Flame Cutting Practices for Economy and Performance*

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ABSTRACT, Flame cutting costs are reviewed and are shown to have a large labour content capable of reduction by good housekeeping and modern practices. Application of optical tracing and numerical control offer considerable potential for improvements plus cost savings. Data processing systems have been developed for a variety of application of NC. Plasma and laser cutting have special applications. Australian research has rationalised code requirements for removal of flame cut edges. Finally more appropriate surface roughness values are tabled and replicas of cut surfaces are described.

1. Introduction

Flame cutting is really only a support to welding, but a vital one, for most weldments are made from materials flame cut to shape or size at some stage. Hence any "Achievements Through Modern Welding Processes" can be very much influenced by flame cutting practices.

Apart from the actual cost of cutting, the indirect expenses for such things are repairs and post-cutting treatments can add significantly to total fabrication costs. These need not arise if the work is done correctly the first time.

For these reasons the authors review a number of basic factors which have an effect on economy and performance of this basic method of material preparation. It is hoped this will lead to a greater awareness of what is necessary for the best use of flame cutting. Emphasis is placed on machine flame cutting as this offers the greatest potential for savings, but much of what is said on housekeeping applies to hand cutting. In addition other thermal cutting processes are described because these must now be considered complementary to flame cutting.

To the average layman, flame cutting is almost unknown. Some may have seen cutting carried out on a building site or at an Exhibition, but in the main very little is known about it. To managers, engineers, foremen and supervisors the process allows economic preparation of materials. It has been around for many years and does not generally get a great deal of their attention, more so as it directly constitutes a small part of the total fabrication costs.

Because the process is simple, familiarity breeds contempt, but in most shops it will be worthwhile for management to take time off to consider where costs are located and often wasted. This must inevitably lead to significant savings, whih can vitally assist competitive tendering.

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2. Breakdown of Cutting Costs

Before going on to look at details it is worthwhile reviewing the major cost areas associated with cutting. Fig. 1 by Smith[1] gives breakdown of the direct cost for both "standard" and "Hi-Speed" nozzles and from this it bears emphasising :

- Labour costs are the greatest areas for savings.
- Plate handling deserves more attention than it normally seems to receive.
- Improvements in cutting time and machine utilisation can significantly cut costs.
- Gas costs, while the least of the costs, involved, can be reduced also.

In addition, the overall cost of fabrication is very much influenced by a number of indirect costs attributable to cutting such as :

- postcutting treatments
- surface roughness
- extra fabrication costs.

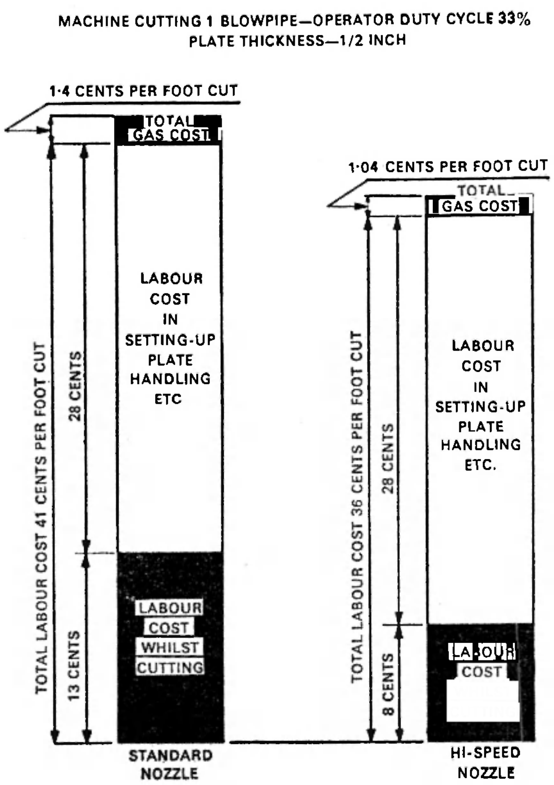

Fig. 1. Breakdown of Cutting Costs for standard and 'Hi-Speed' nozzles shows importance of labour costs.

Each of these various areas for cost saving and improved performance will now be treated in more detail.

3. Labour Costs

As stated above, Fig. 1 shows that labour costs are the greatest areas for savings in cutting and most of what follows is orientated to achieving these economies. Constant attention is needed if the full potential for reductions in fabrication costs are to be realised.

In turn, the pressure to further reduce these costs is a factor that has stimulated much of the effort to develop cutting machines into high productivity tools capable of reducing the labour content per unit cut.

