KCP-613-4808
Distribution Category UC-706

INVESTIGATION OF ARC LENGTH VERSUS FLANGE THICKNESS WHILE USING AN ARC VOLTAGE CONTROLLER

G. J. Daumeyer

Published November 1994

Topical Report
G. J. Daumeyer, Project Leader

AlliedSignal
AEROSPACE

DISCLAIMER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Contents

Illustrations

Figure *Page*

Table

Number *Page*

Abstract

An arc voltage controller (AVC) for gas tungsten arc welding will change arc length when flange thickness changes while all other variables, including AVC setting, are held constant. A procedure for calibrating an LVDT (linear variable displacement transducer) used for electrode assembly motion monitoring was proven for laboratory setups and special investigations. A partial characterization on the deadband and sensitivity control settings of the Cyclomatic AVC was completed.

Summary

Observations of arc voltage control (AVC) in gas tungsten arc welding (GTAW) indicated that the arc length which the AVC produced was dependent on the weld joint geometry, specifically the flange thickness. A simple experiment was set up to quantify the relationship between flange thickness and arc length. Results indicate that for weld joint geometry with large tolerances on machined edges the AVC may not provide adequate control. For this limited investigation, a change in arc length of 0.021 inch occurred from combined flange thickness of 0.020 inch to 0.070 inch. Different arc lengths will occur for different flange thicknesses when AVC setting and all other variables are held constant.

Discussion

Scope and Purpose

The purpose of this investigation was to prove and quantify the relational changes in arc length for changes in flange thickness while holding all other variables constant. The arc voltage control (AVC) is supposed to hold arc length constant by maintaining a constant arc voltage while all other welding variables are being held constant. However, on rare occasions during gas tungsten arc welding (GTAW) of parts the AVC has been observed to behave erratically. The inconsistent performance of AVCs in applications was the reason to investigate further. This experiment was conducted to get data to support observations which indicated that different flange thicknesses gave different arc lengths while the AVC voltage setting (along with all other process variables) remained unchanged.

Arc voltage and arc length have been synonymous in general discussions involving GTAW and AVC control. The AVC controller is set to control voltage. However, arc length is the topic of concern for this report. It was not the intent of this investigation to show the relationship between arc length and arc voltage, but to show that flange thickness affects the arc length. Therefore the scope of this investigation was extremely limited because only a simple verification of observations was desired. Data from a linear variable displacement transducer (LVDT) used for arc length measurement was taken from only five specially made coupons.

Activity

Background

Arc voltage control is a common means for controlling the arc length by maintaining a constant arc voltage of the GTAW process. The relationship between the resistance of the welding arc R_A and the arc length is considered constant between the anode fall space and the cathode fall space. (The fall space is the space right at the anode and cathode where the voltage change is not linear. It is approximately 0.005 inch.) Ohms law of $V_A = I_A R_A$ is used in a feedback control loop to maintain a constant arc length by selecting a desired arc voltage. Obviously any change in arc current will cause a change in arc length for a given AVC setting. Other factors will also change the arc voltage and arc length if the resistance of the arc is affected by these other factors. This study shows that while keeping every welding process variable constant, except the flange thickness, the resistance of the arc will change and produce a resultant change in the arc length.

It has been observed in production as well as in development that the AVC will not always repeat the same arc length from part to part. Different arc lengths for the same AVC setting will occur for changes in other welding parameters including cover gas type, cover gas flow rate, welding current, base metal type, and surface cleanliness. When different arc lengths were observed while all other parameters were being held constant, the weld joint geometry became suspect.

An AVC attempts to control the arc length by maintaining a constant arc voltage. When a positive or negative arc voltage error is recognized, a signal is sent to an AVC motor. The AVC motor then adjusts the arc length until the AVC voltage being sensed is in the tolerance band.

The use of AVC control is simple to implement because the column of arc plasma behaves like a linear resistor between the anode and cathode fall space. The further away the GTAW electrode is from the welding work surface, the more voltage is required from a constant current power supply. Under these conditions the relationship of

$$V = IR \tag{1}$$

should hold from weld to weld. Factors known to change the voltage setting and/or the arc length are any factors that change the current or resistance of Equation 1. The power supply used for GTAW will hold a constant current for welding. Factors that change the resistance (or electrical characteristics of the plasma) are cover gas type and flow rate, arc length, base metal material, electrode shape; and now weld joint geometry has been proven to change this resistance.

Arc voltage and/or arc length affect the heat going into a part for welding according to the equation:

$$H = f_1 \frac{VI}{TS} \tag{2}$$

where:

H = heat into the part,

f_1 = an efficiency factor,

V = voltage,

I = current, and

TS = travel speed.

Arc voltage and arc length have been synonymous in general discussions involving GTAW and AVC control. The AVC controller is set to control voltage. However, arc length is the element of concern here. A manual welder controls arc length because he cannot detect an arc voltage. It is the arc length that we want to control in order to have arc voltage and heat input into the parts being welded.

AVCs have worked in the past, and they will continue to be good process controls in the future. However, every process control has certain limits and conditions, and flange thickness tolerance is one of those conditions.

Experimental Procedure

The experimental procedure was divided into three activities. First, the linear variable displacement transducer (LVDT) was calibrated. Second, a short characterization of the AVC was performed. Lastly, the welds were made on the special coupons (described later) and data was collected.

An LVDT is a displacement measuring device which gives a voltage output that correlates to a distance. The voltage output from the LVDT required calibration with a strip chart recorder in order to relate distance of LVDT movement with changes in divisions of the strip chart recorder. The procedure for calibrating the LVDT involved moving the torch with the AVC. The starting arc gap distance was set at two settings, "3" and "7", and the torch was moved down and up several times. While the torch was moved (basically utilizing the AVC's starting arc gap procedure), a strip chart recorder gave a reading of the LVDT movement signal. During this motion, a dial indicator was visually monitored to see the amount of travel for both starting arc gap settings. The number of lines on the strip chart recorder was divided by the dial indicator reading to give the distance moved for each division.

In order to see the change in arc length with respect to flange thickness (in a simple and straight-forward manner), a specially designed weld coupon was made. This weld coupon is shown in Figure 1. The coupons were made of 304L stainless steel and are approximately 1/4 inch by 1/2 inch by 5 inches. On the top of the mating faces of these coupons is a weld flange that goes from 0.000-inch thickness to 0.045-inch thickness. The combined thickness in the center of the weld joints is 0.090 inch. The height of the flanges was held constant at 0.045 inch.

