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INVESTIGATION OF WELD JOINT DETECTION CAPABILITIES OF A COAXIAL WELD VISION SYSTEM

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Interim Report

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INVESTIGATION OF WELD JOINT DETECTION CAPABILITIES OF A COAXIAL WELD VISION SYSTEM

INTRODUCTION AND SUMMARY

The present report is the second in a series covering an in-depth evaluation of a vision-based control system developed by Ohio State University. This evaluation is a part of the program for development and implementation of robotic technology for welding on the Space Shuttle Main Engine. The OSU vision system was developed under contract as a part of the robotic welding system in the Materials and Processes Laboratory's Productivity Enhancement Facility at George C. Marshall Space Flight Center. Difficulty with weld joint detection in the first series of tests identified the need for a certain minimum feature width. Ideally, the sensor would track a seam with the tightest fit-up obtainable, but the joint feature must be larger than the resolution of the optics, and significantly more prominent than surrounding spurious surface features. Closure of the seam by thermal distortion during welding must also be accounted for. The use of a beveled groove has proven more successful than shims to maintain a sufficiently wide joint feature. The present tests were developed to determine the minimum bevel angle (or seam width) required for consistent detection.

A strip chart recording of the joint detection confidence level was made for each test during welding. Bead-on-plate welds were run first to determine the level of background signal present. Further tests were conducted with total included angles of 0, 5 and 10 deg on the prepared groove. A 5 deg groove angle resulted in a high confidence at the weld start, but thermal distortion caused it to drop back below the threshold. A 10 deg included angle provided consistently good seam detection throughout the length of the weld.

The results indicated that a 0.010 in. wide seam feature is more than adequate for good detection. A wider initial feature must be provided, however, to allow for thermal distortion.

BACKGROUND

The trajectory control mode of the OSU vision system begins with detection of the weld joints, and optionally, the pool edges. The total image acquired is composed of 60,512 picture elements, or pixels. The portions of the total viewing area used for process control are limited to the specific regions of interest, to simplify the detection of features. Thus the image analyzed is composed of two "windows," one for joint detection and the other for pool detection. Limited speed in the data processing hardware makes it necessary to further reduce the number of pixels analyzed by skipping "columns" within the windows, and also by skipping six of every seven frames acquired at 30 Hz.

The joint center and joint edges are extracted from the second differential of the light intensity profile across the window. These features are depicted for a typical joint in Figure 1. The maximum positive second differential defines the joint center, while the maximum negative differentials define the edges.

Each feature is given a "confidence level," based on the number of times it is detected within a single window column. This value may vary from $00 to the number of window rows, currently $30. The $ indicates hexadecimal notation, used when entering these values into the computer program. The confidence level must be greater than a user programmable threshold before it is used to generate a correcting response.

When calculating a tracking error, the detected joint features are used by the system on a priority basis. The first priority is to use the detected joint edge locations to calculate a joint center, which is then used to determine the error. This method provides the greatest accuracy. If the confidence levels of the joint edges are below the threshold, the detected joint center is used in the error calculation. If the joint center confidence level is also below the threshold, no control response is output and the system maintains the existing offset from the programmed path.

Experience with the system has indicated the need for a certain minimum joint gap for adequate detection. Efforts to provide a gap by shimming the joint at each end proved futile, as thermal distortion completely closed the gap ahead of the advancing weld puddle. The next recourse was to machine a bevel on each plate, such that a gap existed at the top surface when the joint was fitted together. With the plates butted at the root, the restraint was sufficient to prevent closure of the gap during welding.

OBJECTIVE

Limitations of the OSU vision system's joint detection capability led to the use of machined bevels in previous tests, to provide a wide joint feature. The objective of the present study was to determine the minimum seam width necessary for consistent joint detection.

EXPERIMENTAL PROCEDURE

Plan of Investigation

Because the joint center is both the most easily detected feature and the last resort for trajectory control, its confidence level was monitored to evaluate the effect of joint gap width. A hard copy of the confidence level was provided via a strip chart recorder linked to a computer output port.

The present tests were solely concerned with joint detection, and not the response to a perceived error. Therefore, a programmed path was used which coincided with the weld joint as closely as possible. This facilitated the identification of spurious features which exceeded the threshold level, because these resulted in visible path changes when none should have occurred.

Sample Preparation

Each joint consisted of two Inconel 718 plates, of dimensions 0.125 in. x 2 in. x 9 in. The plate edges were surface ground flat and parallel to within 0.002 in. Bevels were machined on the butting edges with a vertical mill. Included angles of 0, 5 and 10 deg were studied, for feature widths of 0.00 in., 0.01 in., and 0.02 in., respectively. Sketches of the joint cross sections used are shown in Figure 2. The top surfaces of the plates were sanded parallel to the joint with 80 grit emery cloth in a 1 in. strip on each side of the joint.

Procedures

The plates were clamped in a fixture bolted to the two-axis positioner. The torch manipulator was programmed in a straight path to closely follow the joint. The welding parameters were set to provide full penetration, as follows.

arc length	=	0.060 in. (IIV)
current	=	125 A
travel speed	=	5.0 ipm
primary shielding	=	99.999 percent Ar at 35 cfh
back shielding	=	regular purity Ar at 5 cfh

Both the vision system and the strip chart recorder were enabled at the start of the weld. The strip chart rate was set at 6 in./min.

Evaluation

The effect of varying joint feature widths was evaluated by inspection of the strip chart recordings of joint center detection confidence level and comparing the values obtained with the programmed threshold value.

RESULTS

Strip chart recordings of the joint center confidence level with respect to time for bead-on-plate welds are shown in Figures 3 and 4. Despite the absence of a joint, the confidence level in both cases was about $08. The origin of the detected "features" has not yet been clearly identified. Likely sources are surface finish, electronic noise and limitations of the optics system.

The vision system is designed to detect features aligned parallel to the direction of travel. If surface roughness is a significant factor, a plate sanded with the scratches running parallel to the joint should produce a higher confidence level than a plate sanded transverse. Inspection of the strip charts in Figures 3 and 4 indicated a slight increase in confidence level with parallel sanding over transverse sanding, but the effect was not dramatic.

