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Instrumentation

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**EDDY CURRENT DETECTION  
OF Al-Si PENETRATIONS IN CANNED SLUGS**

by

R. C. Robinson and J. D. Ross

*Applied Physics Division*

December 1957.

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INSTRUMENTATION  
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Richard C. Robinson and John D. Ross  
Applied Physics Division

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ABSTRACT

An instrument for detecting aluminum-silicon alloy penetrations in the aluminum jacket of fuel slugs is described. The instrument is of the eddy current type and the sensing element is a small probe that does not touch the specimen under inspection. Al-Si inclusions 0.020 inch in diameter that penetrate to within 0.005 inch of the surface can be detected. The response of the instrument is such that a slug  
8

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# EDDY CURRENT DETECTION OF Al-Si PENETRATIONS IN CANNED SLUGS

## INTRODUCTION

During the canning operation in which a protective aluminum jacket is bonded to a slug of natural uranium, the uranium is inserted into a can filled with molten Al-Si alloy. The excess Al-Si is forced out of the open end of the can and causes a portion of the can wall to be dissolved. The conditions required for a successful process are critical. Excessive temperatures and improper Al-Si ratio can cause excessive dissolution of the can wall.

Exposure to the process water in a reactor for extended periods at high temperatures may cause some of the aluminum to corrode away with the result that thinly protected Al-Si spikes are exposed. Since the Al-Si is a cast alloy, it is more porous than the extruded aluminum jacket, and water can penetrate through the interstices to the uranium core. Experience has indicated that this process has initiated numerous slug ruptures.

For process control, a statistical sample of the slugs can be analyzed destructively. However, this procedure is costly and incomplete. It is desirable to have a nondestructive method for testing 100% of the slugs. Much work has been done in the past in an effort to develop an instrument for detecting penetrations.<sup>(1,2,3,4)</sup> While these instruments have helped in standardizing the canning process, they either lacked sensitivity to small spike penetrations or could not differentiate between these and acceptable surface defects.

Eddy current techniques seem to offer the greatest hope in the development of an instrument for detecting the penetrations. An instrument that was developed for another purpose<sup>(5)</sup>, which had high sensitivity and was not seriously affected by variations in the distance between probe and sample, showed promise as a solution to this problem.

## SUMMARY

An instrument was developed that can detect a subsurface Al-Si spike in the jacket of a fuel slug. Penetrations 0.020 inch in diameter and 0.005 inch below the surface can be detected in a can wall nominally 0.035 inch thick. Penetrations 0.030 inch in diameter or larger can be detected to a depth of 0.015 inch. The sensing element is a small probe that rides free of the specimen under inspection. The instrument is relatively insensitive to changes in probe spacing and to surface defects. Operation with a laboratory feeder indicates that the tester can be made automatic.

## DISCUSSION

The bonding layer in fuel elements is 12 weight per cent alloy of silicon in aluminum and has an electrical resistivity 1.6 times that of pure aluminum.<sup>(6)</sup> However, the projection of a small spike of this material into the aluminum jacket will have a very small effect on the resistivity of the volume seen by a relatively large test probe.

In eddy current inspection, two effects tend to limit the ability of the test to find small defects. The field from the probe coil is difficult to confine to small volumes, and changes in probe spacing produce signals that mask those produced by small defects. A test circuit that uses a tuned-grid, tuned-plate oscillator<sup>(5,7)</sup> partially overcomes these difficulties. The probe coil is part of the grid tank of the oscillator and can be made very small. Ferrite material can be used to shape and confine the field of the probe coil. The oscillator can be tuned so that it does not respond to a change in probe spacing while it still responds to a change in the resistivity of the material under inspection.

## DESCRIPTION OF THE INSTRUMENT

The completed laboratory prototype is shown in Figure 1 and the circuit diagram is shown in Figure 2. A slug is scanned by translating the probe as the slug is rotated. The probe coil (Figure 3a) is part of the grid circuit of a tuned-grid, tuned-plate oscillator. The alternating magnetic field in the probe gap induces eddy currents in any electrically conducting material placed near it. The magnitude of the eddy currents depends upon the magnitude and frequency of the current in the probe coil, the conductivity of the material under inspection, and the position of the sample relative to the probe gap. The eddy currents in turn produce a countermagnetic field and dissipate energy, therefore, changing the impedance of the probe coil. This change manifests itself as a modification of oscillator amplitude. Both primary and secondary of the plate transformer are tuned and the action of the entire oscillator circuit is such that when the proper frequency and circuit parameters are chosen, the signal output is relatively insensitive to variations in the spacing between the probe gap and specimen.<sup>(8)</sup> The adjustment of all three tuned circuits is very critical for optimum performance. The details of the plate transformer are shown in Figure 3b. The ferrite cup cores are of Ferramic "Q" material made by the General Ceramics Corporation. The entire unit is encased in foam plastic, as the transformer is very microphonic.