The characterization of the AVC was to determine the deadband setting on the Cyclomatic AVC and to demonstrate the effect of the sensitivity setting. The deadband setting on the AVC is a variable setting which allows changing the amount of voltage error permitted before sending a signal to change arc length. The voltage deadband setting allows the tolerance of the set point voltage to change. For example, if the set point voltage is 8 volts and the deadband setting is low, the voltage the AVC will try to maintain would be 8 ± 0.03 volts. If the deadband setting is high, the AVC will attempt to hold the voltage at 8 ± 1.48 volts. The sensitivity setting on the AVC works with the deadband to produce the overall response of the AVC. The higher the sensitivity is

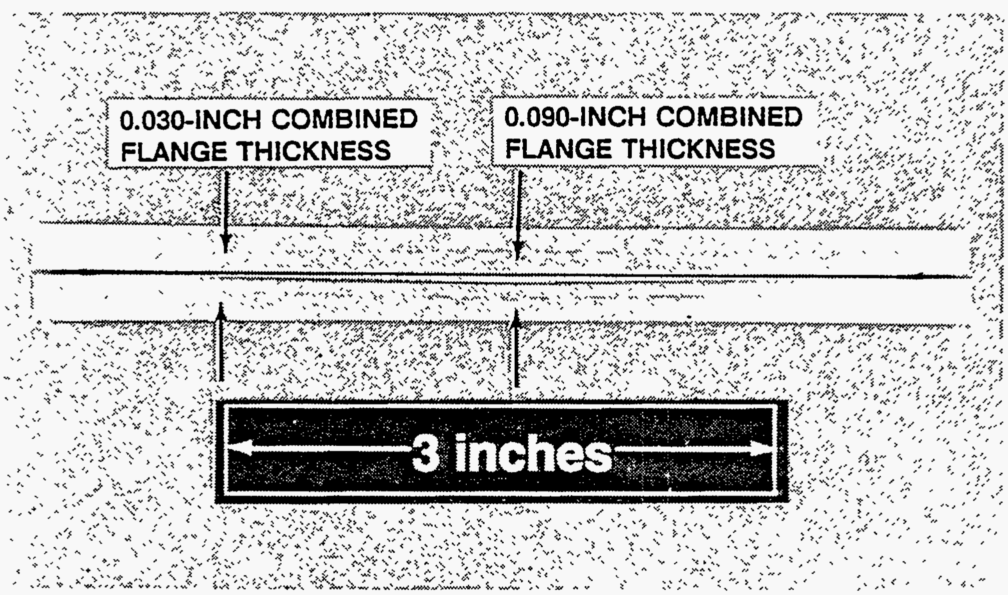


Figure 1. Weld Coupon, 304L Stainless Steel

set, the faster the system will attempt to correct itself. Appendix A contains the manufacturers description of the AVC including deadband and sensitivity settings.

The sensitivity setting was demonstrated by setting it to minimum and maximum values and causing a change. This change was produced by a voltage signal from a voltage generator. The strip chart recorder was set at a constant velocity for both the minimum and maximum settings. The difference in the slope of the line for each setting shows that sensitivity is the velocity adjustment on the AVC motor.

The characterization of the deadband setting was also done with a voltage generator in order to simplify the experiment. A deadband size in volts for each division on the equipment (shown in Figure 2) was determined.

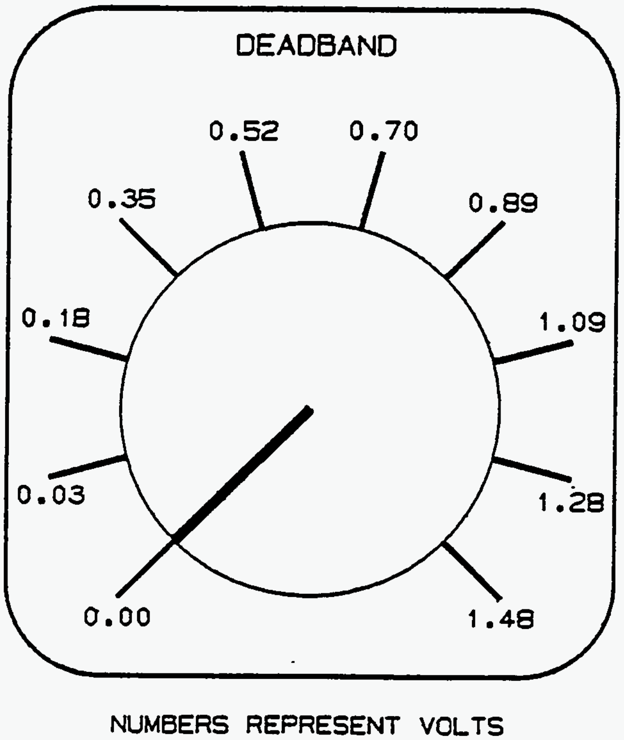


Figure 2. Deadband Voltages for Each Division

The AVC setting was set at two different settings, and a pulsed GTAW weld was made down the length of each coupon. While the AVC adjusted the arc length, the LVDT sent a signal to a strip chart recorder. The change in arc length was recorded while all other variables were held constant.

Experimental Setup

The experimental setup is shown in Figure 3. A Cyclomatic AVC was used with a Dimetrics power supply and a Task Master CNC controller.
An LVDT was placed above the welding torch on a flat, firm location and used to measure the movement of the torch as an arc voltage controller made arc length adjustments during a welding cycle. A 12-volt power supply was used to energize the LVDT while a strip chart recorder recorded the movement. A dial indicator was also on the same flat, firm surface as the LVDT for calibration of the LVDT. The chart recorder was adjustable so that a range of 0.1 inch was possible. Paper speed was set at 12 cm/s for the welding pass over the coupons.

The welding electrode holder used is the same torch design developed for "vision-sensing" welding. A 0.062-inch-diameter electrode with a sharp 15-degree-included angle was placed in the torch. Electrode extension from the electrode collet was approximately 1.5 inches. Extension below the ceramic gas cup was approximately 0.6 inch. The cover gas was argon set at a flow rate of 45 cfh.

The weld schedule was the same as that currently used in production and is summarized below.

