Using Non- Contact technique to measure Temperature during metal processing by "CO_2 laser- gas jet" system at different velocities.

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Abstract

The aim of this research is to measure temperature distribution by non–contact technique (Cyclops 52) during metal processing by CO_2 laser –gas jet system This project is achieved at different speeds .Quick response and accurate results will incourage researchers to adopt this method ,particularly for moving and inaccessible object by Contact methods such as thermocouple .

خلاصة البحث

الهدف من هذا البحث هو قياس توزيع درجة الحرارة للمعادن المعالجة بمنظومة "ليزر ثاني اوكسيد الكاربون والغاز المتدفق" باستخدام تقنية القياس عن بعد (بدون تماس) حيث تم انجاز البحث عند سرع مختلفة.

ان سرعة رد الفعل لجهاز القياس ودقة النتائج ستشجع الباحثين لتبني هذه التقنية وخاصة الاهداف المتحركة والتي يصعب الوصول اليها بطرق قياس التماس مثل المزدوج الحراري

Introduction

An urgent need exists to measure the surface temperature of metals during metal processing by "CO_2 laser gas jet" system , because the sample surface is moving, a non-contact method is most Convenient to use . After a radiation beam interact with the surface of material ,.its intensity is measured by a detector .The detector converts the beams radiation into an electrical signal which is amplified and measured .

At temperature above 650C all objects becomes incandescent indicating that the radiation covers the visible spectrum of light . When temperature is further increased , the colour of the object changes from red to yellow and white as shown in figure(1).

The temperature is directly responsible for the generation of this radiation which called thermal radiation which covers the region from mid infrared to visible radiation (1,2) .

General Principle in Thermal Radiation (2)

1- The parameter that characterize electromagnetic radiation is the wavelength (λ). Black body which absorbs radiation at all wavelengths and in turn radiate in the same range of wavelength are useful for calibration and testing detectors . The radiation emittance at wavelength (λ) which radiated from a black body at an absolute temperature (T) Can be written as :

2-

$$E_{(\lambda,T)} = \frac{C_1}{[(\exp c_2) - 1]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where $C1= \dfrac{8\,\pi\, ch}{\lambda^5}$, $C_2 = \dfrac{ch}{\lambda\, KT}$

C = speed of light (3 * 10^8 m/s)

h = planks constant . (6.6 26 *10^{-34} J .S

λ = wave length in (m)

T = Temperature in (K)

K = Boltzmann Constant (1. 3805* 10^{-23} J/K)

The spectral radiant emittance of an ideal black body at various temperatures as a function of wavelength can be expressed by Wien's Law for black body .

λ_m . T= 2. 898* 10^{-3} m.k……………….(2)

i . e : The wavelength (λ_m) corresponding to the maximum emission for any temperature is constant.

Superiority of non contact over contact techniques

It was found that the non-contact method of measuring temperature offers great advantages over the contact method like thermocouple , particularly in following cases (1,2):

a-The measuring of very high temperatures when metallurgical reasons forbid the use of the thermocouple .

b-Temperature measurements on materials having a very low thermal conductivity or small thermal capacity .

c-Measurement on inaccessible or moving Objects .

d-Temperature measurements requiring a very short response time.

e-Measuring very small or very large area which can be accomplished by the use of different lenses.

Kinds of non-Contact techniques (thermal detectors)

Due to the growing need for temperature measurements a number of highly responsive radiation detectors have been developed .The detectors enable reliable and accurate temperature measurements owing to the recent advancement electonic , allowing processing of a very small signal in the current or voltage range.

Below many of these detectors :

a- Pyrometer techniques.

b- Infrared cell.

c- Photo diod cell.

d- Temper colour .

e- Infrared thermometer (Digital Camera Cyclops 52 .

During the present research the last technique (Cyclops 52) was employed (19).

CO2 gas laser (10)

High power CW laser action was reported in the rotational transitions of the 001 – 100 Vibration band of CO_2 at wavelength near 10.6 µm .The mechanism proposed was collisions of the second kind between ground state CO_2 molecules and excited N molecules :

CO_2(000+ N_2 (v=1) $\rightleftarrows$ CO2 (001 + N_2 (v=0) -ΔE(=18 cm^{-1})

Fig (2) shows pertinent parts of the vibrational energy level diagram of Co_2 and N_2 . shortly afterwards progress toward high power and high efficiency was achieved with the addition of He. The highest power is presently achieved by running a discharge in a flowing gas mixture of CO_2 - N_2 –He.