The output from the oscillator is rectified and is followed by a differentiation circuit. Since the slug is rotated while it is being tested, the time constants of the differentiation circuit are chosen to allow the short pulse produced by a penetration to pass through, but to suppress a longer pulse such as would be caused by any changes in spacing. This technique also greatly increases the signal-to-noise ratio in addition to the inherent compensation for the probe-to-sample effect that is provided by the tuned-plate,

tuned-grid oscillator. The signal is then amplified by a twin triode which is followed by a diode clamp. The clamp acts as a pulse stretcher and makes the signal more suitable for visual display on the Brush recorder.

An automatic alarm system rejects slugs that are judged to contain unsafe penetrations. Following the diode clamp is a phase inverter that couples the pulse to a Holtje discriminator.<sup>(9)</sup> When tripped, this discriminator puts out a series of very short pulses, one of which will actuate the multivibrator, whose plate circuit contains both visual and audible alarms.

The discriminator is set by testing a standard slug that contains a manufactured penetration and adjusting the discriminator level until a reject signal is given. The probe is centered over the defect during the calibration. The Brush chart may be used to assure that the probe is centered on the penetration, as the pulse output will then be a maximum.

An operating frequency of 20 kc was selected to reduce the sensitivity to surface defects. When the newly canned slug is quenched in water, thermal agitation occurs and the slug shrinks and chatters against the slug holder. This effect produces a number of small dents or chatter marks near the bottom end of the slug. Figure 4 shows how the signals produced by these dents were eliminated by reducing the frequency of the oscillator from 60 to 23 kc. While no penetrations show in these charts, the sensitivity to penetrations is only slightly reduced by the change in frequency.

The circuit is tuned in the following manner. The grid and plate tanks are tuned to resonate at 20 kc. With a slug under the probe, the grid tank is adjusted until the movement of the probe toward the slug gives a slight rise in oscillator amplitude. If this condition cannot be achieved, the plate-to-grid feedback is increased slightly until a rise can be obtained. A defect is then rotated under the probe and the grid tank is detuned until a maximum signal-to-noise ratio is found. A slight retuning of the plate tank may be necessary at this point to obtain the best signal-to-noise ratio.

## PERFORMANCE

Although only a laboratory model was constructed, the feeder was sturdy enough to withstand a moderate period of production testing. The scanning mechanism is shown in Figure 5 and is the same basic design as was used in another instrument.<sup>(5)</sup> Two microswitches on the back side of the feeder act as limit switches for the translation of the probe. The motor that rotates the slug runs at 200 rpm. For the translatory motion, a 100-rpm motor is used. This combination allows a slug to be scanned completely in 45 seconds.

As an aid in aligning and testing the instrument, Al-Si penetrations were manufactured in twenty slugs by drilling a hole on the inside of each of the aluminum jackets before canning. Cylindrical holes of various diameters and depths were made. Since the can wall

is 0.035 inch thick, a hole 0.030 inch deep leaves 0.005 inch of aluminum wall covering the Al-Si. If an air bubble is trapped in the tip of the cylindrical hole when the slug is canned, a much larger signal is produced by the tester. Several slugs with presumably identical penetrations were made of each size to guard against this type of misleading result.

The test slugs were scanned repeatedly in the laboratory; then the sizes of the artificial defects were verified by destructive examination. The instrument could not differentiate between a penetration of large diameter 0.015 inch from the surface and one of small diameter near the surface; however, it was relatively insensitive to large penetrations located at a depth greater than 0.015 inch below the surface. Figure 6 shows Brush recordings of complete scans of three slugs containing penetrations 0.060, 0.030, and 0.020 inch in diameter, respectively. The 0.060-inch hole had 0.015 inch of aluminum wall left, and the other two each had 0.005 inch of wall left. The signal increased rapidly with the diameter of the Al-Si spike. The pitch of the scan was approximately 1/16 inch, and the defect was seen two or more times as the probe moved by.