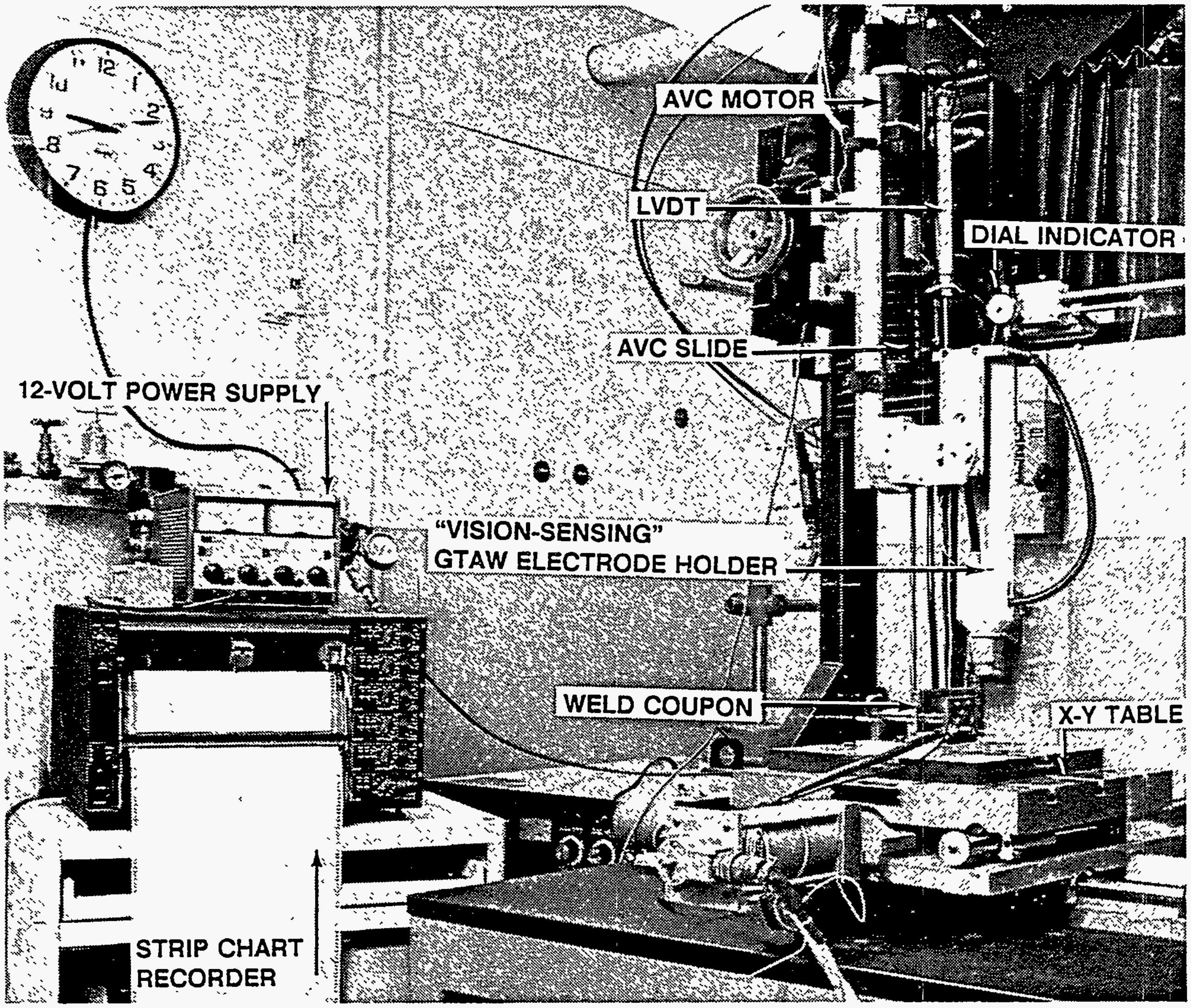


Figure 3. Experimental Setup

Weld schedule:

Welding current peak: 75 amperes (25%)

Welding current background: 30 amperes (75%)

Pulse/Frequency: 20 pps

Cover gas: argon

Cover gas flow rate: 45 cfh; required for adequate coverage with vision-sensing electrode holder (not production setting)

Travel speed: 16 ipm

No water chiller used

Two AVC settings: 8.0 volts and 8.5 volts

The scale on the chart recorder was set at "1" and the voltage "V" was set to "÷ ÷ ÷ ÷". After finding the top of the weld coupons on the strip chart recorder, the starting arc length was set at "3" or approximately 0.030 inch. The unlock delay on the AVC was 0.4 seconds and permitted about 1/2 inch of travel before taking control. The electrode was definitely red hot by this time (and assumed to be stable).

The LVDT was very reliable and accurate. Preliminary adjustments prior to calibration showed high accuracy and repeatability. Care was taken to ensure that the LVDT was electrically isolated from the welding current.

The coupons were taped together on the bottom and clamped tightly in a level vise as shown in Figure 4. The coupons were not tacked together because this would alter the weld joint geometry. Prior to each weld the LVDT was used to ensure that the coupons were level within ± 0.001 inch along the weld length. The coupons were marked every 0.015 inch of flange thickness (not of linear distance). The black marks on the coupons indicate flange thickness measurements. The end of the weld was marked so that the locations of the flange thickness could be marked onto the chart recorder graph paper.

Results

Calibration

In Figure 5 the calibration data is shown for both "3" and "7" starting arc gap settings. The distance per division was