Parameters Dependent on the Target during metal processing by CO_2 laser

A-Absorption of radiation : Absorption of Infrared radiation (and in particular a CO2 laser beam of 10.6 µm wavelength) by a metal with a smooth Surface is very small due its good conductivity .

Fortunately the absorption is significantly affected by metal Surface Conditions. It was reported (6).That the absortion and its Coefficient are a function of heating time , Power level of the laser beam , optical and thermal properties of the material surface temperature .However the infrared absorption of metals is largely dependent on conductivity absorption by free electron.

Arata and king. (6, 12) produced techniques to improve the absorption of a polished surface by adopting the following:

i- Roughing the surface

ii-Coating the surface with a non- metallic thin layer such as colloidal graphite or a fine metallic powder.

iii-Creating a Cavity or Keyhole by focusing the laser beam to work as black body.

Engel (7) and Schawlow(8) pointed out that the distortion of the metal surface is created soon after melting begins , which leads to an increase in the absorptivity . Increasing the absorptivity is very important for drilling , cutting and welding processes using a CO_2 laser as a heat source. It was reported by Gagliano and others (4 , 17) that the subsequent absorption of laser beam radiation Causes a molten puddle to propagate into the bulk material . when the power level is raised , vaporization occurs and a high velocity plume is ejected from the material surface .

For the first stage of metal boiling and just before keyhole creation the emitted vapour becomes highly absorbent to the CO2 laser beam and the greatly increased boiling rate causes local surface depression and the formation of a keyhole. The deeper the cavity , the greater the absorbtivity due to multiple internal reflection inside the keyhole (9)

B-Reflectivity : The reflectivity of the metal surface is a very important parameter which defines the ratio of the light falls on a surface to that actually absorbed (11) .This parameter can be used in heat treatment .The reflectivity in other words , could be expressed as the ratio of the radiant power reflected from the surface to the radiant power incident on the surface. Metals such as gold have very high reflectivity to infrared radiation , and thus such metals are used to coat the mirrors used in laser systems

Gagliano (4)stated that generally speaking , the reflectance of most metals increases with wavelength hence more power is required from a long wavelength laser than a short wavelength one to initiate absorption . Since the CO2 laser is in the infrared region (10.6 µm) , correspondingly high power beams are required for most machining process, i.e. the reflectivity is a problem and could be a big barrier to application of the CO_2 laser in welding and cutting of many metals.

The temperature of the surface another factor which greatly affects the reflectivity of metals .As the temperature increases, reflectivity often decreases due to:

i-Increased temperature affecting the electronic structure of the work piece due to the phase transition .

ii-Surface shape changes due to strain from thermo – mechanical stresses and later evaporation producing a black body hole.

iii-Vapor or gas break down on the workpiece surface causing a plasma. If the plasma frequency exceeds the optical frequency , the plasma can respond to an incoming electromagnetic wave and the reflection coefficient is high , Gagliano (4) explained the role of the vaporization state . He believes that the decrease in reflectivity is due to trapping of the light at the material surface .

iv-surface chemical changes such as oxidation affecting the workpiece electronic structure due to metal reaction with atmospheric air and the assisting gas , forming oxides during heating .

Therefore the reflectivity decreases since the absorptivity of oxides is greater than pure metal at room temperature.

Arata and Steen (6.13) pointed out that , in general , highly polished metallic surfaces have a very high reflectance at a wavelength of 10-6 µm . The reflectivity of metals , however, varies with their surface condition .

C-Thermal properties : It was concluded (1) that the significant factors influencing thermal conductivity of metals are :

i-atomic structure

ii-presence of impurities .

iii-Temperature and heat flow.

Metals such as gold ,silver and copper are difficult to process by laser due to their regular atomic structure, which endows them with high thermal conductivity .

Impurities change the regularity of the lattice structure and reduce thermal conductivity , and hence the formation of layer of oxide (on suitable metals) will decreases conductivity and enhance absorption of laser energy .

Thermals conductivity is found generally to be directly proportional to absolute temperature (5).

The Equipments

7-1- CO_2 laser system (525 Everlase Model).

The 500w CO_2 laser system (525 Ever lase model) is typical of equipment used for metal processing which is now regularity carried out in industry (3 ,14, 17 , 18 , 20) .

7-2 – Infrared thermometer (Digital Camera Cyclops 52):

Cyclops 52 is used for non- contact temperature measurement in the range 600-3000c (19) .According to the supplier , it can work in a wide rang of industrial applications such as metal processing .

