# Welding Automation in Action —Present and Future

By Dr. R. R. Wright*

*The paper discusses the current and future prospects for achieving fully automated welding systems. The present status of such systems is illustrated by reference to an automated welding system designed for "the fabrication of cryogenic road tankers".*

*The inner vessel of a cryogenic tanker is fabricated from stainless steel sheet using the pulsed GTA welding process, therefore the welding speed is subsequently slow. This results in long weld runs particularly on the circumferential welds resulting in low productivity through operator boredom and high weld reject level due to operator fatigue. A welding system has been designed to overcome these problems by introducing a high level of automation into the process. The system includes :*

1. *Closed loop control of the guidance and height of the welding head.*
2. *Closed loop control of the weld penetration.*
3. *Complete sequencing of all manipulation and welding equipment through automated tacking and automated welding. It also includes checking and monitoring of all services of torch coolant shielding gas, backing gas, etc.*
4. *Welding equipment designed specifically to meet this requirement.*
5. *Joint preparations specified to meet automated welding standards.*

*The immense improvement achieved in both productivity and in weld consistency and quality resulting from the introduction of automated welding equipment is mentioned.*

*The paper finishes by discussing the future of automation in welding, the areas which require developing and the exploitation of this technology.*

## 1. INTRODUCTION

Throughout the world there is growing pressure to device methods of increasing the productivity of the fabrication industry. These pressures are inter-related, but of three main types :

—The economic pressure to make more products more quickly.

—The social pressure to ensure as far as possible operators work in an environment free from noise, dirt, glare, heat and other discomforts.

—The labour market pressure which often means (in the UK at least), that a sufficient number of skilled welders is often not available to meet fabricators' needs.

* Automated Welding Products BOC Ltd, Milton Keynes, UK.
This paper was presented at the AWI 1980 Welding Convention, Melbourne.

In response to these pressures, considerable resources have been directed towards developing Automated Welding Equipment. I believe that there will be an increasing need for truly automated equipment which can be set up by a skilled operator, and left to operate under more remote supervision. This sort of equipment goes a long way to meeting the pressures we have outlined above because it allows.

—Productivity to be increased, or at worst ensures a consistency of quality which compensates for an increase in productivity.

—The skill of the operator to be exercised effectively away from the environmental discomforts of the welding process.

—The working capacity of the skilled welder to be leveraged in such a way as to compensate for the lack of numbers.

In building automated welding equipment, much of the technology is freely available and has been for a number of years. All that is theoretically required is suitable control systems which can link together closed loop signals to control in-process changes in the weld position and welding parameters with accurate and repreatable welding equipment, this when added to consistent sequencing and monitoring of the complete welding operation will provide automated welding. However, in practice, there are relatively few successful applications of such equipment, and those that are successful are often highly specialised.

In reviewing the requirements of truly automated, flexible welding equipment, the author has come to three conclusions :

(i) The role of the welder in the welding process is to provide a feedback control loop. All the other functions he executes such as torch positioning and control can be automated.

(ii) The advent of cost-effective sequence controllers and transducers opens up a range of new opportunities to build feedback devices into a new generation of truly automated equipment.

(iii) The full potential of these control devices will not be realised until the performance of the other elements of the welding system is upgraded to meet the resulting requirement for accurate and repeatable controls.

In the sections that follow, I will expand on these conclusions.

## 2 THE WELDER AS A FEEDBACK LOOP

As a weld is produced, the welder acts as a feedback control loop which automatically compensates for variations in the work piece, the equipment, and the welder's own preferred style of working.

### 2.1 The welder compensates for the physical differences between nominally identical components

—Typically, fabrications are not assembled accurately, and as a result, there may be variations of several millimetres in the position of joints on otherwise identical fabrications.

—The components of the fabrication may not themselves be accurately made. This may mean that the first pass of a weld may have to bridge a gap several millimetres wide.

—Variations in the weldability of steels. For example, hot and cold rolled steels of the same nominal specification can perform quite differently during the welding process.

### 2.2 Conventional welding equipment often cannot cope with close tolerance on its performance

—The individual performance of identical welding sets fresh from the production line is satisfactory in all conventional respects but they can differ considerably in operation.

—Similarly, nominally identical wire feeders can perform differently.

As a result, even if these elements were successfully incorporated in an automatic welding system, it would have to be 'tuned' to match their performance. These elements could not easily be replaced in the course of servicing, but would have to be repaired to the original specification.