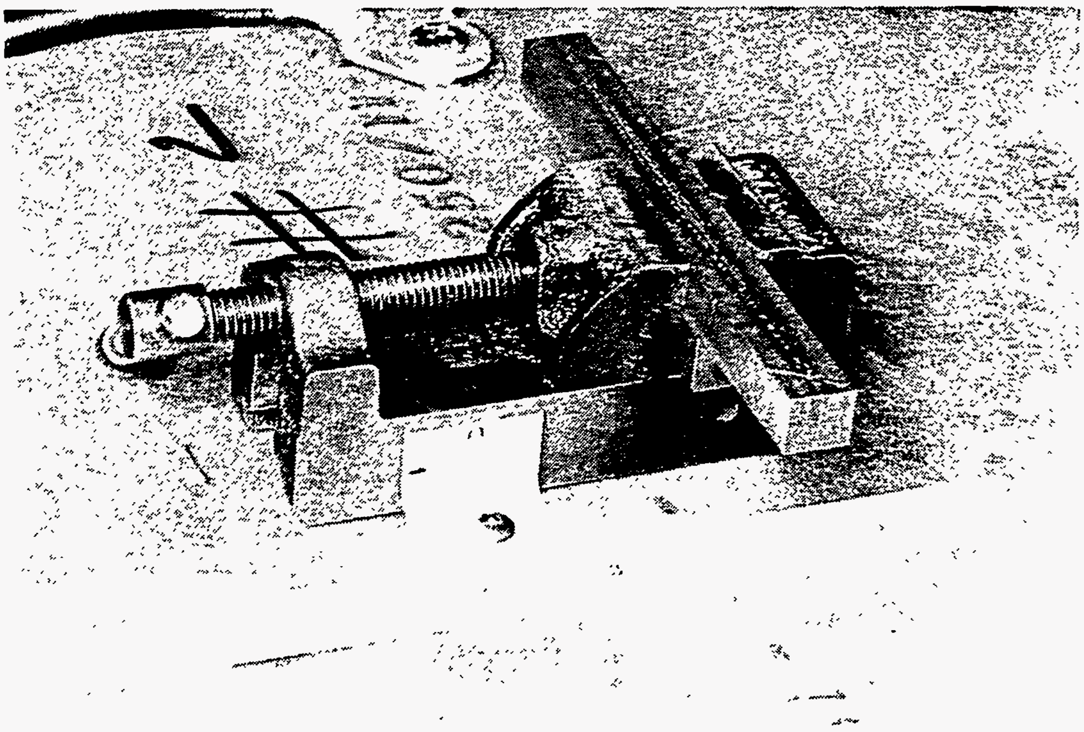


Figure 4. Coupons Taped Together and Clamped

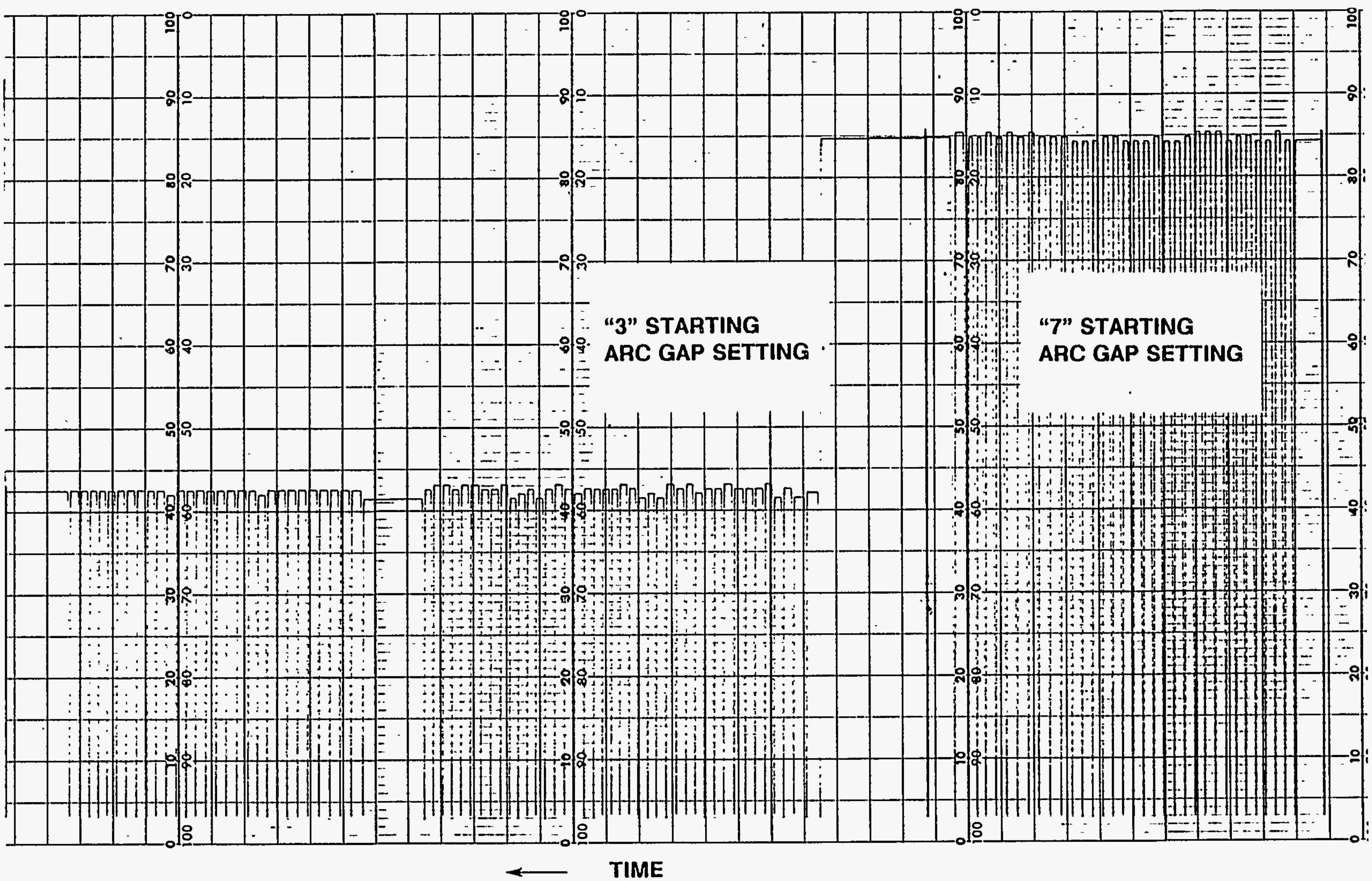


Figure 5. LVDT Calibration Data

0.000865 inch for "7" starting arc gap setting. The distance per division was 0.000861 inch for "3" starting arc gap setting. The difference in Figure 5 for electrode returning is considered negligible. The calculation for this calibration is as follows.

For "7" starting arc gap

Dial indicator observed change = 0.071 inch

Strip chart movement = 82 divisions

0.071/82 = 0.000865 inch per division

For "3" starting arc gap

Dial indicator observed change = 0.034 inch

Strip chart movement = 39.5 divisions

0.034/39.5 = 0.0008607 inch per division

Actual Welds

The actual data for arc length change while welding the changing flange thickness coupons and keeping all other variables constant are shown in Figures 6 and 7. The bottom of the graph is a time line that runs from right to left. The coupons were marked where the weld stops, and the graph shows the arc length increase where the electrode stops and the automatic retract raises the electrode. From the end of the weld, the flange thickness markings can be placed on the graph. Sample number 2 gave a total arc length change from 0.009 inch to 0.030 inch. Sample number 3 gave a total arc length change from 0.014 inch to 0.048 inch. Most of this change was over thicknesses ranging from 0.020 inch to 0.070 inch.

Figures 6 and 7 are the results of the investigation recorded on a strip chart recorder. The arc length did not change much over the 0.075-inch to 0.090-inch range. A steeper than expected change occurred over the 0.020-inch to 0.070-inch range. The flat curve over the 0.075-inch to 0.090-inch range indicates that the AVC is more stable for those thicknesses. These data clearly demonstrate a change in arc length over the range from 0.020 inch to 0.070 inch in thickness. Also, this helps explain why an AVC setting for nominal weld flange thickness needed to be adjusted for thinner flanges to prevent electrode sticking.

The marks at the bottom of Figures 6 and 7 are not necessarily evenly spaced because the coupons were marked at exact flange thicknesses of 0.015, 0.030, 0.045, 0.060, 0.075, and 0.090 inch in both increasing and decreasing order. These locations were used to measure from the end of the weld to the location of flange thickness and were not necessarily evenly spaced on the coupons. Therefore, the marks on the graphs are not uniform in spacing. The same marks for measured flange thickness were used for the penetration measurements discussed later.

The calculation for locating exact flange thickness to chart location required locating the end of the weld physically and on the strip chart recorder. Then the travel speed of the strip chart recorder had to be related to the length location of the measured flange thickness. Because the strip chart recorder operates in centimeters per minute, a conversion from

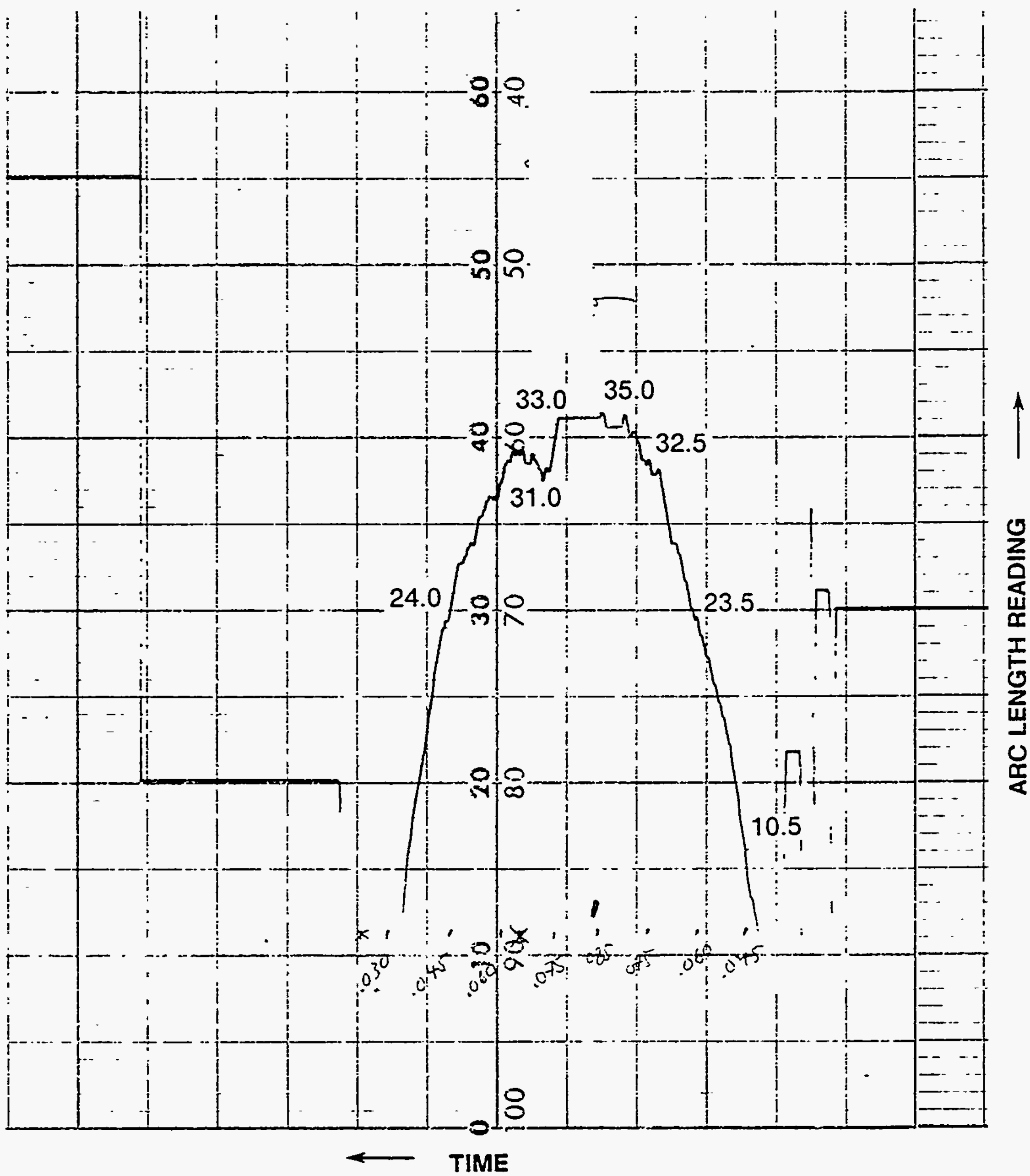


Figure 6. AVC Set at 8.0 Volts

inches to centimeters was required. The calculation is as follows.