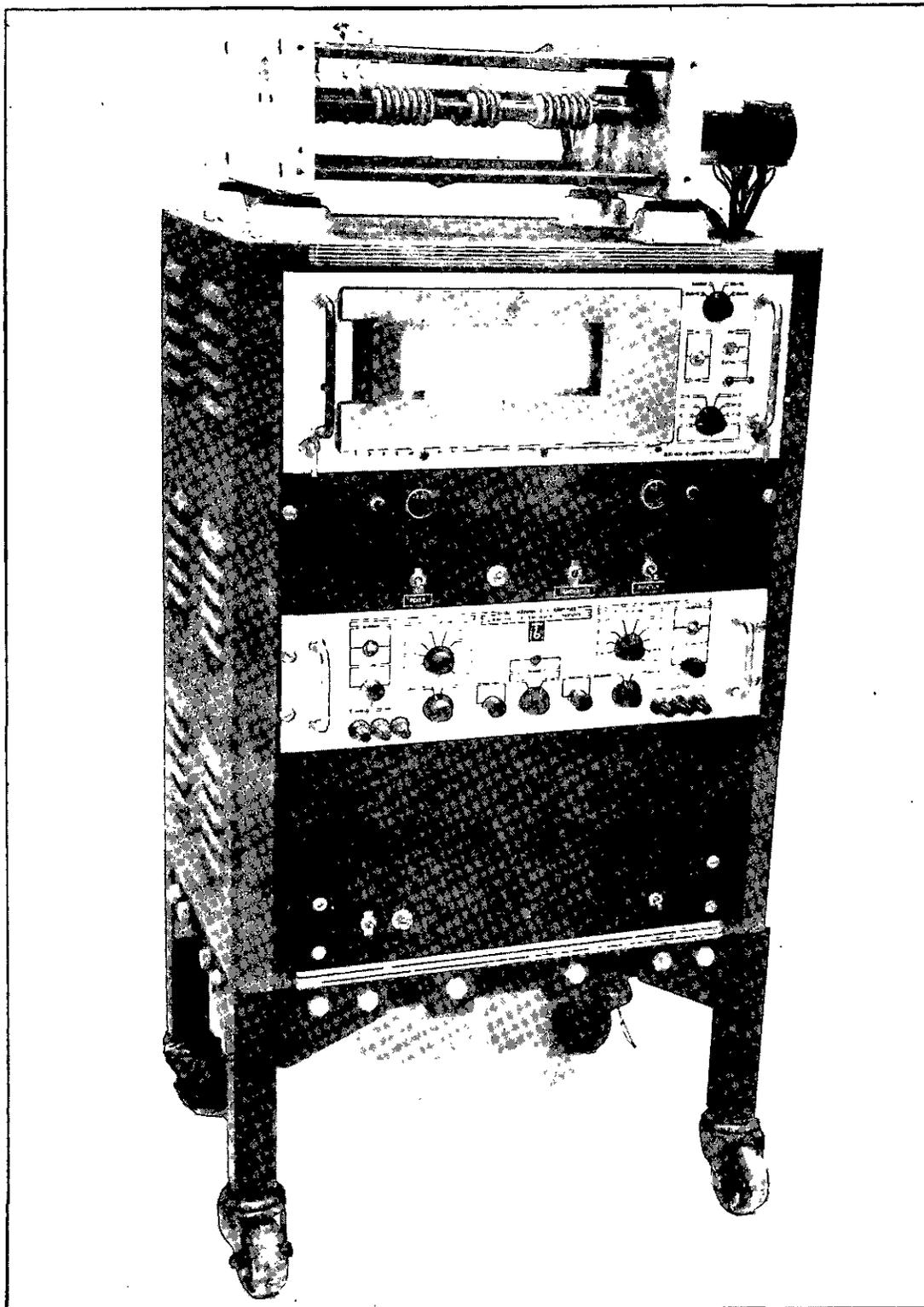
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