Detection of spurious features is the principal reason for setting a threshold value below which a correcting response will not occur. The threshold is currently set at $0E, as shown by the dashed horizontal lines on the recordings.

The confidence level trace for a 0 deg included angle (the tightest fitup which could be achieved) is shown in Figure 5. The confidence level for this joint preparation was comparable to that for a bead-on-plate weld· consistently below the threshold. No tracking control was possible over the entire extent of the weld.

The trace for a different sample with the same tight fitup is displayed in Figure 6. In this case, the confidence level was low on average, but it fluctuated greatly and rose above the threshold for short periods. The excursions of the confidence level above the threshold were apparently elicited by spurious features. Inspection of the tracking accuracy illustrated in Figure 7 indicates path corrections when none should have occurred since the programmed path already corresponded to the joint seam. The deviations from the seam correspond roughly to the periods of high confidence level.

A negligible improvement in joint detection resulted when the edges of the joint were broken with a file. The strip chart recording is shown in Figure 8.

The confidence level trace for an included angle of 5 deg is displayed in Figure 9. The apparent joint gap for this condition was 0.010 in. Confidence was initially well above the threshold, and tracking occurred properly. As the weld progressed, however, thermal distortion eventually closed the prepared groove and the confidence dropped below the threshold level for the remainder of the weld.

Shown in Figure 10 is the trace for an included angle of 10 deg, or an apparent joint gap of 0.020 in. Aside from a short period at the beginning of the weld, the confidence level remained well above the threshold. Experience with more than a dozen runs under these conditions have demonstrated that excellent joint detection can be consistently achieved.

There was one condition tested under which even the 10 deg angle was insufficient. The back shielding gas dam was an aluminum block with a 0.5 in. slot milled into it. Ordinarily, the joints were centered on the slot such that the heat sink was roughly symmetric. When the joint was shifted approximately 3/16 in. to one side of the dam, the asymmetrical heat flow apparently closed the groove, since the confidence level dropped sharply after the start of the weld. The trace is shown in Figure 11. The test was repeated under the same conditions with similar results.

DISCUSSION

The tests conducted in the present study verify the need for a certain minimum joint gap for detection by the OSU vision system. The minimum width appears to be less than 0.010 in. since the samples with a 5 deg included angle provided a high initial confidence level. The minimum theoretical resolution of the system is about 0.004 in., the width of a picture element (pixel) at the present magnification. Lens aberrations and diffraction probably erode the resolution further. In any case, an initial gap or groove wider than the theoretical minimum must be provided to allow for thermal distortion. The gap necessary for a particular application is a function of restraint, heat input and heat flow during welding.

Restraint was provided in the present tests by the clamping fixture and the base material itself. Closure of the gap during welding was reduced somewhat by using machined bevels rather than shimming the ends. The minimum included angle for consistent joint detection was still 10 deg.

CONCLUSIONS

Based on the results of the present set of tests, the following conclusions may be drawn:

1) The minimum feature width for detection by the OSU vision system is approximately 0.010 in.

2) Using a prepared joint groove, the minimum groove angle for repeatably good detection during welding is 10 deg. This provides an initial feature of 0.020 in., to allow for distortion.

3) The background signal level was approximately half the present threshold level. Changing the sanding direction for surface preparation from parallel to the joint to transverse had a minimal effect on the background signal level.

