MANUFACTURING WELDING CONTROL
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ORGANIZATION FOR PRODUCTION WELDING

Before we discuss the control of the welding process let's think for a moment about the Manufacturing Control Organization that leads up to and organizes the various functions necessary for production.

Gentlemen we've got problems! Almost all of the Aerospace producers today have large complex organizations designed to insure a smooth transition from preliminary design through pre-planning, Design Engineering, Value Engineering, Scheduling, Tool Planning, Tool Control, Tool Design, and Tool Fabrication. Alone with these organizations, the Engineering Test Laboratory, the Quality Control Lab., and the Quality Assurance people provide their input after all this, and the use of several computers, the job finally reaches the production shop, and there is where the fun begins.

PROCESS CONTROL

We are trapped between relying on operator skill and depending upon process control. Neither system has proven consistantly reliable.

In the instance of operator skill it is now impossible for the most skilled operator to reliably control the machine welding processes by visual monitoring.

PROCESS CONTROL (Cont'd)

On the other hand it has been difficult to adequately control the weld parameters in order to achieve predictable results.

To add to these difficulties, the radiographic people have been unable to reliably determine quality by X-ray of the heavier, say above 3/4", aluminum. weldments.

Quality Assurance won't buy the first weld, or the second; we have a round of re-certification of operators and equipment.

All this time we are getting further and further behind the production schedule. Finally there is an agonizing re-appraisal of the whole program.

Generally after a round of blame tossing, we find that perhaps the only administrative mistake, other than putting an ex-shoe salesman - with no previous welding experience - in charge of the weld shop, was that we attempted to go into a production program, on a new process, without a Development Program.

DEVELOPMENT PROGRAM

Gentlemen, when we start production on a new welding process, and often we fail to recognize that it is a new process, we are going to pay for, and have, a Development Program. It may be buried under the name of tool try, or production set-up, or learning curve. Unfortunately, development work done under the control of production people, with production schedules and man-hour realization problems is seldom if ever very effective.

DEVELOPMENT PROGRAM (Cont'd)

Assuming that the quality specification is realistic, we find that after sometimes thousands of man-hours of preparation for the control of welding production, one little detail has been overlooked. That is we are not controlling the weld parameters.

During the last few years, the equipment manufacturers have provided us with some excellent equipment, however in certain areas, not good enough.

INSTRUMENTATION

The most glaring weakness generally found throughout the Aerospace welding industry today is inadequate Instrumentation.

How can we expect to maintain absolute, or even adequate control of the weld variables when we don't know what amperage, what voltage, or what speed we are actually using. In many cases the instrumentation as used is misleading and therefore worse than none at all.

In many cases such variables as wire speed and weld speed are not even recorded. Also we now realize that many of the parts of a weld set-up that were previously thought to be constant, are really extremely variable. Fo example we now realize that weld torch resistance, shielding gas quality and tungsten electrodes are variables that must be accurately controlled. In each case it is necessary to determine the degree of control that we are able to maintain in comparison with the required control and what effect these uncontrolled variations of a single or combination of parameters has on the remaining elements of the system.

INSTRUMENTATION (Cont'd)

For example, for ideal measurement of the welding arc, the voltage recorder leads should be connected to the electrode and the work as close to the arc as possible. This connection is not practical in the welding torch, therefore the leads must be connected to the head of the body assembly. The recording then includes the voltage drop in the welding torch barrel assembly, collet, and the electrode as well as the welding arc. The IR drop for welding torches has been measured to vary with different manufacturers by as much as .3 volts when welding at 500 amps.

TORCH RESISTANCE

When welding at 500 amperes D.C.S.P., a resistance variation from one torch to another or from one tightening of the electrode collet to another can cause arc variations beyond the relm of transferability. A resistance of only .0002 ohms results in an IR drop of 0.1 volts. We have measured the voltage drop in three different manufacturers torches to be .338 MV, .434 MV, and .132 MV. Obviously voltage settings from any one of these torches will not be transferable to other equipment.

WELD PARAMETER CONTROL REQUIREMENTS

Now what degree of control of the welding parameters do we need? On a recent development program, involving welding 1" - 2219 aluminum, it was necessary to control each variable as accurately as possible in order to determine the effect on penetration, tensile strength, and microstructure. These welds were made in the horizontal position to similate the welding of Saturn V fuel and oxidizer tanks. The DC straight polarity process was used throughout the program. The welds were made with a square butt joint, double welded, one pass from each side. No filler wire was necessary, which was fortunate from the standpoint of eliminating that variable from the data (See Figure 1).

WELD PARAMETER CONTROL REQUIREMENTS (Cont'd)

After each specimen was welded and cut into tensile specimens, the complete series of tensile specimens was etched and the penetration overlap measured and photographed (See Figure 2). Metallurgical as well as physical data was also recorded and evaluated.

WELD TEST PROGRAM

Preliminary optimum weld settings were established for maximum penetration within controllable limits of each of the variables involved.

