sensors won't function in any other arrangement so an alternative arrangement can't be tried.

The present sensors will detect reliably the edge of a new roll and the edge produced by the 'EziStick' cutting operation. This last edge can also be picked up by the blade after being slightly pressed down by the edge sensors' roller. Assuming a ripped edge is a slightly modified cut edge (i.e. it will probably be angled and have a raised and roughened edge) a ripped edge will be hence detected and the blade positioned accordingly.

7.3 Experiments with the Sensors

Experiments were conducted to determine the importance of the angle and distance of the sensors to the tape. For the more pressed down edge they are very important. For raised edges the distance and angle is less crucial.

7.3.1 Experiment set up

The tape roll is fixed to a dummy mandrel and mounted on the lathe. One optical sensor is fixed on to a plate and hooked to the tool post so that it can be moved forward and backward precisely. As the lathe is a NC lathe, it allows for a digital read out of the distance moved each time. A multimeter is connected to the output lead of the sensor to record the amount of light reflection from the transistor in terms of volts.

7.3.2 Style of experiments

It is decided to mount the tape roll on the lathe and move the sensor back and forth on the tool post and take the readings of the light reflection from the multimeter connected to the output lead of the sensor.

7.3.3 Experiment 1

Aim: The tape roll is held stationary and the sensor is moved away from the tape roll, keeping the sensor at right angles to the tape roll. The results obtained are graphically represented in Figure 7.1. The corresponding data is present in Table 1 in Appendix-E.

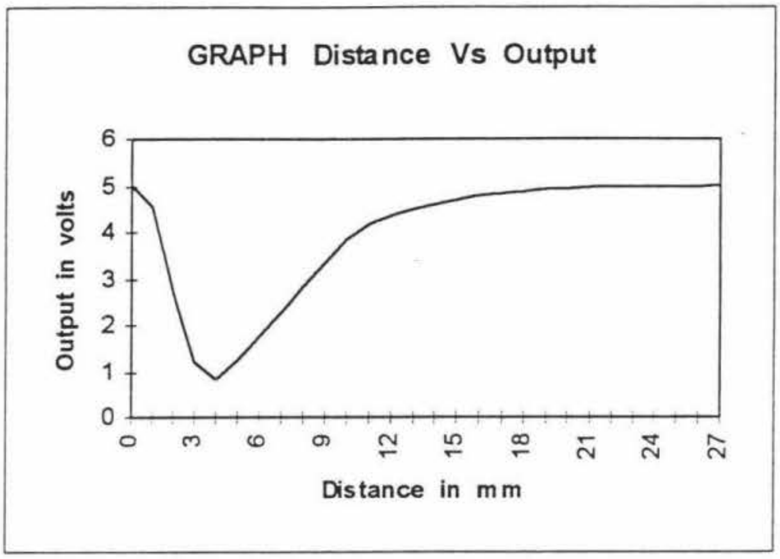


Figure 7.1: Effect of Distance on Edge Sensors

Conclusions

1. The important deduction from the experiment was edge sensors are sensitive to the distance between the sensors and the tape surface.

2. When the sensors are very close (within 2mm), the circuit is getting saturated, giving the reference voltage as the output of the system.

3. When the distance between the sensors and the tape surface is more than 10mm, the circuit gets saturated.

4. Between 2mm to 10mm the sensors give an output according to the distance variation and reflection.

5. At a distance of 4mm, the system is working ideally to the present set-up giving full output (0.85 Volts).

7.3.4 Experiment 2

Aim: In this experiment, the sensors were held at an angle of 15 degrees to the tape roll and the experiment was conducted in the same manner as the previous one. The results obtained are graphically represented as in Figure 7.2. The corresponding data is available in Table 2 in Appendix-E.

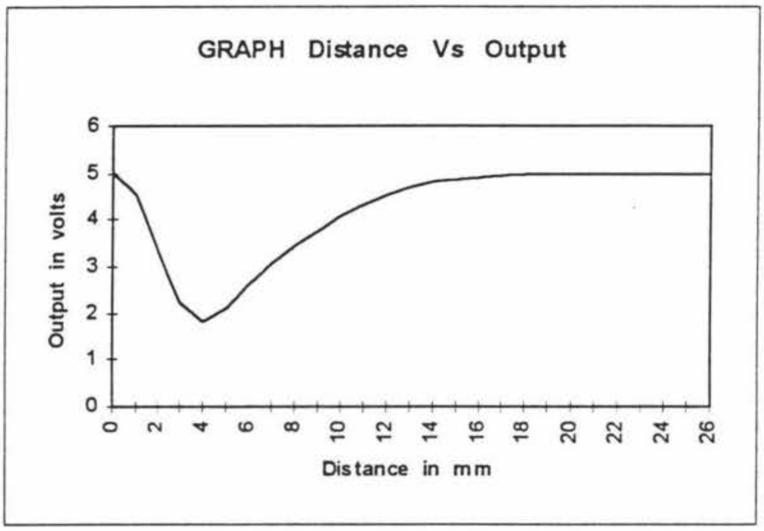


Figure 7.2: Effect of 15 degree angle on edge sensors

Conclusion

1. The following information can be inferred from Figure 7.2.

2. The working range of the sensors before saturation is again the same (between 2mm and 10mm).

3. At 4mm distance the output is good.

4. The voltage levels are increased considerably.

5. The output was 1.83 Volts, roughly 1 Volt more than the previous set-up output.

6. The important deduction from the experiment was a change of sensor focusing angle could alter the results of the system.

7.3.5 Experiment 3

Aim: In this experiment the sensors were held at an angle of 30 degrees to the tape roll and the experiment was conducted in the same way. The results obtained are graphically represented in Figure 7.3. The corresponding data is available in Table 3 in Appendix-E.

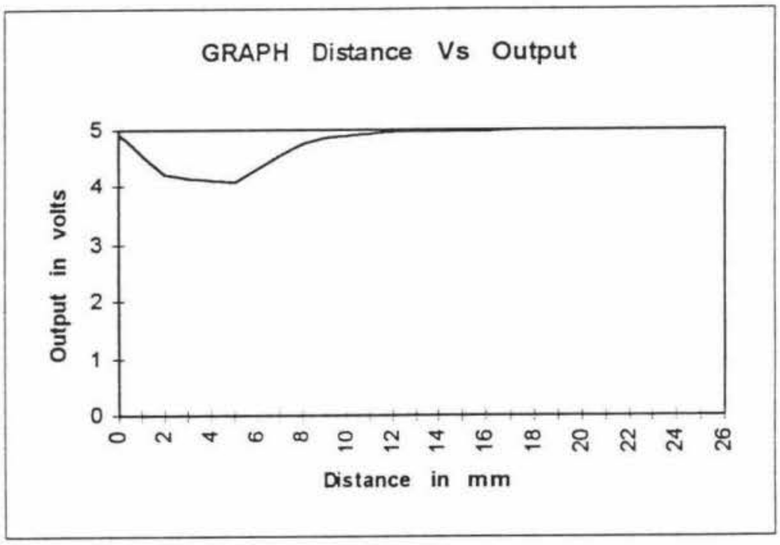


Figure 7.3: Effect of 30 Degree angle on the optical edge sensors

Conclusions

1. From Figure 7.3 the focusing angle dependency of the sensors can be clearly visualised.

2. The circuit is fully saturated throughout the experiment.

3. But at 5 mm distance the output is 4.09 Volts.

4. The output has registered an increase of more than 3 Volts to the first set-up and more than 2 Volts to the second set-up.

5. The system can not run with this type of sensor angle.

6. The most important deduction from this experiment is : a very drastic change in the output can be seen by change in angle.

7.3.6 Further developments in the Edge sensing circuit

The main problem with the previous edge sensing circuit is its dependency on distance and angle of lighting focus[1]. To eliminate the above problem, a new circuit was developed. The old and the developed circuit are enclosed in the Appendix, which explain the differences between the two circuits.

The developed circuit focuses on isolating the sudden peak from the surrounding noise. This peak is used to detect an edge. The developed circuit offers the following advantages:

- Not dependent on the angle and distance.
- At any angle (even a right angle) to the tape roll the sensors pick up the edge
- Distance is no more a critical factor in the edge detection. Sensors are responding to the tape edge in the same manner (within a distance of 3mm to 12mm).
- A wide effective sensing range is available.
- The distance between sensors and tape roll is 8mm.
- The distance can either be changed or kept as it is.

The edge detection to a large extent depends on the light reflected back from the tape surface. Hence, certain limitations are imposed by the system:

---

[1] A comparator which compares the output with a constant threshold voltage and gives an output to the micro controller was present in the old circuit. The output which goes into the micro controller was with lot of noise and created inconsistency in the final output.

- When the edge is hardly pressed it is hard to get detected by the sensor
- If the tape edge is curled or damaged and the light is not reflected back, then the edge may not be detected by the sensor.
- The sensor is a mechanical instrument and lacks judgmental capability. It can not distinguish between an edge and an air bubble in the tape roll. It recognises anything that comes in its way with a height difference as an edge.

7.4 Experiments with the 'Tape Tension Monitoring Module'

Experiments were carried out, to get strain readings from the strain gauge and strain gauge amplifier circuit. The readings were used to determine the load on the robot arm while it applies the metallic tape. This enables the robot to know whether the tape is in good condition or ripped. Though the occurrence of tape ripping is likely to be negligible, it is taken into consideration as a particular case.

7.4.1 Discussion

One of the characteristics of 'EziStick' is monitoring the load (in volts) on the robot arm while applying the metallic tape to the surface. 'EziStick' stops when there is no load and slows down when the load exceeds the normal load. In order to do this, 'EziStick' uses four foil strain gauges (RS stock no. 632-168) connected in a balanced full wheatstone bridge arrangement. The obtained output is fed into an amplifier circuit (RS stock no. 435-692) and amplifier chip (RS stock no. 308-815) which should give a gain of 1000 times (as per RS Data sheet no-8155).

Experiments were conducted in two different ways. In both these experiments, the results were found to be much similar. The experiments are discussed in the following sections.

7.4.2 Experiment One

Aim: part a

Measuring the tape tension by pulling the tape upwards, perpendicular to the s/g bridge using a spring balance.

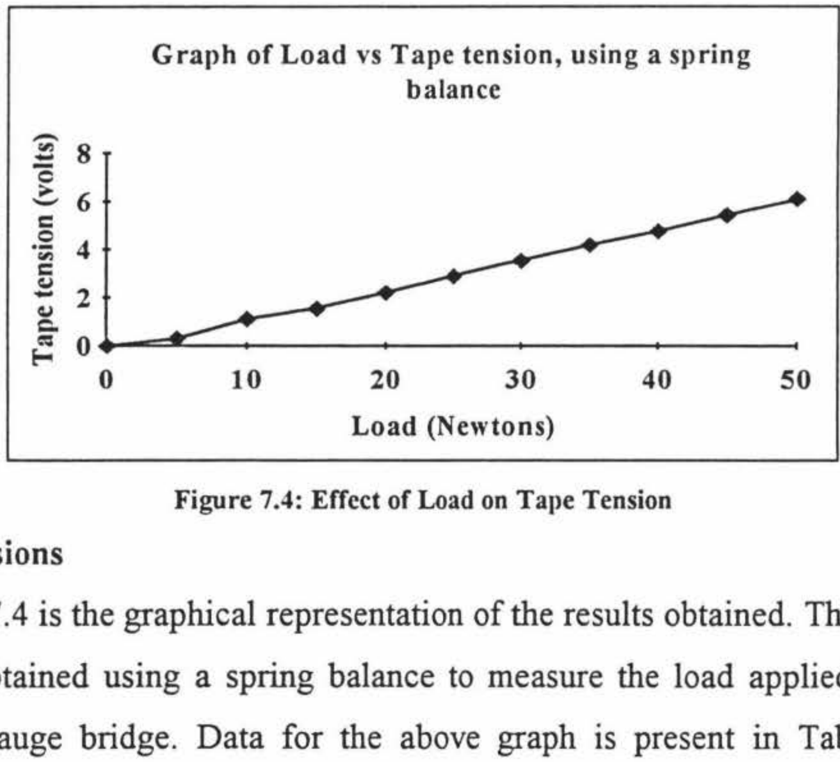


Figure 7.4: Effect of Load on Tape Tension

Conclusions

Figure 7.4 is the graphical representation of the results obtained. The results were obtained using a spring balance to measure the load applied on the strain gauge bridge. Data for the above graph is present in Table 4 of Appendix-E. *Figure 7.4 shows a proportional increase in tape tension to the load applied on the system.*

Aim : part b

Measuring the tape tension by pulling the tape downwards using dead weights.

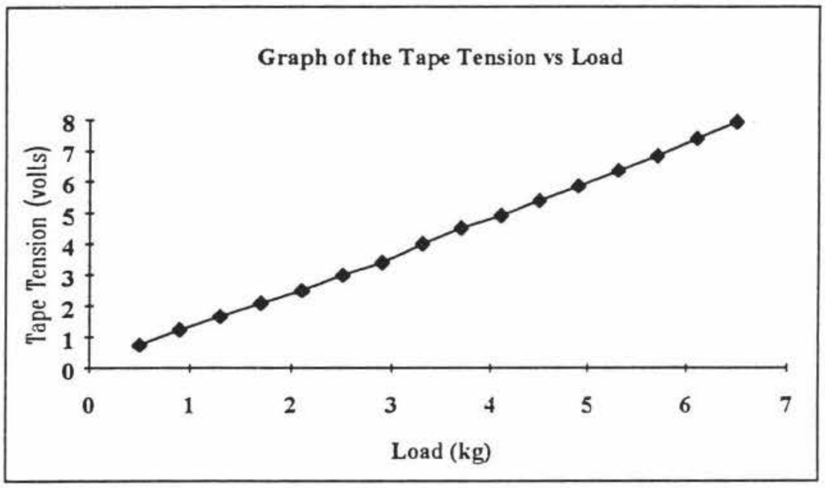


Figure 7.5: Effect of Load on Tape Tension

Conclusions

Weights were used to pull the tape down on the strain gauge bridge instead of spring balance. Data for the above graph is available in Table 5 in Appendix-E. *In Figure 7.5 the increase in the tape tension is found proportional to the increase in the load applied on the system.*

7.4.3 Experiment Two

The experiment was also done in parts. The results were almost similar in both the cases.

Aim: part a

To study the effect of hysteresis. Noted results while loading and unloading on the s/g bridge (in the reverse order).

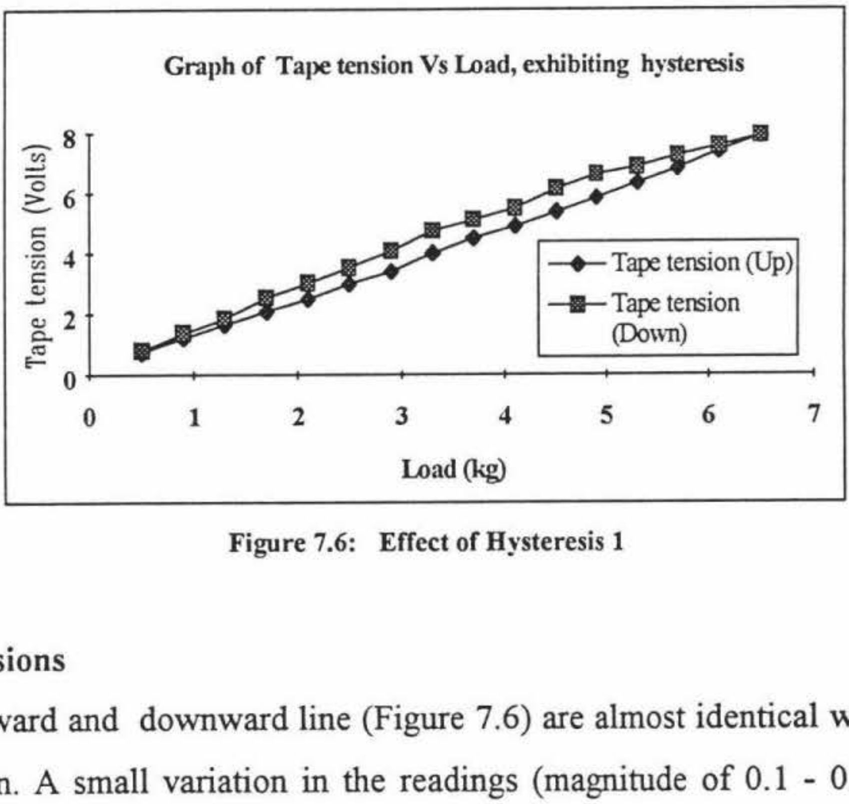


Figure 7.6: Effect of Hysteresis 1

Conclusions

The upward and downward line (Figure 7.6) are almost identical with little variation. A small variation in the readings (magnitude of 0.1 - 0.2 volts) was observed. Data for the above experiment is available in Table 6 in Appendix-E. *The effect of hysteresis on the strain gauge system is not significant enough to change the results of tape tension.*

Aim: part b

To study the effect of hysteresis. Increase/decrease the load on the s/g bridge in random order and note the results

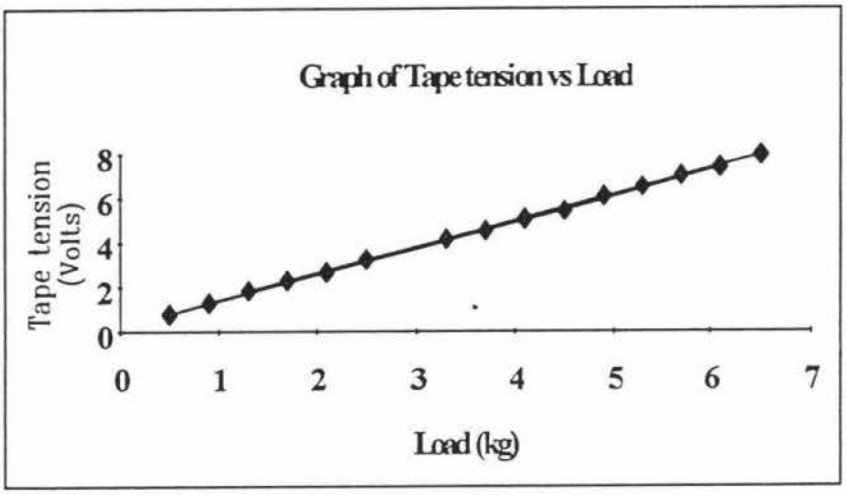


Figure 7.7: Effect of Hysteresis 2

Conclusions

The second experiment also proves the fact that effect of hysteresis on the system is not significant. Even though the load on the system is applied in the random fashion, the results are pretty linear. The values of the tape tension are consistent with the previous experiments. Data for this experiment is available in Table 7 in Appendix-E.

7.4.4 Overall Conclusions

From the above experiments and results, it can be seen that the tape tension changes with change in load conditions. In conclusion the strain gauge amplifier system responds to the load changes being applied on the strain gauge bridge and gives good results.

The effect of hysteresis is considered negligible on s/g amp arrangement for the present application. 'EziStick' is supposed to monitor the tape tension variations during tape application through the tape tension monitoring system. The variations in the tape tensions are monitored by the load applied on the strain gauge bridge by the tape. From the above experiments and observations, breaking strain[2] may be 30 volts considering the fact that a 6.5 kg load causes a tape tension of about 8 volts.

Due to the micro controller limitations the maximum tape tension can not exceed 5 volts. Hence the maximum tape tension value has to be reduced or adjusted accordingly. Maximum tape tension occurs during tape breakage. So the value should be less than 5 volts or around 4 volts. This allows the system to be fairly within the limits of the micro controller safety. For this safety, a Zener diode is added to the circuit to make sure that the maximum value of tape tension that goes into the micro controller never exceeds 5 Volts. This is a safety measure taken to preserve the micro controller from possible damage. The gain of the amplifier circuit is reduced to one fourth of its value so that the maximum tape tension at a possible maximum load of 6kg would be around 2volts. This gives considerable leverage in tape application.

The tape tension calibration experiments were conducted to establish the tape tension values for tape application with the reduced strain gauge amplifier gain.

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[2]Breaking strain is the strain that occurs when the tape stretches so much under a load of 260 N that it breaks. The breaking force of the tape is given as 260 Newton, approximately 26 kg, as per the tape physical specifications

7.5 Experiments for calibrating the strain gauges and amplifier

The strain gauges were calibrated with 3/4 reduction in the strain gauge amplifier gain.

7.5.1 Experiment

Aim: Experiments conducted to establish the different tape tension values, after reducing the amplifier gain to one fourth of its original value.