Welding speed = 16 ipm

Weld length = 3.75 inches = 9.525 cm

Weld time = (3.75)/16 ipm
= 0.2343 min = 14.06 s

Chart speed = 30 cm/min = 0.5 cm/s

Chart length per weld time
= (0.5 cm/s) (14.06 s)
= 7.03 cm

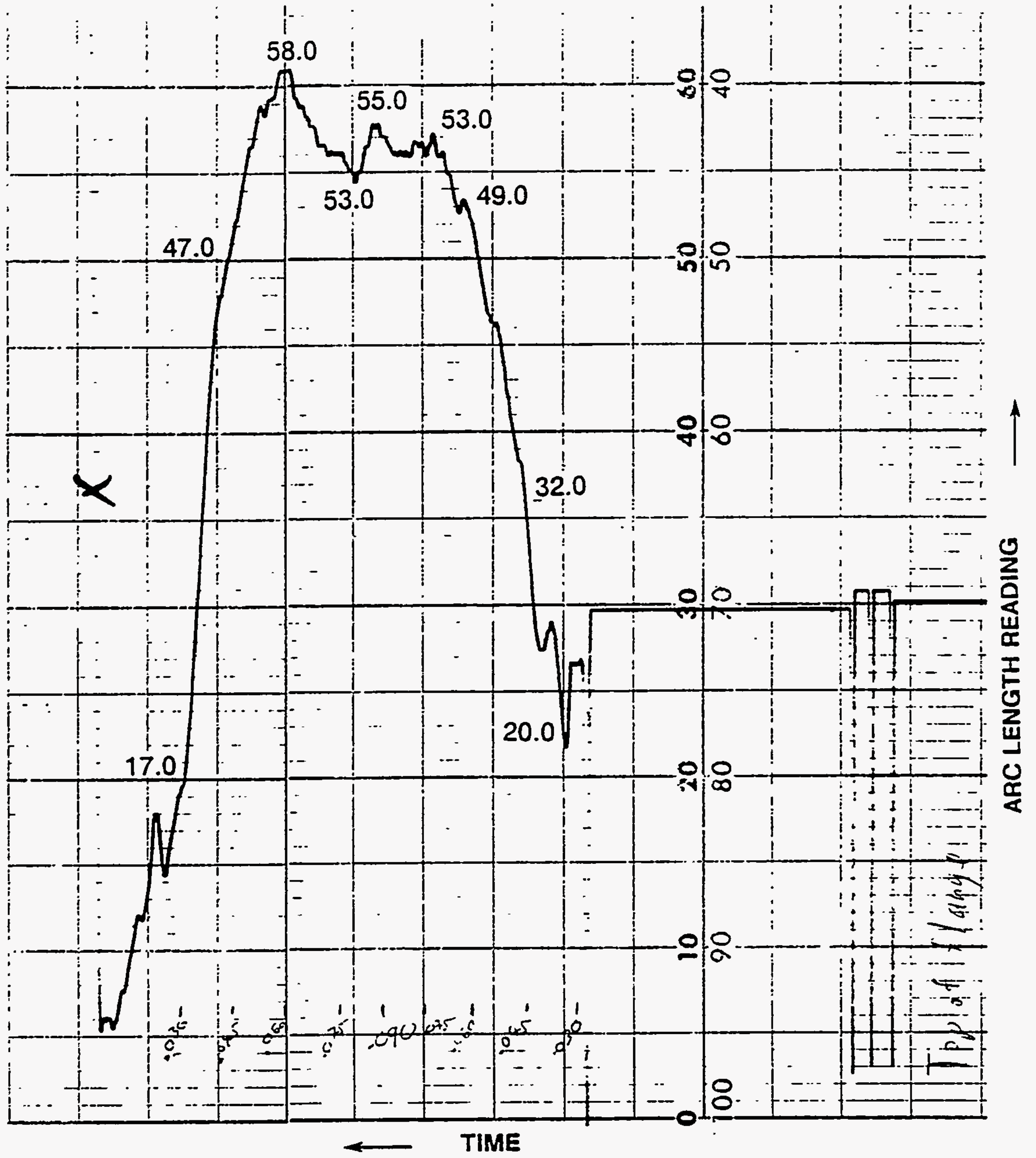


Figure 7. **AVC Set at 8.5 Volts**

From end of weld to end of graph measurement,

(A in inches) (2.54 cm/inch)
[(7.03 cm)/(9.525 cm)] = length on chart in centimeters,

where

A is length from end of weld to flange thickness measurement.

The length location of flange thicknesses was measured with a 0.001-inch division dial caliper. The chart measurements were made with a steel scale. On the graphs in Figures 6 and 7, the X line marks the end of the weld.

Table 1 contains the calculated and measured results for coupons numbered 2 and 3. Coupons 1, 4, and 5 were made with settings which did not produce valuable graphs. In coupon 1 the deadband was too high. In coupon 4 the AVC setting was too high and the graph went off the chart. Coupon 5 had the sensitivity setting too high and stuck the electrode.

Figures 8 and 9 show the coupons in their as-welded condition. It is obvious from the top view that the weld width follows the flange width. The locations where the flange thicknesses were measured are marked by the dots on the coupons. The X locates the end of the weld.

The penetration of the welds was measured only as a matter of record for this experiment. A photo of a typical cross section is shown in Figure 10. Penetration is measured at the center line of the weld to the top of the reinforcement. The penetration measurements for coupons 2 and 3 are recorded in Table 1.

Table 1. Data Sheet for Arc Length Versus Flange Thickness

	X-END	1	2	3	4	5	6	7	8	9
	Flange Thickness	0.030	0.045	0.060	0.075	0.090	0.075	0.060	0.045	0.030
Coupon #2	Distance from weld end	0.345	0.825	1.220	1.620	1.960	2.335	2.710	3.075	3.540
	Distance from chart end (cm)	0.644	1.540	2.277	3.024	3.659	4.359	5.059	5.746	6.608
	Arc Length Divisions	N/A	10.5	23.5	32.5	35.0	33.0	31.0	24.0	N/A
	Arc Length	N/A	0.0091	0.0203	0.0281	0.0303	0.0285	0.0268	0.0208	N/A
	Penetration	0.028	0.040	0.039	0.033	0.028	0.033	0.039	0.043	0.025
Coupon #3	Distance from weld end	0.610	1.020	1.425	1.845	2.170	2.495	2.855	3.280	3.665
	Distance from chart end (cm)	1.139	1.904	2.660	3.444	4.051	4.657	5.329	6.123	6.841
	Arc length Divisions	17.0	47.0	58.0	53.0	55.0	53.0	49.0	32.0	20.0
	Arc length	0.0147	0.0407	0.0502	0.0458	0.0476	0.0458	0.0424	0.0277	0.0173
	Penetration	0.045	0.036	0.031	0.026	0.024	0.030	0.034	0.037	0.015

Note: Dimensions in inches unless otherwise noted.