Cyclops 52 operates in a narrow wave band (0-8-1.1µm) specially selected to answer maximum freedom from errors due to emissivity and atmospheric absorption.

It automatically compensates for ambient temperature changes to give immediate, reliable readings with an accuracy of 0.5% and stable operation.Cyclops has the following facilities:

a- Variable focus optical system allowing focusing from 1 m to infinity.

b- Optional close up lenses to allow measurement of targets as small as 0.4 mm by using lens No 110, and at maximum focus distance which is 205 mm.

c- Precise definition of the target spot together with a digital display of the target temperature in the view finder .

d- Choice of measuring mode, continuous , beak or valley hold.

e- Digital output suitable for driving an optical digital printer.

Figure (3) shows the Cyclops 52 remote sensing thermometer . when measuring above 1200 C, the dark protection filter (R70 C) is attached to the main lens before fitting the close up lens.

It is Possible to store, print or transfer to computer , series or sequences of temperature readings by connecting the portable Dp-c data processer to the digital output socket .

Results and Discussions

Due to minimum spot which could be focused approximately 0.4 -0.5 mm diameter a wide cut (0.5 mm) is necessary otherwise the temperature recorded will be the average of the cut area and part of the heat affected zone. A problem in using Cyclops 52 arose when the cut was reaching completion . The temperature recorded is always less than it should be due to the fact that most of the radiation is pushed to the opposite side of the cut i.e. away from the thermometer by the gas jet (15). Consequently , very little radiation is picked up by thermometer and may not give a correct reading due to the cooling supplied by gas jet used during material processing by CO_2 laser gas jet system. To overcome this problem we suggest either processing without using gas jet , or studying only the marking states (in complete cut) which is the first step towords a complete cut .

The second case was adopted and good results were achieved.

Figure(4) shows the temperature variations a long a "marking path" for different cutting speeds. A marking path is defined as the area of the work piece surface heated by laser beam when a complete cut is not achieved . The marking process was carried out at 5 psi gas pressure and at 170 w output power . An in complete cut is deliberately made for the reasons already explained. The temperature fluctuates from point to point along the whole marking path.

The difference in maximum and minimum temperature recorded is found to be speed dependent , see figures (4) and (5) . For instance , at lower speed of 5% of 25mm/s, the temperature difference is 437 c,while at a higher speed of 18.75% it is 248 c. The average temperature is also speed dependent as shown in figure (6) . As the speed increases there appears to be heat build up in the cutting front so the temperature increases . The heat build up at the cutting front indicates better coupling between beam , gas jet and material and an enhanced absorption process . Absorption enhancement is due to the oxidation process , while the only factor that reduces the amount of heat absorbed at higher cutting speeds compared to lower speed is the interaction time which can be explained as follows; Increasing the marking speed reduces the interaction time which means less energy can be contributed and reduces the dissipation of the heat through the bulk of the work piece (i. e less energy wasted by conducting) .

In other words , There is a thinner liquid layer in comparison with the liquid layer created at slower cutting speed , particularly when the gas pressure and laser power are constant . A thinner liquid layer again can be easily removed by the gas jet available which finally produces a smooth cut surface . From the above explanation , it is possible to conclude that as the marking speed increases , the cut edge surface is expected to be smoother.

In certain length of marking , the number of temperature points which are recorded by Cyclops 52 for higher cutting speeds are less than that of the lower speeds . owing to many temperature points being missed in the interval distance between any two temperature point at higher speed , the curve of the higher speed may look smoother than it should be from the number of points and the difference between higher and lower temperature values , a better clue can be given to produce a general shape .

The temperature changes along the marking path can be attributed to the inhomogeneity of the materials and their properties such as conductivity and other thermal properties .As a result the thermal conductivity process is affected , which gives different temperature at different points . Figure(5) shows a similar relationship to that produced in figure (4) but for higher pressure (20 psi).