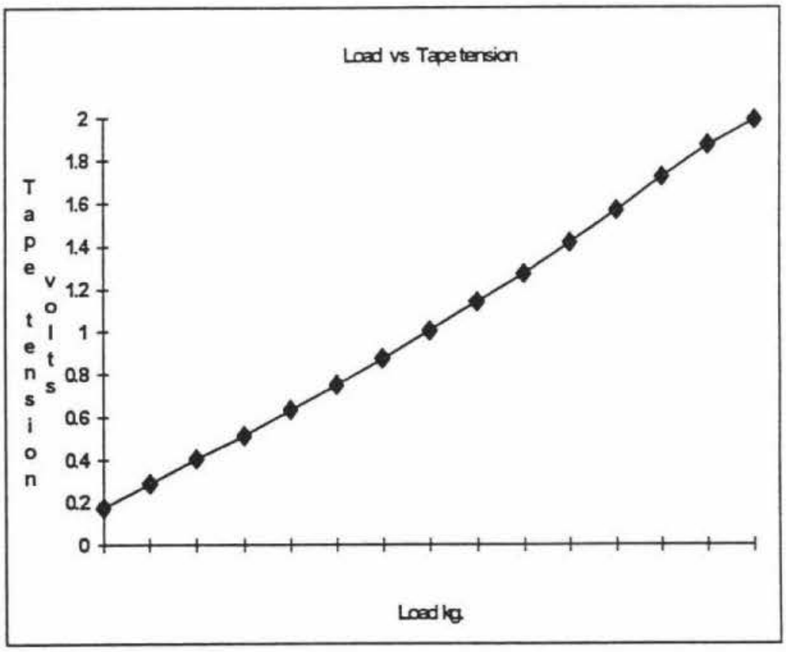

Figure 7.8: Tap tension Vs load at reduced gain of amplifier

Conclusions

The results of these experiments are shown graphically in figure 7.8 and the corresponding data is available in Table 8 in Appendix-E. *The tape tension is observed to increase steadily with the increase of the load on the* *amplifier system.* As it was already established that the hysteresis has least effect, reverse tests were not done. *The operating tape tension is a variable of speed in tape application.*

7.6 Tape Breaking Tension Experiments:

The tape breaking tension is very crucial for the tape tension monitoring module to work effectively. It is not a fixed value and is calculated based on the time taken by the tape tension to drop to a minimum. The slope of this curve plays a very vital role in the calculations. If the slope is very high then the tape is assumed to be broken. This was explained in Chapter 6 in detail.

Based on the above analysis, the algorithm for tape tension monitoring has been written. The results of the experiment conducted to finalise the tape breaking tension slopes are graphically represented in the Figure 7.9 below:

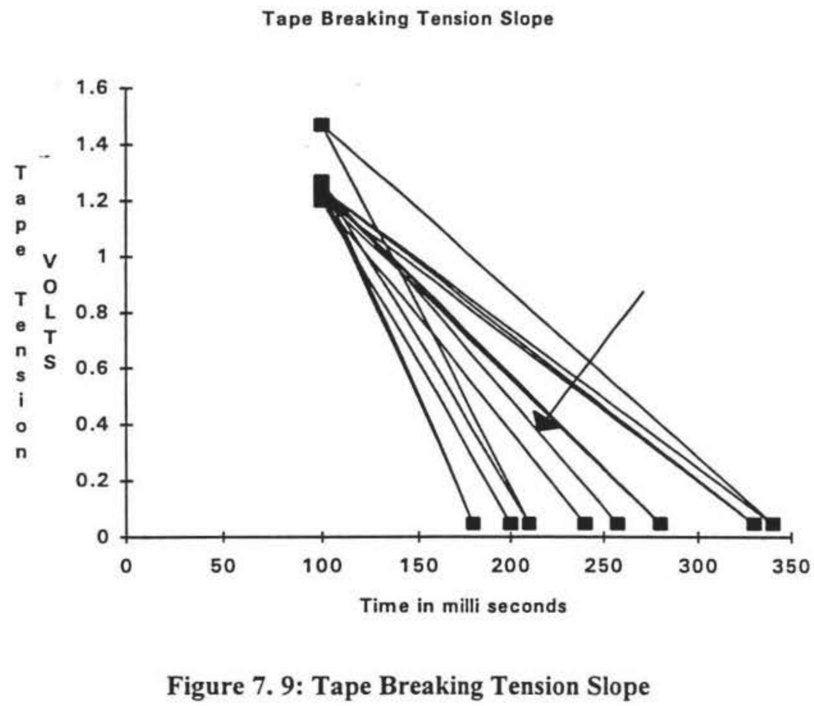

Figure 7. 9: Tape Breaking Tension Slope

Based on the above analysis, the algorithm for tape tension monitoring has been written. The results of the experiment conducted to finalise the tape breaking tension slopes are graphically represented in the Figure 7.9 above.

From the figure 7.9, the time taken for each tape breakage to reach a minimum value, was assessed. And also the slopes of each tape breakage were calculated. In all the above tape breakages, the time period for the tape tension to reach a minimum value varies from 80 milliseconds to 240 milliseconds. These experiments were conducted at a speed of 100 mm/s of tape application. The slope between these time periods indicated that the tape was broken.

The line pointed by the arrow in the above graph is the average value of the tape breaking tension. In the similar way tape finished tension and tape ripping tension values were also obtained for tape tension monitoring.

7.7 Experiments on Tape application using different Applicators and different Tapes

The experiments were aimed at finding the suitability of different applicators developed for tape application. Two applicators were developed for tape application: 'applicator foot' and 'active roller'. To establish the suitability of either of these applicators, tape applications with four different types of tapes were tried. The four types of tapes and their descriptions are summarised in Table 7.1. The tapes pose wide variety of application styles.

Name	Description
Metallic tape	Very strong in adhesion and being metal it is tough in itself, very brittle and stiff.
Brown tape	Basically a paper glued with a strong plastic glue which is quite strong and is generally used in packaging, to seal the box lids and similar things. The interesting thing about this tape is that, it has strong affinity towards itself and also with the surface it is applied to. This causes stretching during the tape application.
Clear tape	Popularly called 'Sellotape'. Widely used tape for any general purpose taping application, both on domestic and industrial sides. The tape is very thin and adheres very fast to any surface. The tape being thin, stretches during the tape application.
Masking tape	Another form of paper tape having good sticking properties strength. General purpose tape used in parallel with Sellotape.

Table 7.1 Different tape characteristics.

The two applicators, used for this experiments were custom built and had this sort of taping applications.

First applicator is 'applicator foot' with a groove to accommodate the tube diameter on which it is applying the tape or with flat bottom to apply tape on the flat surface. This applicator needs to have a surface relating to or corresponding to the surface the tape is being applied on.

The second applicator is called 'active roller' because it is designed to react and accommodate the fluctuations in the working surface and any objects in between. It is basically cylindrical in shape, with foam rubber in the middle, and rolls over the surface as it is applying the tape. This should provide proper cushion during the tape application.

As a part of the experimentation, tape application was carried out on different tapes using both the above described applicators. During these experiments, quality of tape application and tape tension are continuously monitored. and the obtained experiment results are described below.

7.7.1 Experiments with 'Applicator Foot'

a) Aim: Tape application at a speed of 100 mm/s. At this speed record the variations in the tape tensions of different tapes used for the tape application.

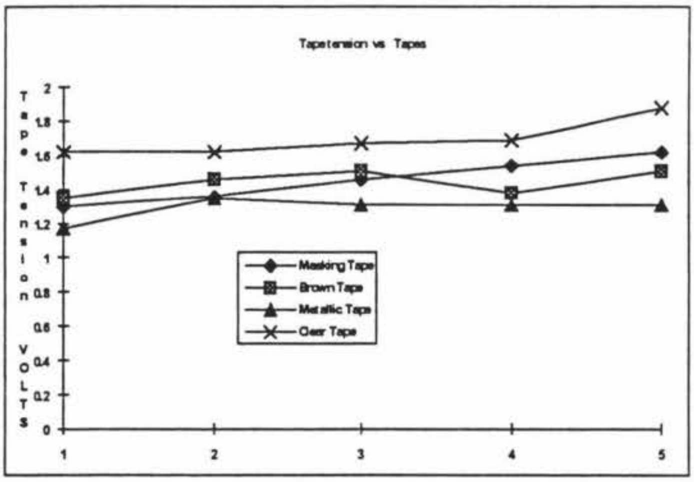

Figure 7.10: Tapes Vs Tape tension at Speed 100 mm/s

Conclusions

The tape tension value obtained during the application of Metallic tape is less when compared to that of other tapes. Tape tension value of Clear tape is higher than that of other tapes. Brown and Masking tape tension values occupy the middle value between Clear tape and Metallic tape. The data for figure 7.10 is available in Table 9 in Appendix-E.

b) Aim: Tape application at a speed of 200 mm/s. At this speed record the variations in the tape tensions of different tapes used for the tape application.

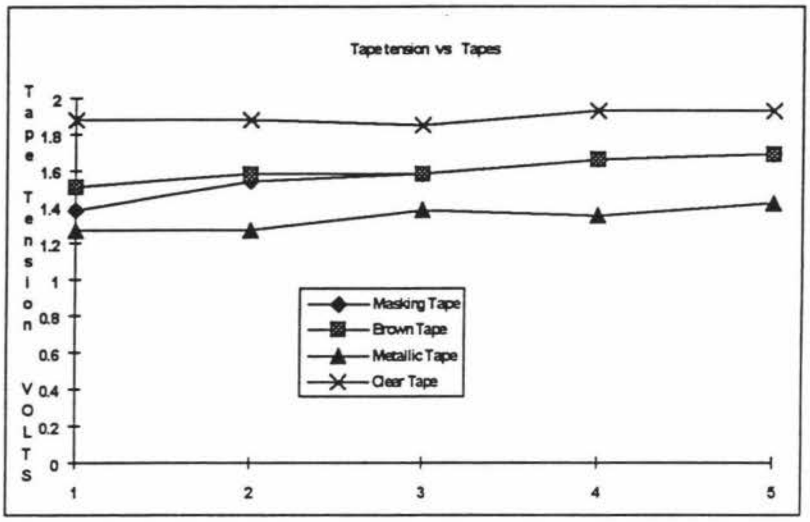

Figure 7.11: Tapes Vs Tape Tension at Speed 200 mm/s

Conclusions

The same trend as the previous experiment was also observed here. Clear tape leading the tape tension values and Metallic tape taking the last position as far as the tape tension values are concerned. Brown tape and Masking tape almost have same tape tension value. The data for the figure 7.11 is available in Table 10 in appendix-E.

c) **Aim:** Tape application at a speed of 400 mm/s. At this speed record the variations in the tape tensions of different tapes used for the tape application.

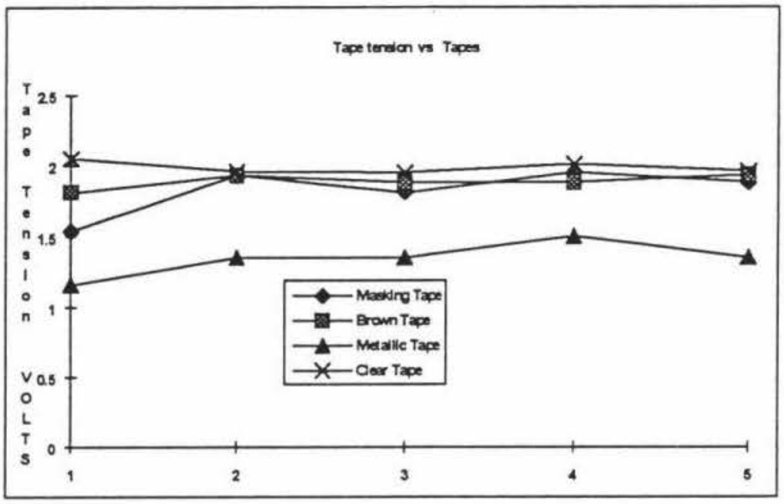

Figure 7.12: Tapes Vs Tape Tension at Speed 400 mm/s

Conclusions

Clear tape leads the tape tension values with Brown and Masking tape following it very closely. It can be seen from the graph that at this speed, *the tape tension values of the Brown tape and Masking tape have increased considerably*. Metallic tape again maintaining its low tape tension value even at this speed. The corresponding data of Figure 7.12 is available in Table 11 in Appendix-E.

d) Aim: tape application at a speed of 600 mm/s. At this speed record the variations in the tape tensions of different tapes used for tape application .

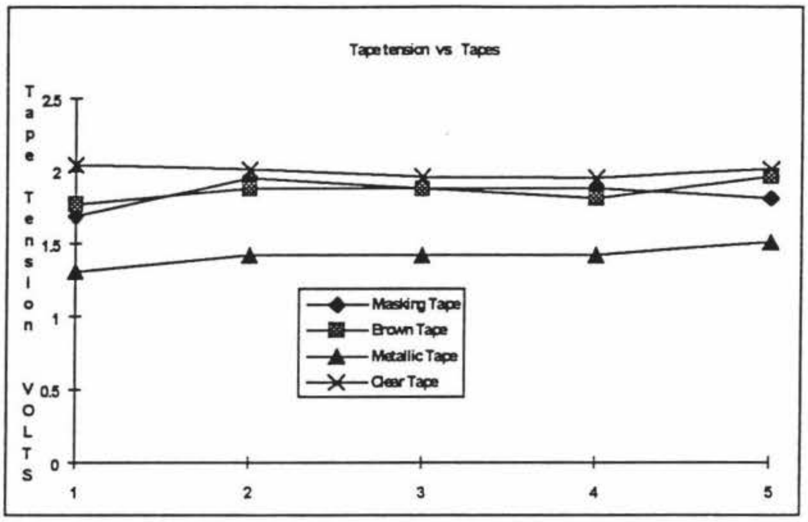

Figure 7.13: Tapes Vs Tape Tension at Speed 600 mm/s

Conclusions

The tape tension values of Clear tape, Brown tape and Masking tape are close. Clear tape tension value being little high than the other two. At this speed also the Metallic tape tension value is still low when compared to the other tapes. Figure 7.13 is available in Table 12 in Appendix-E.

7.7.2 Tape behaviour with 'Applicator Foot'

The above 4 experiments were conducted using the 'applicator foot' and their results were analysed at each step. The average tape tension values of each tape were calculated at different speeds and they are graphically represented in the following figure. Figure 7.14 shows the change of tape tension with changing speed for different tapes.

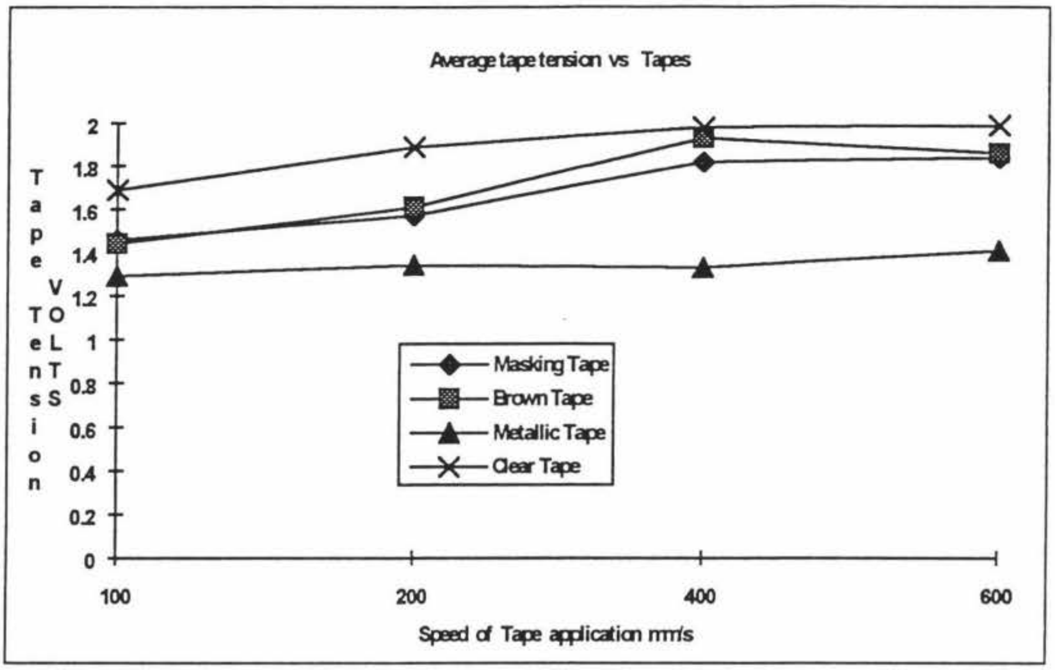

Figure 7.14: Average Tape Tension of different Tapes at different Speeds

From Figure 7.14, it is clear that Clear tape has got the high tape tension value. This may be because of the fact that it stretches and deforms during the tape application. Brown tape takes second position in the Tape tension values. This tape also stretches and deforms during tape application. Masking tape follows Brown tape in tape tension values. This tape also stretches during tape application. Last in the tape tension values is of Metallic tape. The tape exhibits excellent tape application properties with little pressure on the strain gauge bridge (this can be inferred by the less tape tension value). The variation of the tape tension with the speed is not very much but there is a definite increase in the tape tension with the increase in the speed. Metallic tape stretches during tape application giving it a flexibility to adapt to the speed of tape application. Quality of tape application is good at lower speeds than at higher speeds and it is varying with tapes. Quality of the tape application with Metallic tape is very good when compared to that of other tapes. The data for the Figure 7.14 is available in Table 13 in Appendix-E.

7.8 Experiments with 'Active Roller'

a) Aim: Tape application at a speed of 100 mm/s. At this speed record the variations in the tape tensions of different tapes used for tape applications.

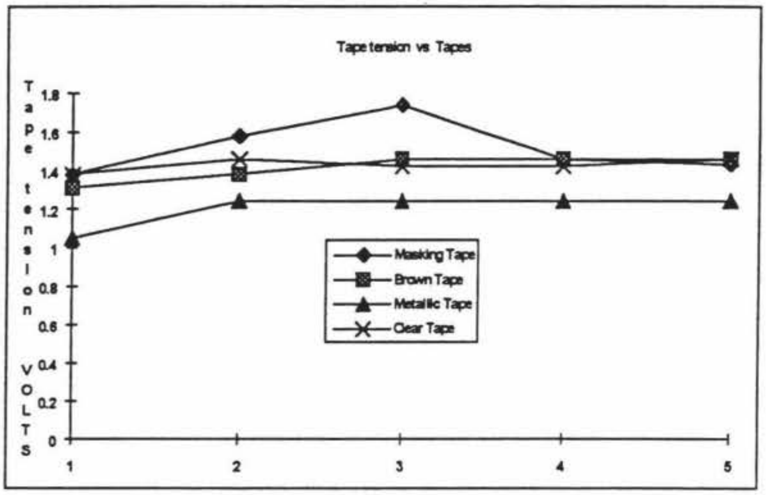

Figure 7.15: Tapes Vs Tape Tension at Speed 100 mm/s

Conclusions

The tape tension of Masking tape is higher at this speed of tape application. Tape tensions of Clear tape and Brown tape are little less than that of Masking tape. Tape tension using Metallic tape is again less compared to other tapes even with a new applicator 'Active roller'. The data of the Figure 7.15 is available in Table 14 in Appendix-E.

b) Aim: Tape application at a speed of 200 mm/s. At this speed the variations in the tape tensions for different tapes used for tape application were recorded.

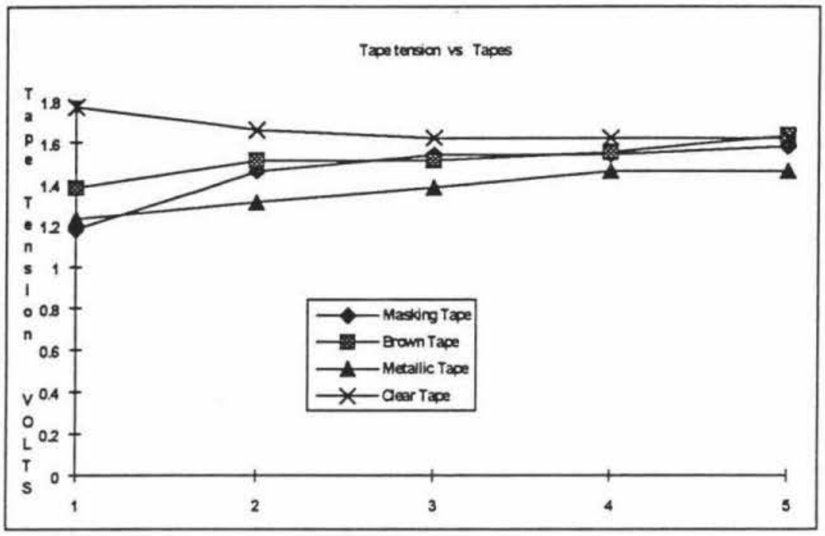

Figure 7.16: Tapes Vs Tape Tension at Speed 200 mm/s

Conclusions

Tape tension of the Clear tape is more than that of the other two tapes Brown tape and Masking tape respectively. Tape tension of the Metallic tape is less again. The corresponding data for this results are available in Table 15 in Appendix-E.

c) Aim: Tape application at a speed of 400 mm/s. At this speed record the variations in the tape tensions of different tapes used for the tape application.

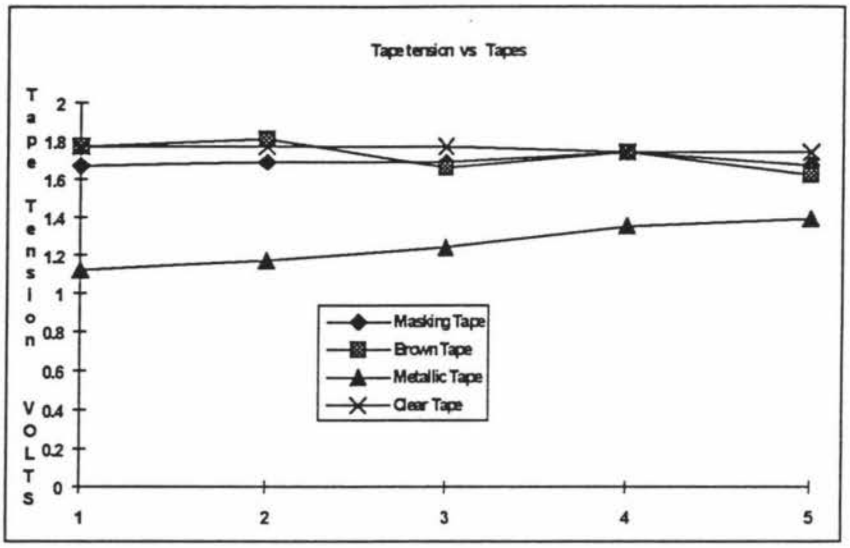

Figure 7.17: Tapes Vs Tape Tension at Speed 400 mm/s

Conclusions

The tape tension of Brown tape is high at this speed of tape application. Clear tape tension is also very close and high sometimes. Masking tape tension is very next to this two tape tensions. Once again Metallic tape keeping low value for tape tension. The data for the above Figure 7.17 is available in Table 16 in Appendix-E.

