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THE APPLICATION OF ULTRASONICS TO WIRE DRAWING

by

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ABSTRACT. A series of draws was performed on copper, aluminum, stainless steel and iron wire, both with and without an ultrasonic radiation environment. It was found that copper and iron responded favorably to ultrasonic environment, whereas the results with aluminum and stainless steel were inconclusive.

U.S. NAVAL ORDNANCE TEST STATION

China Lake, California

18 July 1963

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C. BLENMAN, JR., CAPT., USN — *Commander*
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FOREWORD

This is the first in a series of quarterly progress reports, April through June 1963, concerning the drawing of wire under ultrasonic radiation. The work was sponsored by the Naval Bureau of Weapons under WEPTASK RRMA-24-061/216-1/R007-06-1 and the cognizant engineer is Mr. R. M. Gustafson, Code RMMA-24.

This report represents information issued at the working level and is subject to modification and withdrawal.

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CONTENTS

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FIG. 1-2, none; FIG. 3, LO 85562; FIG. 4, LO 85561; FIG. 5-6, none; FIG. 7, LO 85560; FIG. 8, none; FIG. 9, LO 85559; FIG. 10-11, none.

INTRODUCTION

The objective of this program is to investigate the application of ultrasonic energy to the wire drawing of metals. This investigation will attempt to define the effects of ultrasonic energy on the mechanism of plastic flow during the deformation process and to evaluate the resulting metal structure and properties.

Proposed work is oriented toward the application of ultrasonics to the forming procedures employed in the commercial fabrication of metals. Significant elements of the study have been divided into the following phases:

1. Equipment assembly and check out.

2. Comparison of metal structures and drawing variables with and without ultrasonic transmission. Metals representing the three basic metallic crystal structures - face centered cubic, body centered cubic, and hexagonal close-packed - will be examined.

3. Effects of deformation rates during ultrasonic radiation.

4. Temperature effects during ultrasonic radiation.

5. Effects of ultrasonics to other deformation processes.

EQUIPMENT AND INSTALLATION

An ultrasonic transducer with a ceramic lead zirconate-titanate crystal with a 1/2 wave length titanium horn was purchased from Branson Instruments, Inc. A 5-mm hole runs through the longitudinal axis of the assembly through which wire may be continually drawn. Figure 1 shows the "Sonifier" and wire die assembly. To date only high carbon steel dies have been used with this transducer. Carbide dies have been designed for use with the refractory metals, but their purchase has been postponed until a decision can be reached with the supplier on the method of attachment.

An ultrasonic generator with an output of 250 watts, automatic frequency control and variable power settings has been on order for several months. Borrowed equipment is being used until its delivery. Two power sources have been used in the tests described in this report: a 75 watt Branson generator, Model LS 75, with a variable power output and limited frequency control, and a 20 to 250 watt Glennite generator, Model U-405 VR, with a much wider range of frequency control. Both generators require manual regulation and depend on the operator's judgment and response for optimum tuning.