Conclusions

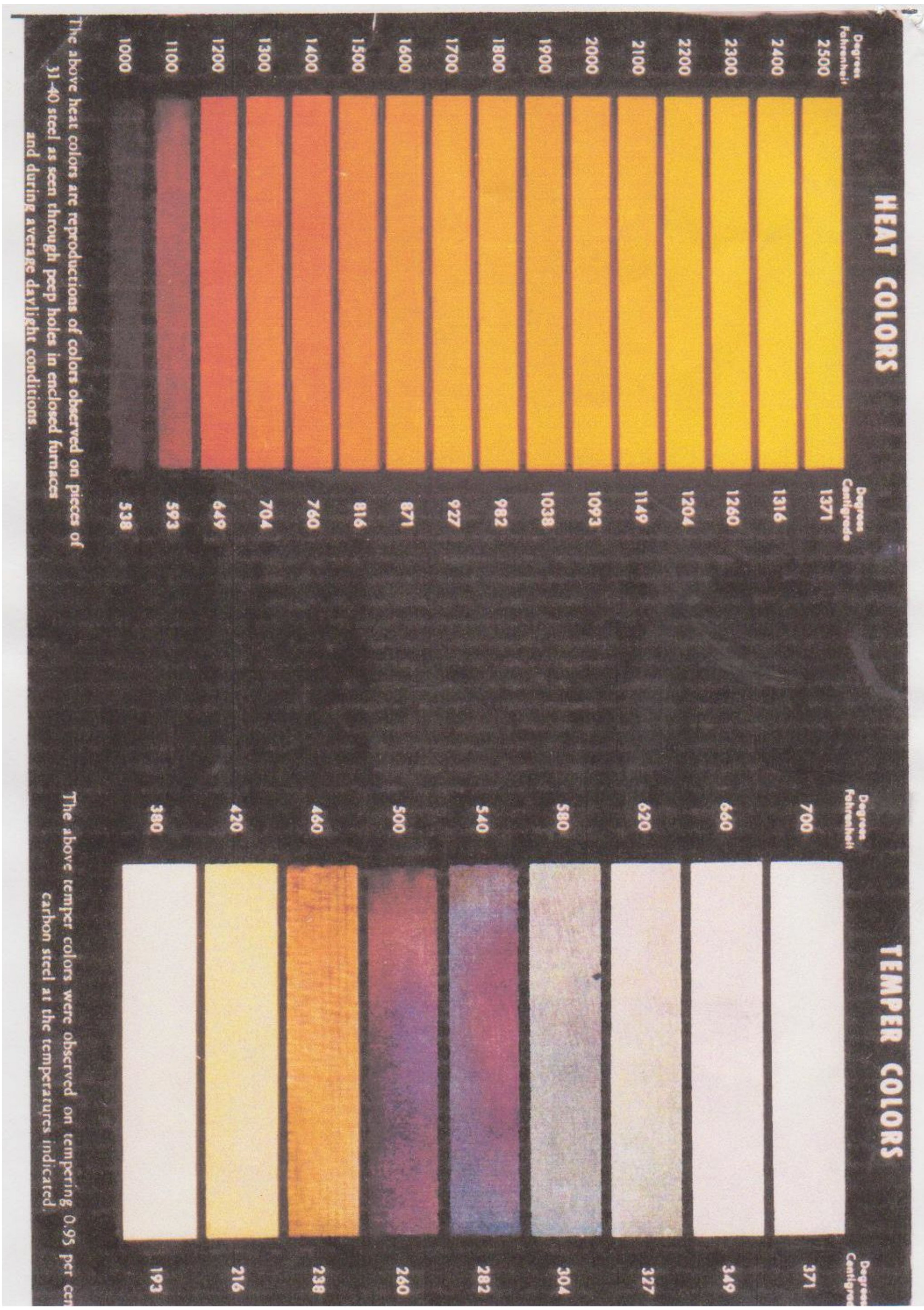
Non–contact method during material processing by "Carbon dioxide laser – gas jet system" to measure temperature distribution was adopted . Relationships between temperature variation and cutting speed ,laser power and gas pressure were produced .

The following point are concluded :

a-It was found that the non- contact technique is easy to use and giving reasonable accurate results .

b- Variation in temperature from point to point a long the marking path has been recorded . The Variation in temperature is considered to be the reason why the cut edge is not smooth (bad quality).

c- Variation in the average temperature along the marking path explain how heat is conducted through the workpiece . Higher average temperature means more evaporation occurs.


HEAT COLORS
Degrees Fahrenheit
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
Degrees Centigrade
1371
1316
1260
1204
1149
1093
1038
982
927
871
816
760
704
649
593
538
The above heat colors are reproductions of colors observed on pieces of 31-40 steel as seen through peep holes in enclosed furnaces and during average daylight conditions.
TEMPER COLORS
Degrees Fahrenheit
700
660
620
580
540
500
460
420
380
371
349
327
304
282
260
238
216
193
The above temper colors were observed on tempering 0.95 per cen
carbon steel at the temperatures indicated.