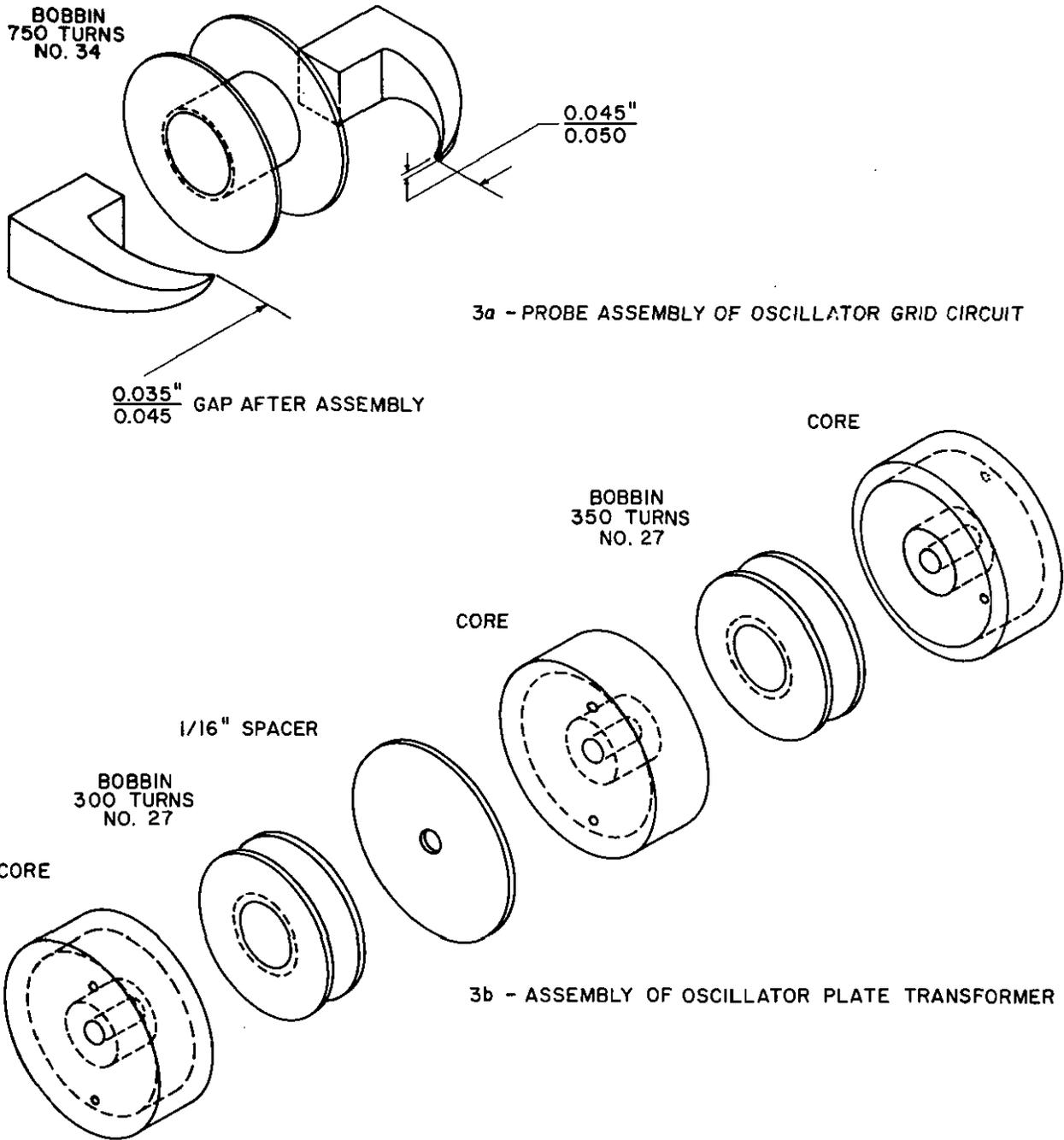
FIGURE 1