From the established optimum weld settings of 480 amperes, 11.5 volts, and 4" per minute weld travel, each of these variables was systematically varied while holding the other two variables constant.

VARYING CURRENT

For instance, Figure No. 3 shows welding current and ultimate tensile values plotted against penetration overlap. At about 430 amps we lose tie-in of the two weld beads. At about 500 amps we lose control of the arc. Therefore the optimum amperage for this weld was about 480 amps which produced ultimate tensile values of about 45,000 psi on a reasonably flat portion of the tensile curve.

The interesting thing here is the slope of the current-penetration curve. A variation of 10 amperes will result in a penetration change of .020". And what difference could a penetration variation of .020" make? Not very much unless you are close to "0" penetration overlap, below which the tensile values drop off rapidly.

VARYING WELD TRAVEL SPEED

Figure No. 4 shows the results of varying weld travel speed while holding current and voltage constant. Above about 6" per minute weld travel speed, penetration overlap is inconsistant. Below about 3.5" per minute, penetration is excessive and uncontrollable due to heating ahead of the weld. At the slow end of the curve, undercut is prevelant along the top of the weld bead.

From the chart, (Figure 4) about 4 inches per minute appears to be a good compromise between maximum pnentration, maximum tensile values, and controllability.

The weld travel penetration curve indicates that for every 0.1" per minute travel speed variation, there is a penetration change of from .008" to .014", according to where you are on the curve.

VARYING WELD VOLTAGE

Voltage was the most difficult variable to obtain data for that we were confident of. However, after several repeat runs we were satisfied that the voltage variation does behave as shown on the curve (Figure 5). Below about 11.3 volts the tungsten will short out in the weld puddle. Above about 11.8 volts, undercutting is excessive, however maximum penetration is greatest at the higher voltage but below that voltage which produces undercutting. Although the tungsten is closer to the work, and operating more efficiently at the lower voltage, the resulting loss of (E x I) power results in less penetration.

From Figure No. 6 showing the ultimate tensile value curve and penetration overlap curve for voltage, an optimum setting of 11.6 volts was choosen. This represents an increase of 0.10 volt over the originally selected voltage. The change was made in order to increase the penetration and additional .017".

VOLTAGE-AMPERAGE TRACE

Figure No. 7 shows a typical voltage-amperage trace where each line on 100 line chart paper represents 0.02 volts and 0.5 amperes. Zero has been suppressed so that we were recording voltages from 10 volts to 12 volts, and amperages from 450 to 500 amperes during this test, with current held constant at 480 amps, voltage was varied from 11.6 volts to 11.3 volts to 11.15 volts and finally at about 11.0 volts the arc shorted out. This test was run using a Lockheed developed electrode holder.

The short-out voltage or "Dive-in-point" is a useful "bench mark" to cross check instrumentation, calibration, shielding gas purity, electrode holder resistance and other variables.

WELD PARAMETERS VS PENETRATION

Finally the voltage, amperage, and weld travel speed settings versus penetration were plotted on one chart (Figure 8).

The chart shows that for a weld setting of 480 amps, 11.6 volts, 4.0 amps, and on 1" thick 2219 aluminum, the penetration overlap will be 0.180". It can be seen from the chart that any deviation of any one of the variables represented will result in an increase or decrease in penetration as the case may be.

It also became apparent that the effect on penetration caused by any combination of simultaneous changes of the variables could be predicted by simply adding or subtracting the deviation caused by each variable from the optimum of 0.180".

WELD PARAMETERS VS PENETRATION (Cont'd)

Any combination of weld parameters between 470 and 490 amps, 11.4 and 11.8 volts, and 3.75" and 4.25" per minute weld travel will result in a penetration overlap of at least 0.125".

We have repeatedly tested the eight minimum and maximum combinations stated above and many other combinations. The chart has been found reliable.

That is, reliable within our ability to control the welding process variables.

STATE-OF-THE-ART

At present we are able to control and record current within ± 5 amperes. This includes the drift encountered in the welding power supply and the recording instrument error.

We can control voltage to within ± .05 volts, if we have good shielding helium, that is less than 100 ppm impurity and we have a consistant voltage drop in the electrode holder, and know how much that IR drop is.

We can control and record weld travel to within 0.10" per minute. This represents 0.04" per minute variation for the motor control, or 1%, and the remaining 0.06" per minute variation is due to instrumentation.

As previously discussed, these limits of controllability represent a combined possible penetration deviation of ± .010" from current, ± .006" from voltage, and ± .014" from weld travel. This represents a total, uncontrollable variation of ± 0.030" maximum. Weld travel speed is most critical.

UNKNOWN VARIABLES

In addition to the known variables we also have electrode holder resistance, shielding gas, weldment temperature, filler wire variations, weld joint fit-up, and a whole array of other variables that we don't know enough about, yet, to anticipate their effect individually, much less in combinations.

Only by means of adequate instrumentation can these variables be monitored and controlled to within established specifications. Then, and only then, can we expect to be able to reliably control weld quality by means of controlling the weld parameters.