7.8.1 Tape behaviour with 'Active Roller'

The above 3 experiments were conducted using the 'active roller' as the applicator device. The results of these experiments were also discussed at each stage. The average tape tension values of each tape is calculated for different speeds and they are graphically presented in Figure 7.18. The figure 7.18 shows the change in tape tensions with the change in the tape application speeds.

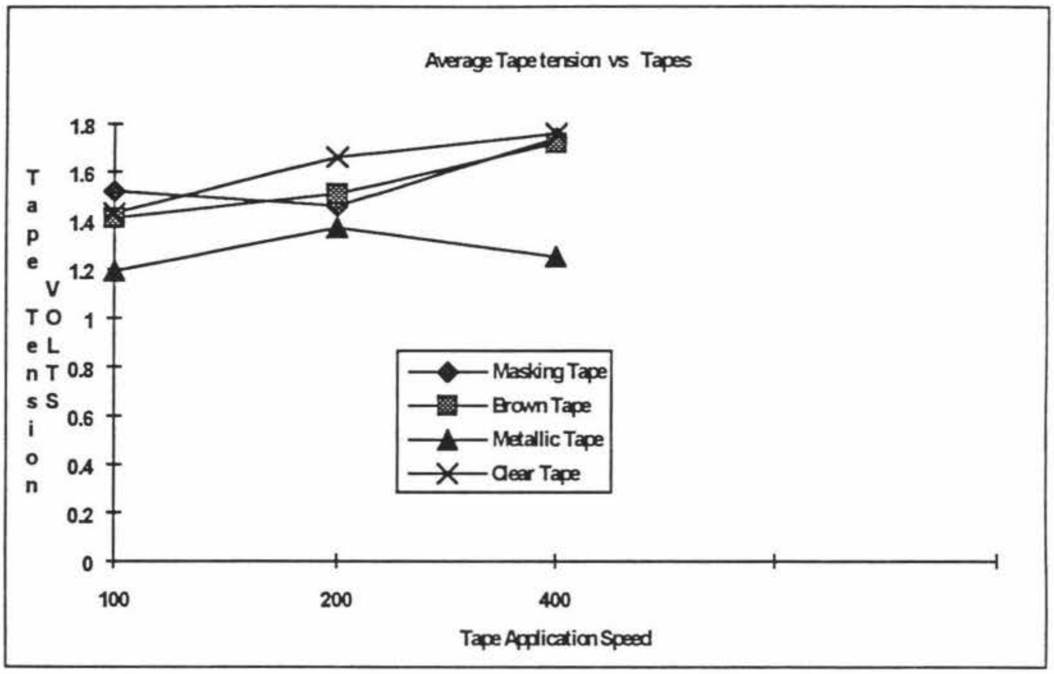

Figure 7.18: Average tape tension of different tapes at different speeds

From Figure 7.18 it can be inferred that, the average tape tension values of different tapes are low when compared to the average tape tension values of tapes applied with the 'applicator foot'. Metallic tape is maintaining the low values for the tape tension all the time and all the other three tapes keeping the higher side of the tape tension values. The data for the figure 7.18 is available in Table 17 in Appendix-E.

The quality of the tape application is not very good with this active roller. It is average with Metallic tape and Masking tape but bad with the other two tapes namely Clear tape and Brown tape. In the way active roller was designed, it has many bangle like supports all over it with rubber foam in the middle, the tape material is getting between this bangles, creating the quality problem for the tape application. It is getting worse with the increase in tape application speed. Hence, it may not be suitable for the use of tape application.

7.9 Experiments with Blade Positioning Module and Tape Picking Module:

Experiments were conducted to analyse the behaviour of blade positioning module and tape picking module. These experiments were conducted in parallel with the experiments of edge sensing. Every time the tape is rotated for its edge to be picked the other two modules were also put to test along with the edge sensing module. The reason for combining these experiments was due to the fact that the working of all other modules are depending on the working of the edge sensing module. The working of the other modules does not come into picture unless the edge sensing module is working properly.

Every time the program was run to sense the edge, blade positioning and tape picking were also allowed to be done. Once the edge is sensed, the program continue to test the blade positioning, once the blade is positioned tape picking was done as the next step.

There was no problem encountered with the blade positioning as this depends mostly on the software of the program. Every time the edge is sensed, blade is positioned automatically and was tested likewise.

However there were few problems encountered with tape picking module. This module is also tested on different types of tapes. There had been no problem in picking up the normal tape edge which is not hardly pressed down or lifted up high. But if the tape happened to be a bit higher than the usual, then it will get stuck to the proximity switch on some occasions. Another problem encountered was the tape getting ripped during the tape peel off from the tape roll. This is happening when the rotation arm is swinging away the tape from the tape roll, probably because of excessive strain caused by the new O-ring arrangement in the bearing block of the new mandrel system. The tape tension at this point could not be measured by the strain gauges because it occurred before the tape hit the cantilever arm.

Another type of edge was also experimented with. An edge was produced by holding the tape tight and cutting with the cutting mechanism. A reasonably straight edge was produced by the cutter. This edge was wound back under the edge sensors roller. This resulted in pressing the edge down in only one point. Fortuitously, this point is also in line to where the proximity switch is located when it comes close to the tape surface. Next the mandrel rotated forward and the edge went under the sensors, being picked up quickly. The rotation arm extended and the blade was driven into the tape surface. The tape edge rotated forward, missed the proximity switch and went onto the blade. And the rotation swung away with the tape on the blade. This sequence was repeated ten times. Twice the edge snagged the proximity switch, producing a slight bend. This may have been flattened back at application.

This problem, getting stuck to the proximity switch, was dealt with by introducing a small rolling back system into the 'EziStick'. This system will press down the edge during the reverse rotation of the mandrel and makes the edge ready for the edge detection and further modules.

Chapter 8

Conclusions

The main feature of this thesis was to develop an intelligent robotic end effector which can apply tape to any surface. The idea was to provide a choice to the users between the products discussed in chapter2 and 'EziStick', when it comes to the point of purchase. Though there are many apparatus available in the market to do the packaging, none can lift the tape edge by itself and no machine can actively measure the tape tension during the actual tape application. This is the novelty of the present research 'EziStick'.

As already mentioned the design of 'EziStick' was modularised to facilitate for easy working of the whole system. The whole system of 'EziStick' is broken down into 4 modules, with 5th module as 'EziStick' itself.

The purpose of the edge sensing module is to detect the edge of the tape. For this purpose 3 miniature optical sensors are used. These sensors work on the principle of detecting the reflective surface in the non-reflective back ground. In the present research, the same sensors are being used to detect the tape edge on the rotating tape roll. Both the tape and tape edge are equally reflective making edge detection very difficult. Many other alternatives were tried to improve the whole scenario. But the present sensors were found more effective than the others. Hence, attempts were made to improve the signal obtained from these sensors and that attempt had been successful so far. A new circuit was developed which is working well on the signal obtained from the sensors.

Another reason forcing the use of miniature sensors was the size and weight constraint on the 'EziStick' system. As it is operating on a robot as an end effector, it should not weigh more than 6kg. This fact necessitated the use of lightweight and miniature components wherever possible. And cost effectiveness of the project was also an important factor.

The tape tension monitoring module also needs further development. This module works on the signals obtained by the strain gauges during tape application. In spite of the efforts to eliminate the noise from the system, the signal is still coming with lot of noise. This has to be eliminated to make the system get a clear signal to work with. And also this module needs a modified software to evaluate the signals obtained from the strain gauges. May be this new software makes the difference.

Other two modules did not pose much of a problem as they are mostly mechanical components. The blade positioning module works with the software and a pneumatic cylinder. As long as the edge is detected properly and the timer values are good, there would be no problem. The tape picking module is a combination of a few movements of the 'EziStick'.

The timings of each module are shown in Figure 8.1. During this exercise it is assumed that the tape edge will rotate 1/4 of mandrel revolution before the edge is detected, though this might vary a little lower or higher. In the case of full revolution the edge detection takes about 9 seconds.

Towards future work, this edge sensing module should be developed further making it more effective in the real factory environment. Both the sensors and the circuit can be further developed to make edge sensing more effective in future.

Towards future work, a system to hold the cut tape after the tape application can be developed. This system will eliminate the need for 'EziStick' to repeat the whole sequence to apply the tape every time. At the present time, 'EziStick' goes over the whole sequence of modules, every time it applies the tape. This would be an important feature of the 'EziStick' in the coming days.

Modularising the whole project can also be taken as another future work. Making 'EziStick', to suit any other system which could move for tape application, will be a step towards the modularisation of 'EziStick'.

Adding visual intelligence to 'EziStick' would also make an excellent future research to the project.

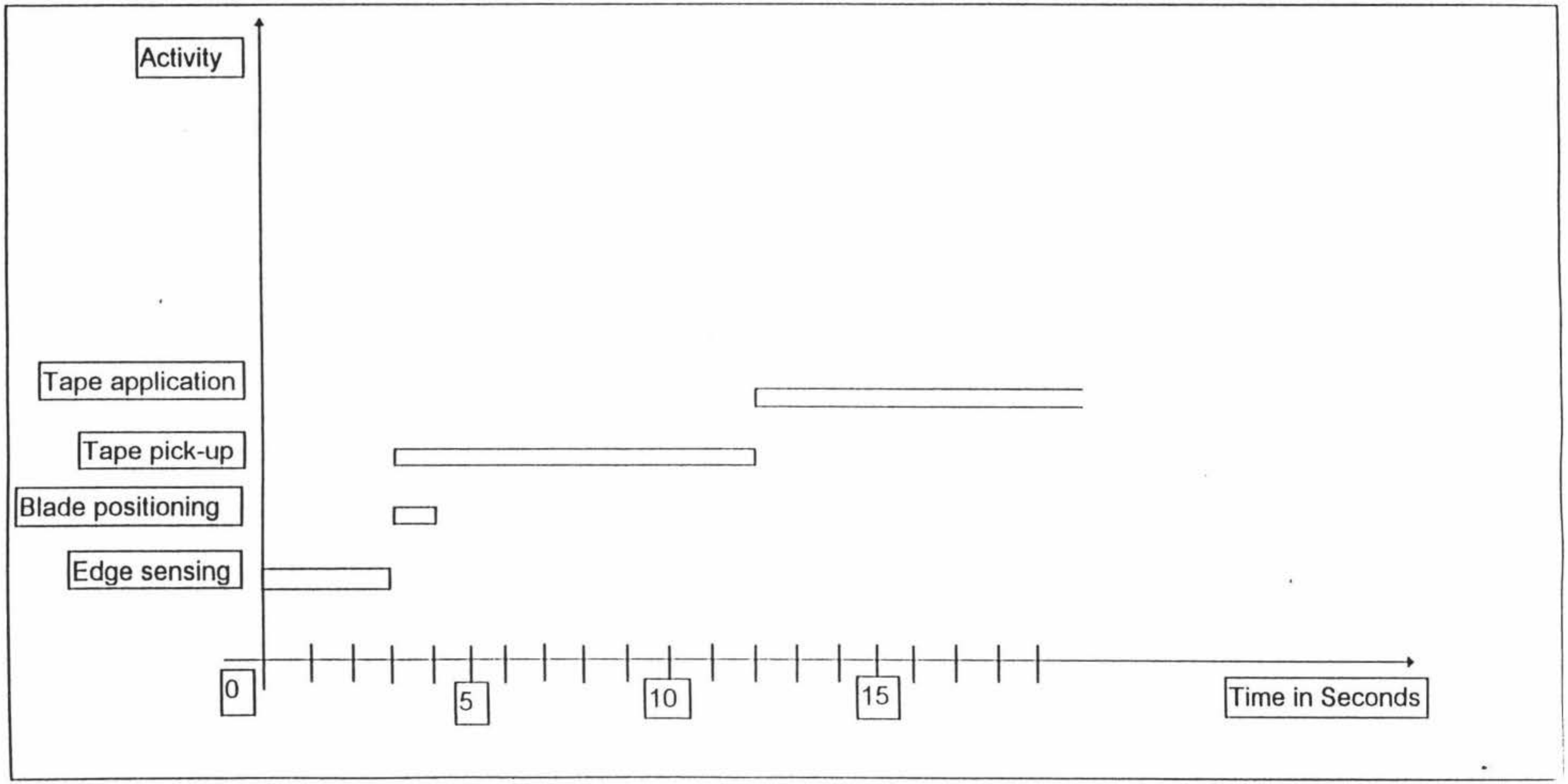

Figure 8.1: Timing Diagram of 'EziStick' sequence

* Tape application varies with speed and length of application

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Appendix-A

Description of 'EziStick' Modules

Figure 1 is a perspective view showing a prototype applicator with a full roll of adhesive tape in place. Various components of the applicator are configured on an aluminium work frame 1. A roll 100 is mounted on mandrel 10 which is rotated through a clutch (hidden from view - between 10 and 11) by motor/gear box 11. The roll is held on a mandrel by a specially designed holder (hidden from view - shown in figure 10), with three legs protruding through the mandrel onto the roll.

Empty rolls are preferably replaced automatically from a batch of standard stock such as are available from 3M. The tape material typically includes a metallic layer for enhanced strength or thermal conductivity, supplied on a roll having a diameter of about 80 mm and a width of about 50 mm. A maximum breaking tension of about 250N at room temperature is typically stated.

A sensor device 12 is able to scan the outer surface of a slowly rotating roll to automatically locate an end edge of the tape as will be described later. A range of sensor types might be used to detect roughness created by the edge but diffuse scan opto switch sensors are preferred. The sensor device may also be moved towards the mandrel as tape is removed from the roll, or away when a roll is replaced.

An edge lifting device is automatically positioned in proximity to the tape surface by blade motor 14 and blade block 15. A range of lifting devices might be used to raise a fresh edge from the roll, such as multiple blades or pneumatic cups, although a single blade is preferred and will be described later. Distance between blade and the roll may be sensed by an inductive proximity sensor (hidden from view - behind 16) when using metallic tape.

A clamping device 16 takes hold of a freshly lifted tape and is pivoted away from the mandrel on arm 17. Various devices may be used to hold the tape end but a ram which clamps the tape to one side of the lifting blade has proved most effective to date and again will be described further below. The arm pivots about a worm gear 18, driven by ram 25 through rake 19, and also carries rams 14, 15 and the edge lifting device 13.

A roller 20 is used to apply tape to an object as the applicator is positioned and moved by a robot arm. Other means for applying pressure to one side of the tape may also be used during this operation. The tape passes first over a load sensor 21 which monitors tension to ensure that the rate of pulling is comfortably below a breakage threshold, and is typically pulled at about 30N.

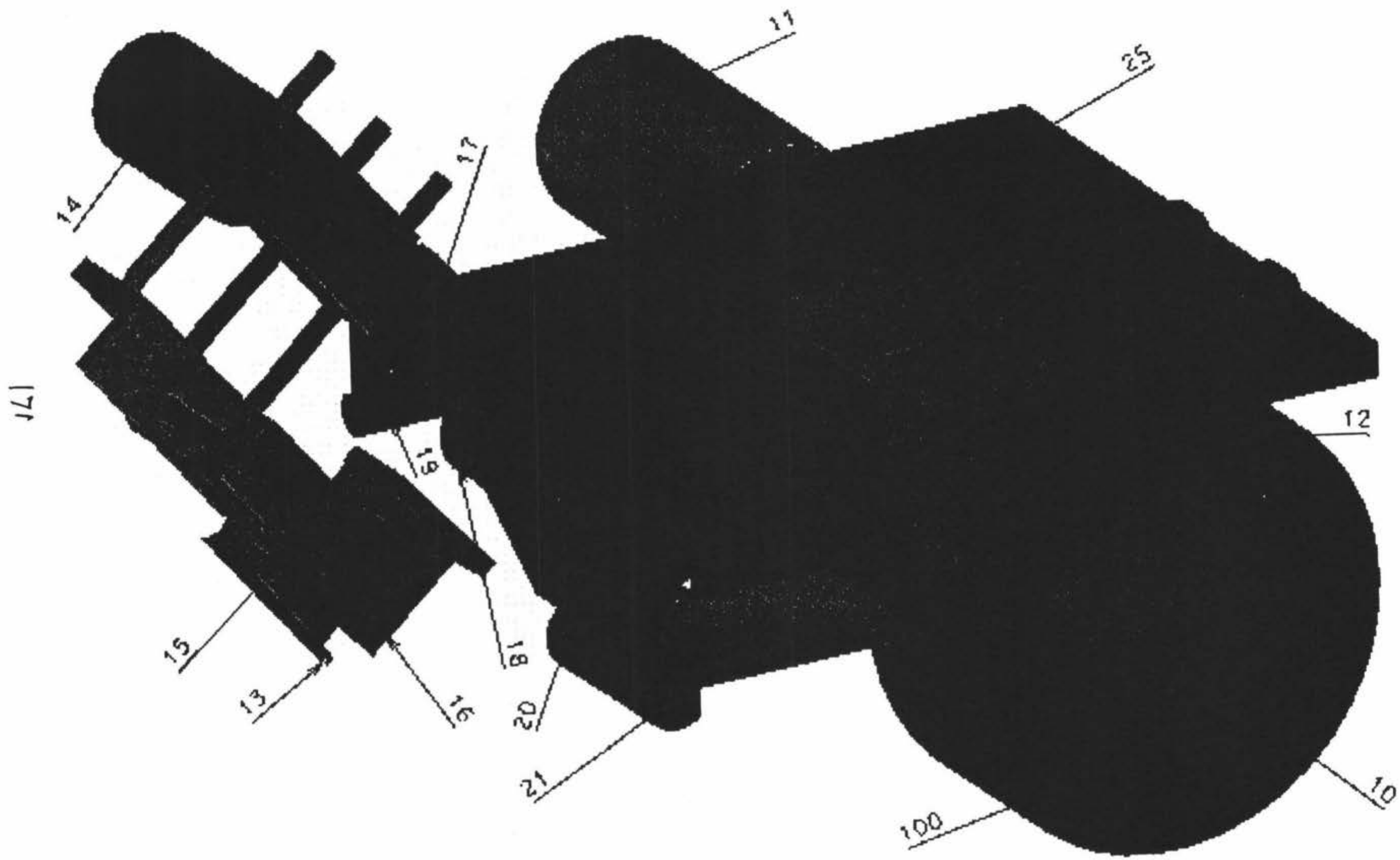


FIGURE 1

Figure 1: 'EziStick'

In ***Figure 2*** an end edge has been located and lifted from the roll 100 and the tape end is held by clamping device 16 as arm 17 pivots about the worm gear 18. Mandrel 10 freewheels independently of motor 11 at this stage. A short length of tape 101 is thereby pulled over the load sensor 21.

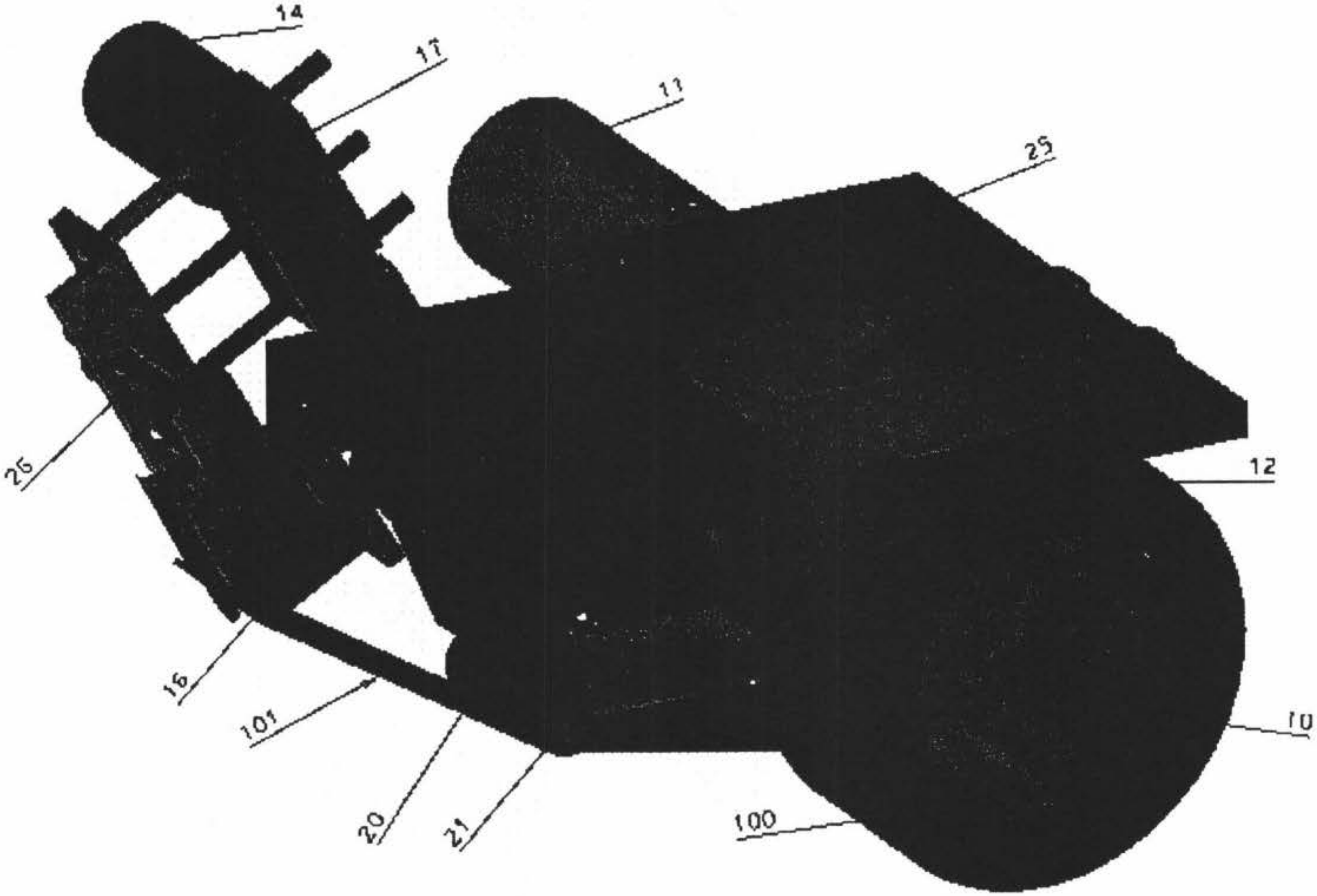


FIGURE 2

Figure 2: 'EziStick' peeling the tape (stage I)

In ***Figure 3*** arm 17 has completed pivoting and the length of the tape is drawn taut over roller 20 and the load sensor.