COMPLETE INSTRUMENT ASSEMBLY

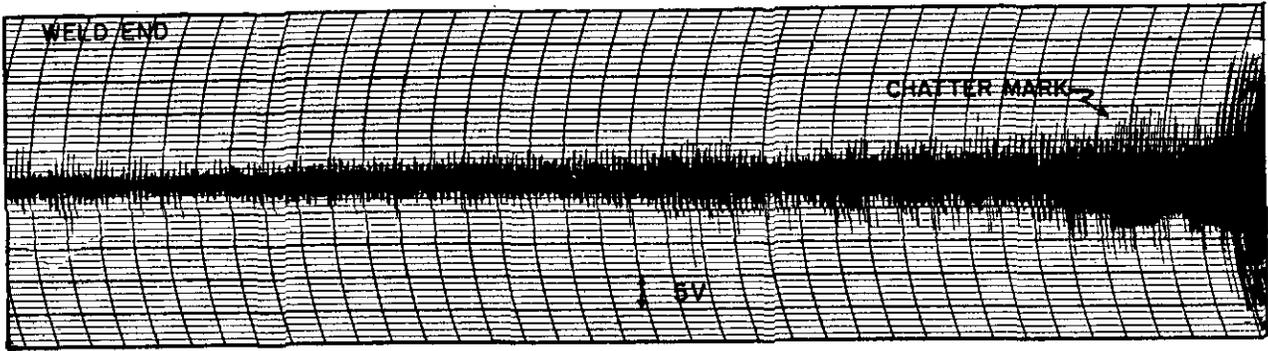


FIGURE 3

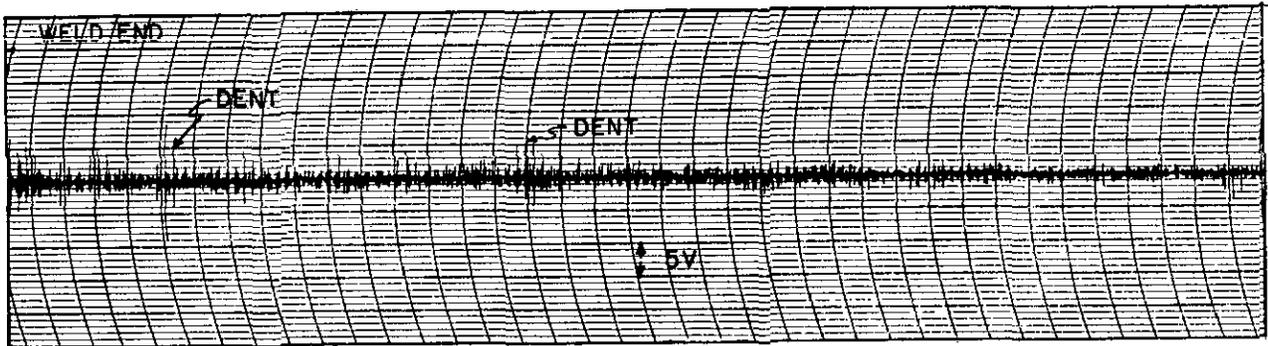


PROBE AND TRANSFORMER