220	straw yellow	310	light blue
240	light brown	325	grey
270	brown	350	grey purple
285	purple	375	grey blue
235	dark blue	400	dull grey

Fig.(1)

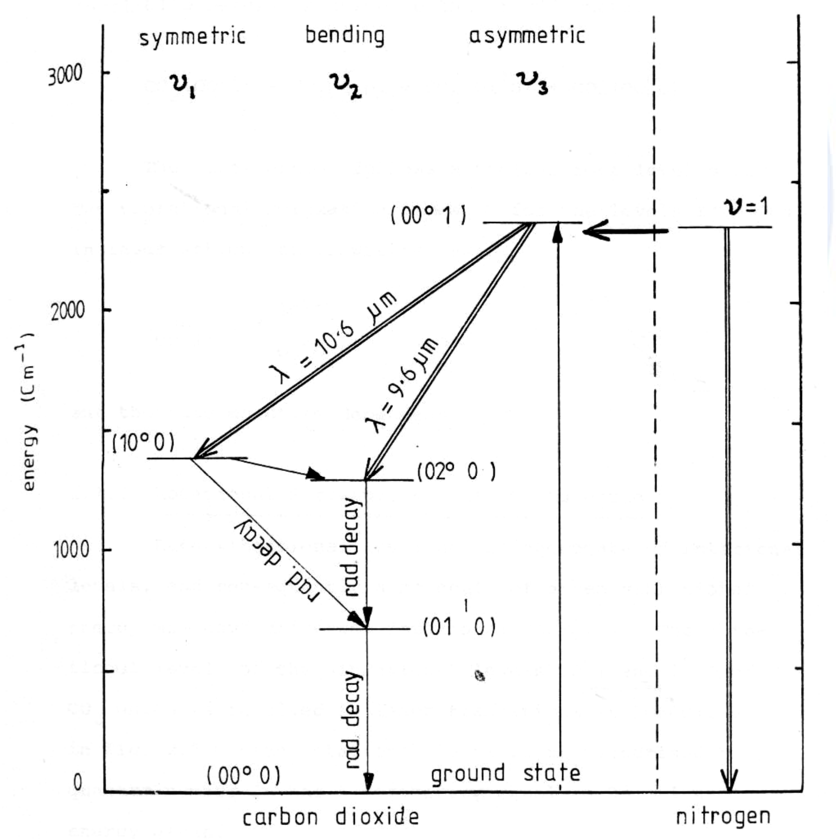


FIG. 2.2: Energy level diagram of lower vibrational levels of CO_2 and N_2.