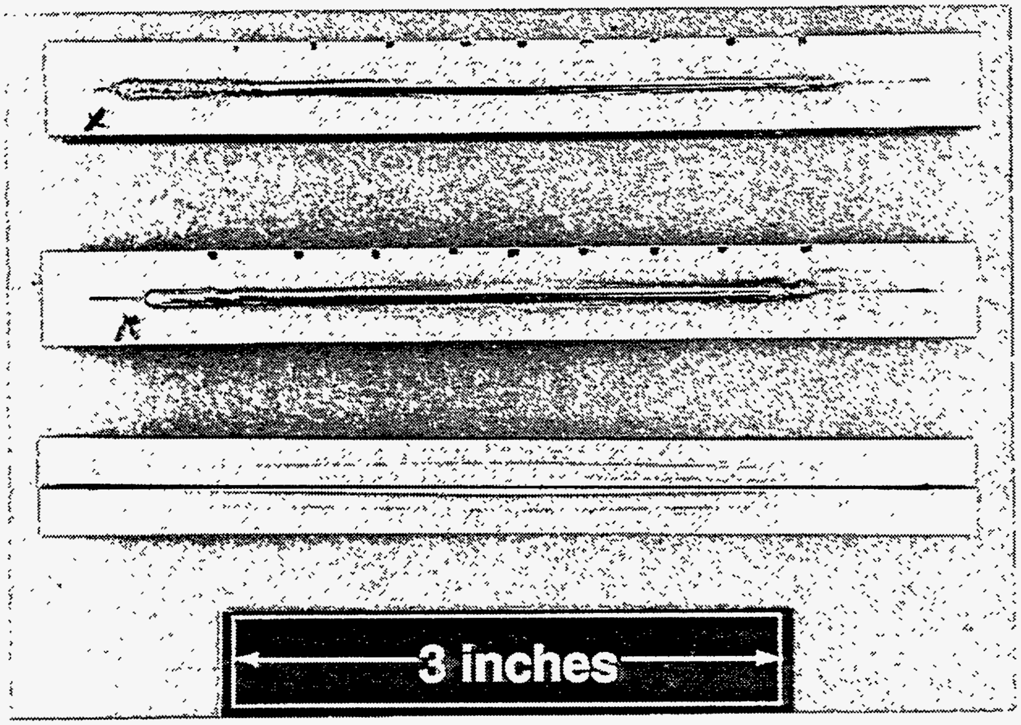


Figure 8. Coupons as Welded (Top View)

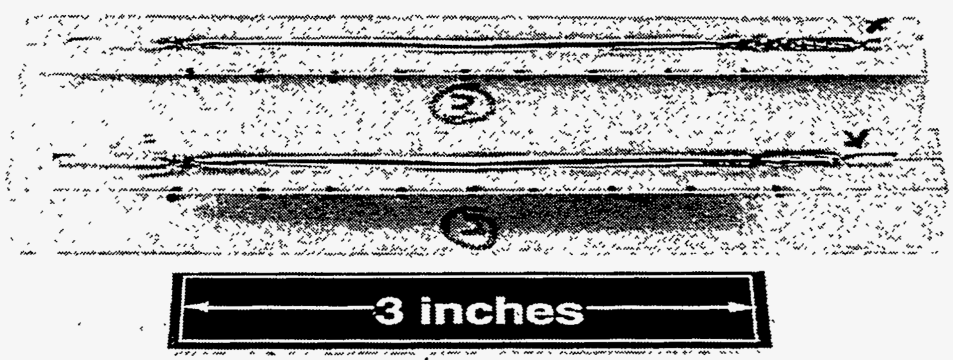


Figure 9. Coupons as Welded

Sensitivity and Deadband Characterization

The data from the sensitivity setting is shown in Figure 11. The maximum sensitivity and minimum sensitivity for the AVC controller are shown. Obviously the sensitivity setting of the AVC controller determines the velocity at which the AVC server motor moves the electrode assembly.

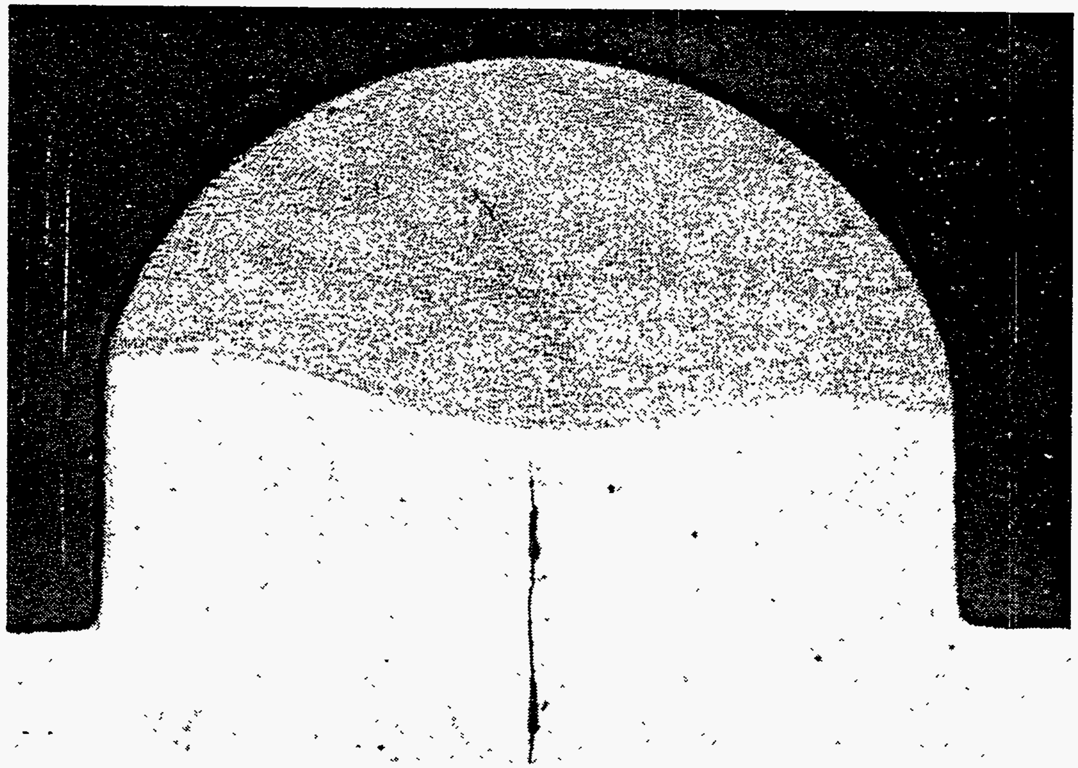


Figure 10. Typical Cross-Section Photograph of a Coupon Weld

The deadband setting on the Cyclomatic AVC was characterized, and the voltage error for each division was determined. The voltage error for above and below the deadband setpoint is the same.