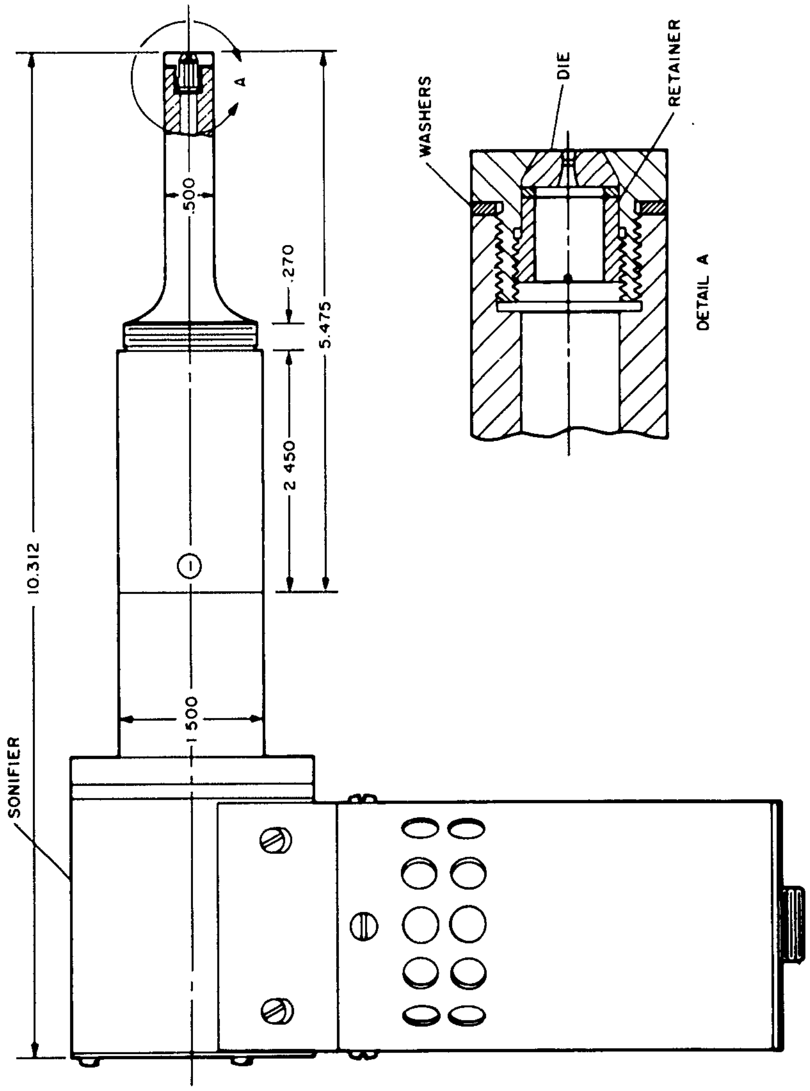

FIG. 1. Sonifier and Wire Die Assembly.

A LeBlond engine lathe with a 14 inch swing and a 6 foot bed has been modified into a draw bench. The transducer flange mounted at the nodal point is bolted to a centering fixture which fastens on the steady-rest near the tailstock end (Fig. 2). Figures 3 and 4 show the method of attachment. The wire is gripped by a Jacob's chuck in tandem with a non-overload device and an Alinco load cell; all of which is held by the compound rest and powered by the lead screw. Figure 5 shows the design of the non-overload device used to limit the load on the transducer, and Fig. 6 shows the design of the load-cell adapter. Figure 7 shows an over-all view of the transducer and the drawing mechanism mounted in the compound rest.

The permissible range of drawing rates is 0.25 to 2.0 in/sec. Relationship between draw speed and quick change gear setting is shown in Fig. 8. The Alinco load cell mounted in tandem with the draw-chuck is used to measure the pulling force during the draw and its signal is recorded on the Y axis of a Moseley X-Y flatbed recorder. A time delay relay, designed and built at NOTS, provides a time proportional signal to the X axis. The input signal can be set for 1, 3, 10, and 20 sec/in. Instrumentation is shown in Fig. 9.

DRAWING OF COPPER

The first draws made in ultrasonic environment were performed on April 30. These draws were made on tin-coated, high-conductivity copper wire of 0.0403 in. diameter with a die of 0.0355 in. and at draw rates of 0.25 in/sec to 2.0 in/sec. Final diameter of the wire was measured to be 0.0365 in., an area reduction of 18 percent. All drawing to date was performed at room temperature. The ultrasonic frequency, when applied, was 20,000 cps, nominal.

Draws were made at power settings numbering from 1 to 8 on the ultrasonic generator. These values are arbitrary and do not reflect quantitatively the energy transmitted from the die to the wire. It was found that draw loads were materially reduced under ultrasonic environment and that optimum results could be achieved at a power setting of 5. Figure 10 illustrates the load-time curves for different power settings. Reductions in pulling force, calculated by integrating under the curves, amount to 34 percent when the dial setting was 5. The intensities under this condition were measured at a later time and found to be about 23 watts/cm^2 at the end of the horn.

At higher power settings than this value, the draw force increased and in addition showed sharp downward excursions at time intervals of 2 seconds. Also at power settings above 5 the drawn wire was roughened at the surface and showed definite striations. These striations are not particularly injurious to over-all surface finish, and can best be described at this time as an annular pattern which occurs at definite intervals along the length of the wire. Furthermore, a relationship is found between the interval distance and draw speed as shown in Table 1.