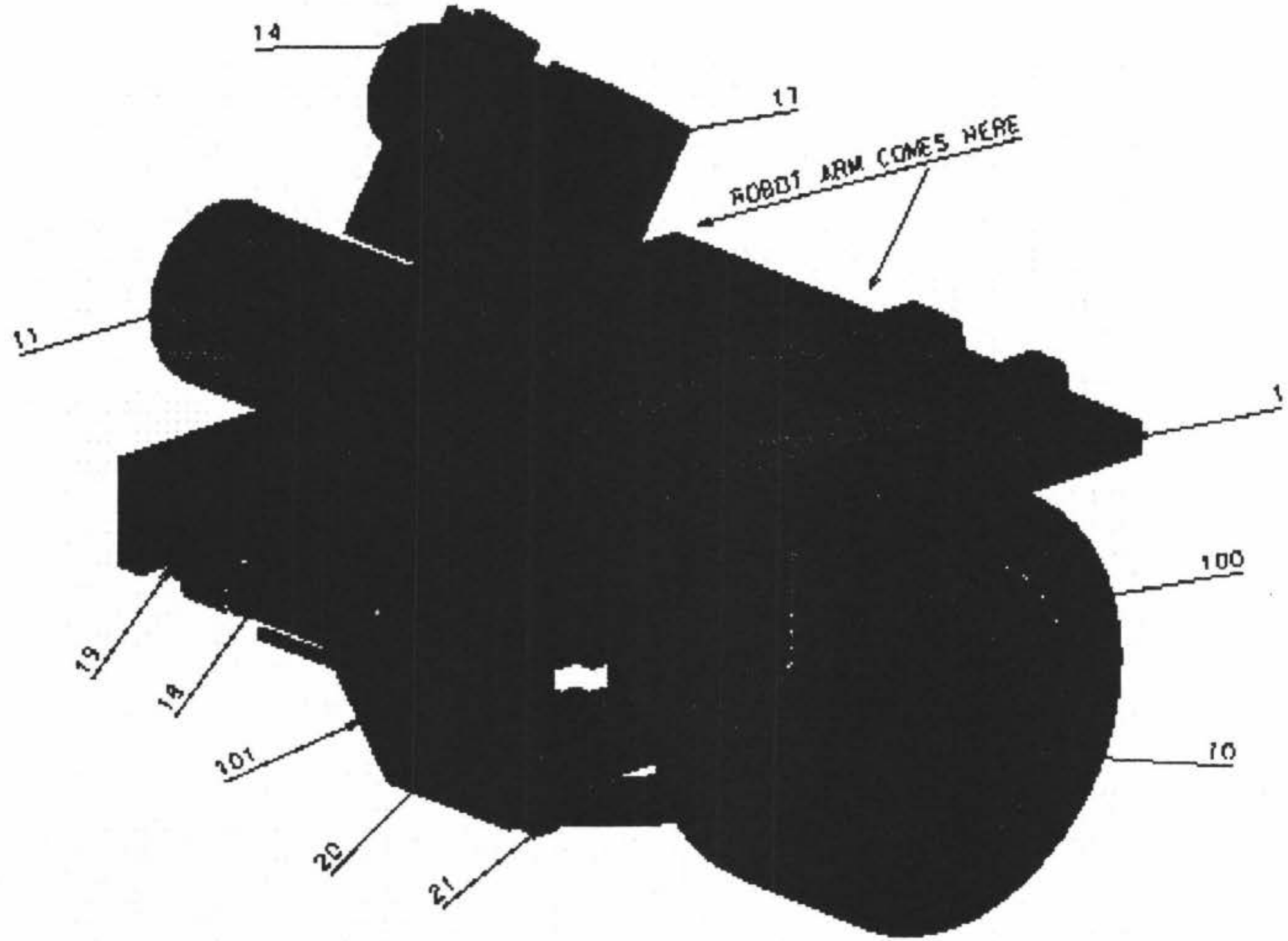


FIGURE 3

Figure 3: 'EziStick' peeling the tape (stage II)

In ***Figure 4*** more tape has been pulled from the roll and applied to an object surface 102. One end of the robot arm 103 is shown moving the applicator in direction 104 while roller 20 applies pressure to from a bond between the tape and the surface. In practice the applicator will have been moved backwards at first to ensure proper adhesion of the tape end released from the clamping device 16. As the operation is nearly complete blade 22 is about to move sideways and cut the tape. As the tape is cut, the mandrel 10 rolls back the left over tape and the subsequent operation is ready to begin.

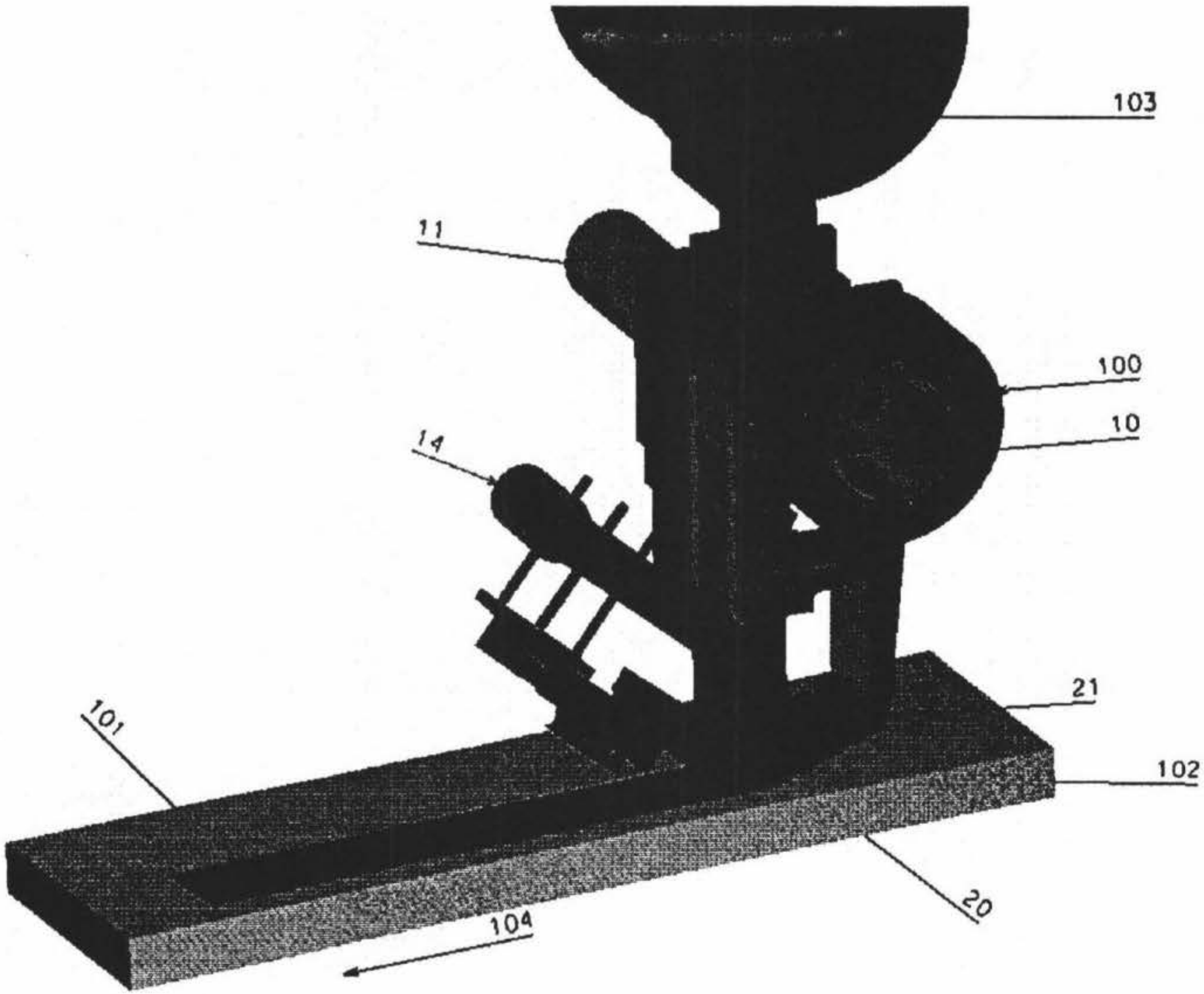


Figure 4: 'EziStick' applying the tape

Figure 5 schematically shows the relation between three Standard Diffuse Scan Opto Switch Sensors set-up 12 in Figure 1 and an end edge of a rotating tape roll. Mandrel 10 rotates roll 100 anti-clockwise as shown. The device comprises three standard diffuse scan opto switch sensors 150 which detect changes in the intensity of light, scattered back by an edge. The light is generated by the sensors themselves. Scanning the tape surface along three parallel lines provides a sufficiently accurate picture of edge 151 which may be straight, angled or possibly V-shaped.

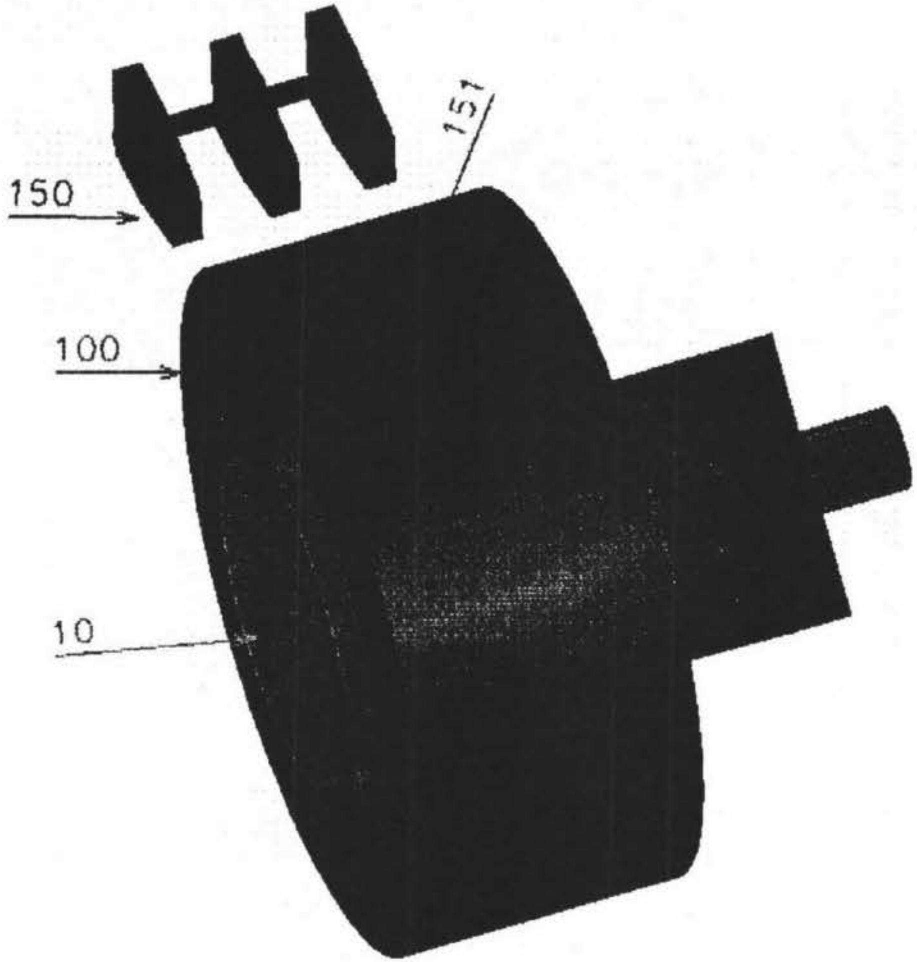


FIGURE 5

Figure 5: Edge sensor arrangement

Figure 6 schematically shows the relationship between the lifting and clamping devices 13,15 in Figure 1 and a freshly lifted tape end. Mandrel 10 rotates roll 100 in the same manner as Figure 5. The lifting device comprises a single replaceable, shaped blade 161 positioned to contact the tape surface according to scanning information determined from sensor device 12. A proximity sensor (hidden from view - behind 16) monitors distance of the blade from the roll to ensure gentle contact and reduce possible scarring of the tape. Another proximity (hidden from view - behind 13) switch detects the presence of the tape end 151 moving over the blade. A non-stick surface is imparted to the blade with a view to reduce possible build-up of adhesive during a sequence of lifting operations. The holding device 15 comprises a piston 160 which clamps tape end 151 to blade 161 after lifting of the edge has been detected.

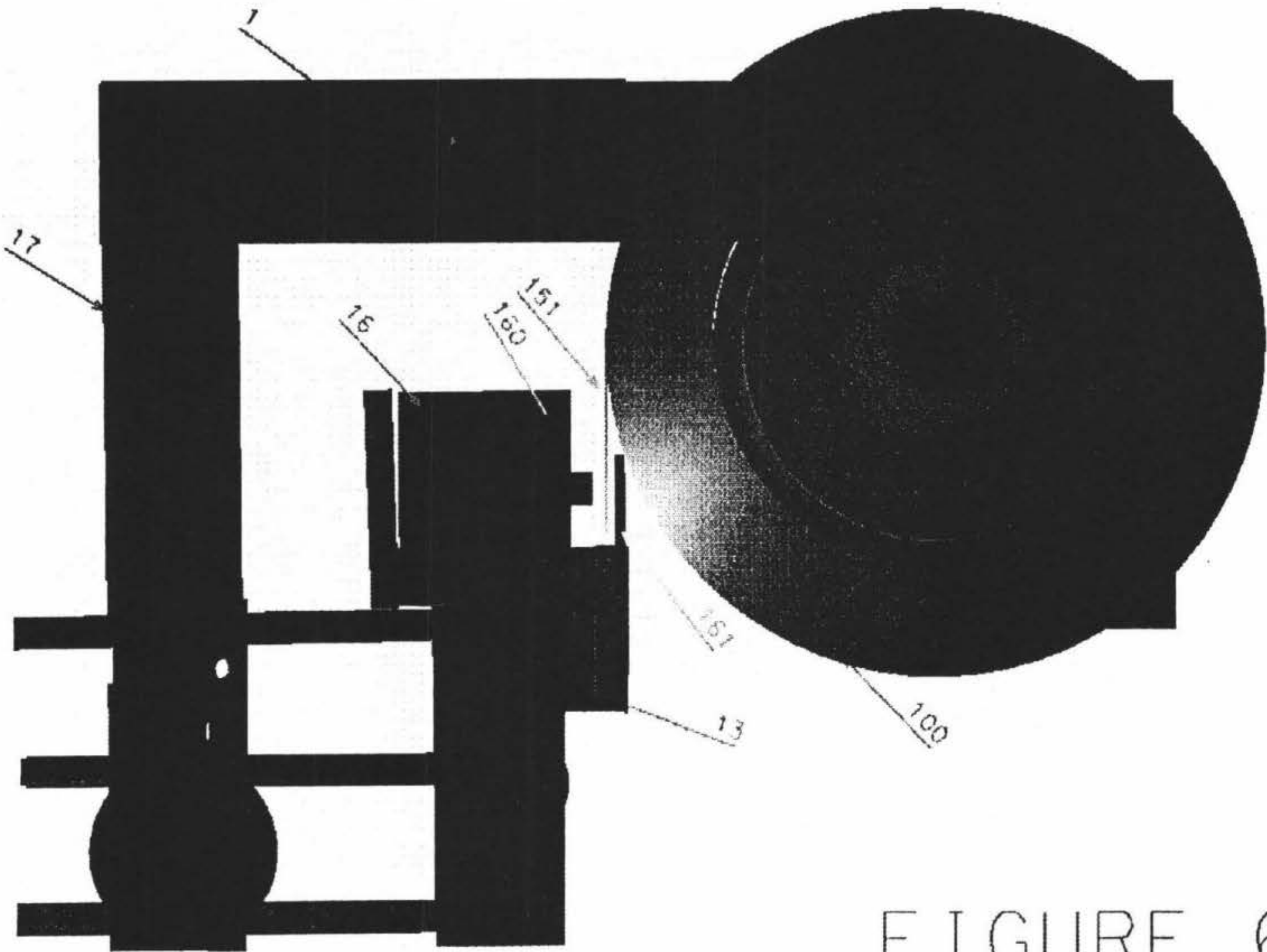


FIGURE 6

Figure 6 : Blade picking the tape

Figure *7* schematically shows the relationship between load sensor 21 in Figure 1 and a short length of tape pulled from a tape roll. Mandrel 10 freewheels at an appropriate speed as the tape is wound off. The device preferably comprises a flexible cantilever arm 170 fixed at one end to support 173 and mounting a tape buffer 171 at the other. The tape is drawn approximately perpendicularly from the roll to pass over the buffer and roller 20. Strain gauges 172 monitor deflection of the cantilever and adjust the rate at which tape is pulled from the roll appropriately. When tape is being applied to an object the rate is controlled by speed of movement of the entire applicator over the object surface.

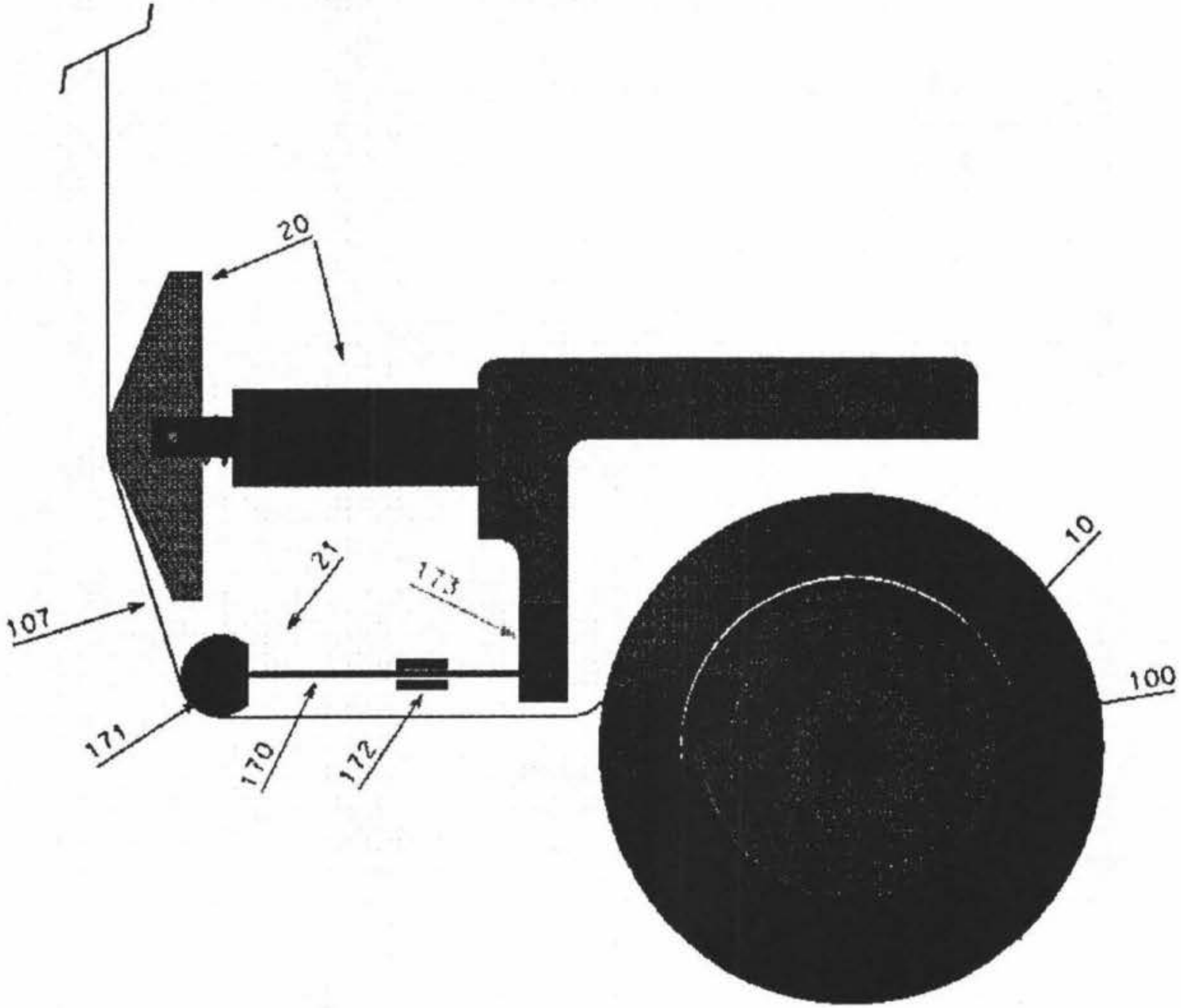
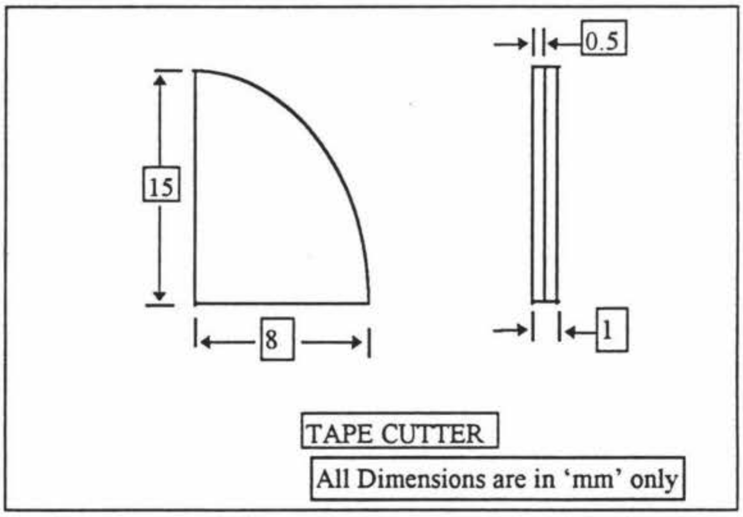


FIGURE 7

Figure 7: Tape tension monitoring arrangement

Figure 8 schematically shows the relationship and location of the tape cutter to the load sensor and the roll. The cutter 31 which is held onto the guide plate 33, will slide past the load sensor end support 173 , over the cantilever arm 170, cutting the tape. The forward and backward motions of the cutter are the forward and backward strokes of the pneumatic cylinder 34, which drive the guide plate back and forth. The cutting mechanism is fastened to the frame by a support plate 32.