Only when we know, without any reasonable doubt, the value of each of the weld variables, and have all of these variables under absolute control, will we be able to anticipate and predict weld quality, transfer weld parameter from machine to machine or facility to facility, and program welds for automation.

All of these things will be done, or are being done now, to meet the Aerospace welding requirements of today.

Tomorrow we will have to do more.

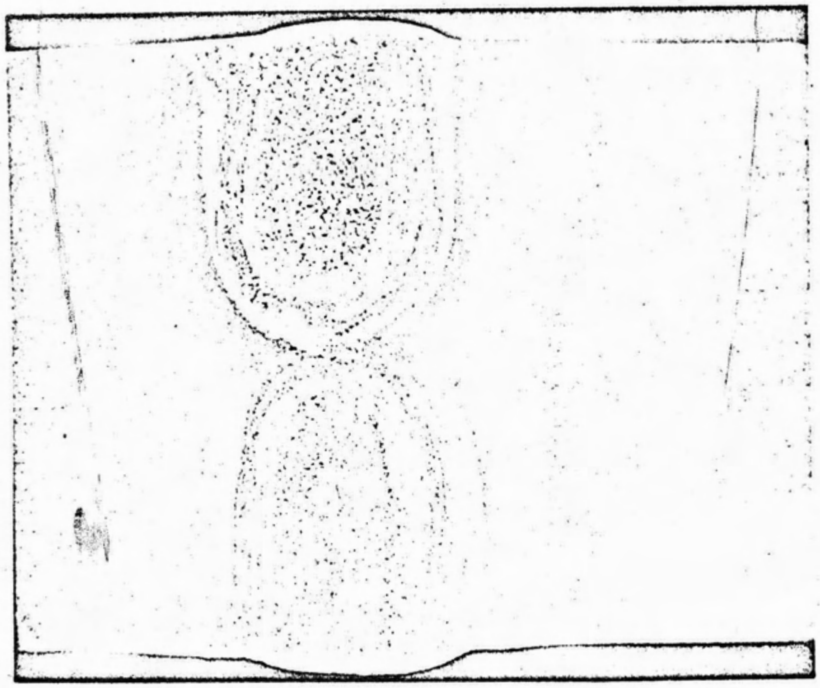


Fig. 123

Etchant - NaOH Magnification - 3X

WELD NO. 1-2-43, 1-2-44
480 AMPS., 11.5 VOLTS, 6.5"/MIN.

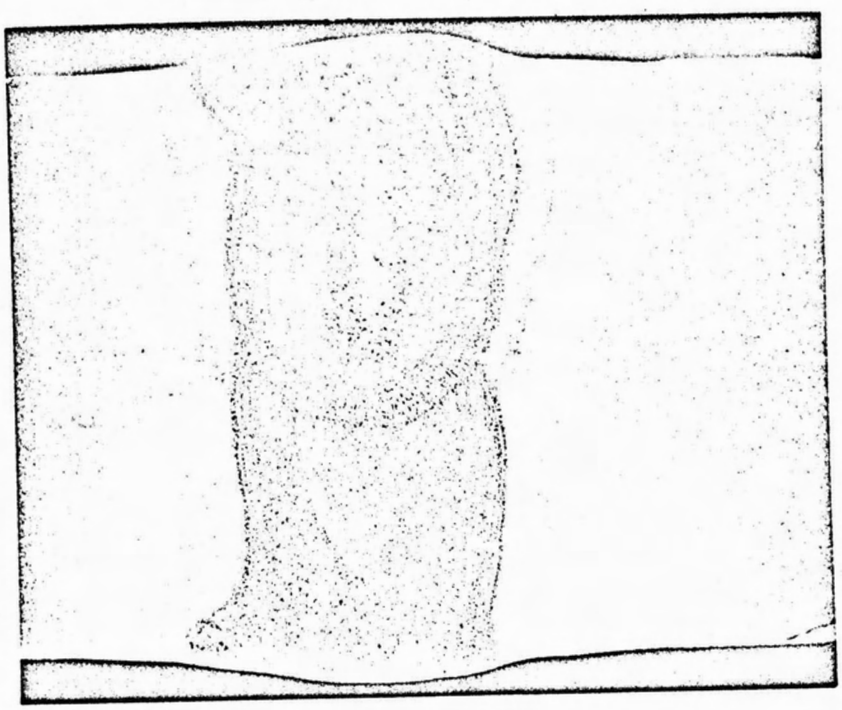


Fig. 124

Etchant - NaOH Magnification - 3X

WELD NO. 1-2-45, 1-2-46
500 AMPS., 11.7 VOLTS, 4"/MIN.