### 2.3 The welder alters the parameters of the weld to suit his personal preference

These variations are often extremely difficult to control in the fabrication shop environment.

—Variations in the setting of power sources and wire feed speeds can affect the properties of the completed weld.

—Variations in electrode stick-out when the MIG process is used cause changes in arc and gas shield characteristics.

—Preferences for the 'weldability' of certain electrodes can influence the choice to the possible detriment of the final weld performance.

—Incorrect setting of the welding parameters can raise the rate at which welding fume is produced —increasing the health risk to the welder and his colleagues.

From our experience of these problems, we believe that an open loop control system for automated welding equipment is only a partial solution. Fully automated flexible welding equipment will only become effective when it is matched by a range of feedback control devices.

In the next section, I go on to review the progress that has been made in developing these.

## 3. TECHNIQUES FOR CONTROLLING CHANGES DURING WELDING

In the last few years the rationale outlined in the first section has become apparent to many of those involved in research into advanced welding systems. As a result, a number of sensors have been proposed, developed, and in some cases are being actively marketed.

It is not my intention to review the advantages or disadvantages of each sensor in depth, but to make the point that for a wide range of joint configurations, it is now possible to devise a reasonably effective feedback system. What is not yet possible is to device a system as versatile as a skilled welder. However, I would expect substantial progress, towards that goal over the next decade. Already microprocessors are making cost-effective sequencing systems that would have been inconceivable only a few years ago. We expect this process to continue. In our discussion we have divided our sensors into two classes:

—Sensors to position the weld head in relation to the workpiece.

—Sensors to control welding parameters.

### 3.1 Positional Sensors

Five main practical approaches to developing positional sensors for welding heads can be identified. In each case I would expect the electrical signal from the transducer to be amplified and used to power a motor driven slide to correctly position the welding head. The signal could also be used to trigger actions in an appropriate sequence controller which could be used to oversee the entire welding operation.

### 3.1.1 Optical Sensors

In these devices the sensor is designed to pick up some optical data relative to the weld joint. When used with low cost fibre optic systems this approach can be both cheap and compact and can provide reliable production performance by locating the light transmitter/detector and its associated electronics remote from the hazards of the welding arc.

On a more sophisticated level systems have been developed to synthesise a pattern of light reflected from the weld preparation and use this information to digitally scan the total weld preparation. This information can be used not only to position the weld head but also to control the welding parameters to ensure accurate joint completion[1]. At this time this sort of system is probably not cost effective but it provides a clear indication of what is possible in the future.

### 3.1. Electromagnetic Sensors

The change in flux through a set of matched coils in an electromagnetic probe caused by the close proximity of a relatively large volume of metal can be used to measure the distance between the probe and the surface of the metal. This has been used in a variety of forms to locate and guide welding heads in many applications.

### 3.1.3 Arc Related Sensors

One of the most interesting methods of sensing is to use the arc itself to measure the distance between the torch and the workpiece. This measurement was first developed at Aachen University[2],[3], and involves deflecting the arc briefly from side to side during welding. Measurement of the resulting change in welding current or voltage or both gives the system sufficient information to follow some types of weld seam automatically. This system has been exhibited commercially and clearly shows potential in some welding circumstances.

Experiments have shown that a signal of adequate strength is easily obtained. The main advantage of this system is that the torch head is not physically encumbered by transducers.

### 3.1.4 Pneumatic Sensors

For some years, the machine tool industry has used pneumatic sensors for tool and workpiece positioning. In welding systems there are applications for either reflected or back pressure gas systems which are simple and effective. Typically in the welding situation, these sensors can operate off the supply of shielding gas. The main advantage of these sensors is that they are physically compact and relatively cheap.

### 3.1.5 Physical Contact Sensors

In many welding systems, the joint configurations are sufficiently simple for physical contact systems to be used. For example, a roller-tipped probe is directly connected to a potentiometer. This system has the merit of simplicity and cost-effectiveness which is offset by its limited range of applications.