The tape cutter 31 mentioned above is made of 1mm high carbon steel strip. The cutting edge is grounded sharp and round. The shape is made rounded to lead the cutting action during the forward stroke of the pneumatic cylinder 34. The geometry of the cutter is shown below.



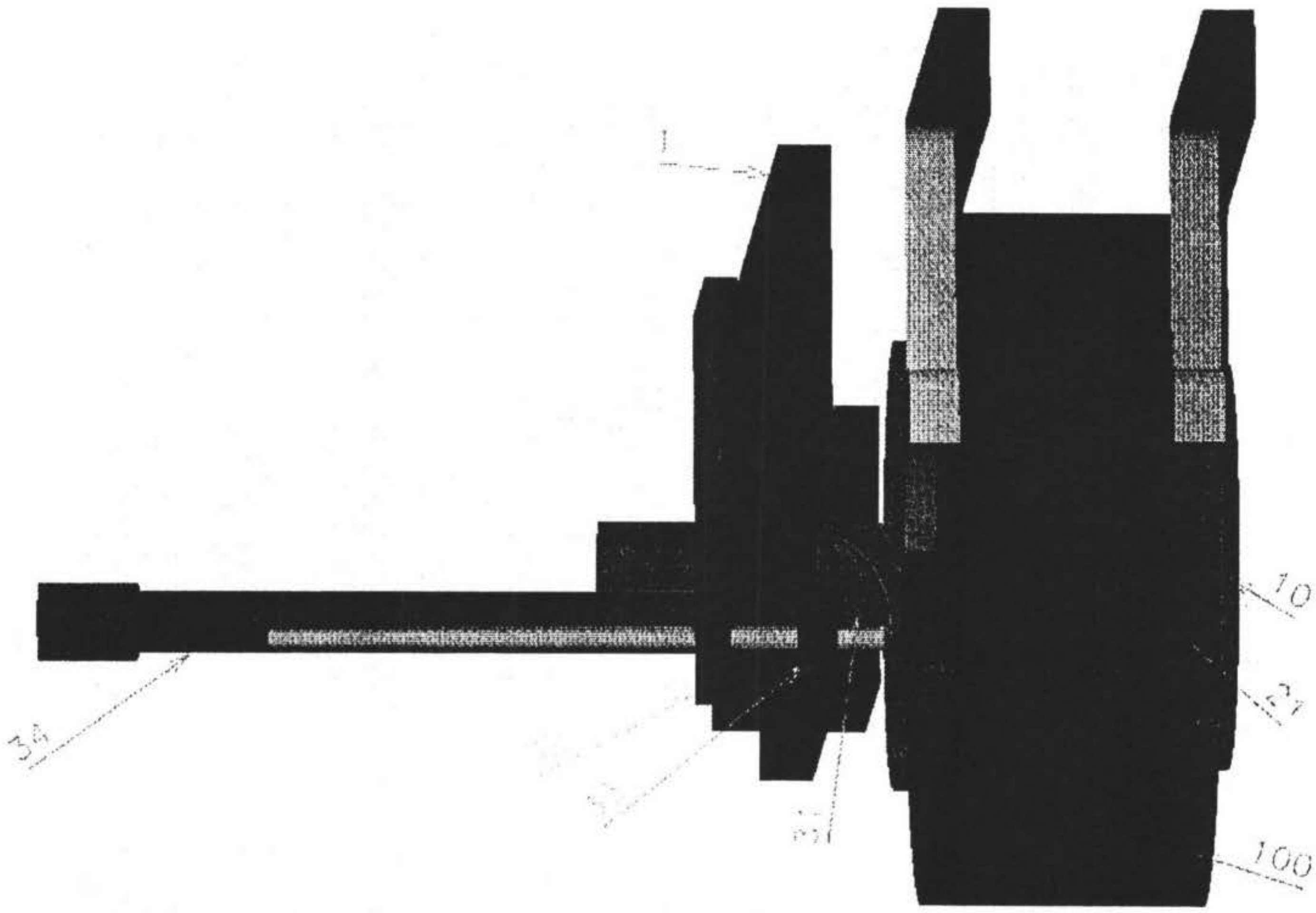


FIGURE 8

Figure 8: Tape cutting mechanism

Figure 9 schematically shows the specially designed clutch mechanism and it's positioning with respect to the other parts. The clutch is divided into several components which are merged into one. One end 41 of clutch is fastened to mandrel motor and the other end 42 to mandrel. Connecting these two, there is a third component 43 which slides into action by a pneumatic cylinder 44, connecting the mandrel and motor and vice-versa. This pneumatic cylinder is fastened to the frame by a support plate 45.

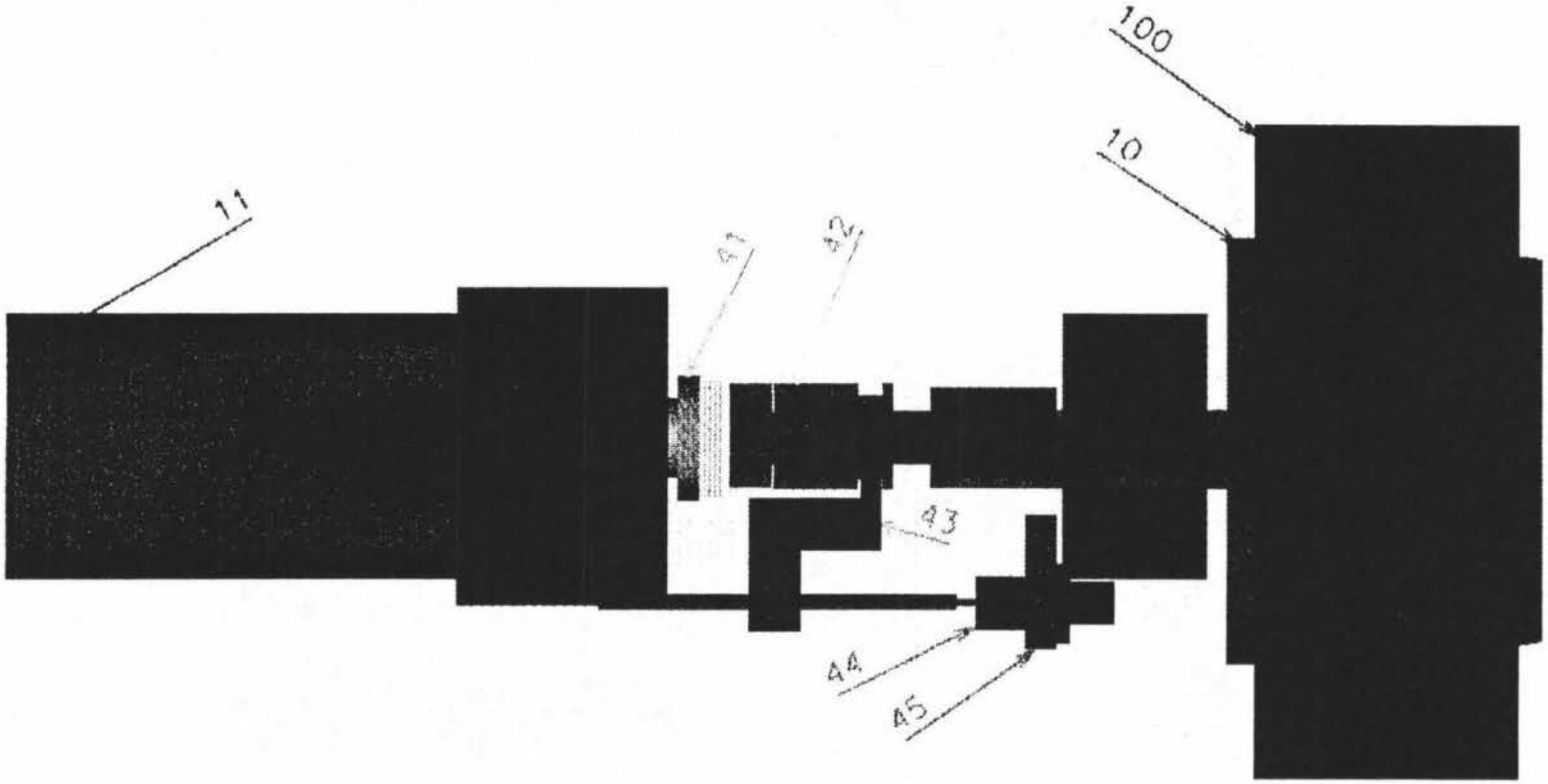


FIGURE 9

Figure 9: Clutch mechanism

Figure 10 schematically shows the specially designed roll holding device and it's location with respect to the mandrel 10 and roll 100. The roll holding device consists of a central block 50, three legs 51, and a lock nut 52. The central block is connected to the mandrel through a pneumatic cylinder 54 (hidden from view - behind 50), which itself is fastened to the centre of the mandrel. The three legs of this device are held loosely in the mandrel and the mandrel has the appropriate relief to accommodate them. In their normal state these legs have no contact with the roll and hence the roll is loose over the mandrel. The roll holding device comes into action by the forward stroke of the pneumatic cylinder 54, which pushes the central block 50 forward and three legs 51 outwards through the mandrel, and holding the roll. The roll holding device is designed such that the three legs will not exert any excessive pressure on the roll.

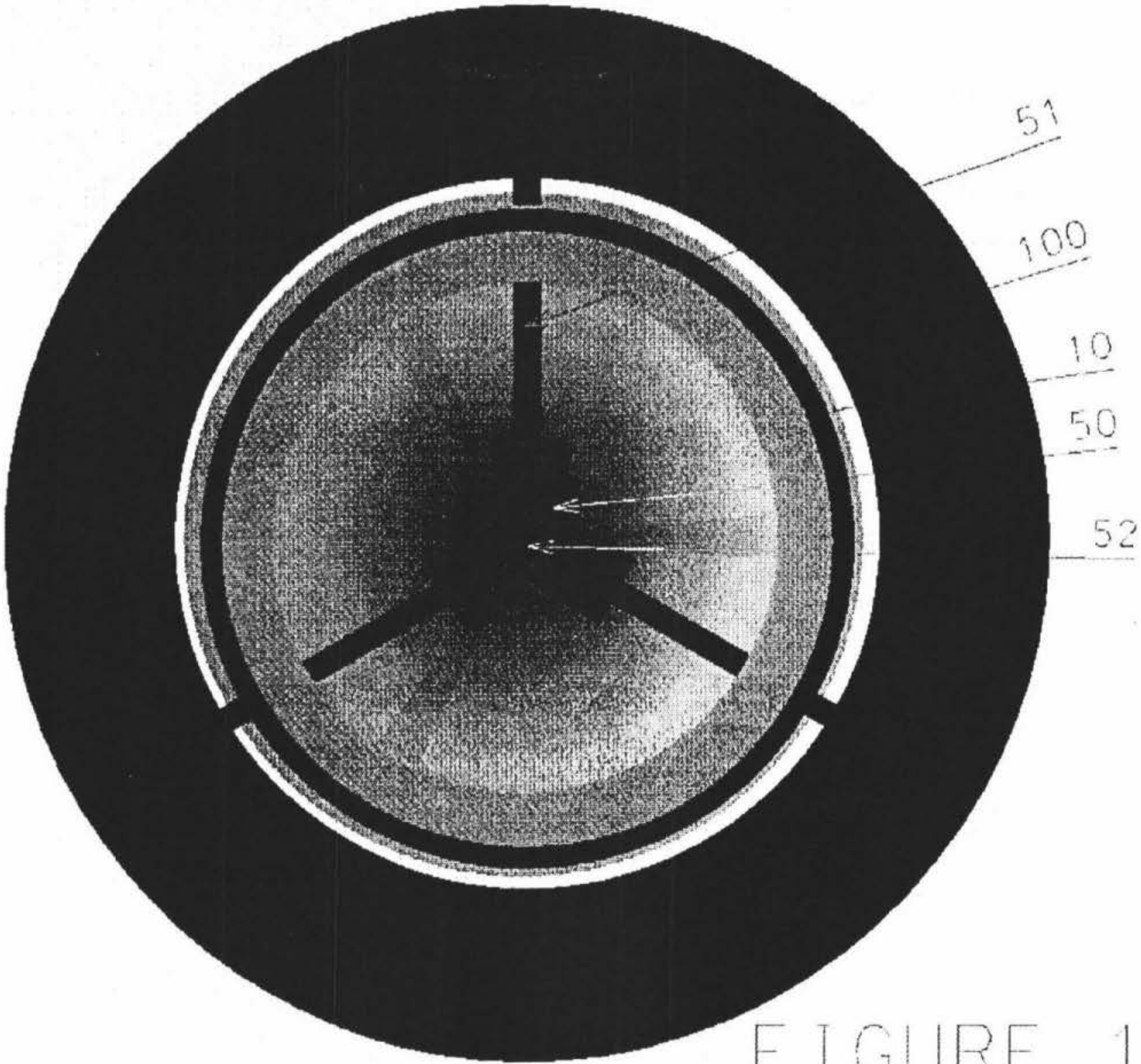


FIGURE 10

Figure 10: Roll holding mechanism

Appendix-B

Calculations of load Measurement System

The load measurement is obtained using the following sequence of steps

Ideal strain (μ)	$= 300*10^{-6}$
Young's modulus (E)	$= 200*10^{9}$ N/m^2
Stress (δ)	$= E*\mu$
	$= 200*10^9*300*10^{-6}$
	$= 60*10^6$ or 60 MN/m^2

From the below calculations it is found that using a 2mm thick cantilever of 80mm effective length gives a stress of

$\delta = 46$ MN/m^2 **min**

$\delta = 61$ MN/m^2 **max**

therefore manipulating the above stress formula, strain values for the load measurement device are obtained.

$\mu = \delta / E$

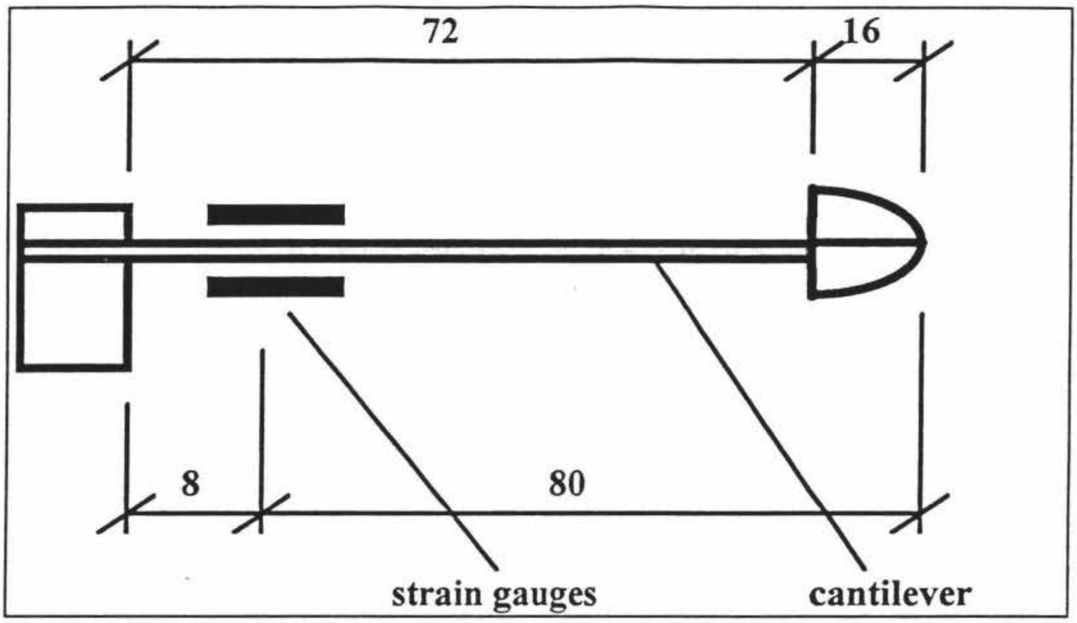
$= 46*10^6 / 200*10^9$

$= 230*10^{-6}$ **min**

$= 61*10^6 / 200*10^9$

$= 305*10^{-6}$ **max**

These calculated strains fit very well into the theoretical values for ideal strain.



Layout of Tape Tension Monitoring System

Moments about point = M

M	$= 80*10^{-3}*18$	where:
	= 1.44 Nm **min**	distance of cantilever=80mm
		force acting on cantilever=18 N **min**
M	$= 80*10^{-3}*24$	=24 N **max**
	= 1.92 Nm **max**	

Second Moment of Area = I

I	$= bd^3 / 12$	where:
	$= 47*(2)^3 / 12*10^{-12}$	b = width of cantilever
	$= 31.3*10^{12}\ m^4$	d = thickness of cantilever

Stress (δ) $= M\,y / I$

$= 1.44*1*10^{-3} / 31.3*10^{-12}$

$= 46\ MN/m^2$ **min**

$= 1.92*1*10^{-3} / 31.3*10^{-12}$

$= 61\ MN/m^2$ **max**

where y = half the thickness of cantilever

Deflection (λ)

$= F\,L^3 / 3\,E\,I$
$= 18*(88*10^{-3})^3 / 3*200*10^9*31.3*10^{-12}$
$= 0.65$ mm **min**

$\lambda = F\,L^3 / 3\,E\,I$
$= 24*(88*10^{-3})^3 / 3*200*10^9*31.3*10^{-12}$
$= 0.87$ mm **max**

where:

F = force acting on the cantilever
L = total distance of the cantilever
E & I from above

The strain gauges are being used to measure the tape tension continuously during the tape application. This information will be used by the micro controller to monitor the tape application. There are four strain gauges used to set up a balanced wheat-stone bridge arrangement. An accurate value of the tape tension during tape application is hence, always obtained. The value from this strain gauges is passed through an amplifier circuit and the output from this amplifier is fed to the micro controller for corrective actions, if any.

The strain gauges used are off-shelf components from Radio Spares limited. The amplifier board and the amplifier chip are also from the RS Limited Stock numbers are given in the previous chapters).