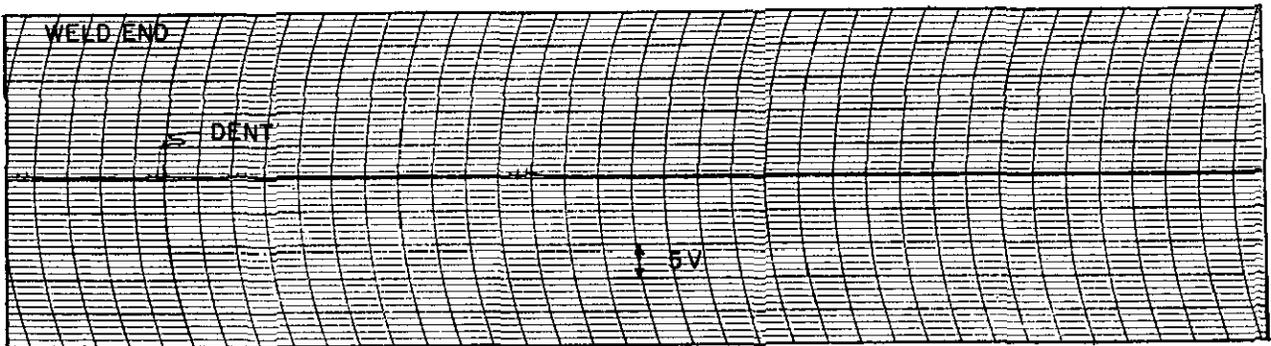
FIGURE 4



4a - TRACING WITH OSCILLATOR TUNED TO 60 KC



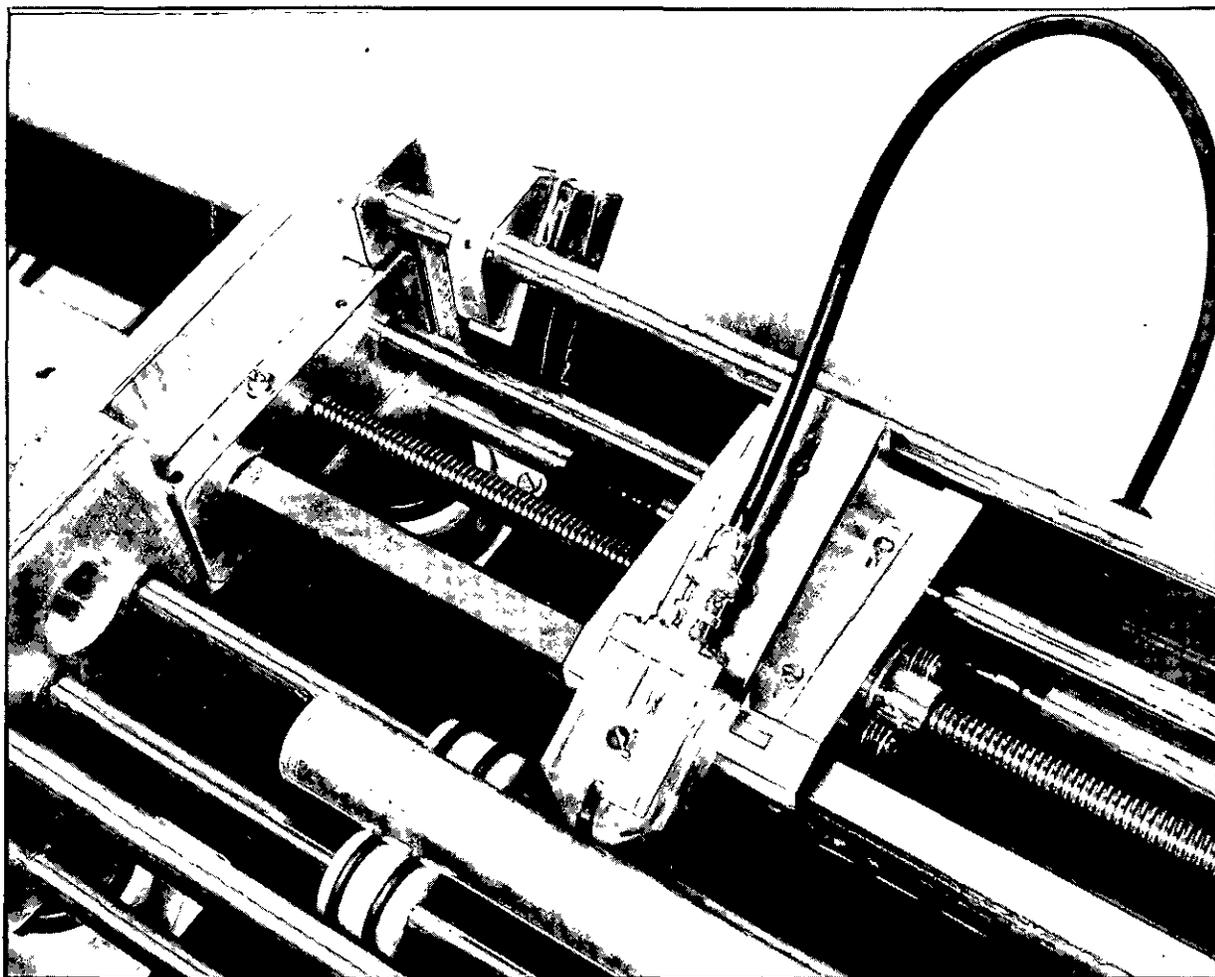
4b - TRACING WITH OSCILLATOR TUNED TO 23 KC