Fig. 2

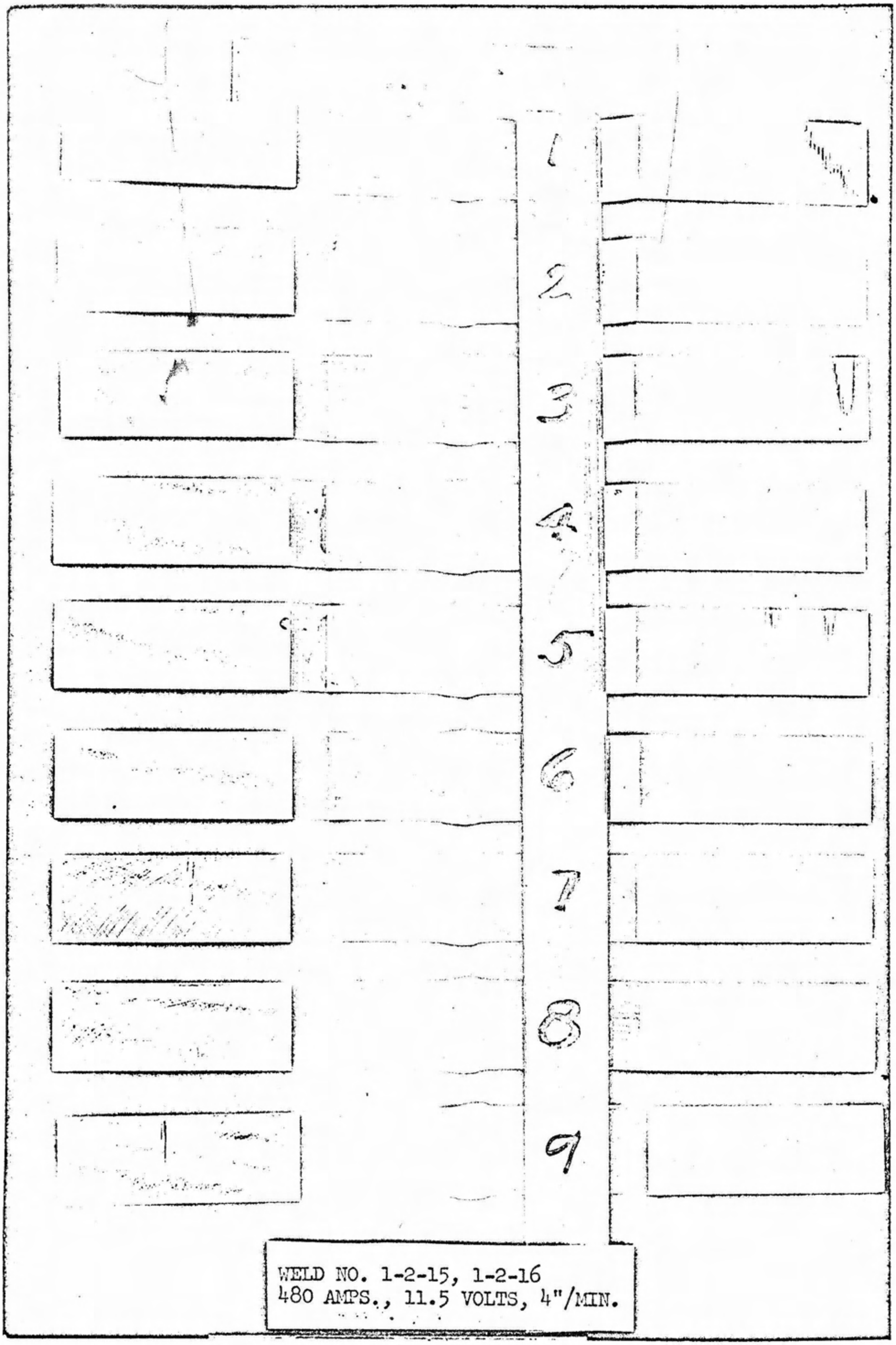