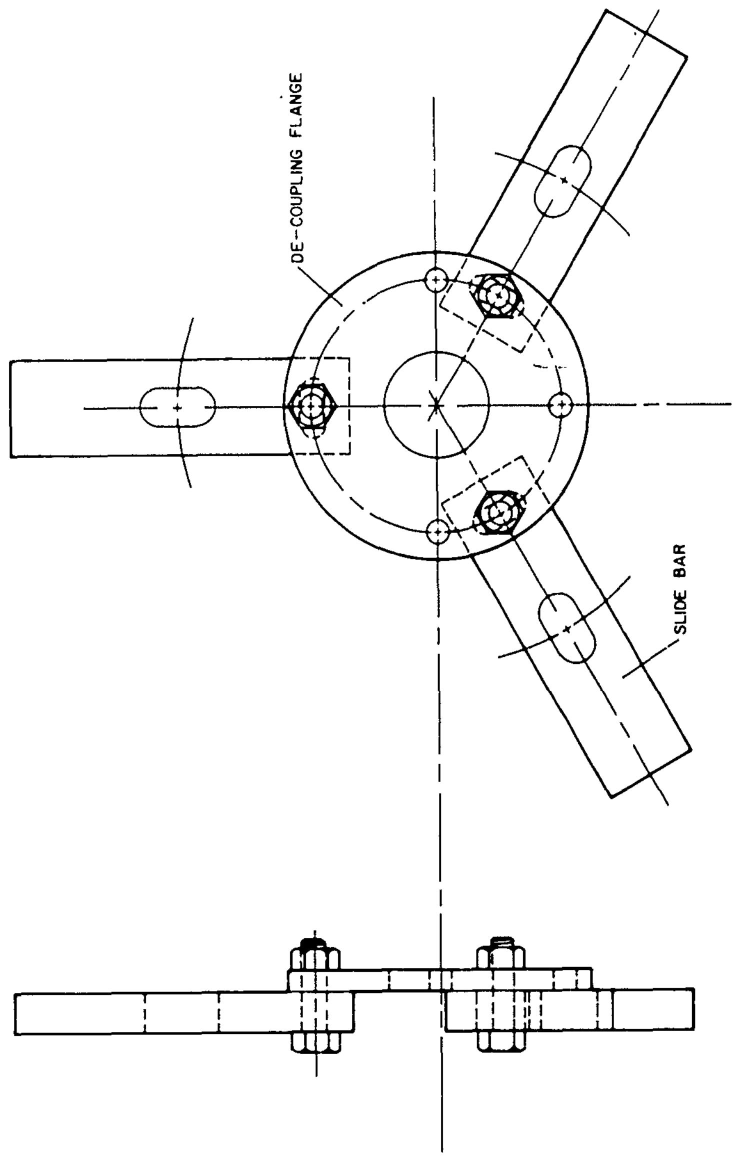

FIG. 2. Holder for Sonifier.

FIG. 3. Left Quarter View of Load Cell and Ultrasonic Transducer.