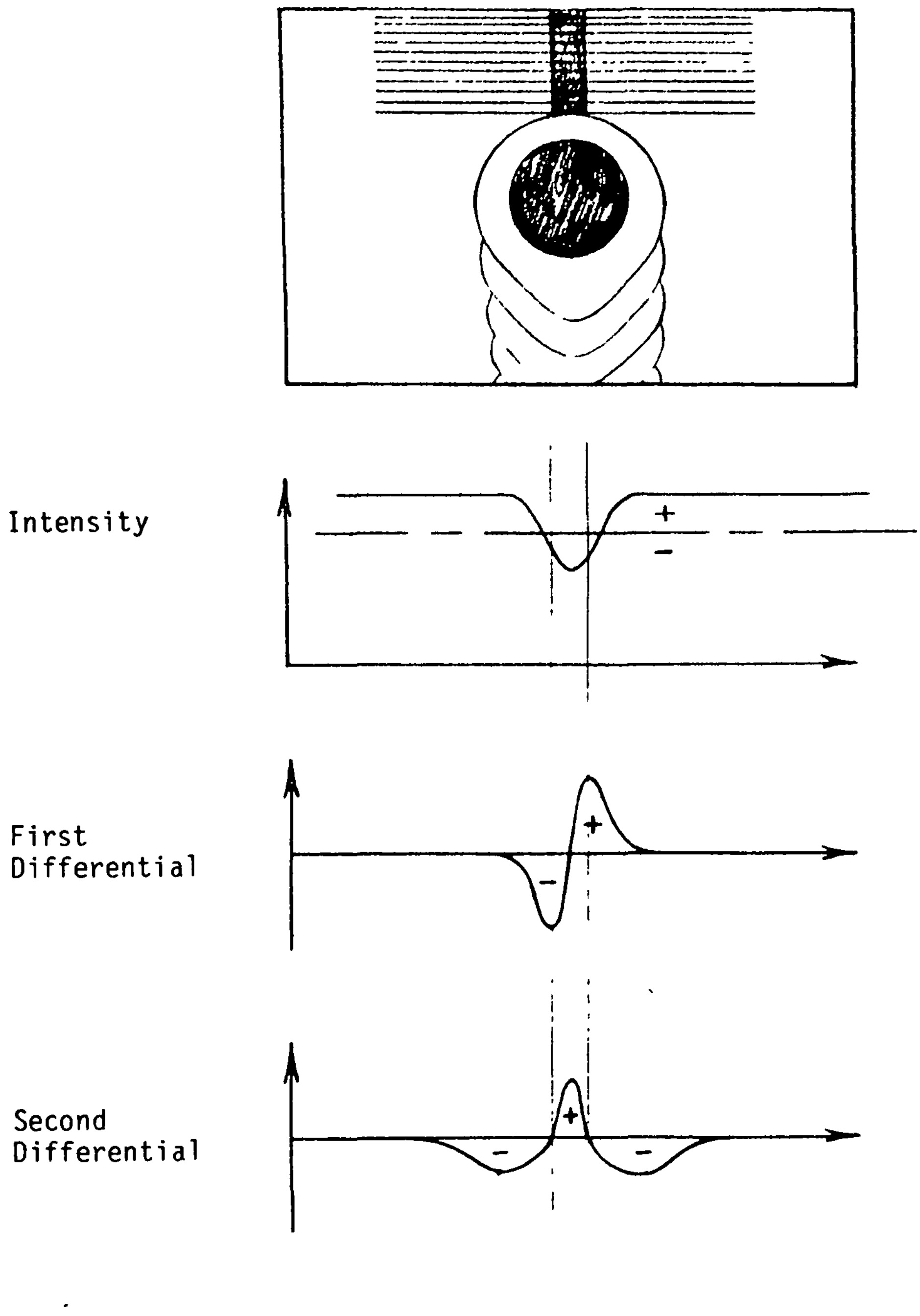

Figure 1. Intensity profile and derivatives used for joint feature detection.

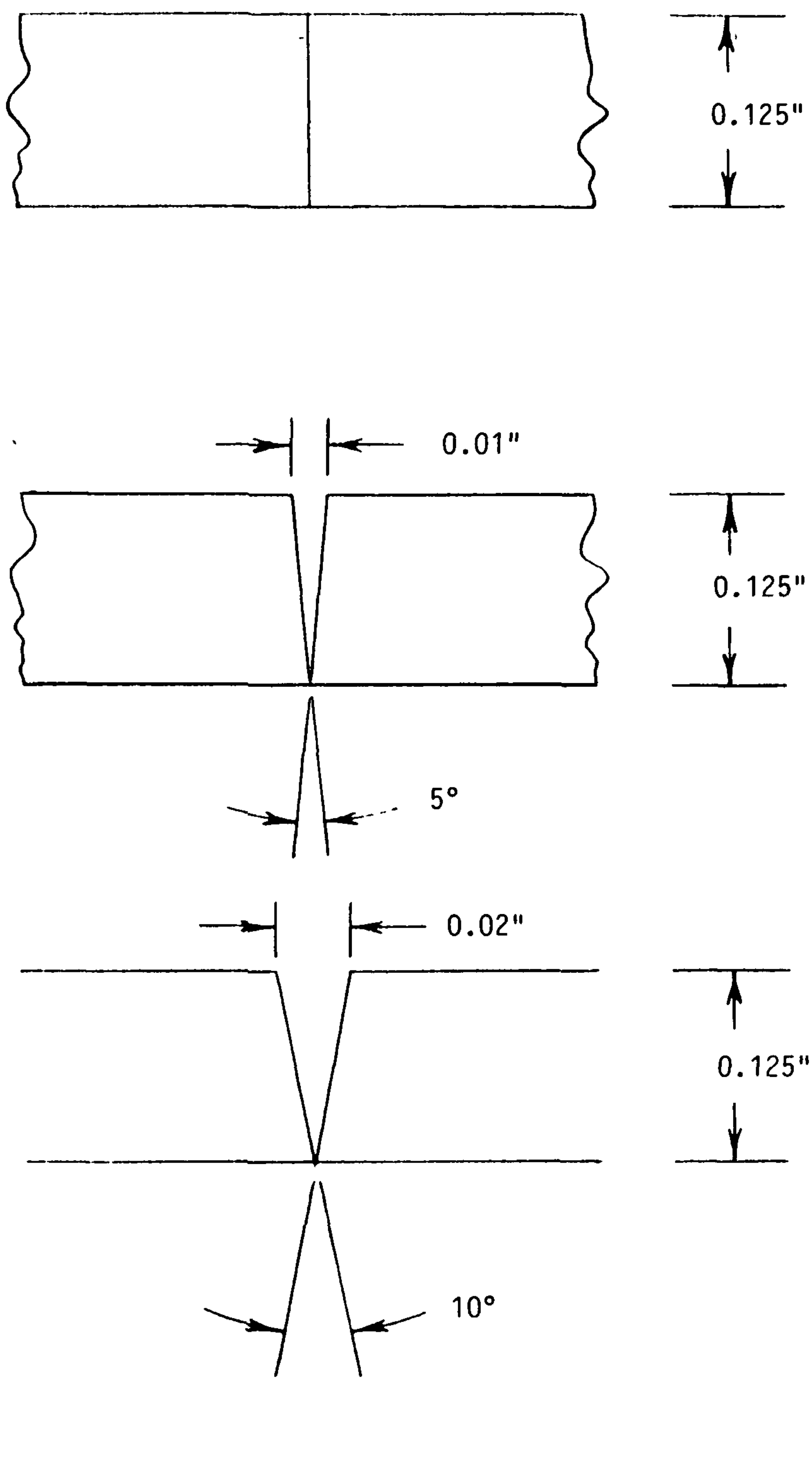

Figure 2. Joint preparations used (not to scale).