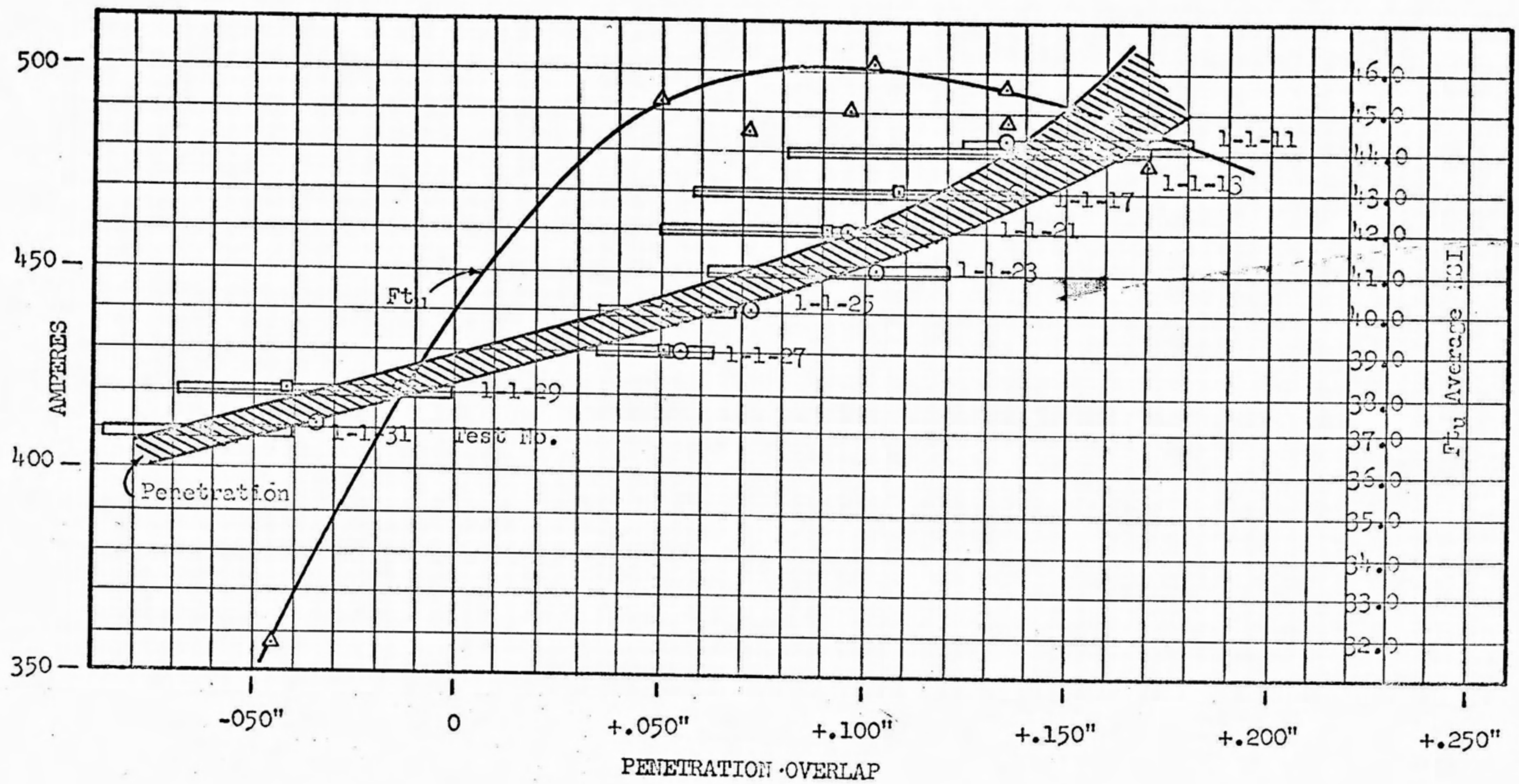