### 3.2 Welding Performance Sensors

The techniques discussed so far in the previous section relate entirely to the positioning and guidance of the welding head. However, this on its own does not totally replace a welder's skill which is still required to compensate for variation in process parameters so that the control of ultimate weld quality is achieved. One method which has been actively persued in the past few years is to identify the most significant aspects of weld quality and to regulate them during welding by feedback control. The basic attributes of a weld are weld bead position, weld bead size, and the metallurgical structure of the weld metal and the heat affected zone. The position and size of the weld arc criteria whose definition is common to all types of weld whereas metallurgical features are often unique to the particular metals being welded. The metallurgical features have been controlled by power source and wire feed unit programming, the positioning of the weld bead has been approached by the techniques described in 3.2.1. This leaves the control of the weld bead size and it is this area which has been neglected in terms of development work. It is for this reason that more and more research is being concentrated on this aspect of the welding process. All kinds of work is being carried out but the four commonest approaches are, joint preparation surveying, top surface weld pool measurement, arc voltage measurement and underbead detection techniques. The first of these techniques to reach the production stage in the United Kingdom has been the control of weld penetration in GTA welding by underbead sensing and it is this system which I would like to describe here.

### 3.2.1 Control of Weld Penetration in GTA Welding

A technique has been developed recently to examine the depth of penetration of a weld, primarily as the root pass or if used, in a single pass weld, and this has been used in a number of practical applications. This ability is probably the most important step that has yet been made towards fully automated welding.

The technique works by viewing the electromagnetic radiation emitted from the underbead and controlling the pulse width of a modulated welding current to ensure that penetration is consistent as the torch moves relative to the joint. The system has also been successfully developed for use on continuous current welding using proportional control techniques. The system is shown schematically in Fig. 1.

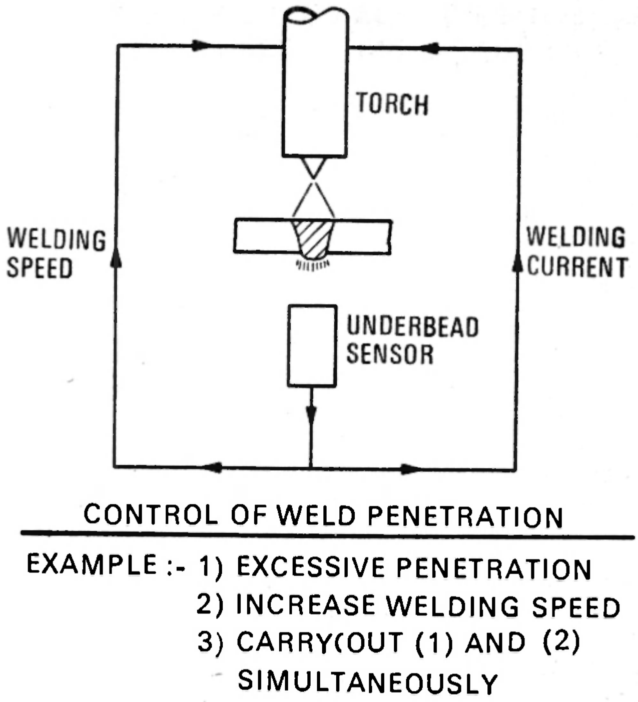


*Fig. 1*

A feedback control technique such as this reduced the effect of disturbances on the process under control. Thus by controlling the penetration or back face bead width, by regulation of the power or energy input with a self-adaptive loop, the effects of variation of arc length, arc efficiency, shielding gas efficiency, material thickness, joint preparation, and preheat are minimised. The objective of the techniques is to produce consistent penetration despite variation in the parameters previously stated, this is what an experienced welder will achieve and therefore must also be achieved by an automated welding system.

The following table shows some results which have been achieved in practice.

This illustrates that despite considerable variation in tolerances the feedback system can cope with a much wider range of variation and still maintain welds within specification.

## 4. OTHER ELEMENTS IN THE WELDING SYSTEM

To achieve maximum effectiveness of the feedback systems for positional control and weld parameter control the remainder of the welding system must reach a certain minimum level of performance. This means that the welding equipment must be designed specifically for mechanised and automated use, the system must include a sequencing and monitoring unit and the joint must be prepared to a certain standard and this must be repeatable to within preset tolerances.

### 4.1 Welding Equipment

We have already commented on the need to tighten the precision with which the other elements in the welding system perform. Until equipment is widely available which can perform within an acceptable specification and is consistent, the effectiveness of the sensors I have described will not fully be realised. As a result we will see a need to re-evaluate the performance requirements of each element of the welding system.