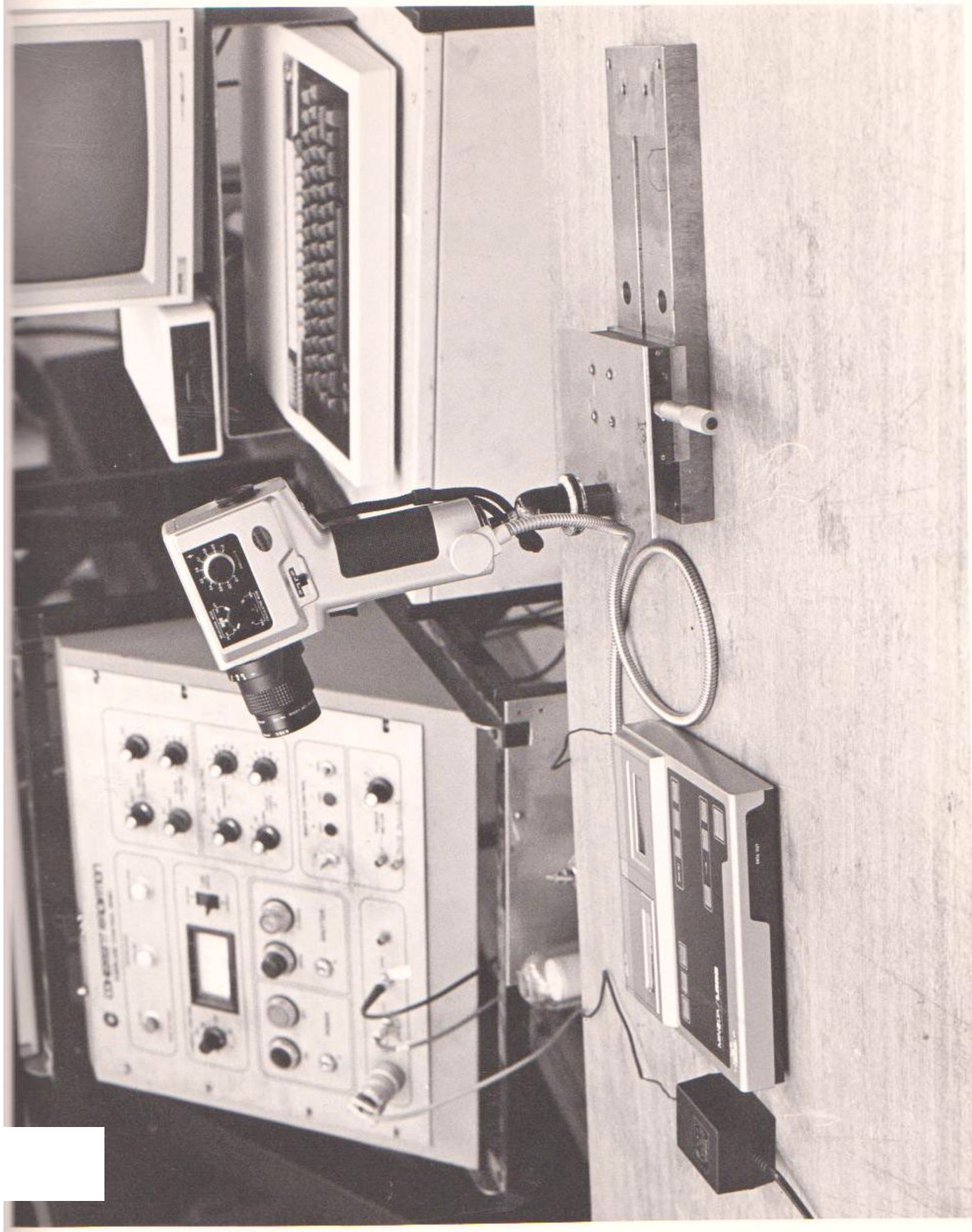


Fig. 4. 5. General view of the Non-Contact Infrared Thermometer. (Cyclops 52)

Fig. 3

Using Non- Contact technique to measure Temperature