Fig. 3



WELD SETTING

11.5 Volts

4 IPM

Variable Current

PENETRATION TEST
VARIABLE CURRENT

1"-2219, SQUARE BUTT
DOUBLE WELD, TIG

▭ Penetration Scatter

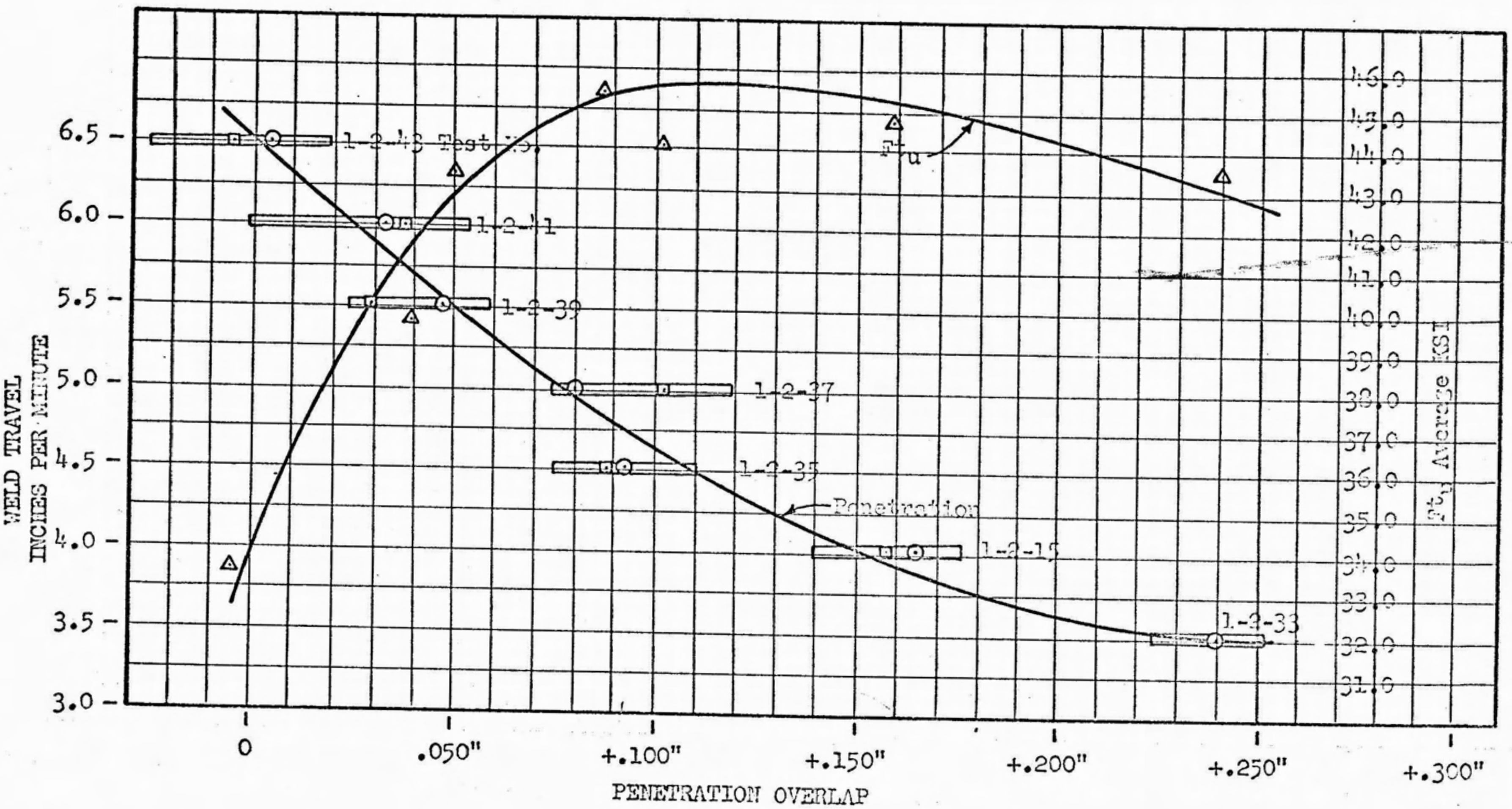
⊡ Average Penetration

⊙ Average penetration corrected for material thickness

△ Ft_u - Penetration

TABLE 3

Fig. 4



WELD SETTING

480 Amps

11.5 Volts

Variable Travel

PENETRATION TEST
VARIABLE TRAVEL

1"-2219, SQUARE BUTT
DOUBLE WELD, TIG