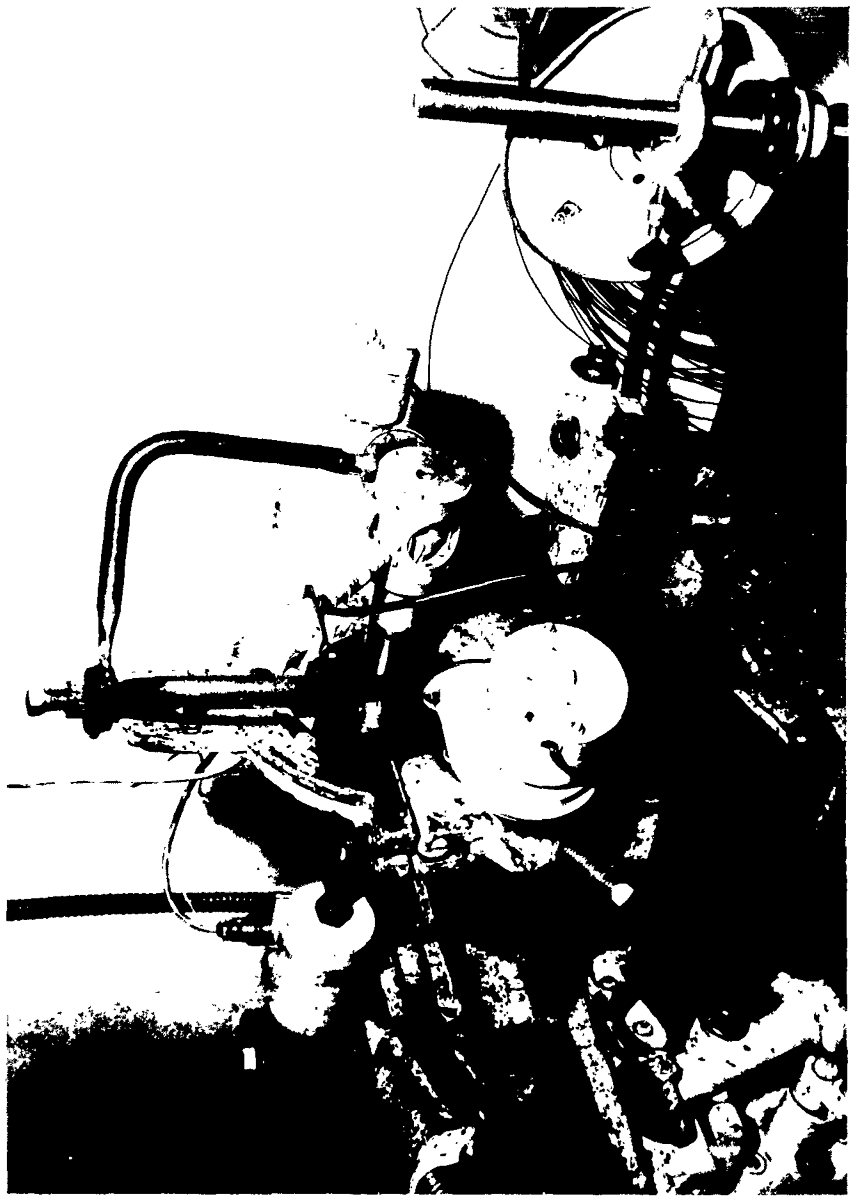

FIG. 4. Right Quarter View of Load Cell and Ultrasonic Transducer.

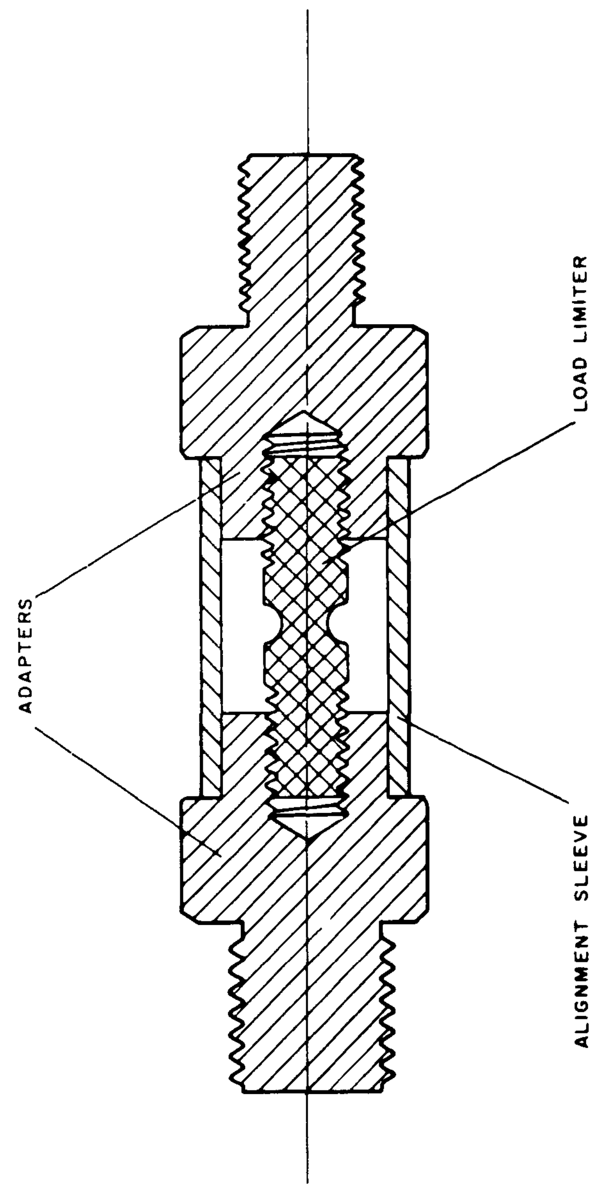

FIG. 5. Non-Overload Unit.