4. Materials Handling

This important area for savings involves much more than just cutting and is something to be continually looked at with a view to improving existing facilities. The ship-building industry in particular is worthy of study to see what can be done for greater economy when the need arises.

In regard to cutting itself, three of the many facets of the problem can be mentioned to indicate the breadth of enquiry needed to cover this subject :

1. Greater use of portable machinies to cut materials in situ rather than bringing it to machines.
2. Extended tracks for machines so that plates can be placed in position while cutting is going on elsewhere on the machine.
3. Alternative handling equipment such as fork lift trucks to over-come bottlenecks with overhead cranes which are usually at a premium.

5. Equipment Usage

As noted above, any reduction in time taken for cutting or improvement in equipment utilisation will give significant reductions in the cost of labour involved. Fig. 1 shows how the use of "Hi-Speed" divergent cutting nozzles can reduce these labour costs as well as gas costs. A further example might be the use of four cutting nozzles instead of the traditional three, which will overcome the problems of cutting double bevel and land preparations and give faster cutting speeds with a good quality under-bevel.

The use of water sprays immediately behind the cutting heads allows easier separation of scrap from plate in this application. Further reductions can be achieved by use of :

multi-blowpipe machines
fastest travel speeds practicable for the quality of cut required
accessories like pilot lights, quick-start preheat and automatic piercing.

However, much of this will be offset if the quality and accuracy of cutting is not also of a high standard leading to increased costs elsewhere from poor fit up and extra welding to correct the position. **Do it correctly the first time** for there is no excuse for poor cutting.

One of the main things affecting the quality of cutting is the nozzle. More cuts are ruined by faulty cutting nozzles than for any other reason.

The operator must know this and ensure the nozzles are properly maintained in first class operating condition. Likewise it is vitally important to properly maintain all cutting equipment including track surfaces and alignment if the full benefits of cost reductions from its proper usage are to be a reality. This cannot be stressed too much.

6. Gas Costs

On the assumption that the best price for gas has been arranged commercially, the other factors to be looked at are the costs associated with gas usage which can be influenced by a number of items :

- Cylinder handling arranged to minimise labour and gas wastage.
- Bulk supply and pipeline installation where economically justifiable.
- Correct regulators installed with gauges operating accurately, Fig. 2 & 3.
- Oxygen pressures correctly set by operator to recommended values, Fig. 3.
- Rubber tubing in good order with no leaks.
- Cutting nozzles sized for work and properly maintained, Fig. 4.
- Correct flame setting in use for actual job of cutting.
- Equipment regularly maintained.
- Pressure drop leak tests periodically carried out on the installation.

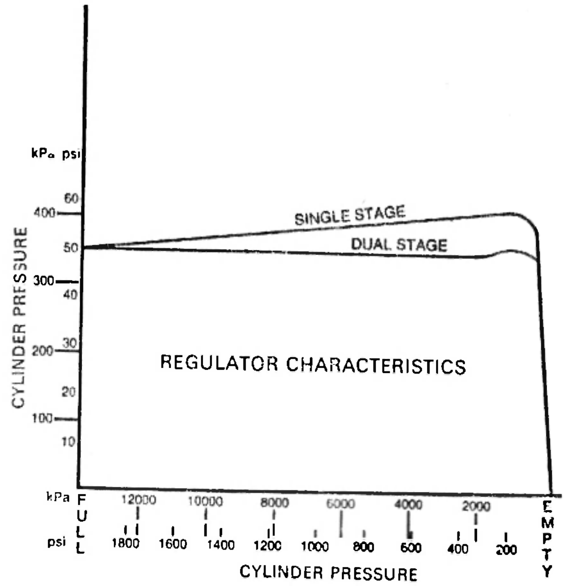

Fig. 2. Dual stage regulators hold set delivery pressures and therefore should be used to control Cutting Oxygen.

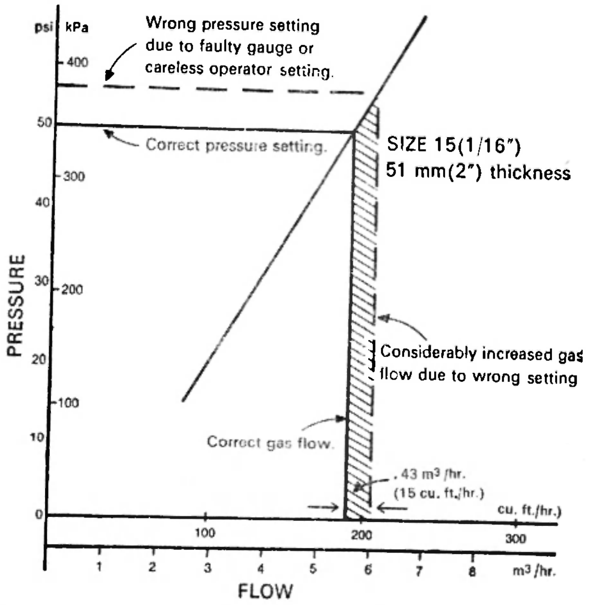

Fig. 3. A faulty reading gauge or incorrect operator setting can cause considerable additional gas usage.