Appendix-C

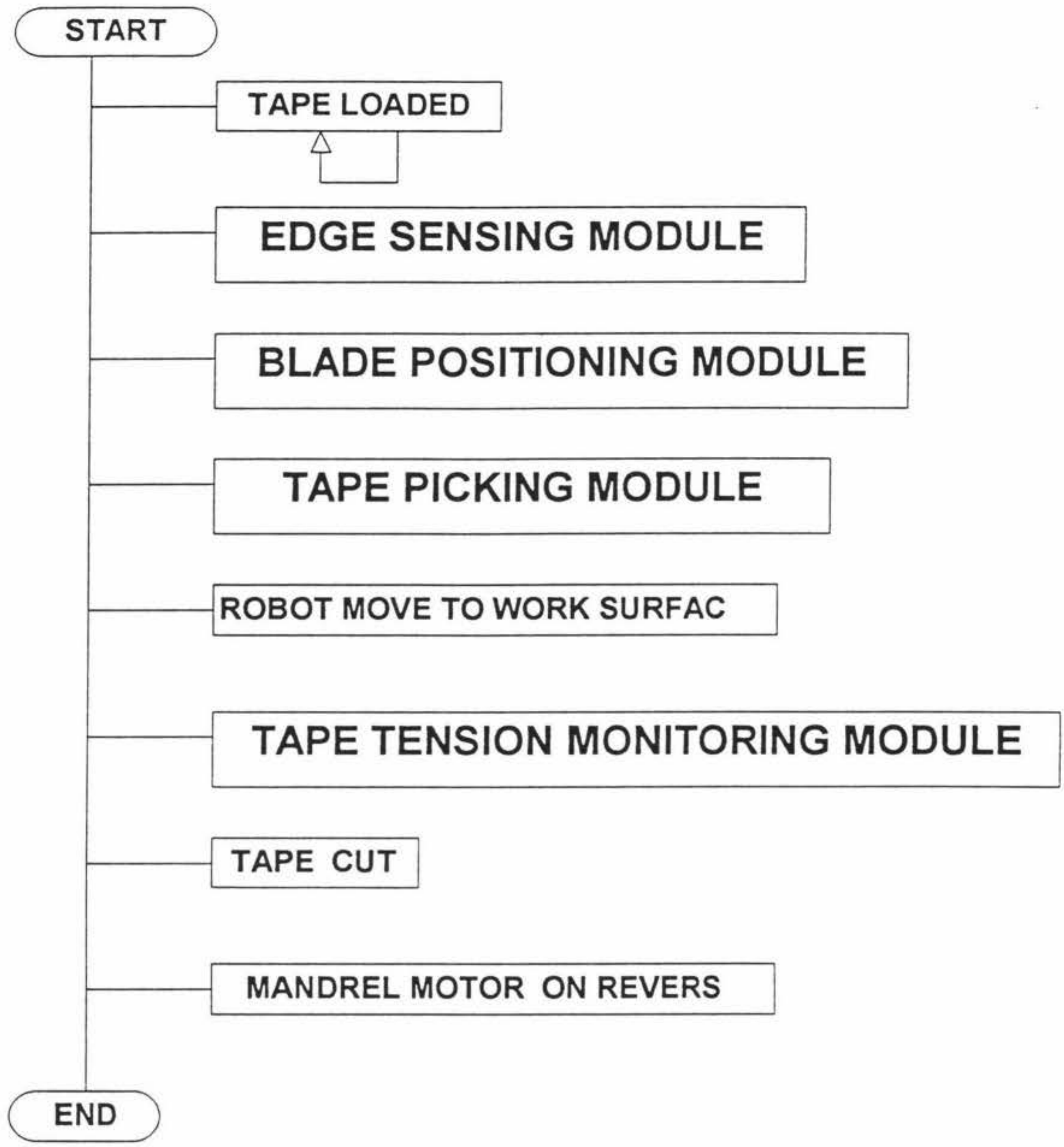


Figure 1: 'EziStick' Module

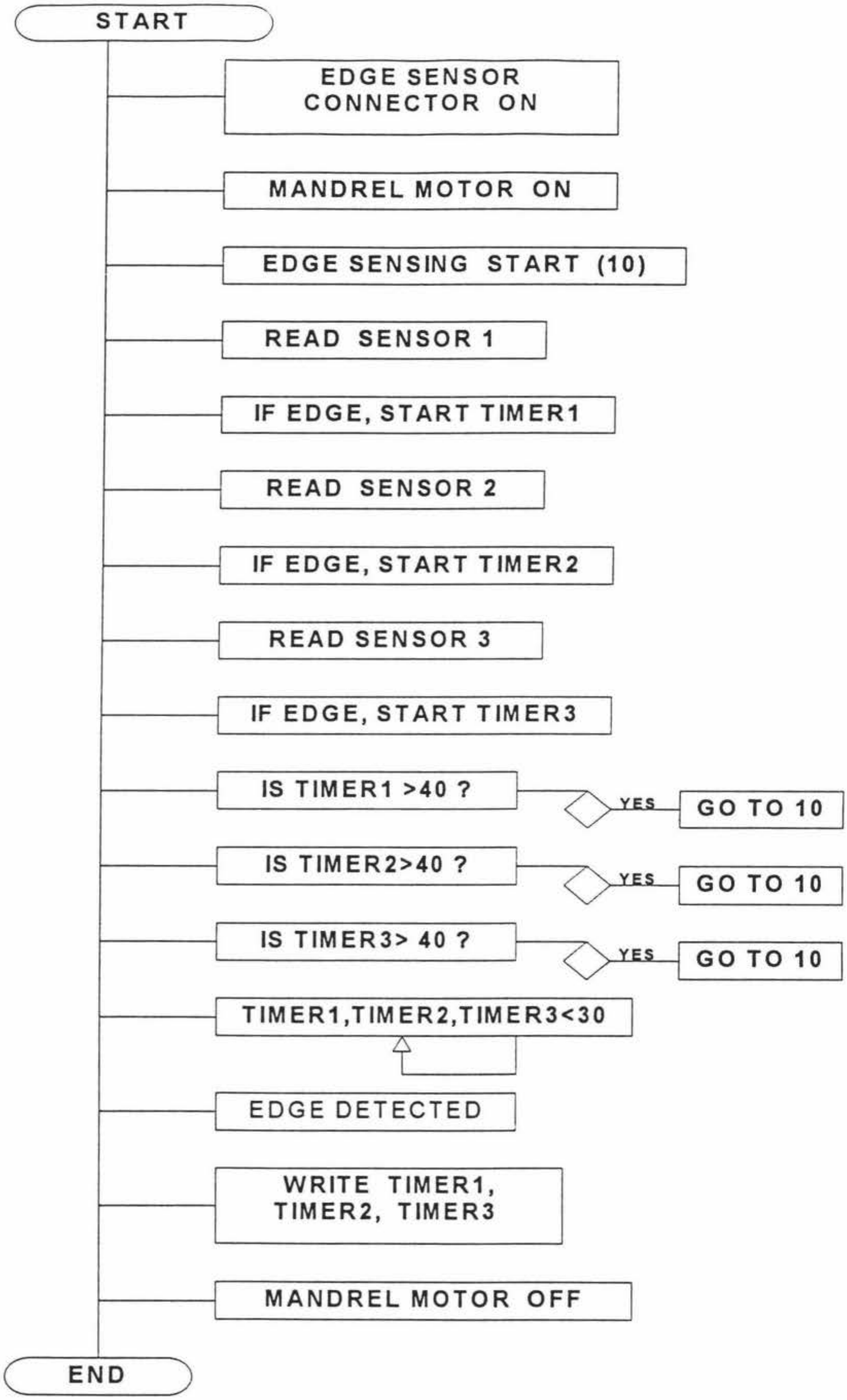


Figure 2: Edge Sensing Module

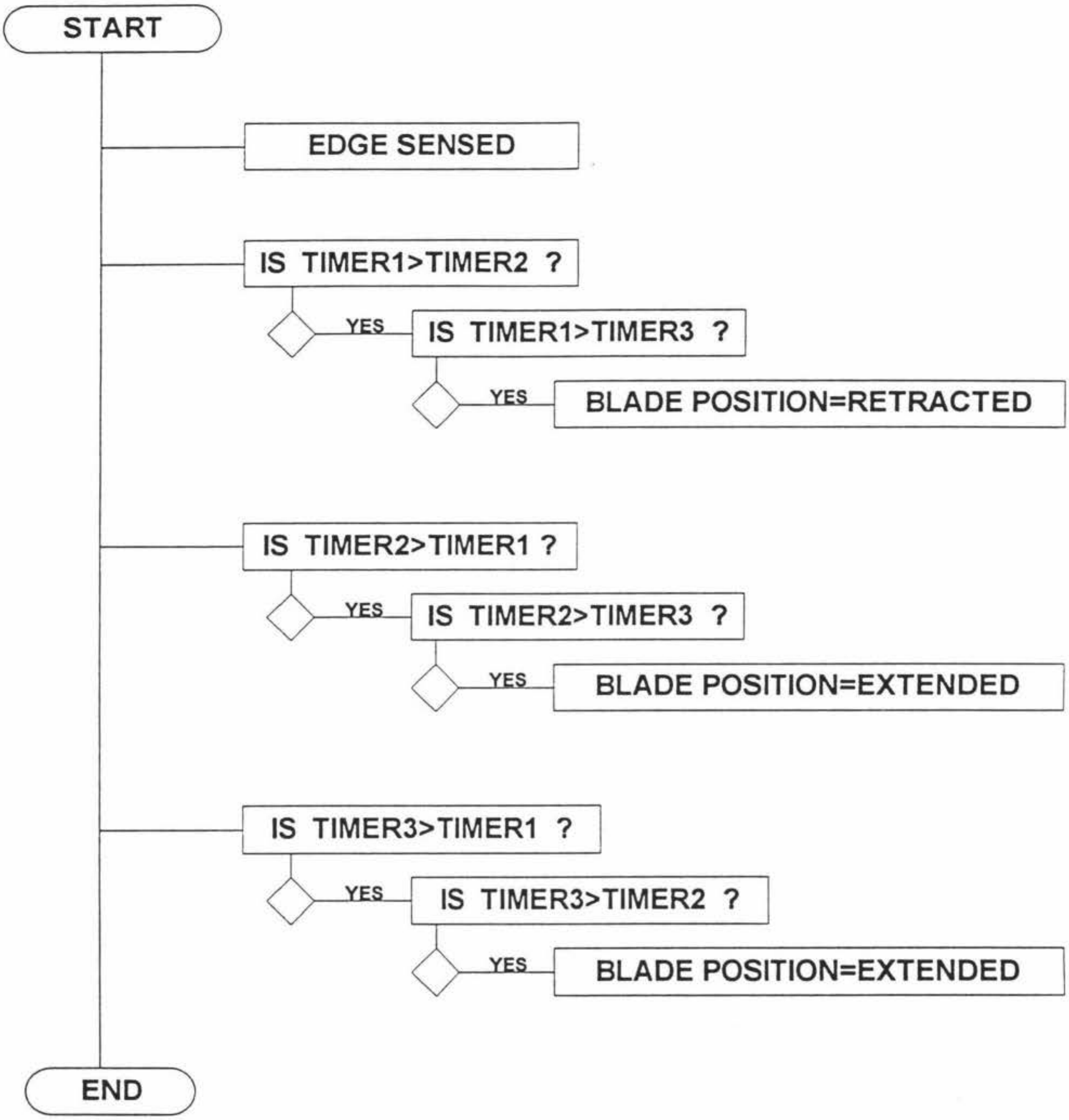


Figure 3: Blade Positioning Module

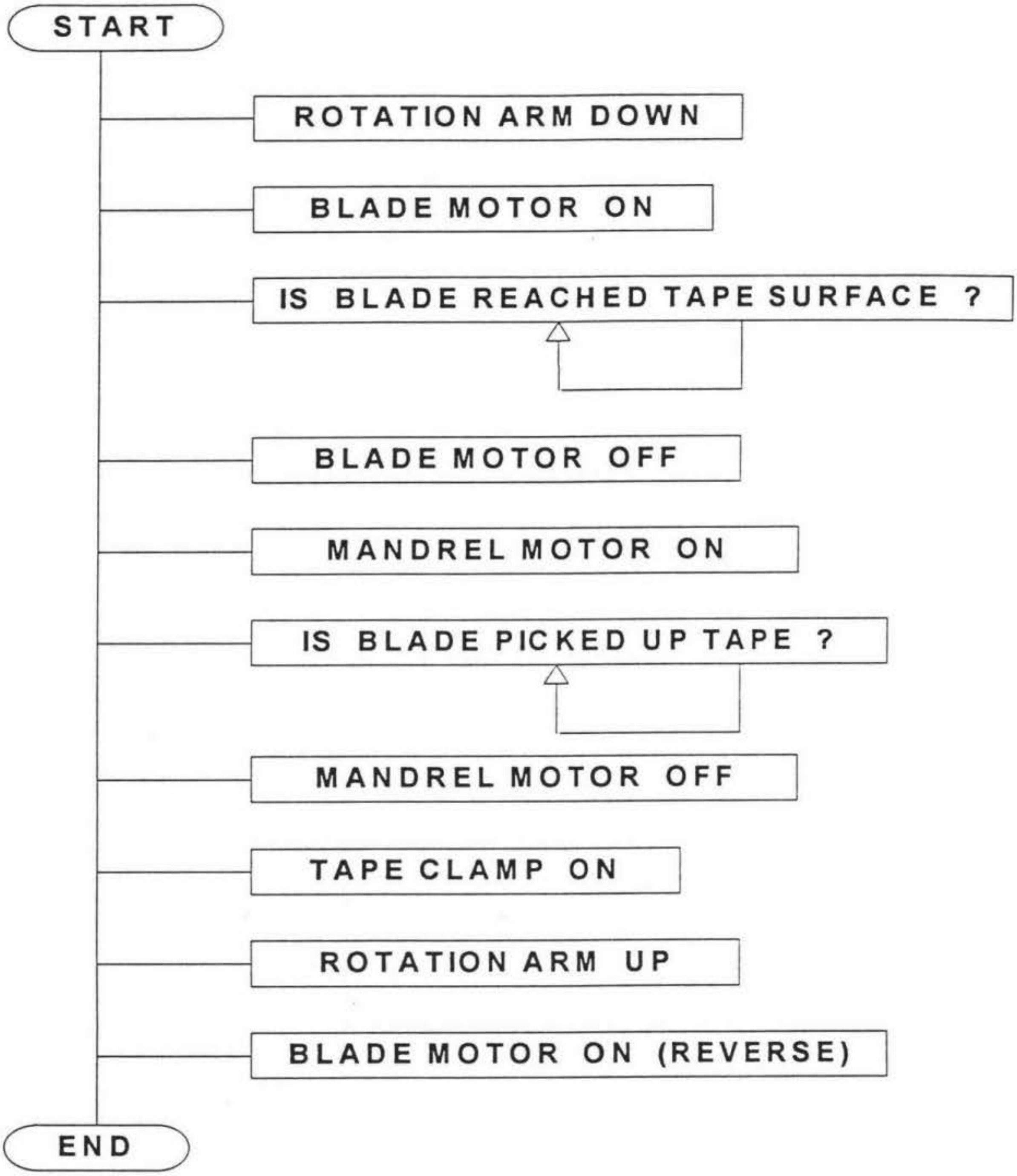


Figure 4: Tape Picking Module

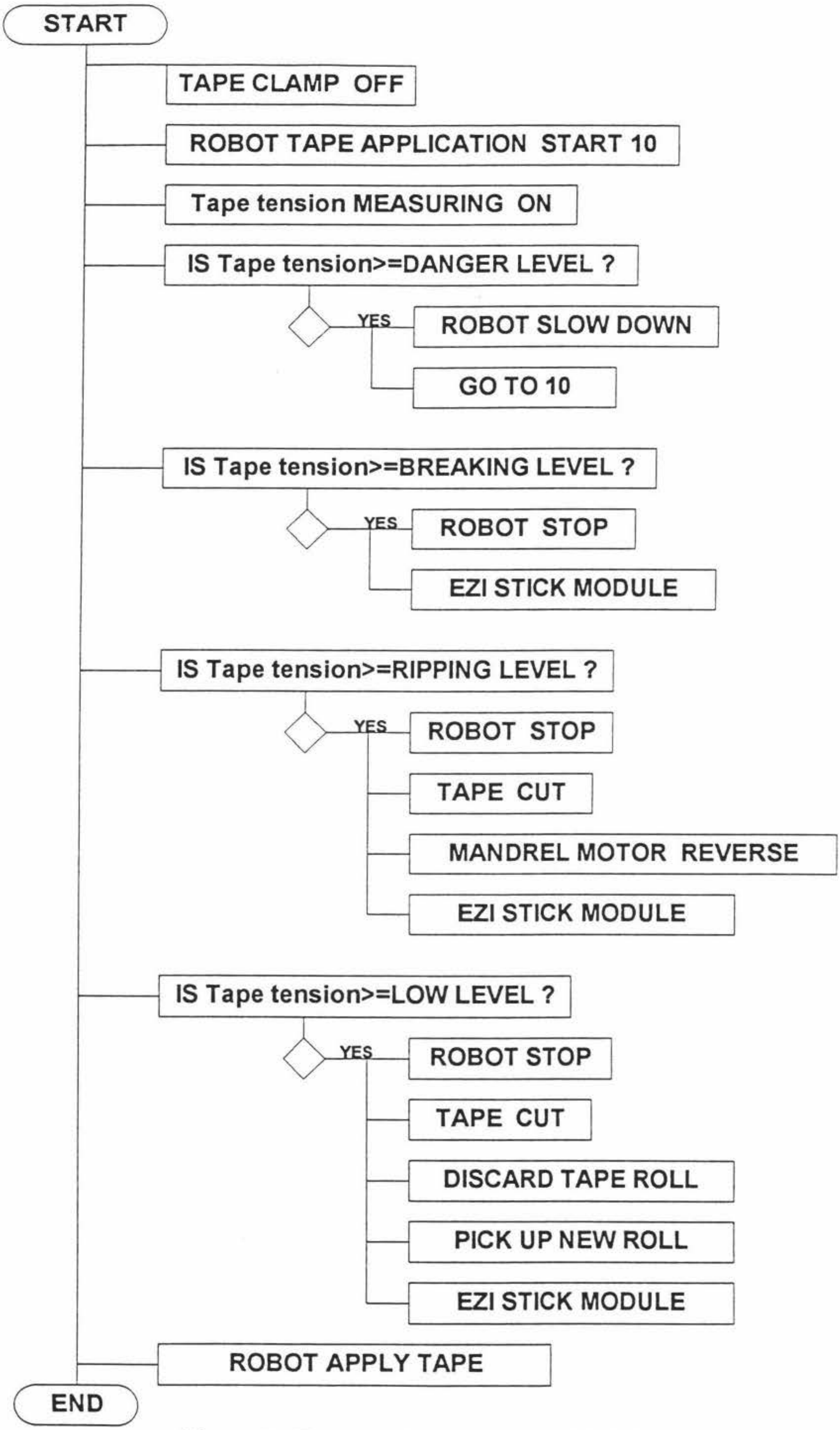


Figure 5: Tape tension monitoring Module

Appendix-D

C.1 Notes about Robot control program

Robot moves are pretty much governed by the Robot Controller (RC) by the set instructions given in the form of a program. This program interacts with the Micro Controller (MC), accepting the inputs and giving the outputs to MC. These input / outputs are very much action oriented. When MC sends a signal to RC, robot performs certain action and viceversa.

The details of each input and output commands used in the robot control program are listed below.

INP1	Input1	Signal to RC to start the tape application sequence.
INP2	Input2	Signal to RC to stop the tape application sequence.
INP3	Input3	Signal to RC to slow down the speed of tape application.
INP4	Input4	Signal to RC to pick up new tape roll from tape roll magazine.
INP5	Input5	Signal to RC to interrupt the execution of the instruction.

OUTP1	Output1	Signal the MC to unclamp the tape before the start of tape application
OUTP2	Output2	Signal the MC to start measuring tape tension.
OUTP3	Output3	Signal the MC to cut the tape.
OUTP4	Output4	Signal the MC to Start the sequence again.
OUTP5	Output5	Signal the MC to reset the sequence after the interruption.

The robot program also has the facility of calling the sub-programs when a specific action needed to be performed. The sub-program calls will be generally conditional. After performing the specific action the sequence returns to the main body of the program. There are few conditional sub-program calls in the program.

Sub-Program 10 The set of instructions for robot to pick-up a new roll from the tape roll magazine in case of tape finishing during tape application.

Sub-Program 20 Enables the robot to slow down in case of higher tape tension values.

Sub-Program 30 Enables the robot to stop the tape application in case of increasing tape tension values.

Sub-Program 40 Enables the robot to store the location at which the tape has ripped so that it can start from there again after the tape has been reloaded. (In conjunction with sub-program 50).

Sub-Program 50 Enables the robot to start the tape application from the point of stoppage in the case of uneventuality.

A brief flow chart of the robot program sequence is shown in figure 1 below.

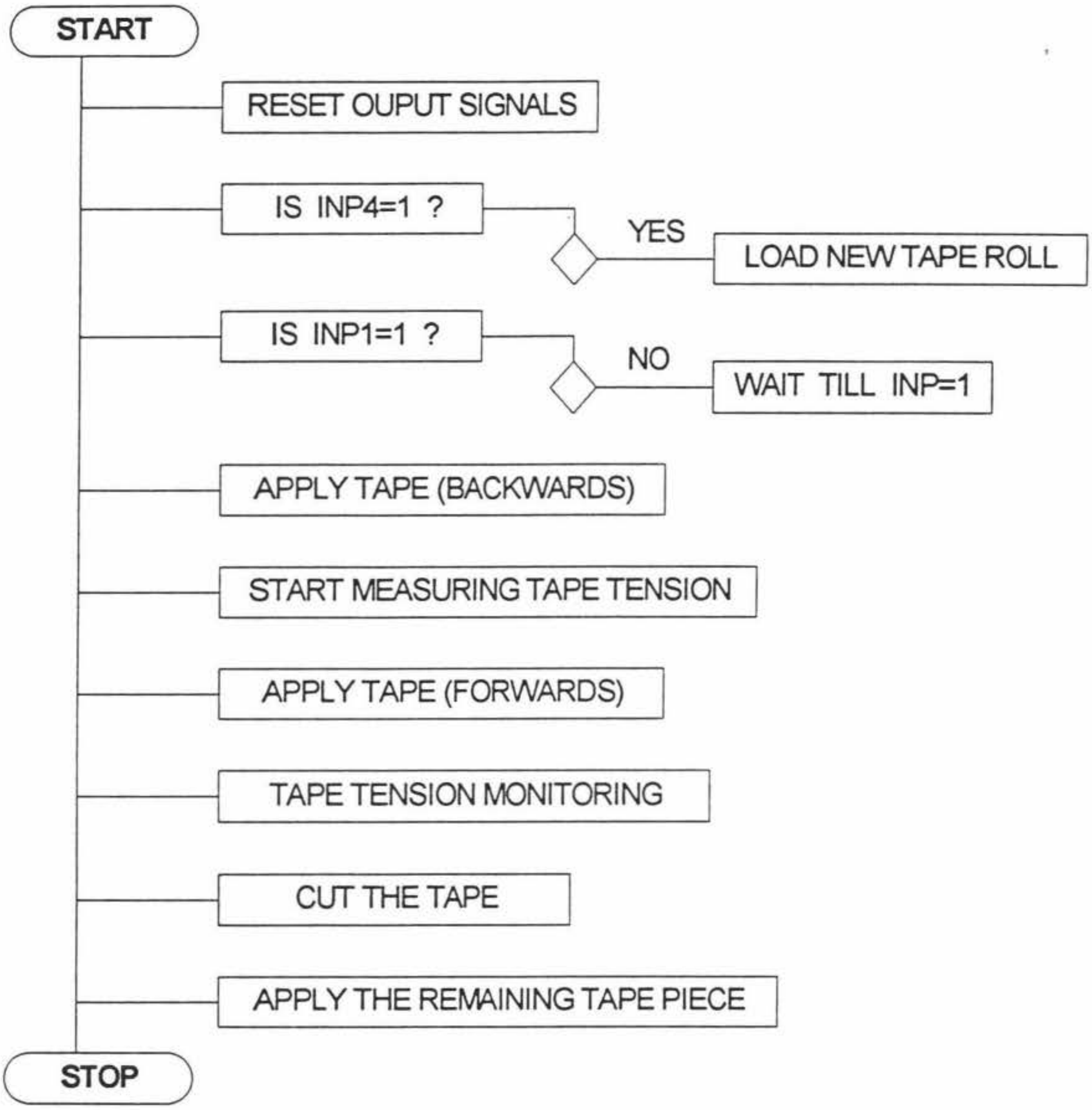


Figure 1: Robot program sequence

The following section describes the robot control program.