### 4.1.1 The Power Source

There is a wide variety of welding power sources available world wide. However it has only been in recent years that we have even seen commercially available power sources that can be remotely described as accurate or repeatable. However this is changing rapidly and we will see in the near future a variety of power sources that are more skin to the machine tool industry than the welding industry.

TABLE 1. COMPARISON OF PARAMETER TOLERANCES BETWEEN CONVENTIONAL AND FEEDBACK WELDS IN AN AISI TYPE 321 JOINT

| PARAMETER | | TOLERANCE | |
|---|---|---|---|
| | UNIT | OPEN LOOP WELD | CLOSED LOOP WELD |
| CURRENT | AMPS | 120 ± 3 | 120 ± 20 |
| SPEED | mm/sec | 1 ± 0.1 | 1 ± 0.5 |
| ARC LENGTH | mm | 1.6 ± 0.05 | 2.0 ± 0.5 |
| MATERIAL THICKNESS | mm | 3.5 ± 0.15 | 3.5 ± 1 |
| ROOT GAP | mm | 0 + 0.15 | 0 + 1.6 |
| AXIAL ALIGNMENT | mm | 0.7 | 1.6 |

We are currently manufacturing, in the UK, a range of power sources which are of the transistor controlled series regulator type. This equipment can be used at current levels of up to 800 amps on either GTA or GMA welding. The current level can be controlled to better than 0.3% and complicated waveforms can be preset and varied precisely. The power sources are completely digitally controlled by their own microcomputer system which allows enormous flexibility in programming and provides a sound basis for communicating with other components of the welding system. It also makes fault diagnosis and on site servicing considerably easier to perform.

### 4.1 Wire Feed Systems

The purpose of a wire feed system is to supply filler wire to the weld pool at the required feeding rate. In automated systems the control of the wire speed will be of considerable importance. Wire feed units which incur minimum slip between the drive mechanism and the filler wire such as the Capstan Drive System developed by the Welding Institute become the standard technique as will the use of stepper motors or low inertia solid state motors for the drive systems. The measurement of the wire feeding speed beyond the drive rolls with this signal being used to change the motor speed with the aim of producing consistent and repeatable wire feed speeds will become more common and in fact necessary.

### 4.1.3 Welding Heads

Welding head development will not change as radically as the power source and wire feed unit. Clearly, heads will be designed for higher duty cycles. As far as possible they will have to operate without the need for cleaning or replacement of parts for significantly longer periods. This allows us to use materials for such welding heads which although previously advantageous would be prohibited for manual welding torches because of their cost. One typical example is the use of silicon nitride for gas nozzles, etc. At the same time the weight and balance of the torch is less important in mechanical and automated applications than when it is used by a welder.

### 4.2 Sequence Control Systems

During any welding operation a considerable level of controlled sequencing of the complete operation must be carried out. In addition to this services such as shielding gas, purge gas, coolant flow, power connections, etc., have to be monitored and controlled as has the main weld cycle programme carried out in conjunction with the operation of manipulation equipment such as manipulators, booms, rotators, etc. The advent of cost effective standard control systems has brought this part of the weld cycle to be relatively easily controlled. The type of sequence control and monitoring system which is used for a particular job can vary enormously and the more flexible approaches will allow management decisions to be programmed into a decision making procedure. For instance, we can typically monitor shielding gas in two ways as gas pressure and as gas flow. A reduction in gas pressure below its preset acceptable minimum level could be illustrated by an audible and/or visual warning but no action taken automatically whereas a reduction in the flow rate of the shielding gas to the weld head will give the same audible and visual warning but the monitoring unit will automatically initiate a rapid slope out procedure previously preprogrammed. This will allow welding engineers to make correct management decisions on the way to handle such failures and know that the action will be taken consistently. Again if we are to genuinely weld in an automated manner then the introduction of the last range of cost effect sequencing and monitoring systems is essential to the welding operation.

### 4.3 Joint Preparation

It is obvious if we are going to reap the benefits then the ability to reproduce weld joint preparation in an acceptable and repeatable manner is absolutely essential as paft of the necessary functions in total automation. There is very little point in producing welding equipment to a very high standard if the total system approach is destroyed because our joint preparations are not to a specification which allows the advantages of such automation to be used.

## 5. SUMMARY

To achieve genuine automation in welding technology we must approach the process from five different points.