Attention to good housekeeping in all these areas will lead to cost reductions.

7. Postcutting Treatments

One aspect of flame cutting definitely not in the best interest of economy has been the costly requirement to remove, by machining, flame cut surfaces to

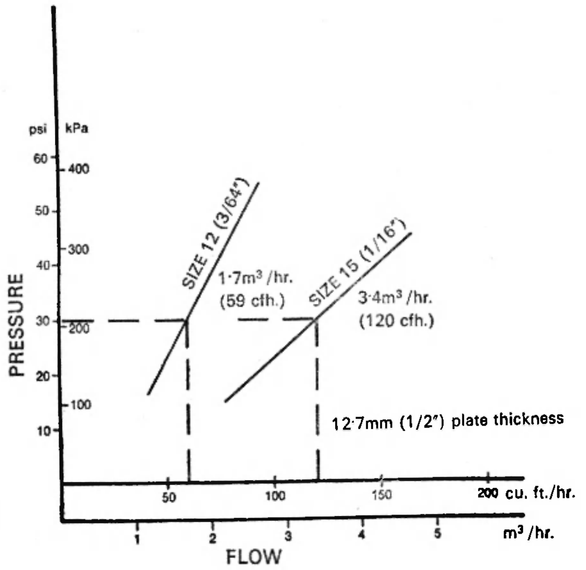

Fig. 4. Significant increases in cutting oxygen flow result from use of even the next larger size of nozzle.

remove notches and heat-affected zones. This was previously specified in ASCAI and is still required by some inspecting authorities, when dealing with medium strength steels. Both metallurgical effects as well as surface roughness and defects are involved in this problem.

The question was investigated in the laboratories of Australian Iron & Steel Pty Ltd, Port Kembla. Miller reported on the work in his paper "Oxygen Cutting of Steel"[2], and basically it was shown maximum hardness can be controlled by varying cutting speeds. In addition to giving detailed information on the various aspects of oxygen cutting, Miller also gave recommended cutting conditions using standard machine cutting nozzles for various steels and service requirements so that the material can be employed directly for all normal use without the need to machine the flame cut edge.

This work has been extended by Smith[3] who has developed a range of large diameter nozzles to allow medium tensile steels to be cut at normal cutting speeds and used in the most severe duty without machining the cut edge. This obviates the need to use the slower speeds recommended by Miller and is yet another step towards greater economy in cutting.

Research carried out for AWRA to determine the ductility of good commercial flame cut surfaces has supported the findings of the other investigations-Wheatley[4] reported this work in detail and recommended the re-examination of exiting codes to ensure they do not unnecessarily require the removal of flame cut edges. Quite importantly this paper also draws attention to the importance of repairs to defects in cut surfaces and gives recommendations for procedures to ensure any repairs do not induce cracking.

The results of these investigations and the various recommendations have been recognised in the latest revision of ASCAI-1972 and Amendment No. 1, March 1973 (Ref. 5I). No longer is it mandatory to remove flame cut edges and this "extra" on flame cutting costs can generally be eliminated for structures covered by this code, although it may still be required in some other applications like pressure vessel fabrication.

8. Surface Roughness

Frequently, considerable time is spent interpreting or debating the standard of cut surfaces and whether or not these are acceptable for the service entailed.

The requirements for surface roughness have been considered by several investigators and a review of Australian industrial cutting practice suggests the following values :

Class	*Surface Roughness**	*Description*
1	< 200 CLA	Good quality
2	200-200 CLA	Medium quality
3	> 750 CLA	Reject quality

* Measured in accordance with AS B131 (Ref. 6), Centre-Line-Average Height Method.

These values are significantly different from those presently nominated and consideration is being given to the adoption of these lower values when the code is amended next.

Actual measurement of surface roughness of these large values is not easy and is beyond the range of much of the equipment existing in workshops. To assist industry in this regard. AWRA has undertaken to produce replicas of each of the three classes of flame cutting. It is intended these will be used for direct comparison with the cut edge to give an assessment of the roughness value or class of cut. The replicas will be inexpensively priced and should be valuable for inspectors, supervisors and tradesmen when deciding the quality of the flame cutting.