Penetration Scatter

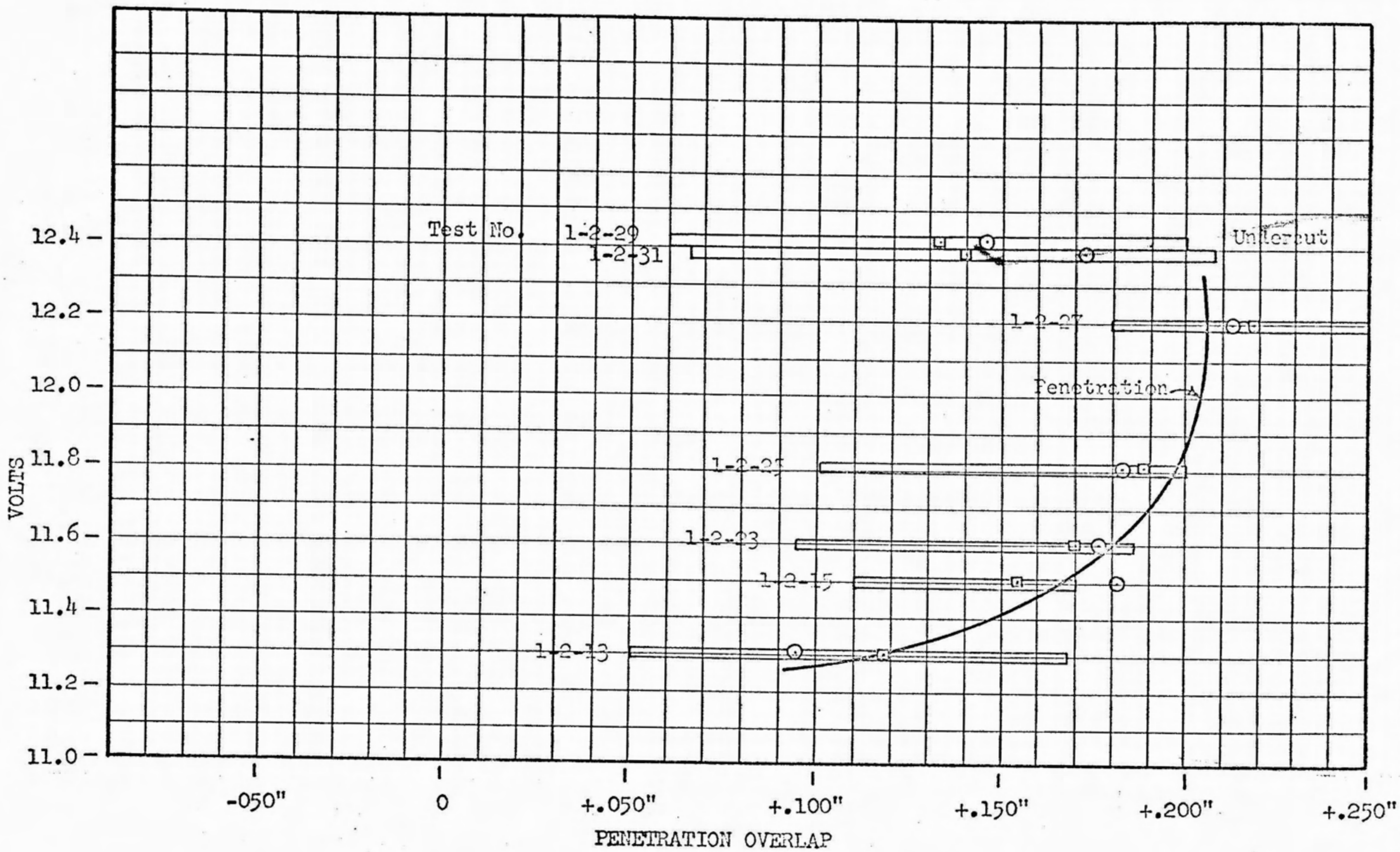
Average Penetration

Average Penetration corrected for material thickness.

Ft_u - Penetration

TABLE 12

Fig. 5



WELD SETTING
480 Amps
4 IPM
Variable Voltage

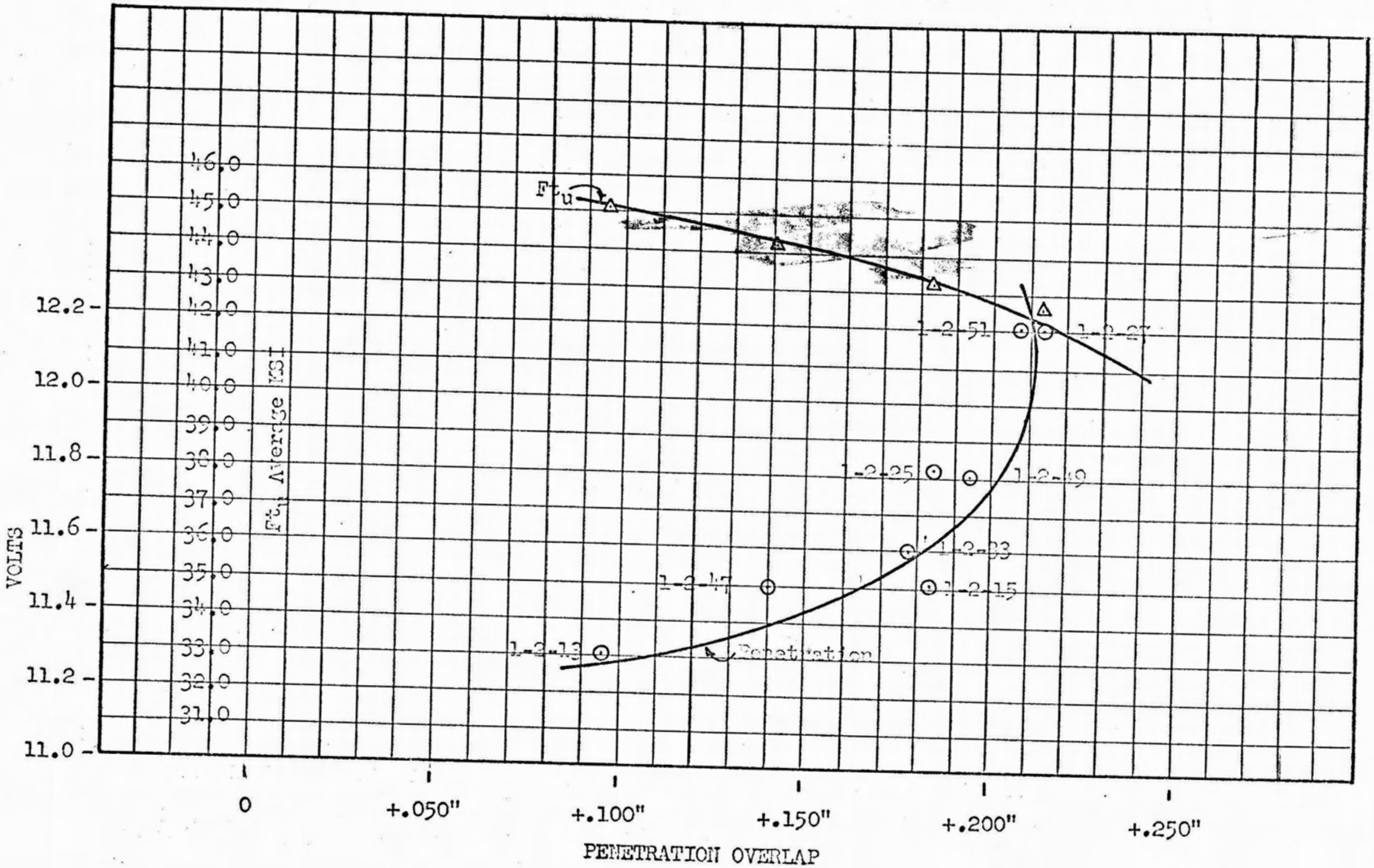
PENETRATION TEST
VARIABLE VOLTAGE

1"-2219, SQUARE BUTT
DOUBLE WELD, TIG

TABLE 8

Penetration Scatter
Average Penetration
Average penetration corrected for material thickness.