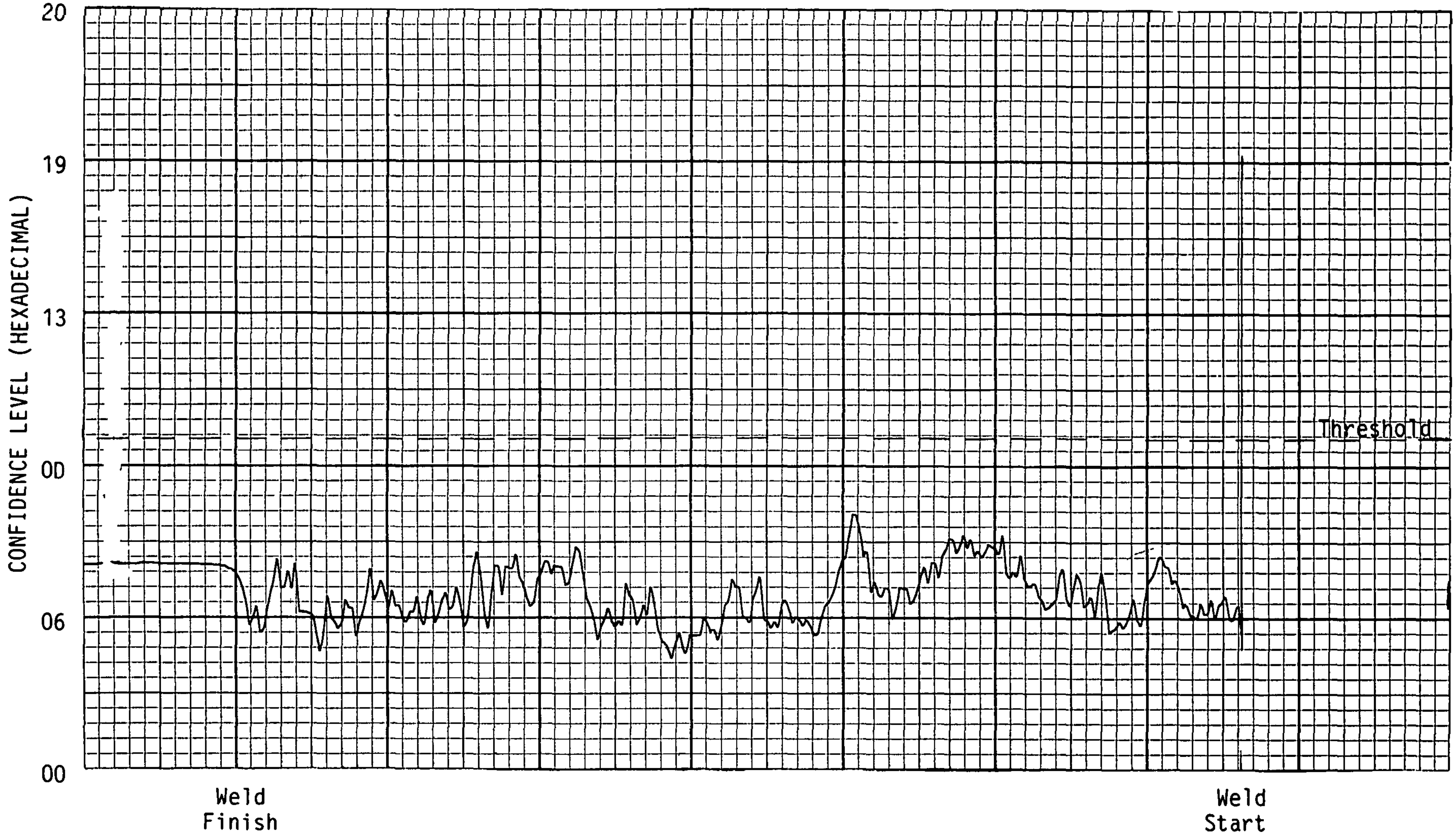

Figure 3. Confidence level recording for bead-on-plate-weld, sanded parallel to weld seam.

Figure 4. Confidence level recording for bead-on-plate weld, sanded transverse to weld seam.

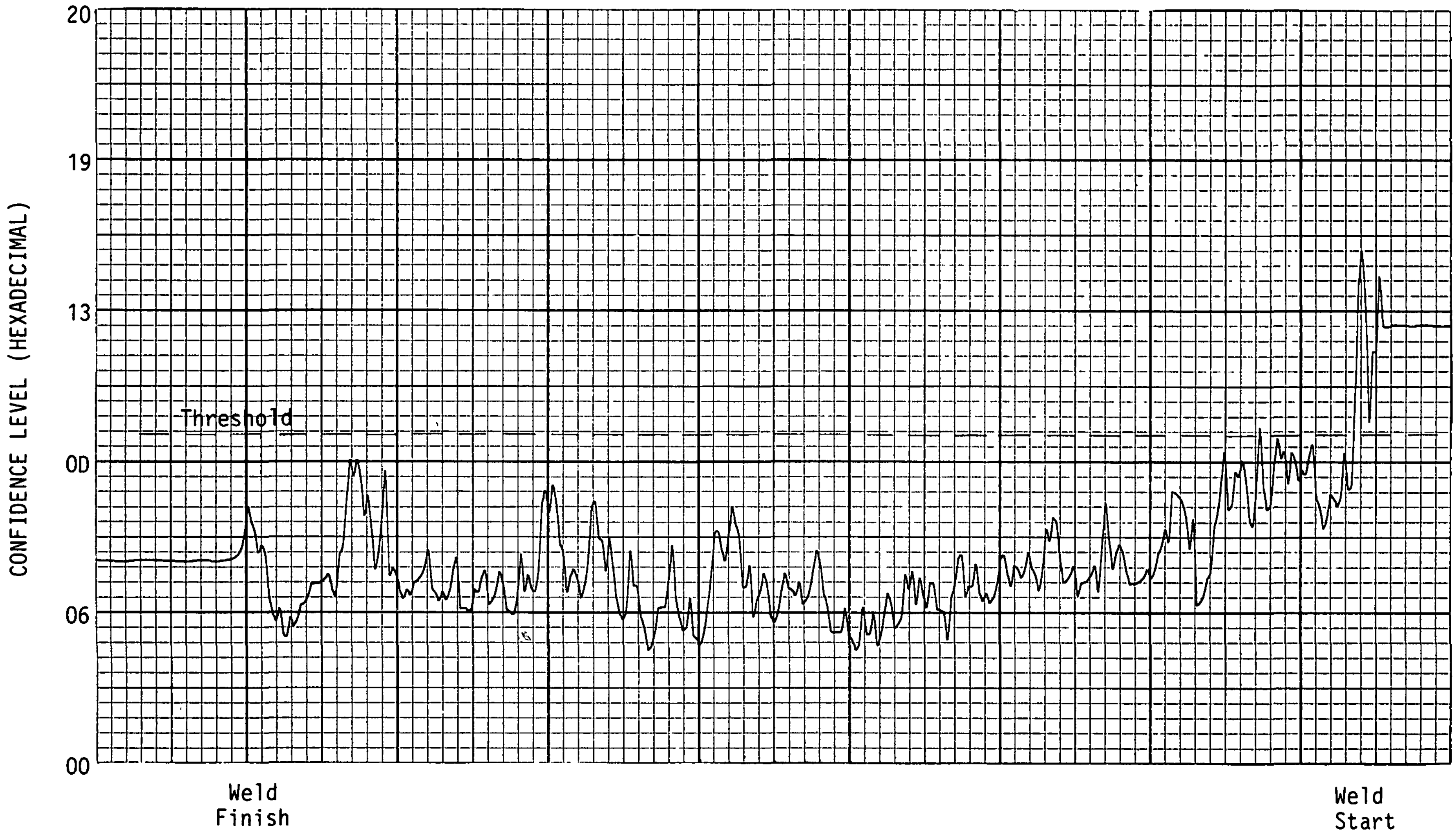

Figure 5. Confidence level recording for tight fit-up joint (0 deg included angle).