9. Extra Fabrication Costs

It is a well recognised fact, poor cutting significantly increases fabrication costs due to the extra effort necessary to make good the resulting defects. Extra weld metal is too frequently required at high extra cost to bridge poor fit up or inaccurate plate preparations.

Repairs to correct isolated cutting defects are also extra cost not really necessary and cracking of badly cut edges in subsequent forming operations can even lead to rejection of the plate with all the extra costs and time delay involved. Likewise extra costs can indirectly result from poor cutting standards preventing the optimum welding process being used.

In contrast to this, but to emphasise the need to ensure cutting provides the most economic overall fabrication costs, Iizuka and Sugawa[7] describe a system of assembling egg-box ship sections at Sumitomo's Oppama Shipyard based on the accuracy available from numerically controlled cutting machines. Without this high standard of cutting, the precise construction needed to permit automatic welding to be used to give useful economies would not be possible.

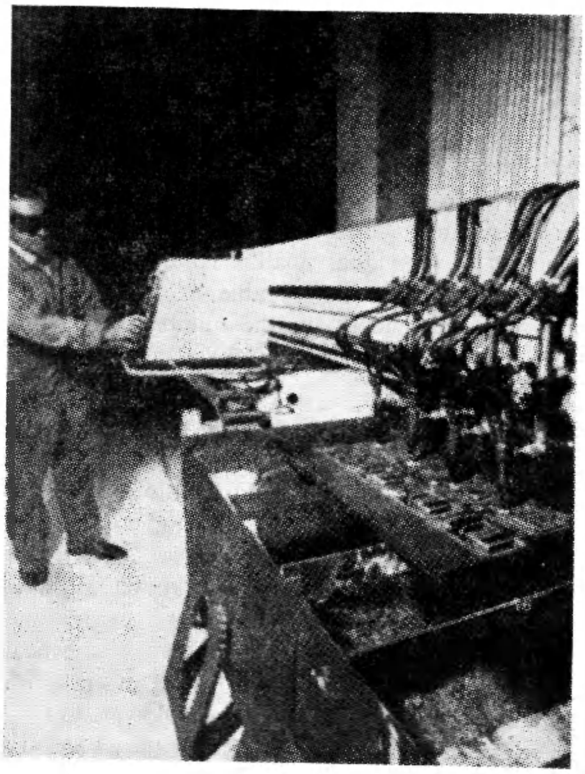

Fig. 5. Multiple blowpipe machines can give increased production and lower labour cost per unit cut.

10. Development of Cutting Machines

Cutting machines have been the subject of a great deal of development in an effort to achieve the economies outlined above, for not only do they have the potential for high productivity and reduced labour content with improved quality and performance, but are now recognised as being an integral part of a total system for metal fabrication. More emphasis is being given to this aspect of their development to the end that labour costs are reduced but some stages of the overall process can be done away with altogether. The preparation of drawings and templates, the marking of plates and the layout of components to ensure the best use of materials can be superseded in many cases to give a considerable saving from these indirect reductions. Numerical control and data processing play an important role in these developments.

Early machines developed from the mechanisation of hand cutters ; the portable straight line tractors came first, then the hinged-arm type machines. The latter had the disadvantage that it was impossible to fit additional blowpipes without major modification to the machine. Also as the tracing mechanism was magnetically operated, a steel templet was required which the magnetic roller rotated around to produce the desired shape.

The cross-carriage machine was developed later and did not suffer from these two disadvantages. Multiple blowpipes could be used and also photo-electric optical tracing could be adopted, meaning that drawings only were necessary for the component to be cut. Thus the advent of the cross carriage machine had a considerable bearing on the reduction of labour costs because much less time was required producing the drawing than the steel templet and greater production could be obtained with multi-blowpipes, Fig. 5.

In fact, a cross carriage machine with six blowpipes will produce four times the amount of work as compared with a single blowpipe machine—both employing one operator. To take this to the next logical stage, larger machines with heavier beams, etc., can be designed to mount more blowpipes. These blowpipes naturally require special accessories, again to reduce the labour costs. For example, it is not much use having twenty blowpipes on a machine and then find you have to employ several operators to raise and lower the blowpipes on the machine arm if the plate is distorted or the work supports are not level.

Therefore, mechanised raising and lowering units should be used to allow the operator, in a suitable location, to raise or lower individual blowpipes, as required. Alternatively, automatic height sensing may be employed by the use of probes which touch the plate at regular intervals and ensure correct distance. Capacitor non-touching sensing devices are now being used extensively on cutting machines overseas. Pilot lights would also be necessary for multi-blowpipe machines such as described.