1. Closed loop control of the position and direction of the welding head in relation to the joint.

2. Feedback control of the welding parameters during welding to produce a consistent weldment.

3. Complete sequence control of the welding operation including monitoring of variable functions.

4. Welding equipment specifically designed to meet the minimum requirements of repeatable automated application.

5. Joint preparations of a sufficient standard to permit consistent results to be obtained when used in conjunction with the other four essentials.

## 6. APPLICATION OF AUTOMATION IN WELDING

A typical example of how such automated technique can be used in practice can be demonstrated by looking at a recent installation for the automated manufacture of cryogenic vessels. The road transport of liquid gas is carried out using a double skinned container with the inner vessel being the most critical component. In the particular example I have considered this vessel was fabricated from 3mm thick stainless steel sheet. A 3m diameter canister of stainless steel was prepared by longitudinally GTA welding the sheet (see Fig 2), three such canisters are joined together and dished ends are welded in place thus giving a cryogenic road tanker inner vessel.

Originally the circumferential weld joining the canister and dished ends were carried out using a double operator technique with the vessel being rotated on a roller bed. The 'turn round' time for this particular weld from arrival of the canister at the welding station until the weld had been completed was approximately five and a half hours. The arcing time required to complete the welding was approximately one hour using pulsed GTA welding. This gave rise to weld defects caused by operator boredom and fatigue. Thus there was a considerable driving force to mechanise this particular weld and in fact the opportunity was taken to automate the total circumferential welding operation. To automate the system, the welding head was moved to an overhead boom with the cylindrical workpiece being

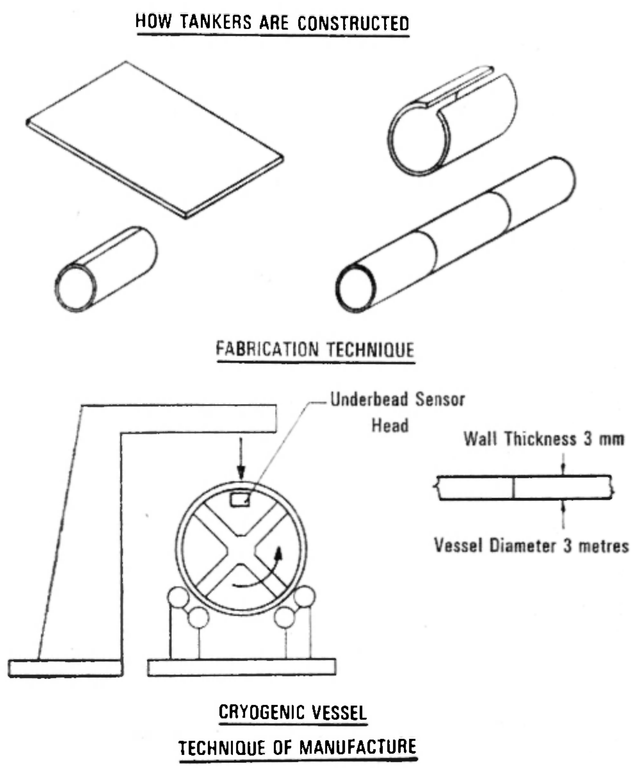


*Fig. 2*

rotated underneath the welding head by means of combined internal expanding shot and drive mechanism (see Fig 2). The head incorporated a joint tracking and height sensing system. The operation also contained feedback control of weld penetration with signals from the underbead being monitored by a combined sensing and back purging unit located inside the vessel These signals were transmitted some 60 metres, via a fibre optic, to the welding power source to control the welding current.

The complete welding operation from when the canister arrives at the welding station, through a clamping procedure, tacking procedure, welding operation and a repositioning procedure the functions are all automatically sequenced. The operator's control panel shown in Fig 3 illustrates that the controls are very simple with the total operation being controlled by a start and a pause button with all other functions being automated. The other features on the control panel allow the operator to have fine adjustment of the wire feed speed during welding and to set up the wire position prior to welding commencing. The controls on the right hand side is a key locked panel which allows joy stick control of the motorised slides on the head should any of the automated systems fail. The sequencing systems completes the operation in a logical step by step manner with in-built warning and automatic action procedures should any function not happen in the correct mode. It also checks and monitors the consumables such as shielding gas, backing gas, cooling water, filler wire, etc., and takes the automatic action should any of these functions fail. A separate illuminated display panel within view of the operator illustrates the exact status of the sequence and also indicates any failure mode.