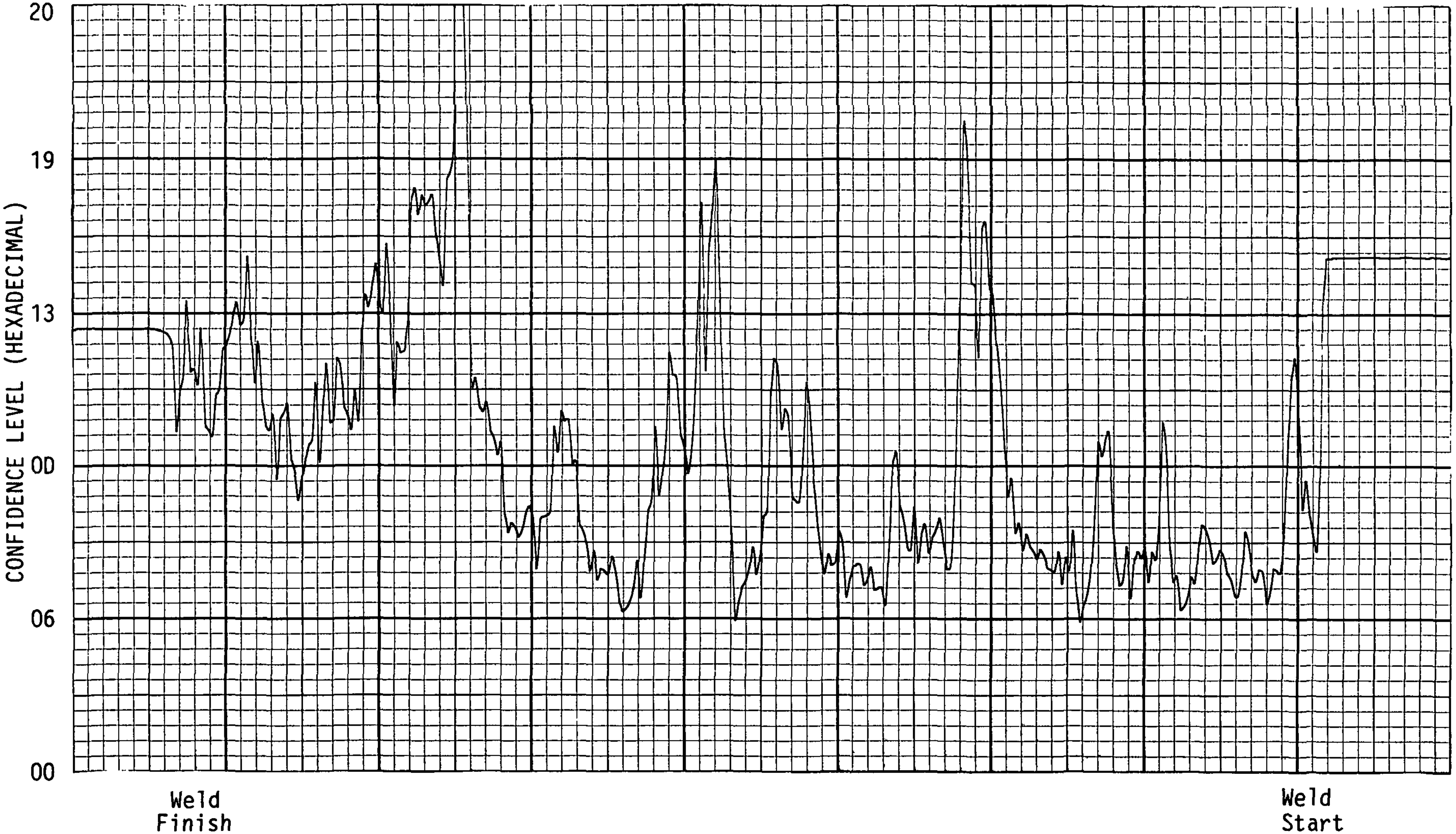

Figure 6. Confidence level recording for tight fit-up joint showing defection of spurious features.