Because the amount of heat provided to start a cut is well in excess of that required to continue it and get best quality top edge, a special attachment is available to allow the preheat flames to be softened after the cut has started. Where a large amount of piercing has to be carried out, special timer controls can be added to allow this to be done without the molten slag coming back on to the face of the nozzle. Again it will be appreciated that, where multi-blowpipe machines are used, slag cannot be allowed on even one nozzle face as it will cause distortion of the cutting oxygen stream with resultant rejects because of faulty cuts. It is therefore recommended that where piercing has to be carried out, special controls are added to allow this to be done and ensure that the nozzles are always in first class condition. Alternatively, consider using a hand blowpipe to pierce the holes for starting cuts on plates over 50mm thickness to make certain that the nozzle used for the machine cutting does not have a lowered efficiency because of slag adherence.

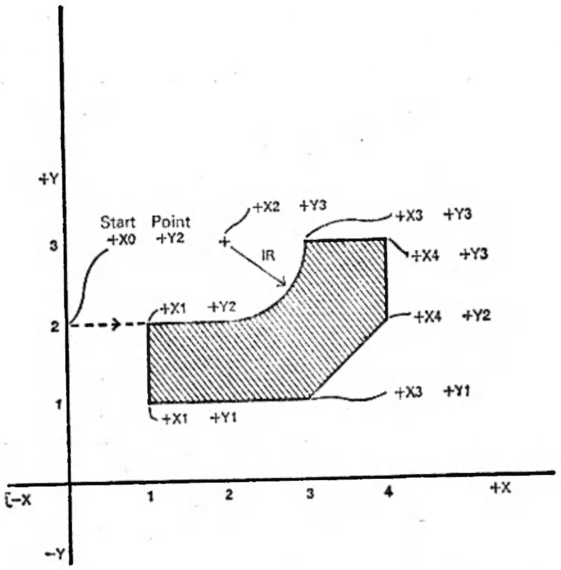

Fig. 6. A shape may be defined by nominating co-ordinates thus making drawings unnecessary.

11. Optical Tracing

With optical tracing it will be appreciated that plates may be 12m in length and these would require an equivalent length of drawing if the standard 1/1 optical tracing method is to be employed. With a drawing of this length, inaccuracy can creep in because of paper stretch etc. and in addition such drawings are difficult to handle and store. These problems resulted in the development of ratio flame cutting machines where for example, the drawing can be reduced to 1/10 scale and the machine is constructed to magnify this drawing to full size. Naturally, these drawings have to be extremely accurate and in fact lines must be drawn to an accuracy of plus and minus 0.05mm and special magnifying spectacles are necessary for use by the draftsman. Such machines have the ability to cut a standard contour in the plate and at the same time cut, if necessary, a mirror image of that contour—an important feature in the flame cutting of ships plates. Marking of the plate during the cut is possible using either electro-magnetic or pneumatic punches.

12. Numerical Control

The next development is the use of numerical control (NC) for flame cutting machines. Numerical control is not new to the machine tool industry and it would seem an obvious improvement to eliminate preparing drawings. Such machines are now available based on a punch tape control system suitable for the production of individual small, medium or large components. They are also capable of mass producing similar parts dependent on the number of blowpipes fitted or, if necessary a mirror image cut is possible.

Instead of drawings, the shape to be cut is purely on a numerical basis working from an X and Y axis as shown on Fig. 6. This information is tabulated and is then placed on tape. If simple shapes only have to be cut this tape may be used directly on the flame cutting machine operating through a director. If complicated curves need to be cut, a computer is used to save tedious calculating. As an intermediate stage, the tape may be fed to a drafting machine which automatically draws the item, thus allowing the tabulator to check on his work or to nest the various components so that maximum utilisation of plate and the minimum of scrap is obtained. Overseas computer programmes are available to simultaneously carry out this nesting operation.

The advantage of an NC installation over an optical type is as follows :

- Less time is required to programme the punch tapes than to produce drawings.

- Fully automatic operation from beginning to end of the cut reduces production time of the components. The operator simply starts the machine, after which his function is purely supervisory.

- Higher accuracy is obtainable than with optical controlled machines since data is fed in without tolerance allowances. Inaccuracy arising in the production and scanning of drawings is thus eliminated.

- Since the programme can arrange resting in the preparatory stage of the work, the material can then be utilised to the fullest possible extent.