C.1.2 Robot Control Program

```
10    V=2000 mm/sec max=2000 mm/sec
20    TCP 1                        {TCP at applicator foot}
30    RECT COORD
40    FRAME 0
50    ENABLE INTERRUPT             {a high on the interrupt input will
                                        skip to the next instruction}
60    RESET OUTP1
70    RESET OUTP2
80    RESET OUTP3
90    RESET OUTP4
100   RESET OUTP5
110   JUMP TO 130 IF R1>0          {stops register one from being set
                                   back to zero after several iterations}
120   LET R1=0
130   POS V=100% FINE              {home position}
140   WAIT UNTIL INP1=1            {wait for robot signal}
150   JUMP TO 650 IF INP4=1        {load new roll}
160   POS V=20%                    {home position}
170   WAIT 10S
180   WAIT UNTIL INP1=1         {wait until tape pickup
                                   sequence finished}
190   JUMP TO 670 IF R1=1          {if register one has value one in it do
                                   second pipe}
191   JUMP TO 1200 IF R1=2 {if reg 1 has value2 in it then do third
                                   pipe}
200   POS V=25%                    {position above unclamp position}
```

This is so the applicator comes vertically down onto the pipe.

```
220   POS V=5% FINE                {unclamp position}
240   SET OUTP1                    {tell the m/c that ready to unclamp}
250   WAIT UNTIL INP1=1            {wait for the m/c to unclamp}
260   JUMP TO 720 IF R1=1
261   JUMP TO 1250 IF R1=2
270   POS V=5% FINE                {start position, applying free end of
                                        tape}
```

```
290    POS V=5% FINE          {unclamp position again, in
                              opposite way}
310    SET OUTP2              {tell m/c to start measuring strain}
320    JUMP TO 762 IF R1=1
321    JUMP TO 1272 IF R1=2
323    POS V=5%               {starting point-pipe1}
325    POS V=5%
327    POS V=5%
328    POS V=5%
329    POS V=5%
330    POS V=5% FINE          {cut position}
350    JUMP TO 850 IF INP1=1  {recover from ripped edge}
360    JUMP TO 550 IF INP3=1  {The m/c can interrupt the
application process if the strain gets too high, the tape breaks, the tape rips
or a new roll is needed. In these cases the m/c sets the interrupt input and,
before this, sets the appropriate input. These inputs are tested to see
which sub-program to call. If the tape is successfully applied these inputs
should be zero, so nothing happens.}

370    JUMP TO 600 IF INP2=1  {to see if a stop is needed}
380    JUMP TO 500 IF INP4=1  {to see if a new roll is needed}
385    JUMP TO 810 IF INP5=1  {to interrupt the instruction}
390    SET OUTP3              {tell the m/c that it can cut the tape}
400    WAIT UNTIL INP1=1      {wait for the m/c to say tape is cut}
410    JUMP TO 800 IF R1=1
411    JUMP TO 1350 IF R1=2
420    POS V=5% FINE          {apply free end of cut tape}
440    POS V=25%              {move vertically up, to allow m/c to
                              perform tape pickup process}
460    SET OUTP4              {tell m/c safe to start pickup
                                          sequence}
463    JUMP TO 1000 IF R1=1
465    JUMP TO 1101 IF R1=2
470    LET R1=1               {If R1=0 then R1=1 and 'jump' to
                              480}
480    POS V=25%
490    RETURN                 {perform robot program again}
```

{all the following sections call a subprogram, when a conditional jump is made to here. The first three also remember the position the end effector was at when the jump was made, and return to this position when the subprogram is complete.}

```
500    POS V=5% STORE LOCATION5
510    POS V=5% LOCATION5 OFFSET X=0 Y=0 Z=300 MM
520    CALL PROG10
530    CALL PROG50
535    SET OUTP3
536    JUMP TO 800 IF R1=1
537    JUMP TO 420 IF R1=0
538    JUMP TO 1350 IF R1=2
540    JUMP TO 810

550    POS V=5% STORE LOCATION6
560    CALL PROG20
570    POS V=5% LOCATION6
580    SET OUTP5=1
585    SET OUTP3
586    JUMP TO 800 IF R1=1
587    JUMP TO 420 IF R1=0
588    JUMP TO 1350 IF R1=2
590    JUMP TO 810

600    POS V=5% STORE LOCATION7
610    CALL PROG30
620    POS V=5% LOCATION7
630    SET OUTP5=1
635    SET OUTP3
636    JUMP TO 800 IF R1=1
637    JUMP TO 420 IF R1=0
638    JUMP TO 1350 IF R1=2
640    JUMP TO 810

650    CALL PROG10
660    JUMP TO 160
665    POS V=25% FINE
670    POS V=5% FINE           {ABOVE PIPE 2}
680    POS V=5% FINE           {UNCLAMP PIPE 2}
710    JUMP TO 240
720    POS V=5%                {FREE END OF PIPE 2}
730    POS V=5%                {UNCLAMP AGAIN PIPE 2}
```

```
760     JUMP TO 310
762     POS V=5%                {STARTING POINT-PIPE2}
764     POS V=5%
766     POS V=5%
768     POS V=5%
769     POS V=5%
770     POS V=5%                {CUT PIPE 2}
790     JUMP TO 350

800     POS V=5% FINE           {FREE END PIPE 2}
810     POS V=25%               {UP IN AIR PIPE 2}
840     JUMP TO 460

850     CALL PROG40
860     JUMP TO 330

1000    LET R1=2                {INCREMENT PIPE COUNTER}
1010    JUMP TO 480

1101    LET R1=0                {RESET PIPE COUNTER}
1110    JUMP TO 480

1200    POS V=25%               {PIPE 3 ABOVE UNCLAMP}
1210    POS V=5% FINE           {PIPE 3 UNCLAMP}
1220    JUMP TO 240

1250    POS V=5% FINE           {PIPE3 FREE END}
1260    POS V=5%                {UNCLAMP AGAIN}
1270    JUMP TO 310
1272    POS V=5%                {STARTING POINT-PIPE3}
1273    POS V=5%
1274    POS V=5%
1275    POS V=5%
1276    POS V=5%
1300    POS V=5%                {CUT PIPE 3]
1310    JUMP TO 350
1350    POS V=5% FINE           {FREE END PIPE3}
1360    POS V=25%               {PIPE 3 IN AIR}
1370    JUMP TO 460
```

SUBPROGRAM 10

{This subprogram picks up a new roll}

```
10   POS V=25%
20   POS V=25%
30   POS V=25% FINE XL
40   POS V=25%
50   POS V=5% FINE
60   POS V=5% FINE
70   POS V=5%
80   POS V=5%
90   POS V=5%
100  POS V=5%
110  POS V=5%
120  POS V=5%
130  WAIT UNTIL INP1=1        {waits for m/c to grip roll and tell
                              robot to pick up roll}
140  POS V=5%
150  POS V=5%
160  POS V=5%
170  POS V=25%
180  POS V=25%
190  RETURN
```

SUBPROGRAM 20

{This sub-program reduces basic and max speeds in an effort to slow the robot down}

```
10 V=50MM/SEC MAX=100MM/SEC
20 RETURN
```

SUBPROGRAM 30

{This sub-program stops the robot by not moving until input 2 goes high. As input 2 isn't connected, the **sim** button has to be used}

```
10 WAIT UNTIL INP2=1
20 RETURN
```

SUBPROGRAM 40

{This sub-program recovers from a ripped tape.}

```
10  POS V=5% STORE LOCATION 5
20  CALL PROG50
30  RETURN
```

SUBPROGRAM 50

{This sub-program goes through the sequence again, once tape has ripped or a new roll is needed.}

```
10  RESET OUTP1
20  RESET OUTP2
30  RESET OUTP3
40  POS V=50% LOCATION5 OFFSET X=0 Y=0 Z=300 MM
50  WAIT FOR INP1=1            {Tape pickup sequence ended}
60  POS V=5% LOCATION5         {place app. foot on surface}
70  SET OUTP1=1                {Unclamp}
80  WAIT UNTIL INP1=1
90  POS V=5% LOCATION5 OFFSET X=0 Y=80 Z=0 MM{Free end}
100 POS V=5% LOCATION5
110 SET OUTP2                  {Start measuring strain}
120 RETURN
```

C.2 Brief note about 'EziStick' control program

This section explains the control program for the function of 'EziStick'. The working of the 'EziStick' is governed by a Micro Controller (MC). This makes the program a MC program. But as MC controls the 'EziStick' it is being called control program of 'EziStick' rather than MC program. MC communicates through its various ports with the outside world. All these ports have individual numbers and they should be addressed by them only.

The 'EziStick' control program starts with the declaration of the different variables used in the program. It is mandatory in any program. These variables are given names corresponding to their actual function. This makes lot easy to identify the variables. The structure of the program is divided into number of procedures. These procedures are called upon wherever they are required. The names of procedures are also given according to their functions in the program. This makes very easy for the reader to understand the program. The main program calls the procedures in a particular order as per the sequence of operations.

A flow diagram of the sequence in brief is shown in figure 2 below.

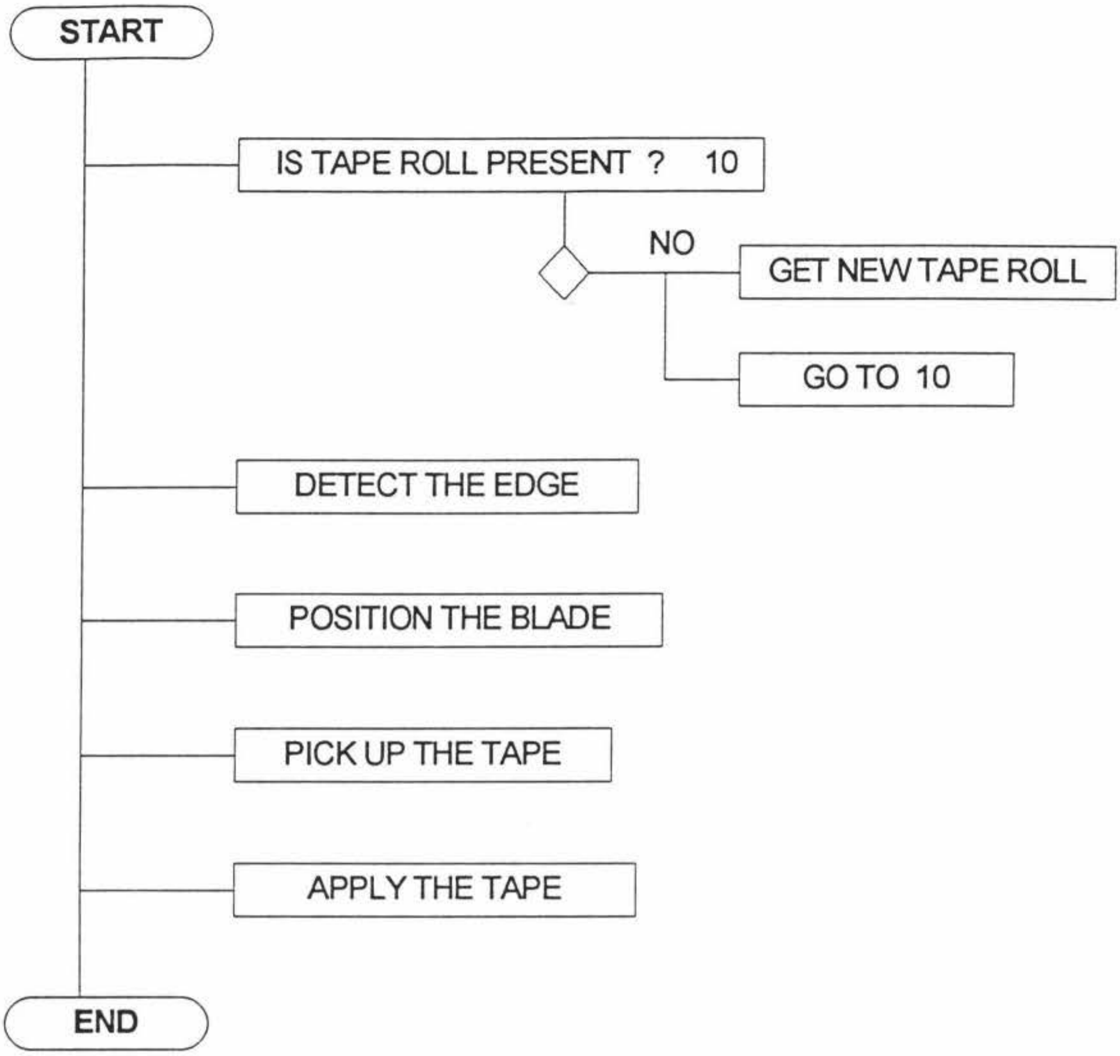


Figure 2: 'EziStick' program sequence

This is the brief sequence of major operations performed in this program. Each operation calls upon few procedures each. The functioning of the procedures is self explanatory as comments were incorporated wherever possible.

The following section describes the control program for 'EziStick' or Micro Controller.

C.2.2 'EziStick' Control Program'

```
PROGRAM Ezistick_Control;

VAR

        bladepos, time1, time2, time3 : BYTE;
        Debugging: BOOLEAN;
        edge1, edge2, edge3, roll_ran_out_while_applying : Boolean;
        port6 : byte bitaddressable;
         rotation_arm : boolean at p1.0;
        blade_position : boolean at p1.2;
        clamp : boolean at p1.3;
        edge_sensors : boolean at p4.4;
        tape_cutter : boolean at p1.6;
        {p3.0 and 3.1 talk to serial connection so can't use}
        motors_direction : boolean at p4.6;
        mandrel_motor : boolean at p3.3;
        motors_on : boolean at p3.5;
        robot_signal : boolean at p3.4;
        slow_down_robot_instruction : boolean at p1.1;
        stop_robot_instruction : boolean at p1.7;
        new_roll_robot_instruction : boolean at p3.2;
        interrupt_robot_instruction : boolean at p1.5;
        {p3.6 and 3.7 are control signals to external memory so can't use}
        operation_switch : boolean at p4.2;
        {p5.0 is output one from the robot controller
        p4.0 is output two from the robot controller
        p4.1 is output three from the robot controller
        p4.3 is output four from the robot controller
        p4.5 is output five from the robot controller
        p5.1 is the tape-reached-surface prox switch (on when at surface) P1
        p5.2 is the tape-on-blade prox switch(on when enough tape on blade) P2
        p5.3 is tape loaded micro switch (on when tape loaded)
        p5.4 is edge sensor 1   (on when edge detected)
        p5.5 is edge sensor 2   (on when edge detected)
        p5.6 is edge sensor 3   (on when edge detected)
```

p5.7 is the blade holder retracted micro switch (on when motor retracted)
p7.0 is the output of the strain gauge. This is an analog input.}

{Procedure to 'wait' while actuators actuate. Parameter time is the length of the wait. With time = 1, wait approx half a second.}

```
PROCEDURE Wait(time:BYTE);

VAR
      fillintime: WORD;
      j:byte;
      BEGIN
            j:=0;
                  REPEAT
                        BEGIN
                              fillintime:=0;
                              REPEAT
                                          inc(fillintime)
                                    UNTIL (fillintime=20000);  {delay}
                              inc(j);
                        END;
                  UNTIL (j=time);
                  {$IFDEF debugging}
                  writeln('wait finished');
                  {$ENDIF}
      END; {Wait }
```

{Procedure to send a signal to the robot. As there is only a limited number of inputs to the robot, the input used is reset}

```
PROCEDURE Signal_Robot;

      BEGIN
            robot_signal:=FALSE; {turn on robot input 1}
            wait(2);          {wait for robot to get input}
            robot_signal:=TRUE;  {turn off robot input 1}
      END;
```

{Procedure to initialise variables at the start of the sequence}

```
PROCEDURE Initialisation;

    BEGIN
        mandrel_motor:=TRUE;
        motors_direction:=TRUE;
        motors_on:=TRUE;
        Debugging:=true;  {turns on/off debugging messages}
        time2:=0;
        time3:=0;
        time1:=0;
        edge1:=FALSE;
        edge2:=FALSE;
        edge3:=FALSE;
        port6:=p6;     {making port six bit addressable}
        robot_signal:=TRUE;
        slow_down_robot_instruction:=TRUE;
        stop_robot_instruction:=TRUE;
        new_roll_robot_instruction:=TRUE;
        interrupt_robot_instruction:=TRUE;
        roll_ran_out_while_applying:=TRUE;
        blade_position:=TRUE;     {blade position normal - ie extended}
        ADCON0:=%00000000; {Initialise the a/d to use p7.0 and
                            internal trigger}
        ADCON1:=%00000000;
    IF Debugging THEN
        writeln('INITIALISATION completed');
    END; {Initialisation}


PROCEDURE Move_Edge_Sensors_Out;

    BEGIN
        edge_sensors:=TRUE;     {move edge detector sensors out, away
                                 from the tape}
    IF Debugging THEN
        writeln('EDGE SENSORS out');
    END; {Move edge sensors out}
```

```
PROCEDURE Load_Tape; {load tape onto mandrel. When its loaded
                      properly switch turns on}

    BEGIN
        new_roll_robot_instruction:=FALSE;    {tell robot to go get a
                  new roll. Robot discards any empty roll on way}
    IF roll_ran_out_while_applying THEN    {if the robot has run out of
tape in the middle of an application, then it must go get a new one, so the
interrupt has to be set}
        interrupt_robot_instruction:=FALSE;
        Signal_Robot;    {robot actually moves once this
                          procedure is executed}
    REPEAT UNTIL p5.3;  {waits until robot is positioned to pick up
                          tape, when the micro switch will engage}
        new_roll_robot_instruction:=TRUE;    {reset after a short wait}
        interrupt_robot_instruction:=TRUE;
        wait(2);        {wait to allow robot to be properly positioned}
    END; {Load Tape}


PROCEDURE Move_Edge_Sensors_In_And_Grip_Roll;

    BEGIN
        Signal_Robot; {once tape loaded, robot is instructed to return to
        the home position, where it can carry out edge detection, etc}
        edge_sensors:=FALSE;
    IF Debugging THEN writeln('EDGE SENSORS in and TAPE loaded');
    END; {Move_Edge_Sensors_In}


PROCEDURE Get_New_Roll;

    BEGIN
    IF Debugging THEN
        writeln('**** Loading Tape****');
        Move_Edge_Sensors_Out; {move sensors out so tape can be
                                loaded}
         Load_Tape;        {once a roll of tape is loaded, sequence
starts}
```

```
        Move_Edge_Sensors_In_And_Grip_Roll; {move sensors back
                                              when tape loaded}
    END;
```

PROCEDURE Turn_On_Mandrel_Motor;

```
    BEGIN
        mandrel_motor:=FALSE;
        motors_on:=FALSE;
        IF Debugging THEN
            writeln('MANDREL MOTOR is turning now');
    END; {Turn on mandrel motor}
```

PROCEDURE Timer1;

```
    BEGIN
        inc(time1);    {timer for edge sensor 1}
    IF Debugging THEN
        writeln('got to timer1: ',time1);
    END;{timer1}
```

PROCEDURE Timer2;

```
    BEGIN
        inc(time2);    {timer for edge sensor 2}
    IF Debugging THEN
        writeln(' got to timer2:    ',time2);
    END;{timer2}
```