during metal processing by "CO_2 laser- gas jet" system at different velocities.

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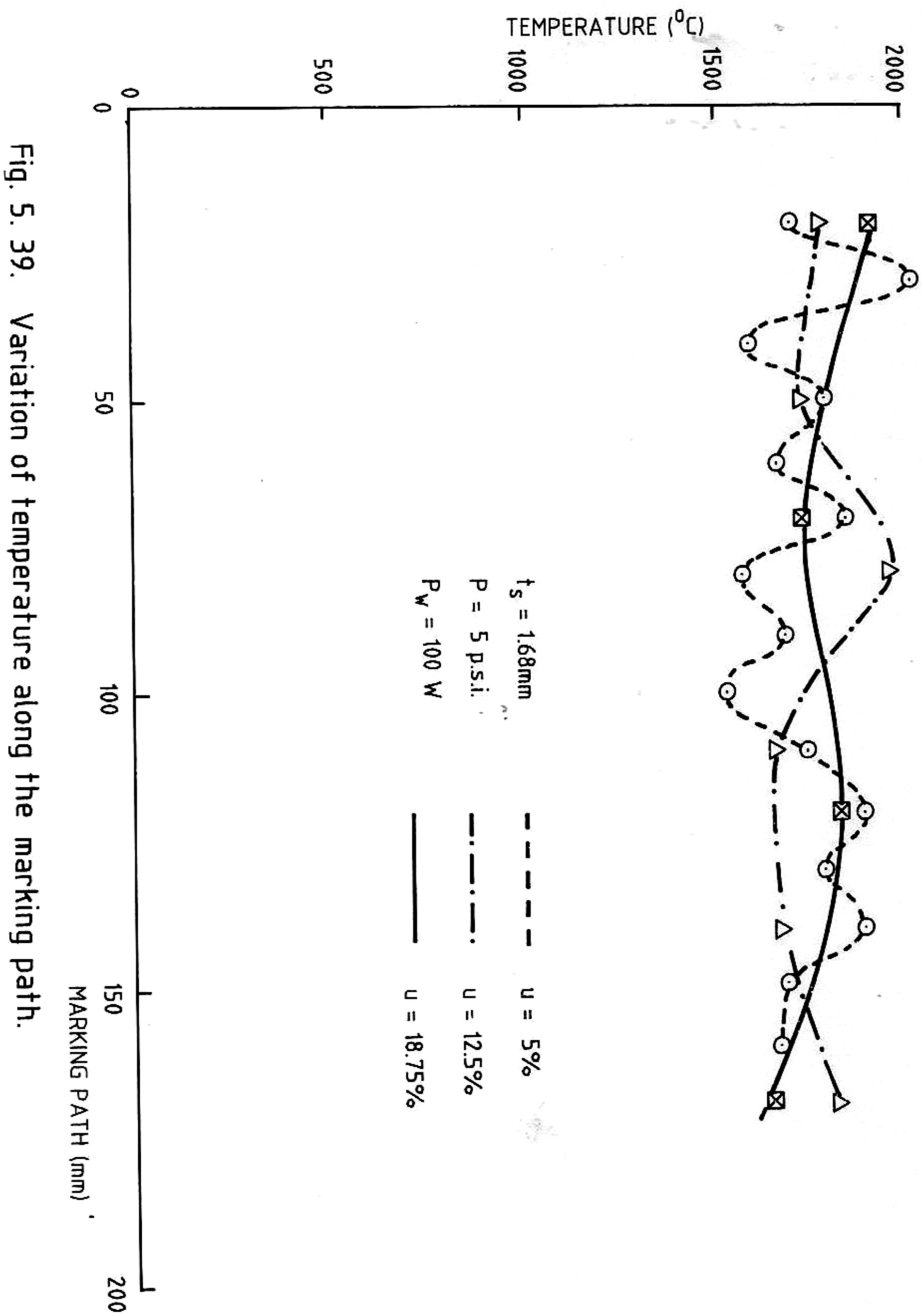