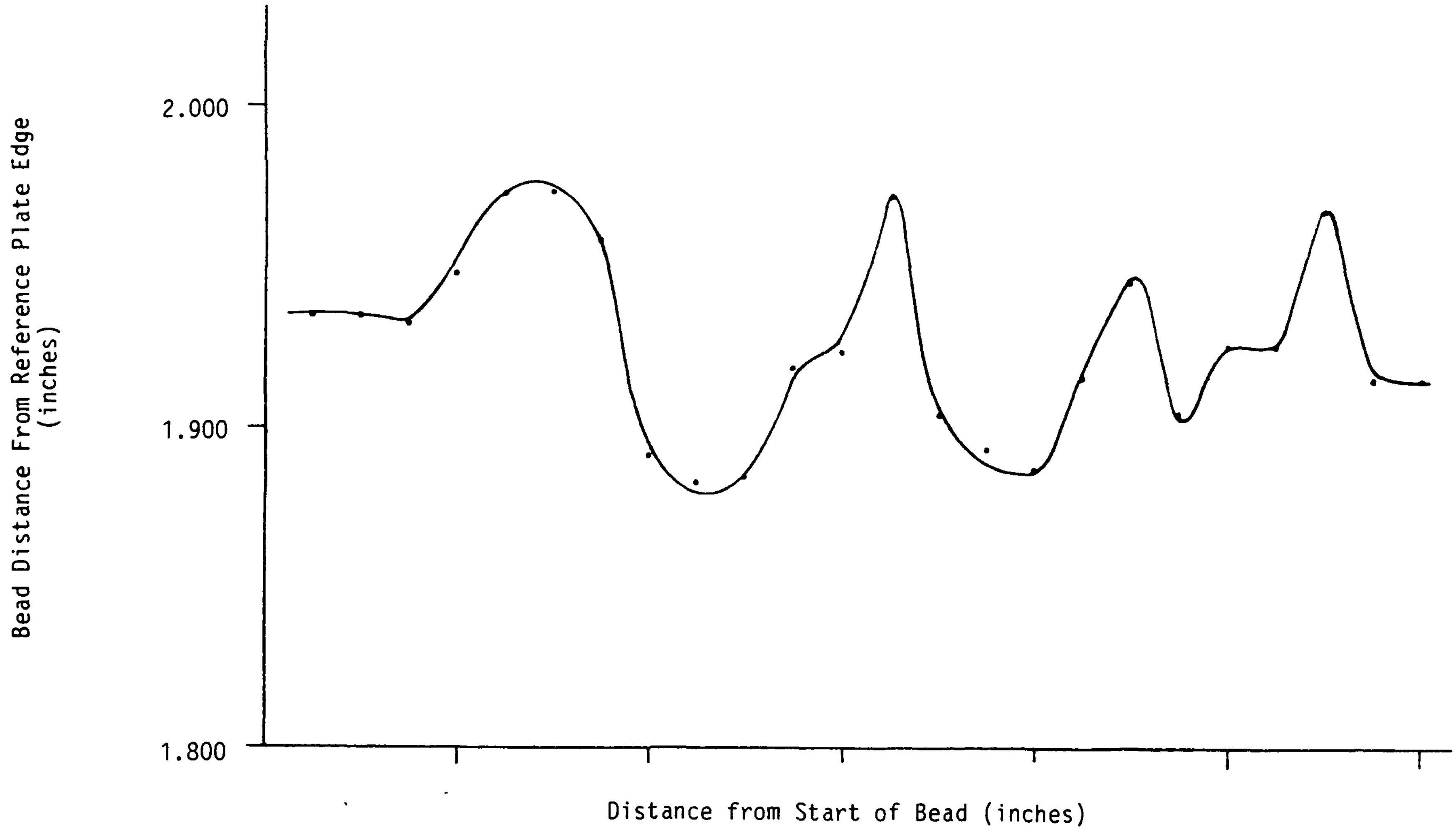

Figure 7. Bead position with respect to plate edge for sample with tight fit-up.

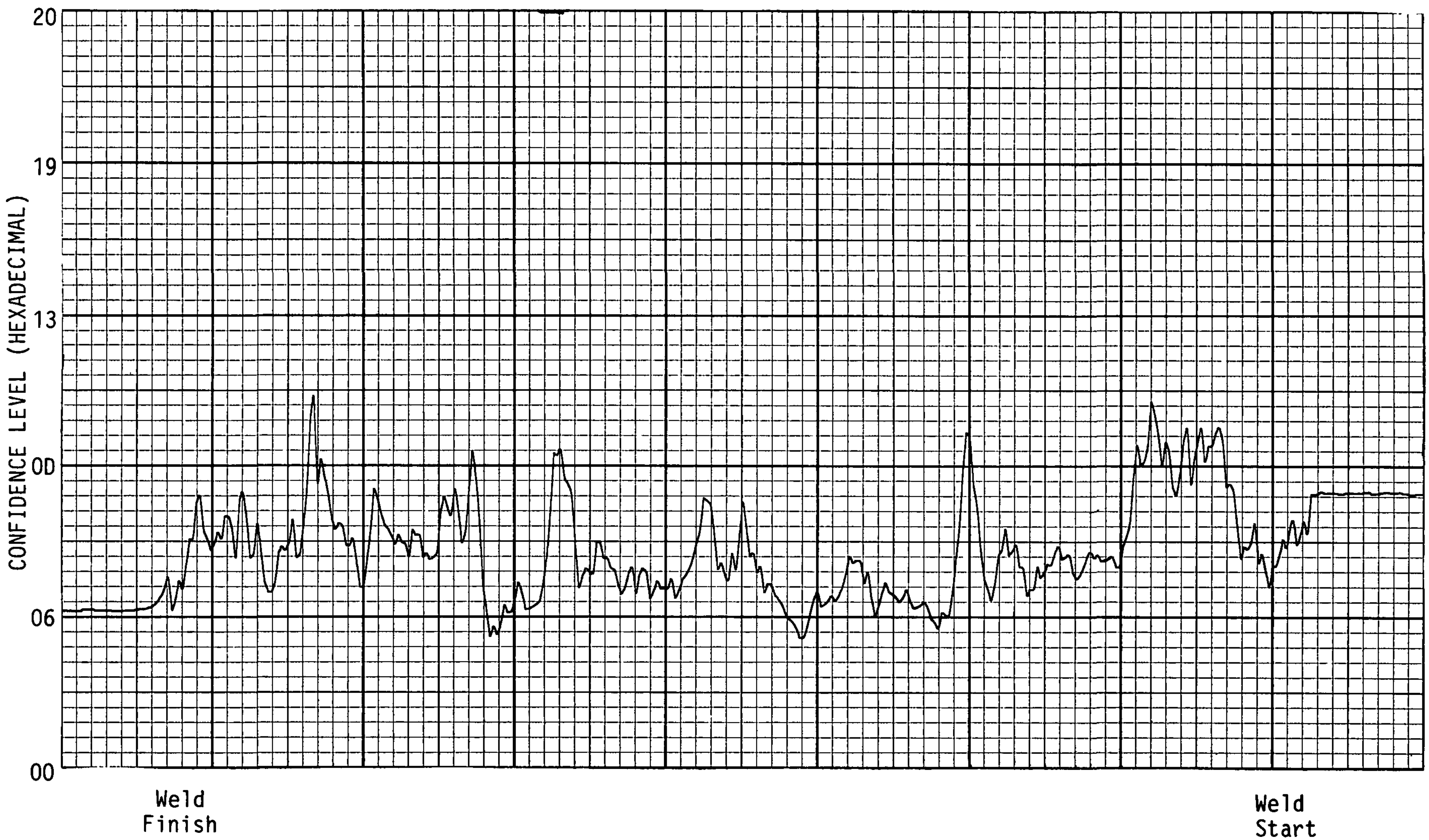

Figure 8. Confidence level recording for tight fit-up joint with edges filed.