In addition to these features, the preparation of the joint was specified such that consistent results could be achieved. The specification of each part of the welding equipment was examined to ensure the tolerances on the equipment were within the acceptable limits. This in fact let to changes in both the wire feed unit and the power source. The power source eventually used was an accurate programmable unit which could supply welding power to a specification well within the operating criteria laid down for the manufacturing process. The result of the change to automated control has been a reduction in the turn round time from five and a half hours to one hour which demonstrates the enormous advantages that can be achieved with this type of investment.

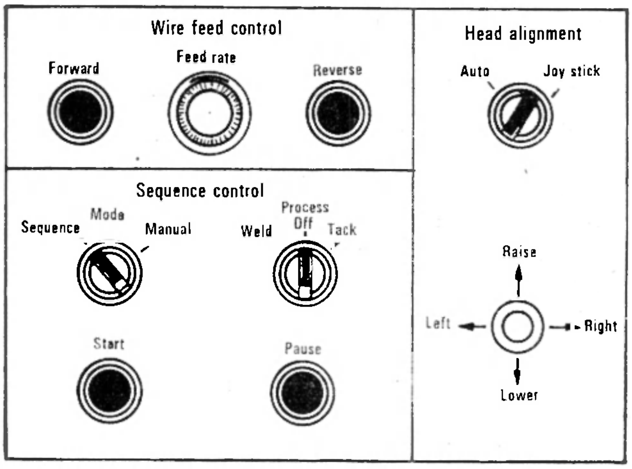


*Fig. 3 Cryogenic Vessel Control for total welding operation*

This is just a brief description of the total system but it does illustrate that to achieve automation in welding then we must attack all five basic points mentioned in section 5.

## 7. FUTURE DEVELOPMENTS IN AUTOMATED WELDING

Automated welding is, in industrial terms, a very new concept. For this reason many possible enhancements to the process have yet to appear in available systems. It is, however, possible to forecast some future development which over the next few years, will become available as standard products. Undoubtedly the major impact on welding equipment will be that of the microprocessor. The numerical machine tool industry, which is ahead of welding in its use of automation has already responded to the availability of the microprocessor and today most NC machine tools are based around this device. As welding catches up we will see a growing move towards 'smart' welding equipment. By this I mean equipment in which the ultimate weld quality is independent of the skill of the machine operator and which can be operated as a component of a larger 'weld production system'. In the past operator skills have been used to compensate for unwanted variation in the output from a welding power source. The development of digital control centered around a microprocessor has enabled machine parameters such as timing and current/ voltages settings to be held accurate to $<0.5\%$ thus obviating the need for operator intervention. The microprocessor also allows any variation of parameters outside of defined limits to be detected and recorded for quality control purposes. This ability will enable fabricators to produce welds with a much higher degree of confidence than was previously attainable.

The use of a welding power source as a component in a larger system is another area where there is plenty of room for development. Present systems usually treat the production of an arc and the positioning of the arc as two separate problems. However, as soon as advanced techniques such as seam tracking and penetration control are applied it becomes necessary for the power source and the positioning system to be tightly linked. The microprocessor facilitates this process by enabling international standard interfaces such as RS232 or IEEE488 to be employed. The use of such standard interfaces allows mixing of equipment from many manufacturers in a single system.

Where large systems are constructed for welding it is often necessary to feed production results directly into a management information system. In this way it is possible to obtain early warning of problems occurring in production and thereby 'tune' the manufacturing process for maximum output. The use of microprocessor based welding equipment makes such an information link very easy to achieve. Again the use of a standard interface means that virtually any data processing computer can be linked direct to the welding system thus monitoring it for management purposes.

## 8. CONCLUSION

It can be seen therefore, that we are beginning to see the introduction of genuine automation in welding processes. There are at least five different aspects of the welding procedure which must be considered if we are to achieve such automation. In the future we will begin to use more sophisticated techniques which will give us greater flexibility to meet these different criteria in a more effective manner. However many of the tools required to achieve automation are already with us and only require some application to the problem. The advantages to be gained are enormous and often in excess of those expected when the initial specification was considered.

### References

1. BAGGERUD, A., "Automation in Arc Welding". Lecture given at the Cranfield Institute of Technology, 17 May 1978.
2. British Patent 1514407
3. British Patent 3204081