Fig: 4

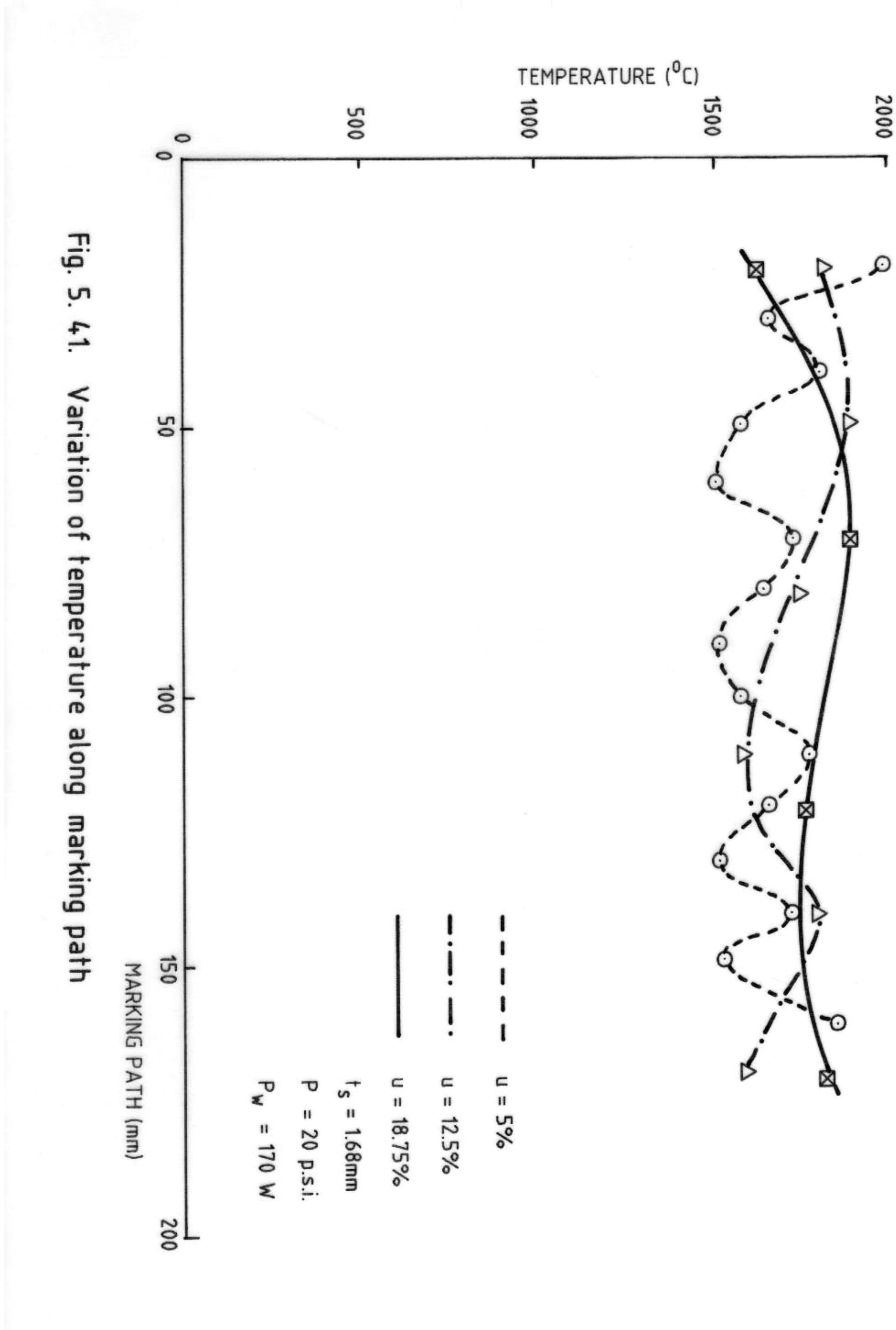

Fig. 5. 4.1. Variation of temperature along marking path

Fig: 5

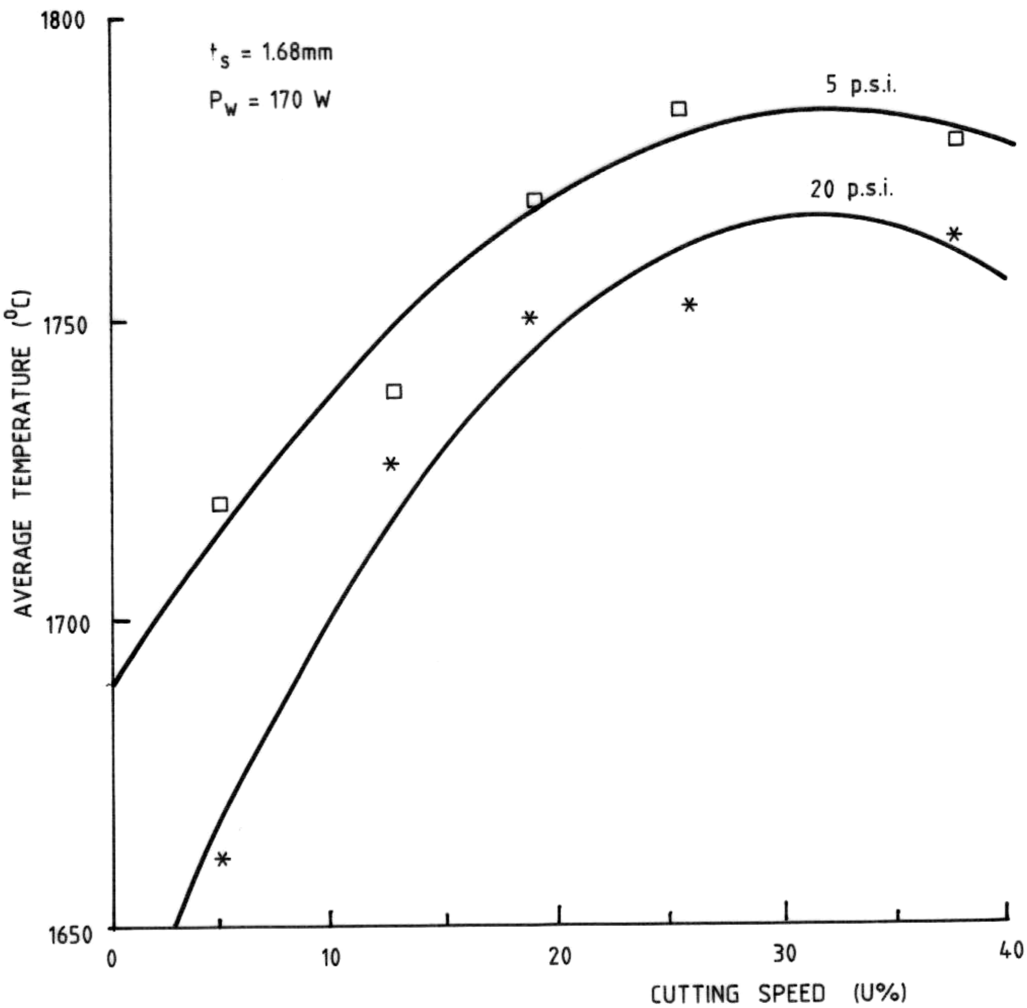

Fig. 5. 40. Relationship between average temperature and cutting speed.

Fig: 6

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