Fig. 6



<u>WELD SETTING</u>

480 Amps

4 IPM

Variable Voltage

<u>PENETRATION TEST</u>
<u>VARIABLE VOLTAGE</u>

1"-2219, SQUARE BUTT
DOUBLE WELD, TIG

<u>TABLE 7</u>

⊙ Average penetration corrected for material thickness.

△ Ft_u - Penetration

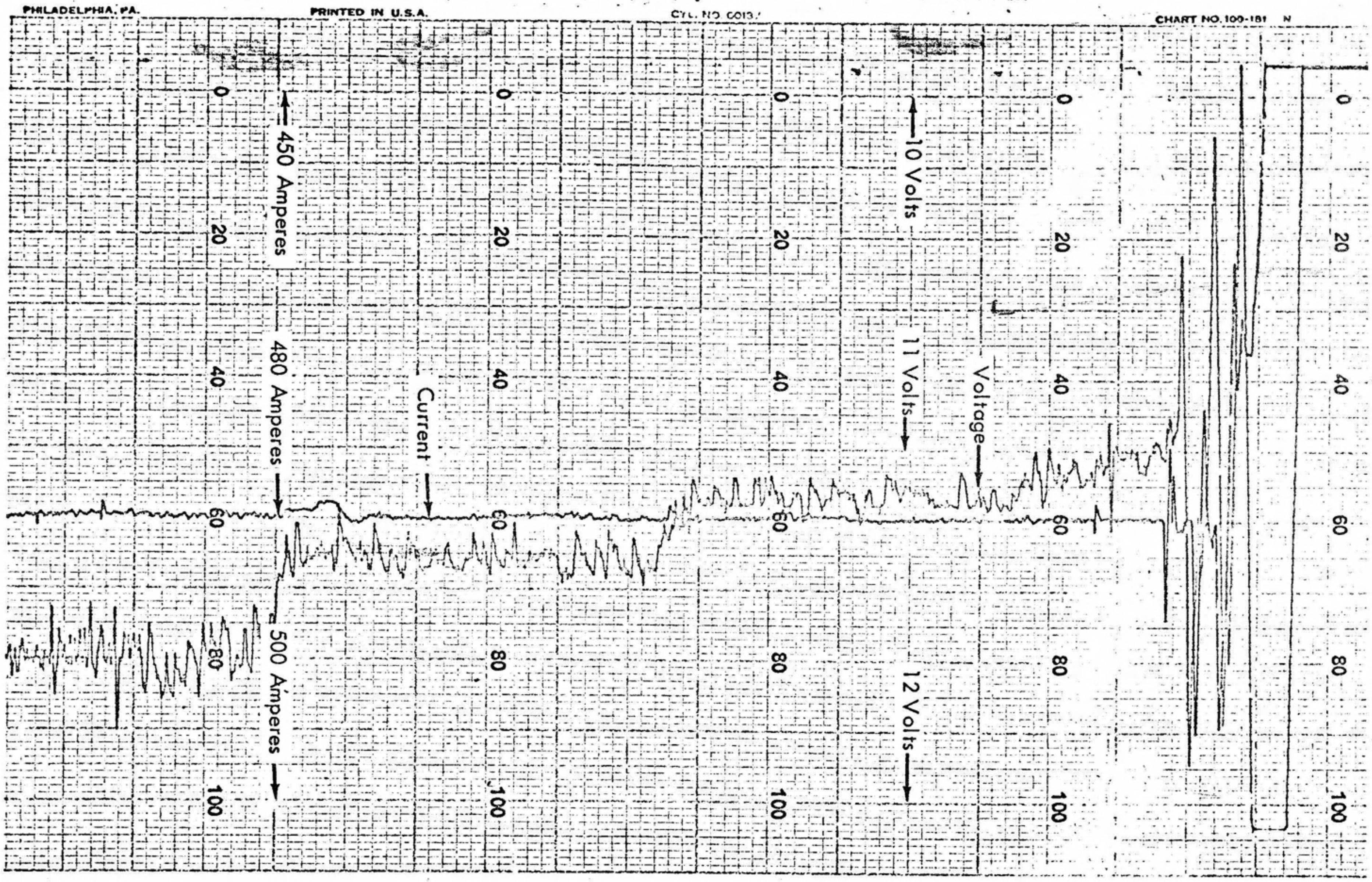


Figure 5
Typical Voltage - Amperage trace from a Minneapolis-Honeywell Electronic 17 recorder to determine the minimum possible operating voltage.

In this test the current was maintained at 480 amperes and the welding voltage held at test levels of 11.6 volts, 11.3 volts and 11.15 volts. At 11.0 volts the arc was unstable and the tungsten shorted out in the weld puddle. For this test 11.0 was determined to be the "dive-in-point."

TABLE 16

Fig. 8