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Plasma-arc Cutting control: Investigations into machine vision, modelling and cutting head kinematics

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Abstract

Plasma-arc cutting (PAC) is widely used in industry, but it is an under-researched fabrication tool. A review of the literature reveals much study is needed to improve the PAC process regarding efficiency, quality, stability and accuracy. This research investigated a novel control method for PAC. The PAC process was investigated to identify the gaps, and develop feasible methods, methodologies and systems to improve the PAC cutting quality and process control using machine vision. An automated, visual-inspection algorithm was successfully developed. The algorithm uses NC code to path plan and perform kerf width measurement. This visual inspection facilitated research into several aspects of PAC such as the extent of radiative heat transfer, the significance of kerf asymmetry, and a model describing the slope of the leading edge of the kerf-with respect to feed rate and material thickness. A kinematic investigation was conducted on 3 bevel capable plasma heads to complete the elements of a novel control method.

An automated, visual-inspection (AVI) system for PAC was designed that consists of a vision unit and a mounting rig. This system is able to perform real-time, kerf width measurement reaching an accuracy of 0.1mm. The methodology was validated by experiment, testing cuts on parts with varying size, shape and complexity. The outcomes of this research were published in the International Journal of Mechanical and Production Engineering and the proceedings of the 2017 Mechatronics and Machine Vision in Practice (M2VIP) international conference.

With this developed vision rig, further research was conducted such as an empirical investigation into the relationship between kerf angle and kerf width with respect to torch height, feed rate and material thickness. This investigation was comprised of 35 combinations of the process parameters with 9 replicates for each. A relationship between the process parameters and quality measures was developed, and the magnitudes of kerf asymmetries were quantified.

The understanding of the phenomenology of PAC is deficient in several areas. An experimental study was undertaken that reduced the effects of heat transfer by conduction and convection in order to estimate the contribution by radiative heat transfer. This experimental study maintained an arc between a water-cooled anode and plasma torch for 15 seconds. A test piece was specifically designed with imbedded, resistance-temperature-device thermometers positioned around the transferred arc and the temperature was measured. This investigation was able to estimate the effects of radiation from the plasma-arc. The study found radiative heat transfer is less than 3% of the total power input.

Another experimental study obtained information on the shape of the leading edge of the kerf. For this study slots were cut into steel plates of 6, 8 and 10mm thickness, at feed rates between 350 and 2000mm/min with a torch height of 1.5mm. Edge points for the centre axis of the leading profile were obtained. A relationship between surface angle and material thickness and feed rate was established and is validated through the test range.

A study on obtaining cutting profile data on the front face of the kerf was also undertaken. Slots were cut into plates of 6 and 10mm thickness. Edge points were obtained for the front 180 degrees of the kerf face at sections in 2mm increments. A 3D representation of the shape of the face was then able to be presented.

Finally, the kinematics for 3 bevel capable PAC heads was developed. Two of the heads are existing industrial heads, and the third head is being developed by Kerf Ltd. The kinematics investigation produced the DH parameters and transformation matrices for the forwards kinematics. These were validated using MATLAB®. The resulting dynamics were also produced.

In conclusion, PAC is a complicated process. This research carried out several studies and has addressed several literature gaps with the proposed methods, methodologies and systems, developed through machine vision and PAC head kinematic study.

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Nomenclature

Symbol	Variable	Description	Units
A_{i+1}^{i}	homography matrix		-
A_{rtd}	RTD coefficient 1	coefficient 1 in RTD relationship	-
B_{rtd}	RTD coefficient 2	coefficient 2 in RTD relationship	-
M_u	molar mass		$kgmol^{-1}$
c_V	specific volume		m^3kg^{-1}
c_p	specific heat capacity	specific heat capacity	$Jkg^{-1}K^{-1}$
${}_{i+1}^{\ i}R$	rotation matrix		-
$\acute{m}$	mass flow rate		kgs^{-1}
$\vec{\boldsymbol{C}}$	camera offset	distance between camera center and torch center	mm
$\vec{\boldsymbol{c}}$	disk center	location of the disk center in the camera reference fame	pixels
$\vec{\boldsymbol{d}}$	disk center	location of the center of the callibration disk	m
$\vec{\boldsymbol{e}}$	edge point coordinate	coordinate of the edge point on circle circumference	pixels
$\vec{\boldsymbol{f}}$	force vector		N
$\vec{\boldsymbol{t}}$	torch head location	location of the center of the torch	m
α_f	fisheye parameter 1	first constant in the equation for fisheye scaling	-
α_t	connicity, kerf angle	the deviation of the kerf wall from 90 degrees	degrees
α_d	thermal diffusivity		$Jm^{-2}K^{-1}$
β_f	fisheye parameter 2	second constant in the equation for the fisheye scaling	-
δ_z	change in height	change in height from a set point	m
h	torch height	the distance between the torch nozzle and plate	m
Γ	scaling parameter		-
A	quadratic coefficient 1		-
Ar	area	the area being considered	m^2
B	quadratic coefficient 2		-
C	quadratic coefficient 3		-
E	energy		J
HAZ	Heat Affected Zone width	the width of the area affected by the heat of plasma cutting	m
I	current		A
J	Jacobian		-
KW	kerf width	distance between two edges of kerf	m
L	latent heat		J
M	mach number		-
MRR	mass removal rate	the rate at cut material is removed	kgs^{-1}
Nu	Nusselt number		-
P	pressure		Pa

Po	power		W
Pr	Prandtl number		-
Q	Heat	the energy transferred via heat	J
R	ideal gas constant	8.314	$Jmol^{-1}K^{-1}$
Re	Reynold's number		-
SR	surface roughness	density of surface deviations from the average surface	µm
T	temperature		K
V	voltage		V
a	slope	slope in line equation	-
b	intercept	intercept in line equation	-
c	speed of sound	the speed of sound	ms^{-1}
d	distance		m
f	feed rate	rate of torch advancement	ms^{-1}
g	plenum pressure	the pressure of the pl asma in the plenum	Pa
i	horizontal pixel count	horizontal pixel coordinate	pixels
j	vertical pixel count	vertical pixel coordinate	pixels
m	mass		kg
pm_0	pixel scaling constant	constant for linear scaling relationship between pixels andmm.	$Pixmm^{-1}$
pm_h	pixel scaling factor	rate of change of scaling factor with respect to height	$Pixmm^{-1}$
r	radius	distance from center	-
r'	adjusted radius	radius adjusted for fisheye compensation	-
res	resistance		Ω
s	distance	distance between two points	m
th	plate thickness	thickness of plate	m
u	surface unevenness	the amount of deviation in the surface from its average level	m
v	velocity		ms^{-1}
x	X coordinate		m
y	Y coordinate		m
z	Z coordinate		m
α, θ	rotation		rad
γ	specific heat ratio	specific heat / specific volume	-
κ	thermal conductivity	thermal conductivity	$Wm^{-1}K^{-1}$
μ	viscocity		Pas^{-1}
ρ	density		kgm^{-3}
τ	torque		Nm
ω	angular velocity		$rads^{-1}$
ϵ	emmisivity	the effectivenes sin emitting energy via radiation	-

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