It will be appreciated from the foregoing the advantages and flexibility of NC flame cutting machines has been widely recognised and will continue to be the subject of much activity in the future. Considerable development work is presently being concentrated on the use of mini-computers or elaborate calculations in conjunction with flame cutting machines. It is fair to speculate that advances with NC will be rapid and this will be seen in cutting machines as well. This could lead to their wider use in the 70's just as optical tracing was adopted in the last ten years.

13. Data Processing Systems

Fig. 7 shows one system which is available overseas. In the first scheme, the customer sends drawings of complicated components via mail to the computer centre. From the drawings, the various ordinates are taken out and tabulated in a suitable form to feed into the computer. The tape prepared can then be forwarded via mail to the customer who feeds it into a digital director and this controls not only the direction of cutting but also miscellaneous functions as blowpipe lighting, raising and lowering, etc. on the machine owned by the company. This means that the customer is involved in only the drawings and the cutting, and the balance of the work is carried out by the computer service centre.

As the customer becomes larger he can undertake to not only do the original drawing but also the tabulating and coding. This is then sent via telex to the service centre where the computer work is carried out. Again telex is used to relay the information back to the customer for use on the machine. The final and more elaborate stage is for the customer to own the complete unit, including, computer, drawing machine, etc.

Within the last few years the "dial-in" system (Fig. 8) has become very popular in US and on the Continent, and provides for the flame cutting of non-complicated geometric shapes without the manufacture of drawings or punched tapes. It is really a small NC unit based on integrated circuits which allows the following geometrical shapes to be cut fully automatically or semi-matically, depending on the requirements :

- Squares
- Rectangles
- Circles
- Flanges
- Triangles
- Combinations of circle quadrants and any straight line.

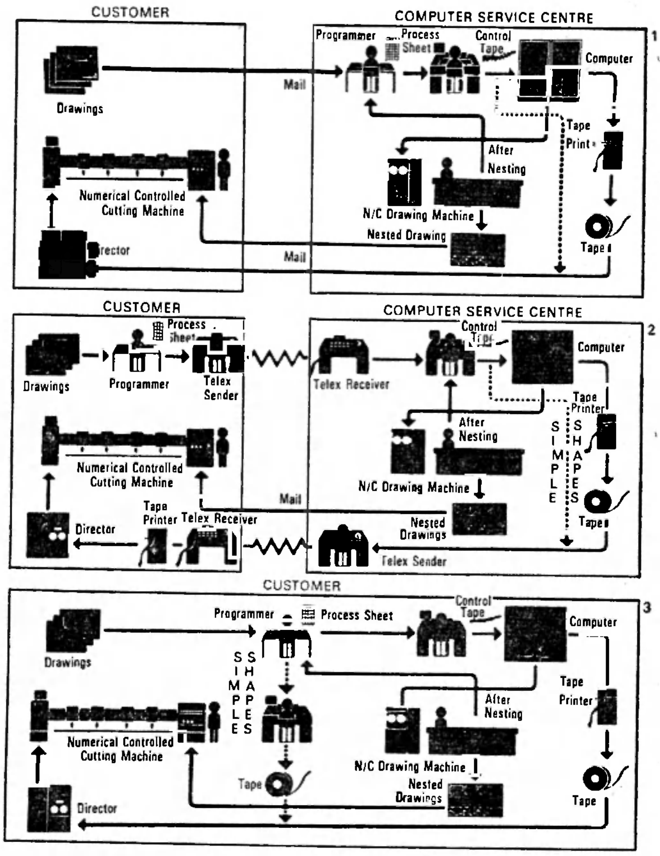

Fig. 7. Data processing system for numerically controlled flame cutting.

These have been developed mainly for steel service centres or for the bigger engineering shops where large numbers of regular shapes have to be cut and the preparation of drawings or punch tape would become a burden.

Pre-selection switches and size setting thumb wheels are fitted at the operating panel. Using these, the desired working cycle with the required dimensions can be programmed. Thus for cutting squares the following setting selections must be made :

- Position of lead in ;
- Length of lead in ;
- Direction of driving (clock-wise or anti-clock-wise) ;
- Kerf width ;
- Transverse dimensions ;
- Longitudinal dimension ;
- Speed.

After having positioned the machine and actuated the "start" push button, the complete cutting operation runs fully automatically. For duplicating cuts, the machine has only to be positioned again and the pre-selected cycle started again.