4c - TRACING WITH OSCILLATOR TUNED TO 23 KC AND DIODE CLAMP IN CIRCUIT

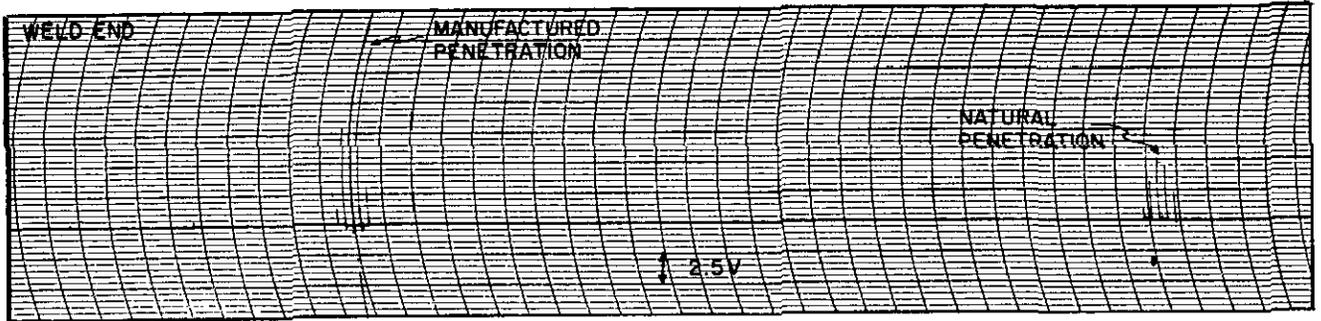
EFFECT OF FREQUENCY ON SIGNAL-TO-NOISE RATIO

FIGURE 5

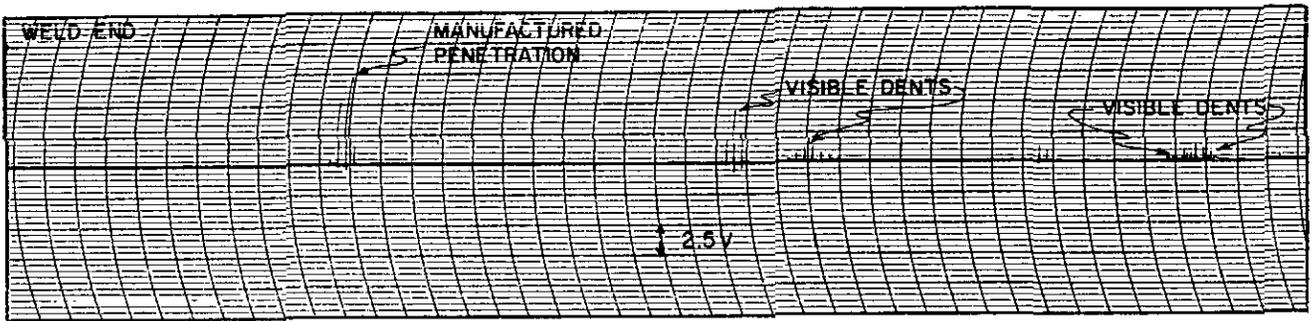


SCANNING MECHANISM

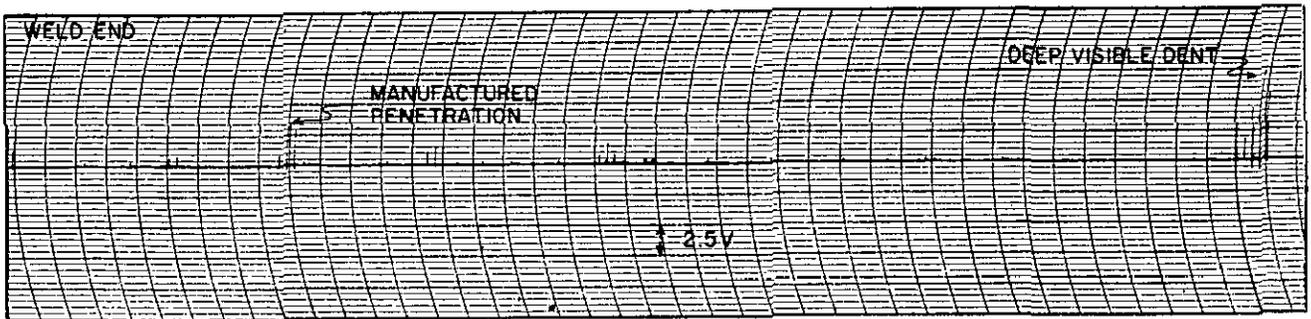
FIGURE 6



6a - Al-Si PENETRATION 0.060 INCH IN DIAMETER, 0.015 INCH BELOW SURFACE



6b - Al-Si PENETRATION 0.030 INCH IN DIAMETER, 0.005 INCH BELOW SURFACE



6c - Al-Si PENETRATION 0.020 INCH IN DIAMETER, 0.005 INCH BELOW SURFACE

RECORDINGS OF MANUFACTURED Al-Si PENETRATIONS

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