Accomplishments

The most significant accomplishment is that this investigation quantifies and verifies that an AVC controller for GTAW will change arc length when flange thickness changes while holding all other variables, including the AVC setting, constant. The experiment showed that for a change in flange thickness the AVC will change the arc length. For proper process control, arc length needs to be controlled. When using arc voltage to control arc length, the variability of flange thickness over normal tolerance ranges might not permit adequate process control.

A procedure for calibrating an LVDT used for electrode assembly motion monitoring was proven for lab setups and special investigations.

A partial characterization on the deadband and sensitivity control settings of the Cyclomatic AVC was completed.

It was determined that arc length control must be pursued for the "vision-sensing" feedback control project for two reasons. First, if a feedback control loop changes the welding current, the AVC will not function properly because of the current-voltage characteristic relationship of the GTAW arc. Second, if the welding current is not adjusted for feedback control, arc length must still be controlled because

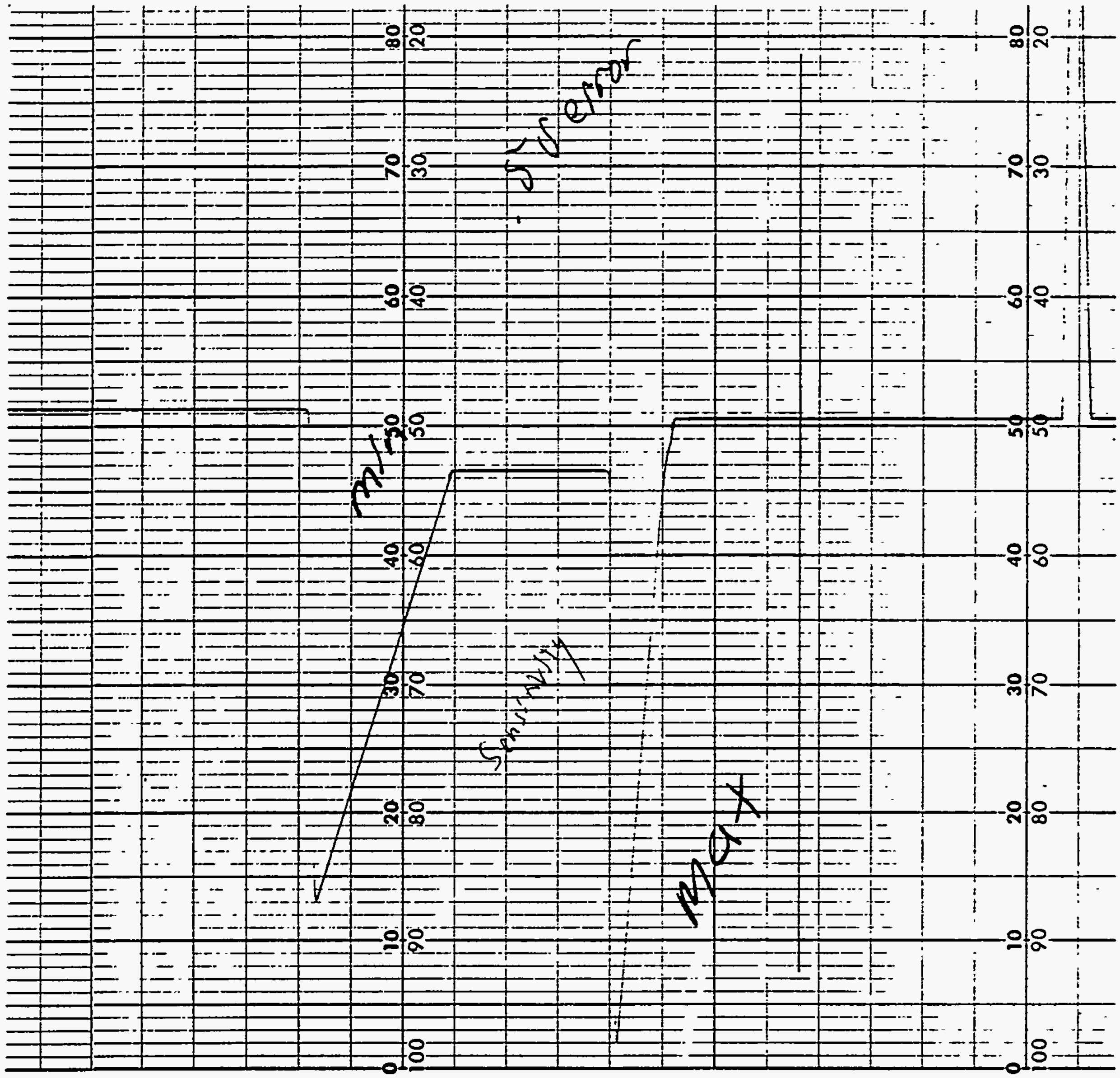


Figure 11. Sensitivity Characterization

different flange thicknesses will cause different arc lengths, and thus the welding heat would not be controlled.

Future Work

- A more thorough characterization of the Cyclomatic and Dimetrics AVCs should be completed in order to determine what range of welding variables will cause unwanted results and to determine flange thickness reliability limits.
- Development of a production-ready arc length controller should be completed and implemented.
- Future weld joint geometry studies should have either a fixed arc length,

measured arc length change, or consideration of the arc length/flange thickness relationship as a dependent variable.

Bibliography

American Welding Society (AWS), *Welding Handbook*, Vol. II, 8th Edition, Chapter 3.

Dereskiewicz, J. P. *GTAW Characterization for Weld Penetration on 304L Stainless Steel.* (Topical Report). Kansas City Division: BDX-613-3931, June 1988 (Available from NTIS).

Richardson, Richard W. *A Vision-Based Adaptive GTA Welding System for Aerospace Applications.* (Research Report). Edison Welding Institute, Columbus, OH. September 1986. (Ref. MR 8702).

Appendix A

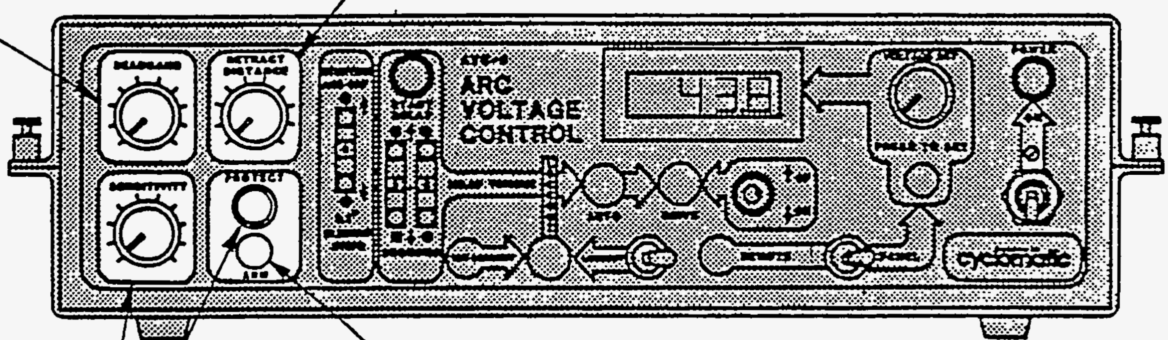
Cyclomatic AVC Description

DEADBAND: SETS A DEAD ZONE AROUND THE ARC VOLTAGE SET POINT OVER A RANGE OF ± 1.5 VOLTS. THE AVC WILL NOT MAKE HEAD CORRECTIONS DURING A WELD CYCLE UNLESS THE ARC VOLTAGE EXCEEDS THE UPPER OR LOWER LIMITS OF THE DEADBAND. THIS PROHIBITS THE AVC HEAD FROM MAKING CONTINUAL FUTILE CORRECTIONS DUE TO ARC VOLTAGE FLUCTUATIONS CAUSED BY GAS INSTABILITY, POWER SUPPLY RIPPLE, ETC.