PROCEDURE Timer3;

```
    BEGIN
        inc(time3);    {timer for edge sensor 3}
    IF Debugging THEN
        writeln('  got to timer3:       ',time3);
    END;{timer3}
```

```
PROCEDURE Fake_Edges;

     BEGIN
          Time1:=0;
          Time2:=0;
          Time3:=0;
          edge1:=FALSE;
          edge2:=FALSE;
          edge3:=FALSE;
          writeln('false edge detected ');
     END; {Fake Edges Check}

PROCEDURE Read_Sensors;

VAR
  edge_sensors, first_sensor, second_sensor, third_sensor:BYTE;

     BEGIN
     REPEAT
          BEGIN
               edge_sensors:=p5;
               {writeln(edge_sensors);}
               first_sensor:= edge_sensors AND 16; { Read edge
                                                  sensors}
               second_sensor := edge_sensors AND 32;
               third_sensor := edge_sensors AND 64;

               IF first_sensor=16 THEN
                    edge1:=TRUE;
               IF second_sensor=32 THEN
                    edge2:=TRUE;
               IF third_sensor=64 THEN
                    edge3:=TRUE;

               IF edge1 THEN
                    Timer1;
               IF edge2 THEN
```

```
                    Timer2; {This if then section increments a
                          counter if the sensor is latched true}
             IF edge3 THEN
                    Timer3;

             IF (ABS(Time3-Time1) >= 30) OR (Time1=30) OR
                    (Time3=30) OR (Time2=30) THEN
                    Fake_Edges;
      END;
 UNTIL ((edge1 AND edge2 AND edge3)=TRUE);
{keep looping until all three sensors have registered.}
 IF debugging THEN
      writeln('time1: ',time1:5,' time2: ',time2:5,' time3: ',time3:5);
 END; {Read Sensors}


PROCEDURE Decide_On_Edge_Type;

 BEGIN
 IF debugging THEN
      writeln(' got to edge decision');
 IF ((time1>time2) AND (time1>time3)) THEN  {left to right sloping
                                                      back edge}
      bladepos:=1                      {bladeholder extended}
 ELSE
      IF ((time3>time2) AND (time3>time1)) THEN  {right to left
                                                  sloping back edge}
            bladepos:=2                 {bladeholder retracted}
  ELSE
      IF ((time1=time2) AND (time1=time3)) THEN  {straight edge}
            bladepos:=1 {bladeholder extended}
 ELSE
      bladepos:=1;       {something else}
 IF debugging THEN
      writeln('bladepos (1 extended, 2 retracted): ',bladepos);
 END; {Decide on edge type}
```

```
PROCEDURE Edge_Detection;

    BEGIN
    IF debugging THEN
        writeln('Edge detecting!!!!!!!!!!!');
    Read_Sensors;
    Decide_On_Edge_Type;
    IF debugging THEN
        writeln(' EDGE DETECTION  completed ');
    END; {edge detection}


PROCEDURE Turn_Off_Mandrel_Motor;

    BEGIN
        mandrel_motor:=TRUE;
        motors_on:=TRUE;
    IF debugging THEN
        writeln(' MANDREL MOTOR turned off ');
        wait(2);
    END; {Turn off mandrel motor}


PROCEDURE  Extend_Rotation_Arm;

    BEGIN
    rotation_arm:=FALSE;
    IF debugging THEN
        writeln(' ROTATION ARM is extended to tape surface');
        wait(14);           {wait while arm moving}
    END; { Move_Rotation_Arm_Down}


PROCEDURE Position_Blade;

    BEGIN
    IF debugging THEN
        writeln(' BLADE to be positioned');
    IF (bladepos=2) THEN
        blade_position:=FALSE         {retract bladeholder}
```

```
ELSE
        IF (bladepos=1) THEN
                blade_position:=TRUE;     {leave bladeholder extended}
END; {Position_Blade}
```

PROCEDURE Extend_Blade_Holder_Motor;

```
BEGIN
IF debugging THEN
        writeln('BLADE HOLDER to be extended ');
        mandrel_motor:=TRUE;
        motors_direction:=FALSE;        {motor direction on}
        motors_on:=FALSE;               {motor on}
REPEAT UNTIL p5.1; {when surface prox switch P1 turns on stop
                                doing loop}
        motors_direction:=TRUE;
        motors_on:=TRUE;                {motor off.}
        motors_direction:=TRUE;         {motor direction off}
        clamp:=TRUE;
        blade_position:=TRUE;
IF debugging THEN
        writeln('BLADE HOLDER reached the TAPE surface');
END; {Move_Blade_In}
```

PROCEDURE Pick_Up_Enough_Tape;

```
BEGIN
IF debugging THEN
        writeln('TAPE to be picked up');
        mandrel_motor:=FALSE;           {Turn on mandrel motor}
        motors_on:=FALSE;
REPEAT UNTIL p5.2       {prox switch P2 turns on when enuff tape on
                        blade}
        motors_on:=TRUE;
        mandrel_motor:=TRUE;            {Turn off mandrel motor}
        wait(2);                {wait to allow clutch to disengage so roll
                        can freewheel}
        blade_position:=TRUE;
```

```
        clamp:=TRUE;
    IF debugging THEN
        writeln('BLADE got the TAPE');
    END; {Pick_Up_Enough_Tape}
```

PROCEDURE Activate_Clamping_Ram;

```
    BEGIN
        clamp:=FALSE;
        wait(2);                    {wait for ram to clamp}
    IF debugging THEN
        writeln('tape CLAMPED to the blade');
    END; {Activate_Clamping_Ram}
```

PROCEDURE Retract_Rotation_Arm;

```
    BEGIN
        rotation_arm:=TRUE;
        wait(10);                   {wait for arm to move}
    IF debugging THEN
        writeln('ROTATION ARM moved away');
    END; {Move_Rotation_Arm_Up}
```

PROCEDURE Retract_Blade_Holder_Motor;

```
    BEGIN
        mandrel_motor:=TRUE;
    IF debugging THEN
        writeln(' retracting');
        motors_on:=FALSE;           {motor on}
    REPEAT UNTIL p5.7;          {Repeat until limit switch reached}
        motors_on:=TRUE;
    IF debugging THEN
        writeln('BLADE HOLDER MOTOR retracted');
    END;
```

```
PROCEDURE Place_App_Roller_On_Work_Surface;

    BEGIN
    IF debugging THEN
          writeln('going to the WORK SURFACE');
          Signal_Robot;
    END; {Place_App_Roller_On_Work_Surface}


PROCEDURE Release_Clamping_Ram;

    BEGIN
    REPEAT UNTIL p5.0;      {don't release clamp until robot controller
    output one goes high, saying that it has placed app roller on surface}
          clamp:=TRUE;
    IF debugging THEN
          writeln('CLAMP released');
          wait(1);               {wait for ram to release}
    END; {Release_Clamping_Ram}


PROCEDURE Slow_Down;

    BEGIN
          slow_down_robot_instruction:=FALSE; {set slow down
                                                     instruction}
          interrupt_robot_instruction:=FALSE; {interrupt robot
                                                     movement}
    REPEAT UNTIL p4.5; {move back to reading strain gauge once robot
                              has slowed down}
    END;

PROCEDURE Stop;

    BEGIN
          stop_robot_instruction:=FALSE; {set stop instruction to robot}
          interrupt_robot_instruction:=FALSE; {interrupt robot
                                                     movement}
    REPEAT UNTIL p4.5; {move back to reading strain gauge}
    END;
```

PROCEDURE Cut_Tape;

```
BEGIN
      tape_cutter:=FALSE;     {turn on extend tape cutter}
      wait(3);
      tape_cutter:=TRUE;      {turn off extend tape cutter}
IF debugging THEN
      writeln('Ooh! the tape is CUT');
      Signal_Robot;           {turn on robot input and tell it to apply the
            free end of the tape that resulted when the tape was cut}
END; {Cut tape}
```

PROCEDURE Recover_From_Ripped_Tape;

```
BEGIN
      Cut_Tape;     {Hopefully get a nice straight edge. Need to
                    detach any remaining tape joined to roll. If a long
                    rip, may be impossible to detect.}
      robot_signal:=FALSE;
      interrupt_robot_instruction:=FALSE;
REPEAT UNTIL p4.5;
END;
```

PROCEDURE Apply_Tape_To_Surface;

```
BEGIN
IF debugging THEN
      writeln('APPLYING the TAPE to the surface');
      Signal_Robot;           {robot starts to move, applying the free end
                              of the tape and then taking up the strain}
END; {Apply tape to surface}
```

PROCEDURE Do_Sequence;

```
BEGIN
IF debugging THEN
        Writeln('Do Sequence procedure starting');
        Initialisation;              {reset variables, etc}
IF (p5.3=FALSE) THEN
        Get_New_Roll         {if the tape loaded prox switch isn't on, then
                              get a new roll}
ELSE
        Signal_Robot;
        Turn_On_Mandrel_Motor;          {rotate edge under sensors}
        Edge_Detection;              {detect edge type}
        Turn_Off_Mandrel_Motor;         {stop rotation once edge
                                          detected}
        Position_Blade;              {move blade for angled edge}
        Extend_Rotation_Arm;           {move blade parallel to roll}
        Extend_Blade_Holder_Motor;       {move blade until it touches
                                          the tape}
        Pick_Up_Enough_Tape;          {slide blade under tape edge}
        Activate_Clamping_Ram;        {clamp tape to blade}
        Retract_Rotation_Arm;         {pull tape off roll}
        Retract_Blade_Holder_Motor;    {move blade holder so it won't
                    hit application surface when tape is being applied}
        Place_App_Roller_On_Work_Surface;      {start applying tape}
        Release_Clamping_Ram;         {free tape}
        Apply_Tape_To_Surface;        {start robot moving}
END;  {Do sequence procedure}
```

{Procedure to read the analog input from the strain gauge.Based on routine written by M. Weehuizen (August 1994)}

PROCEDURE Read_Strain_Gauge;

```
CONST
  danger_strain=2.0;
  breaking_strain=2.2;
  ripping_strain=0.8;
  low_strain=0.5;
```

```
  min_oper_strain=1.1;
  max_oper_strain=1.8;
  no_load_strain=0.05;

VAR
  latest_sgr, old_sgr, oldest_sgr: REAL;
  normal_operating_strain: BOOLEAN;
      BEGIN
      IF debugging THEN
            writeln('at strain gauge reading');
      REPEAT UNTIL p4.0;  {start reading strain gauge once strain is being
                              applied}
            latest_sgr:=1.0;      {strain gauge reading variables initialisation}
            old_sgr:=1.0;
            oldest_sgr:=1.0;
            normal_operating_strain:=TRUE;
      REPEAT
            ADDATL:=%01000000;      {Internal trigger to begin A/D}
      REPEAT UNTIL (NOT BSY);  {Wait for A/D to occur}

            oldest_sgr:=old_sgr;
            old_sgr:=latest_sgr;
            latest_sgr:=0.0196*ADDATH;        {Read result of A/D}

      IF ((latest_sgr > min_oper_strain) AND (latest_sgr < max_oper_strain))
      THEN {1.25 is the minimum normal operating strain and 2.0 is the max
                                          normal operating strain}
                  normal_operating_strain:=TRUE
      ELSE
                  normal_operating_strain:=FALSE;
      IF (normal_operating_strain=FALSE) THEN    {only if the normal
      operating strain isn't, does the program check to see how it is different}
      IF ((latest_sgr > danger_strain) AND (old_sgr > danger_strain) AND
      (oldest_sgr > danger_strain)) THEN {assuming the strain on the tape is
                                    rapidly increasing to dangerous level}
            BEGIN
                  Slow_Down;
                  slow_down_robot_instruction:=TRUE; {reset}
                  interrupt_robot_instruction:=TRUE;
            END
```

```
ELSE
        IF ((old_sgr-latest_sgr)>=breaking_strain) THEN  {assuming the
                                                          tape is broken}
                BEGIN
                        Stop;
                        stop_robot_instruction:=TRUE;       {reset}
                        interrupt_robot_instruction:=TRUE;
                END
ELSE
        IF ((old_sgr-oldest_sgr)>=min_oper_strain) AND ((old_sgr-
        latest_sgr)<=no_load_strain) THEN
                BEGIN   {assuming the roll is finished}
                        roll_ran_out_while_applying:=TRUE;
                        Stop;
                        Get_New_Roll;  {robot instructions are reset in
                                        this procedure}
                REPEAT UNTIL p4.5;  {let end effector get to a safe
                                        height}
                        Do_Sequence;
                END
      ELSE
        IF ((old_sgr-oldest_sgr)>=ripping_strain) AND ((old_sgr-
                latest_sgr)>=no_load_strain) THEN
                BEGIN       {assuming the tape is ripping}
                        Stop;
                        Recover_From_Ripped_Tape; {cut the tape
and tell robot to lift up so that the pick up sequence can be done}
                        Do_Sequence;
                END;

                        oldest_sgr:=old_sgr;
                        old_sgr:=latest_sgr;

        IF debugging THEN
                writeln(latest_sgr);
UNTIL p4.1; {third robot output ie, ready to cut}
END;
```

PROCEDURE Roll_Tape_Back;

```
BEGIN
IF debugging THEN
        writeln('rolling the tape back');
        mandrel_motor:=FALSE;           {turns on mandrel motor}
        motors_direction:=FALSE;        {mandrel reverse turning}
        motors_on:=FALSE;               {motors on}
        wait(20);
        motors_on:=TRUE;
        motors_direction:=TRUE;
        mandrel_motor:=TRUE;            {turn off mandrel motor}
IF debugging THEN
        writeln('TAPE rolled back');
REPEAT UNTIL p4.3;          {let robot put end eff at safe height to
                                         reinitiate tape}
END; {Mandrel motor reverse turning}
```

MAIN PROGRAM

```
BEGIN
        reset(serial);
        writeln;
        writeln;
        Writeln('Program starting.  Waiting for operation switch to be
                              turned on.');
REPEAT    {program loops infinitely}
        BEGIN
{REPEAT UNTIL (operation_switch);}  {when the op switch is turned
                on the sequence starts, ie it waits for the op switch to be
                turned on to begin the while loop}
        Do_Sequence;        {Procedure to load a tape, if required,
                        detect the edge and pick up the tape and apply the
                        tape. This procedure is also used if the tape breaks,
                        rips or runs out}
IF debugging THEN
        writeln('finished do sequence');
        Read_Strain_Gauge;
        Cut_Tape;                   {cut the tape when enought tape laid}
        Roll_Tape_Back;                {roll the cut edge under the edge
                                    sensors to press it down a little}
IF debugging THEN
        writeln('the   SEQUENCE   ran SUCESSFULLY');
END; {repeat loop. }
UNTIL FALSE; {Infinite loop}
END. {main program body}
```

Appendix-E

Experiment Results

The following tables are the results of the experiments conducted to study the performance of 'EziStick'. The following is only the data corresponding to the experiment results which were discussed in detail in chapter 7.

Distance mm	Output Volts	Distance mm	Output Volts
0	5.02	14	4.62
1	4.56	15	4.7
2	2.7	16	4.77
3	1.19	17	4.83
4	0.85	18	4.87
5	1.24	19	4.91
6	1.76	20	4.94
7	2.29	21	4.97
8	2.83	22	4.98
9	3.37	23	4.98
10	3.85	24	4.99
11	4.18	25	4.99
12	4.38	26	5
13	4.52	27	5.01

Table 1: Effect of Distance on Edge Sensor Performance

Distance mm	Output Volts	Distance mm	Output Volts
0	5.01	14	4.82
1	4.56	15	4.88
2	3.37	16	4.92
3	2.23	17	4.95
4	1.83	18	4.97
5	2.12	19	4.98
6	2.64	20	4.98
7	3.08	21	4.99
8	3.45	22	4.99
9	3.77	23	4.99
10	4.08	24	5
11	4.34	25	5
12	4.55	26	5
13	4.72		

Table 2: Effect of 15^0 Angle on Edge sensor Performance

Distance mm	Output Volts	Distance mm	Output Volts
0	4.93	14	4.97
1	4.57	15	4.98
2	4.21	16	4.98
3	4.14	17	4.99
4	4.1	18	4.99
5	4.09	19	4.99
6	4.32	20	4.99
7	4.56	21	4.99
8	4.75	22	4.99
9	4.85	23	4.99
10	4.91	24	5
11	4.93	25	5
12	4.95	26	5
13	4.96		

Table 3: Effect of 30^0 angle on Edge Sensor Performance

Load Newton	Tape tension Volts
0	0
5	0.3
10	1.1
15	1.56
20	2.2
25	2.9
30	3.55
35	4.2
40	4.77
45	5.43
50	6.1

Table 4: Effect of Load on Tape Tension (Spring Balance)

Load kg	Tape tension Volts	Load kg	Tape tension Volts
0.5	0.75	3.7	4.51
0.9	1.24	4.1	4.91
1.3	1.67	4.5	5.38
1.7	2.1	4.9	5.85
2.1	2.5	5.3	6.35
2.5	3	5.7	6.82
2.9	3.4	6.1	7.39
3.3	4.01	6.5	7.92

Table 5: Effect of Load on Tape Tension

Load kg	Tape tension(up) Volts	Tape tension(down) Volts
0.5	0.75	0.81
0.9	1.24	1.39
1.3	1.67	1.85
1.7	2.1	2.54
2.1	2.5	3.02
2.5	3	3.52
2.9	3.4	4.08
3.3	4.01	4.75
3.7	4.51	5.12
4.1	4.91	5.5
4.5	5.38	6.15
4.9	5.85	6.62
5.3	6.35	6.87
5.7	6.82	7.25
6.1	7.39	7.56
6.5	7.92	7.92

Table 6: Effect of Hysteresis1

Load kg	Tape tension Volts	Load kg	Tape tension Volts
6.5	7.95	3.7	4.55
5.7	7.01	0.5	0.78
4.1	5.05	2.5	3.25
1.3	1.84	4.1	5.09
6.1	7.4	3.3	4.17
4.5	5.45	4.9	6.1
1.7	2.29	2.1	2.67
5.3	6.52	0.9	1.3

Table 7: Effect of Hysteresis2

Load kg	Tape tension Volts	Load kg	Tape tension Volts
0.4	0.175	3.6	1.143
0.8	0.288	4.0	1.275
1.2	0.407	4.4	1.421
1.6	0.515	4.8	1.57
2.0	0.635	5.2	1.724
2.4	0.753	5.45	1.874
2.8	0.875	5.85	1.992
3.2	1.008		

Table 8: Calibration of Tape Tension Monitoring System

TAPE TENSION (Volts)

Sl No.	Masking Tape	Brown Tape	Metallic Tape	Clear Tape
1	1.3	1.35	1.17	1.62
2	1.36	1.46	1.35	1.62
3	1.46	1.51	1.31	1.67
4	1.54	1.38	1.31	1.69
5	1.62	1.51	1.31	1.88

Table 9: Tapes Vs Tape tension at Speed 100 mm/s

TAPE TENSION (Volts)

Sl No.	Masking Tape	Brown Tape	Metallic Tape	Clear Tape
1	1.38	1.51	1.27	1.88
2	1.54	1.58	1.27	1.88
3	1.58	1.58	1.38	1.85
4	1.66	1.66	1.35	1.93
5	1.69	1.69	1.42	1.93

Table 10: Tapes Vs Tape tension at Speed 200 mm/s

	TAPE TENSION (Volts)			
Sl No.	Masking Tape	Brown Tape	Metallic Tape	Clear Tape
1	1.54	1.81	1.16	2.04
2	1.93	1.93	1.35	1.96
3	1.81	1.88	1.35	1.96
4	1.95	1.88	1.5	2.01
5	1.88	1.93	1.35	1.96

Table 11: Tapes Vs Tape tension 400 mm/s

	TAPE TENSION (Volts)			
Sl No.	Masking Tape	Brown Tape	Metallic Tape	Clear Tape
1	1.69	1.77	1.31	2.04
2	1.95	1.88	1.42	2.01
3	1.88	1.88	1.42	1.96
4	1.88	1.81	1.42	1.96
5	1.81	1.96	1.51	2.01

Table 12: Tapes Vs Tape tension at Speed 600 mm/s

Speed of Tape application	AVERAGE TAPE TENSION (Volts) Masking Tape	Brown Tape	Metallic Tape	Clear Tape
100 mm/s	1.46	1.44	1.29	1.69
200 mm/s	1.57	1.61	1.34	1.89
400 mm/s	1.82	1.93	1.33	1.98
600 mm/s	1.84	1.86	1.41	1.99

Table 13: Tapes Vs Average Tape tension

Sl No.	TAPE TENSION (Volts) Masking Tape	Brown Tape	Metallic Tape	Clear Tape
1	1.38	1.31	1.05	1.38
2	1.58	1.38	1.24	1.46
3	1.74	1.46	1.24	1.42
4	1.46	1.46	1.24	1.42
5	1.43	1.46	1.24	1.46

Table 14: Tapes Vs Tape tensions at Speed 100 mm/s

TAPE TENSION (Volts)

Sl No.	Masking Tape	Brown Tape	Metallic Tape	Clear Tape
1	1.18	1.38	1.23	1.77
2	1.46	1.51	1.31	1.66
3	1.54	1.51	1.38	1.62
4	1.54	1.55	1.46	1.62
5	1.58	1.63	1.46	1.62

Table 15: Tapes Vs Tape tensions at Speed 200 mm/s

TAPE TENSION (Volts)

Sl No.	Masking Tape	Brown Tape	Metallic Tape	Clear Tape
1	1.67	1.77	1.12	1.77
2	1.69	1.81	1.17	1.77
3	1.69	1.66	1.24	1.77
4	1.74	1.74	1.35	1.74
5	1.67	1.62	1.39	1.74

Table 16: Tapes Vs Tape tensions at Speed 400 mm/s

AVERAGE TAPE TENSION (Volts)

Tape Application Speed	Masking Tape	Brown Tape	Metallic Tape	Clear Tape
100	1.52	1.41	1.19	1.43
200	1.46	1.51	1.37	1.66
400	1.74	1.72	1.25	1.76

Table 17: Tapes Vs Average Tape tension