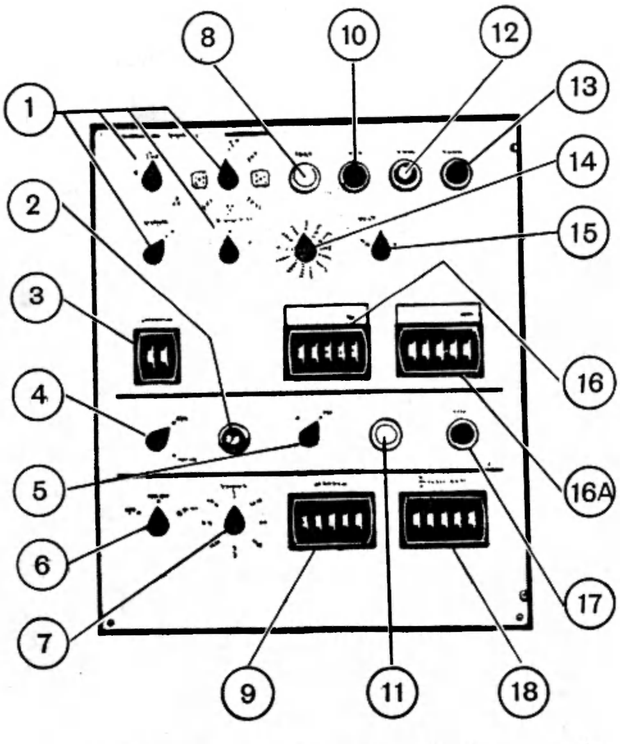

Fig. 8. Control unit for "dial in" flame cutting machine.

1. PROGRAMME SELECTOR :
To select shape of cut lead-in point length of lead in (approximately 1, 2 or 3 inches) and direction of cut (clockwise or counter-wise).

2. HOLD :
Pilot light indicates when in hold position.

3. KERF WIDTH :
For setting kerf width according to nozzle size (inches to nearest hundredth).

4. AUTO-POSITION :
To select operation in the automatic mode (upper Panel) or manual positioning (lower panel)

5. HOLD-RUN :
Suspends machine operation when in hold position. Stored logic is not cleared.

6. LINE ARC :
To select linear or circular travel—manual control.

7. DIRECTION :
To select travel direction in manual control. N. S. indicate straight longitudinal motion. E. W. indicate straight lateral motion. Any angular direction in 90 deg. quadrants between cardinal points is set by turning Knob to NE, SE, SW, or NW, as appropriate.

8. ORIGIN :
Pilot light indicates torch is at reference position.

9. POS :
Sets dimensions for cross travel direction.

10. PIERCE :
Pilot light indicates torch has moved to pierce position.

11. CLEAR
Pushbutton clears all stored logic.

12. COMPLETE :
Pilot light indicates torch has completed programme and stopped at pierce position.

13. ERROR :
Pilot light indicates some malfunction :

14. SPEED DIAL (ipm)
Dual range

15. SPEED SELECTOR :
For low (50 ipm) or high (250 ipm) speed range. "Traverse" automatically gives top speed (250 ipm) for positioning without resetting speed dial.

16 & 16A. DIMENSIONAL DIALS
Sets dimensions in cross carriage travel direction for squares and rectangles or inside diameter of circle cuts (inches to the nearest hundredth).
Sets dimensions in main carriage travel direction for squares and rectangles or outside diameter of circle cuts (inches to the nearest hundredth).

17. START :
Pushbutton initiates complete cutting cycle, including lead-in, for dry run or to position torch to pierce position.

18. POS OR RADIUS :
Sets dimensions for main carriage travel direction or radius in circular travel.

14. Plasma Cutting

Plasma cutting has developed as a complementary thermal cutting process to the extent that an appraisal of its strength and weaknesses is now possible, particularly if compared to the more traditional process. The oxy-fuel gas process is limited to ferrous metals and principally carbon steels, but it can be used to cut stainless steel with the addition of metallic powders which have dis-advantages. The plasma process, on the other hand, can be used to cut all ferrous and non-ferrous metals which include stainless steel, aluminimum, magnesium, copper, monel, inconel and similar metals and alloys.

The oxy-fuel gas cut is almost self sustaining in its reaction throughout the full depth of cut and the majority of the heat generated is developed by the actual combustion of the iron with the oxygen. This means that there is virtually no limit to thickness. In the plasma process however, the heat input is essentially a surface or near surface phenomenon supplied completely from external energy. The heat to sustain the cut at depth below the surface is therefore more difficult and this influences the maximum thickness that can be cut. Normally, for carbon steel this thickness is limited to 60mm, but it will be appreciated that this probably counts for 90% of the cutting applications. In Australia, cuts in 125mm stainless steel have been made.

Plasma cuts at a much higher speed than the oxy-fuel gas flame cutting and therefore the cutting time will be reduced, offsetting the higher equipment costs.