NOTE: THE DEADBAND AND SENSITIVITY SETTINGS ARE IMPORTANT TO EVERY AVC APPLICATION: PLEASE READ SECTION 3.6 FOR FURTHER EXPLANATION OF HOW TO UTILIZE THESE FUNCTIONS FOR OPTIMUM RESULTS.

RETRACT DISTANCE: SETS THE END OF WELD CYCLE RETRACT DISTANCE OF THE AVC HEAD OVER A RANGE FROM 0 TO 4 INCHES.

FIGURE 9



SENSITIVITY: SETS THE SPEED/ERROR RELATION SHIP OF ARC VOLTAGE CORRECTION. (HOW FAST THE HEAD WILL CORRECT FOR A GIVEN ERROR.)

MINIMUM = FULL COMPENSATION SPEED WITH ± 6V ERROR.

MAXIMUM = FULL COMPENSATION SPEED WITH ± 1V ERROR.

PROTECT ARM: MANUALLY ENABLES THE BURN-THROUGH PROTECT CIRCUIT WHEN TOUCH SENSING (PRE-POSITIONING) IS NOT BEING USED. (NOTE: WHEN TOUCH SENSING IS BEING USED, THE BURN-THROUGH PROTECT CIRCUIT IS AUTOMATICALLY ENABLED.) SEE SECTION 3.6 FOR FURTHER DESCRIPTION OF THE BURN-THROUGH FEATURE.

PROTECT CIRCUIT INDICATOR: THE YELLOW LAMP ABOVE THE PROTECT ARM SWITCH WILL INDICATE WHEN THE BURN-THROUGH DETECT CIRCUIT IS ARMED. IF A BURN-THROUGH IS DETECTED, THIS LAMP WILL GO OUT.

3.6 SETTING DEADBAND AND SENSITIVITY CONTROLS

These controls allow the operator to optimize the voltage accuracy for any condition of gas or gas mixture, material, arc current, travel speed and arc voltage. Without these controls, every arc voltage control application is a compromise.

The white HEAD DRIVE indicator light turns on whenever the AVC makes a correction of torch position. The brightness of the light shows the amount of torch movement. During normal welding, the torch should be making only small corrections and the HEAD DRIVE light will be barely visible. If the DEADBAND/SENSITIVITY controls are set improperly, the HEAD DRIVE light will either be too bright or completely off.

The most sensitive setting is minimum (completely counterclockwise) DEADBAND and maximum (completely clockwise) SENSITIVITY. The most sensitive settings will, for most applications, either cause instability ("stitching") or overcorrection (torch movement too "busy") and the HEAD DRIVE light will be bright all of the time. Overly busy torch movement is not desirable because it is overshooting the set voltage and also causing unnecessary wear.

The least sensitive setting is maximum DEADBAND and minimum SENSITIVITY. These settings in most applications give too little correction, and the HEAD DRIVE light will always be off. This type of setting doesn't hold the set voltage very well.

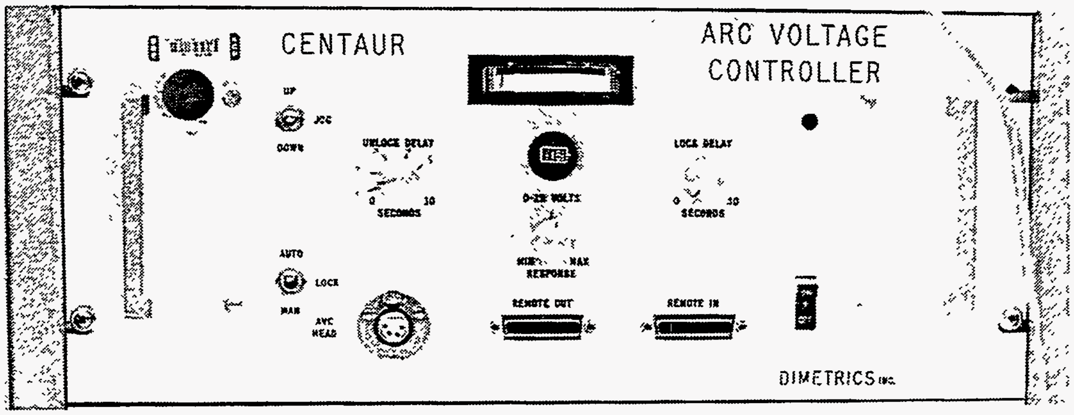
Obviously, the best settings are those which produce moderate torch movement (indicated by the HEAD DRIVE light being barely visible). The best combination of DEADBAND and SENSITIVITY settings must be determined by experimenting with different settings while using the specified weld current, gas, etc. The object is to get the DEADBAND set as low as possible (counterclockwise) and the SENSITIVITY set as high as possible (clockwise) without excessive "busyness" of the HEAD DRIVE.

For some applications the operator may want to achieve lower DEADBAND rather than high SENSITIVITY and vice versa. For example, if a weld is being made on a smooth part relatively level to torch travel where little torch height correction is required, then the DEADBAND should be set more toward minimum while adjusting the SENSITIVITY to get desired HEAD/TORCH drive correction. This makes sense when you consider that the DEADBAND controls how much error is allowed before the drive begins to move, and the SENSITIVITY controls how fast to correct once the error is detected.

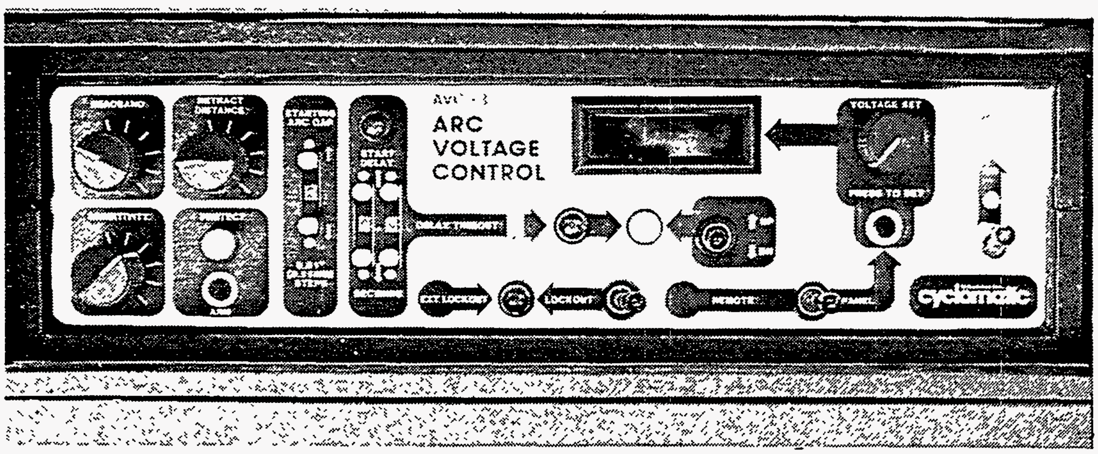
Conversely, if a weld is being made on a rough surface where large corrections are rquired in a short period of time, then the SENSITIVITY should be set more toward maximum while adjusting the DEADBAND control to get the desired HEAD/TORCH drive correction.

Appendix B

Cyclomatic and Dimetrics AVCs



Cyclomatic AVC



Dimetrics AVC