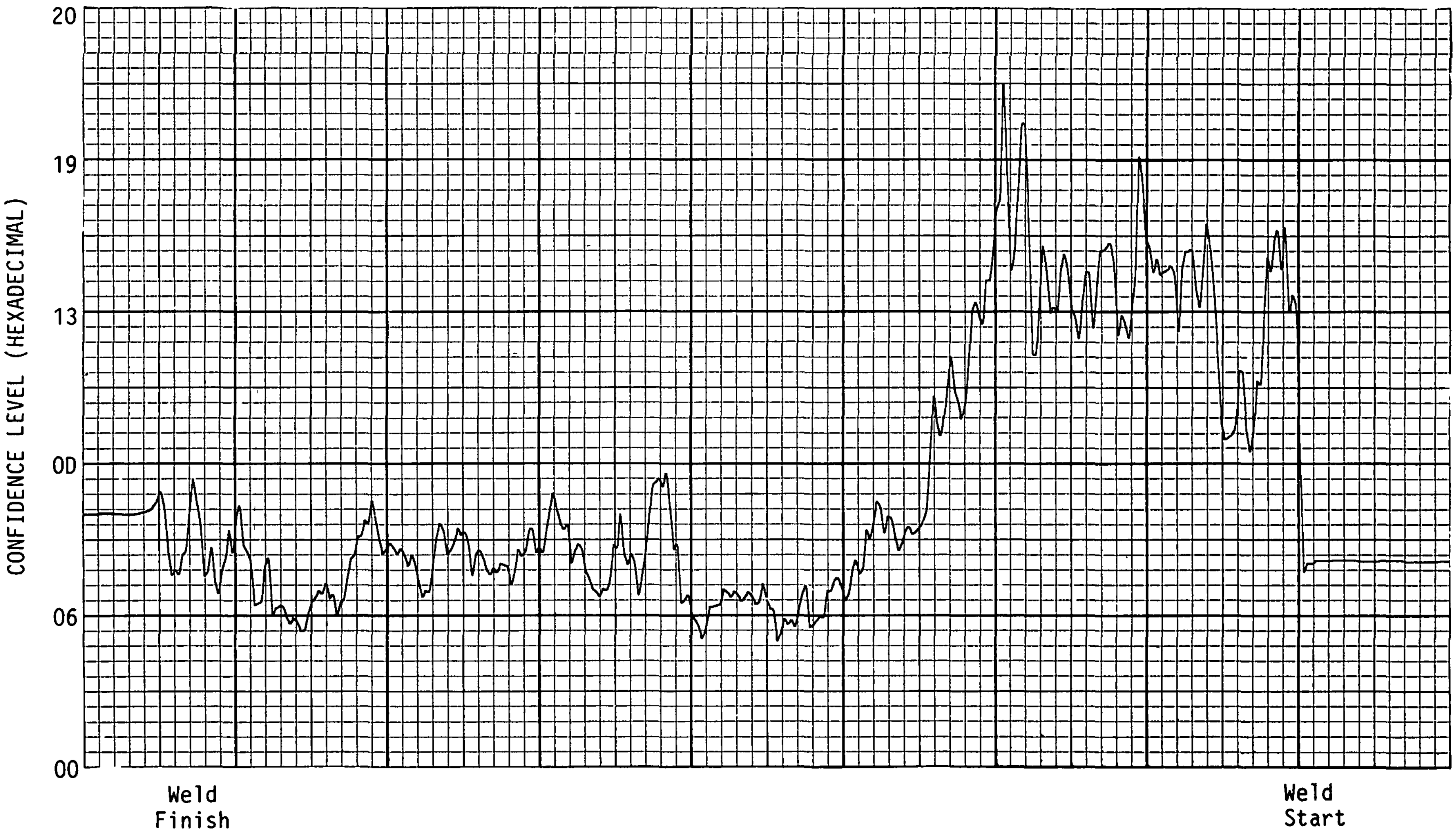

Figure 9. Confidence level recording for an included angle of 5 deg.