In general, there is a limitation to the number of cutting heads used on any one machine not only due to the power requirements and the high capital costs but also because it has been found with multi-plasma cutters difficulty is experienced in monitoring the operations due to the limited visibility. In this area oxy-guel gas cutting is superior and is the main reason why it is still utilised almost universally for cutting steel.

Cuts on carbon steels using plasma have now reached the stage where the quality is almost identical to oxy-fuel gas. Special techniques have been evolved which have over-come the tendency for the kerf to be tapered in the case of plasma cutting and it has the advantage that instant starts are obtained and there is no need for the preheat dwell normally required with oxy-fuel gas cutting.

In regard to personnel protection the oxy-fuel gas process requires eye goggles for the operator and clothing to protect against flying sparks and hot metal droplets. Natural ventilation is normally adequate.

In plasma cutting eye protection with dark lenses is absolutely essential and clothing coverage is also required. The eye protection commonly used with the plasma cutting is the helmet and dark lens normally used for electric welding processes. Due to the bright intensity of the plasma all areas of the body must be protected by dark clothing to prevent the "sunburn" effect. Ventilation in the case of plasma cutting must be sufficient to ensure the personal comfort of the operator and in many cases fume concentration does become a major problem as well as a safety hazard due to possible build-up of noxious gases mainly the oxides of nitrogen. The noise level from plasma cutting is much higher than oxy-fuel gas cutting and in some cases requires ear protection for operators or personnel nearby.

Based solely on consumables used per hour, oxy-fuel gas cutting costs are in general higher than plasma. Obviously one has to take into account the difference of speed where this can be utilised and hence the output of work which is possible with each process in that hour. If multi-blowpipes are utilised, then oxy-fuel gas is the cheaper metod. There has been an overseas trend to lower the power requirements for plasma so that the speeds are more controllable and cuts may be carried out on conventional oxy-fuel gas flame cutting machines. This may lead to a narrowing of the cost differential in favour of plasma.

A number of plasma cutting units are in operation in Australia, particularly in metal service centres offering plates including stainless steel and aluminium cut to customer's requirements for shape and size. It seems plasma will continue to find application with the "hard-to-cut" metals but it is not likely to replace oxy-fuel gas cutting in the next decade.

15. Laser Cutting

The CO_2 laser has been used to cut a variety of materials as listed in Table 1 which gives the cutting speeds achieved with the power available.

Some advantages of laser cutting over other methods are :

- very narrow kerf width with parallel sides
- high speed cutting

- reduced buckling and distortion
- absence of contamination
- reduction of heat-affected zone on either side of cut
- further reduction of charring of non-metals by use of cooling gas jet.

The only laser cutting machine in commercial operation in Australia is employed for cutting 18mm thick plywood forms for use in carton manufacture.

Table 1 Some materials cut by Laser Gas-Jet Technique at a power of 200W

Material	*Thickness mm*	*Gas*	*Speed mm/min.*
Mild Steel	0.5	Oxygen	635
Stainless Steel	0.5	Oxygen	2600
Titanium	0.6	Air	200
Zirconium	0.25	Air	915
Carborundum (Sintered)	1.6	Air	760
Asbestos Cement	6.3	Air	25
Glass (Soda-Lime-Silica)	4.0	Air	100
	1.6	Air	380
	0.2	Air	5000
Perspex	25.0	Air	100
	10.0	Air	200
	4.6	Air	635
Nylon	0.8	Air	5000
P.T.F.E.	0.8	Air	6100
G.R.P.	2.4	Air	635
Leather	3.2	Air	635
Wood-Deal	50.0	Air	100
Oak	18.0	Air	200
Teak	25.0	Air	75

As seen from Table 1, laser cutting is mainly applicable to the more difficult to cut materials and in the opinion of the authors, will not be a serious competitor to flame or plasma cutting within the next decade. It could find growing application for such materials as plastics, leather, cloth and timber.

16. Conclusions

Flame cutting is an important support operation to welding and metal fabrication which can reduce overall costs if used correctly with proper attention to good house-keeping.

As in welding technology, there have been significant developments in flame cutting and complementary thermal cutting processes over the last two decades to increase productivity, reduce costs, improve the performance of cutting and to enable a wide range of materials to be cut satisfactorily.

Particular attention has been given to reducing labour costs while at the same time improving quality by the use of advanced machines with optical tracing and numerical control.

The application of numerical control and data processing systems is increasing and it is expected this will be further increased as cutting comes to be recognised as an integral part of a total system.

Research has enabled earlier and somewhat arbitrary requirements to remove cut surfaces to be modified by suitable cutting techniques. In addition, replicas are becoming available to overcome the subjective differences in evaluating surface roughness.

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