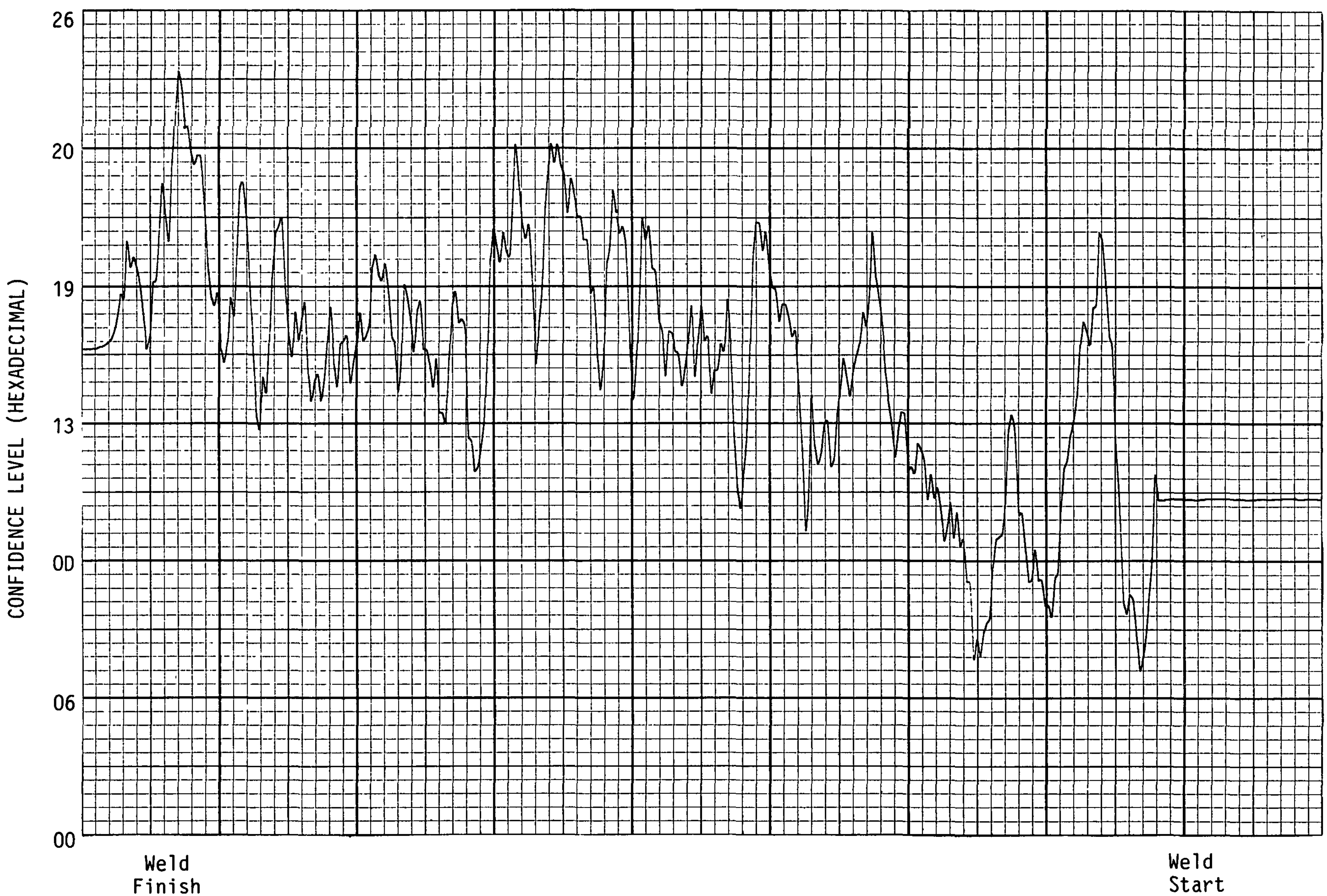

Figure 10. Confidence level recording for an included angle of 10 deg.

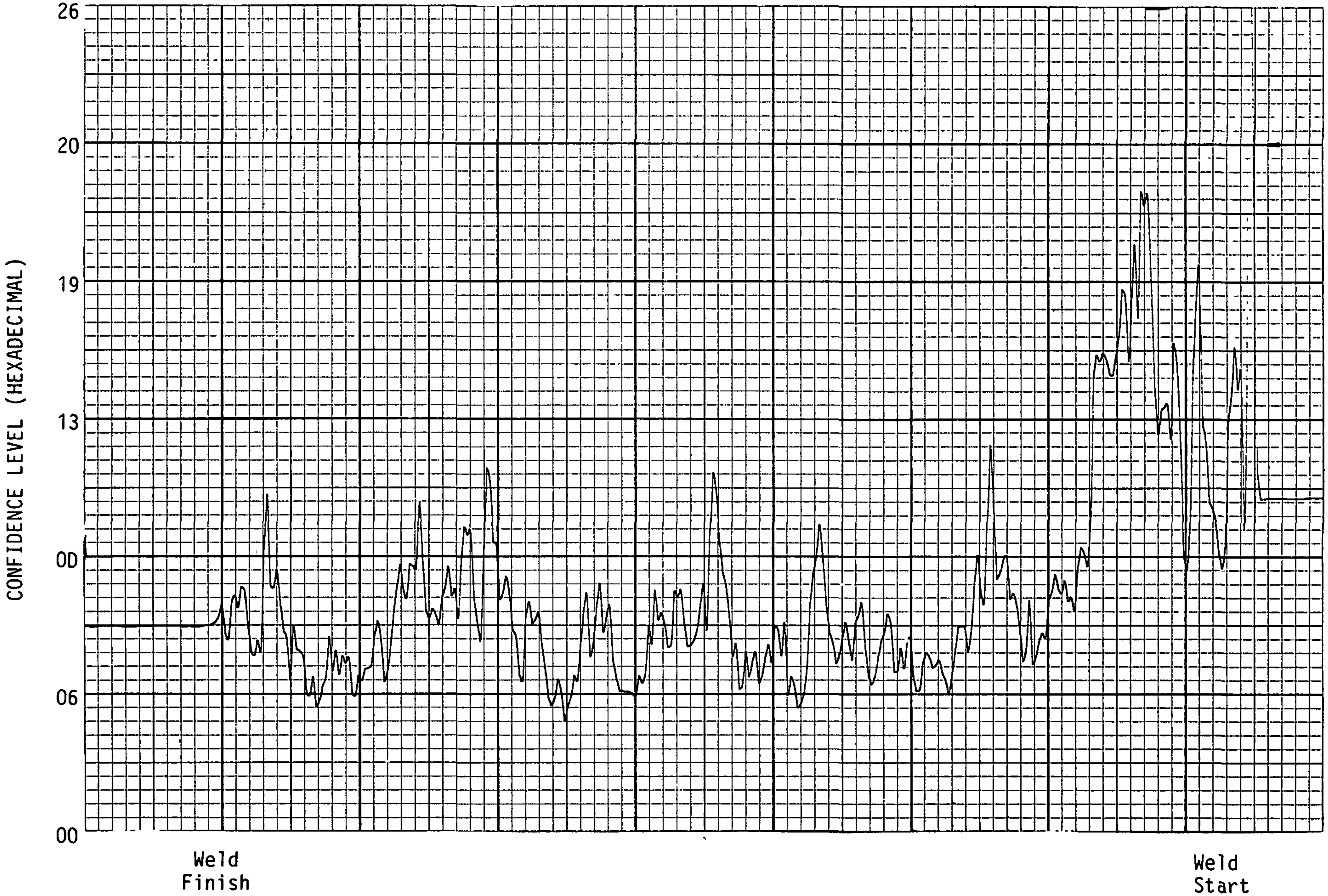

Figure 11. Confidence level recording for an included angle of 10 deg with asymmetrical heat sink.

CONCURRENCE

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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Based on development work under the direction of the Metals Processes Branch of the Materials and Processes Laboratory

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16. ABSTRACT

This report describes the second phase of a series of evaluations of a vision-based welding control sensor for the Space Shuttle Main Engine Robotic Welding System. The robotic welding system is presently under development at the Marshall Space Flight Center. This evaluation determines the factors influencing the minimum joint gap required for consistent detection of the weld joint.

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