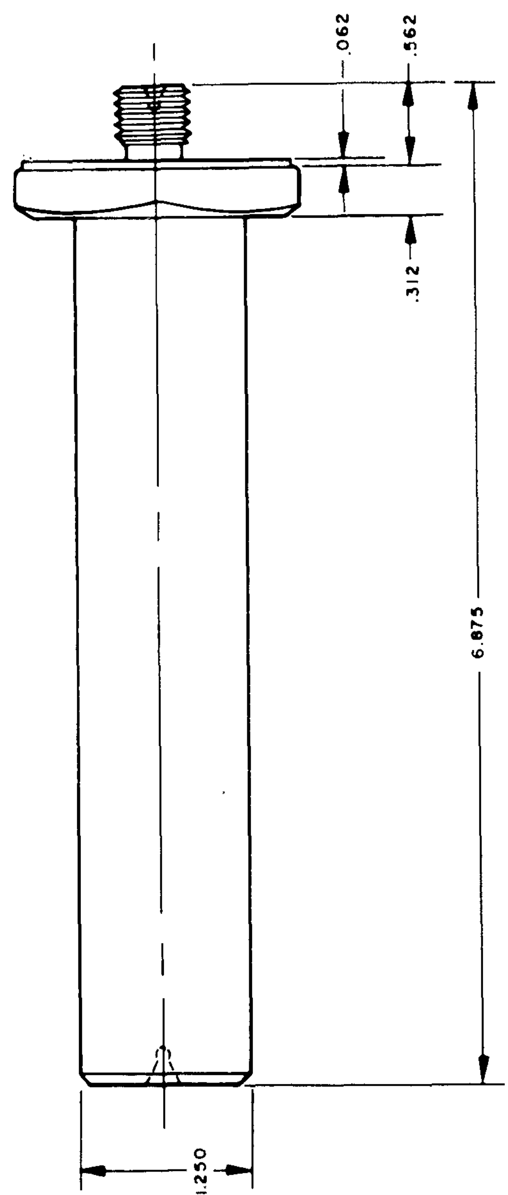

FIG. 6. Load Cell Adapter.

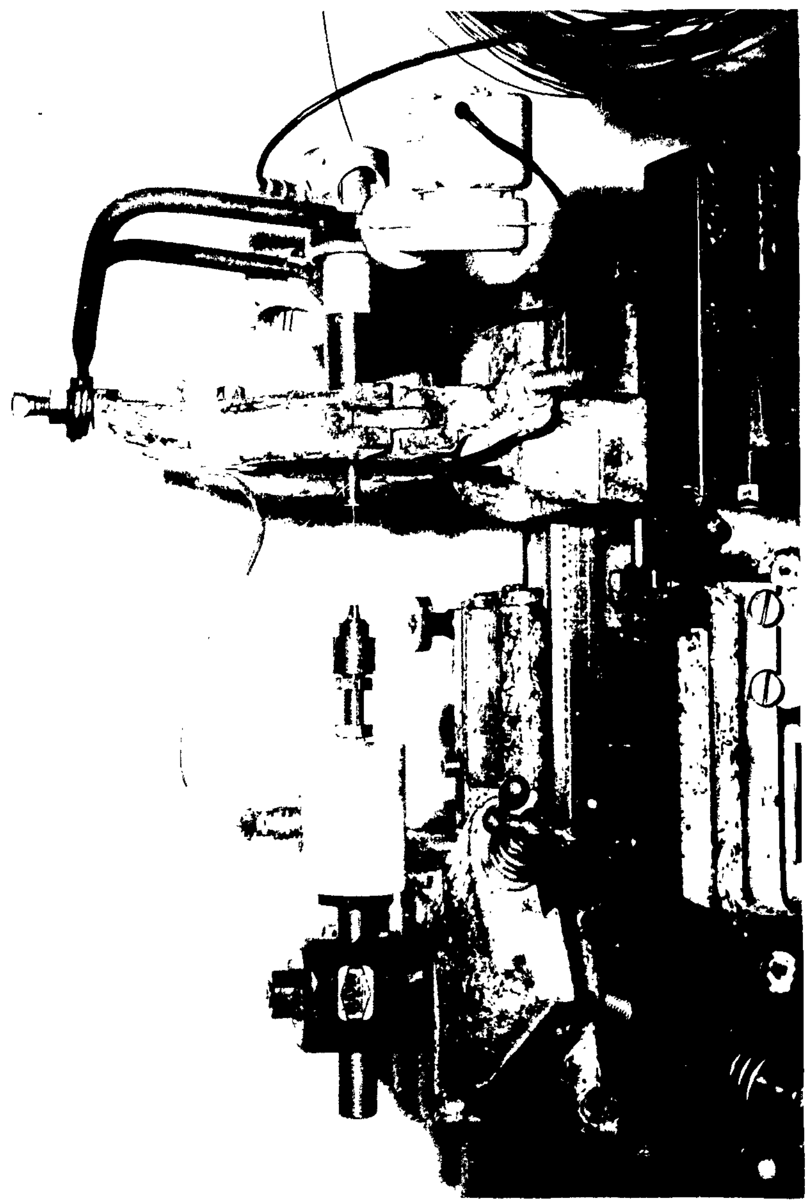

FIG. 7. Side View of Load Cell and Ultrasonic Transducer.

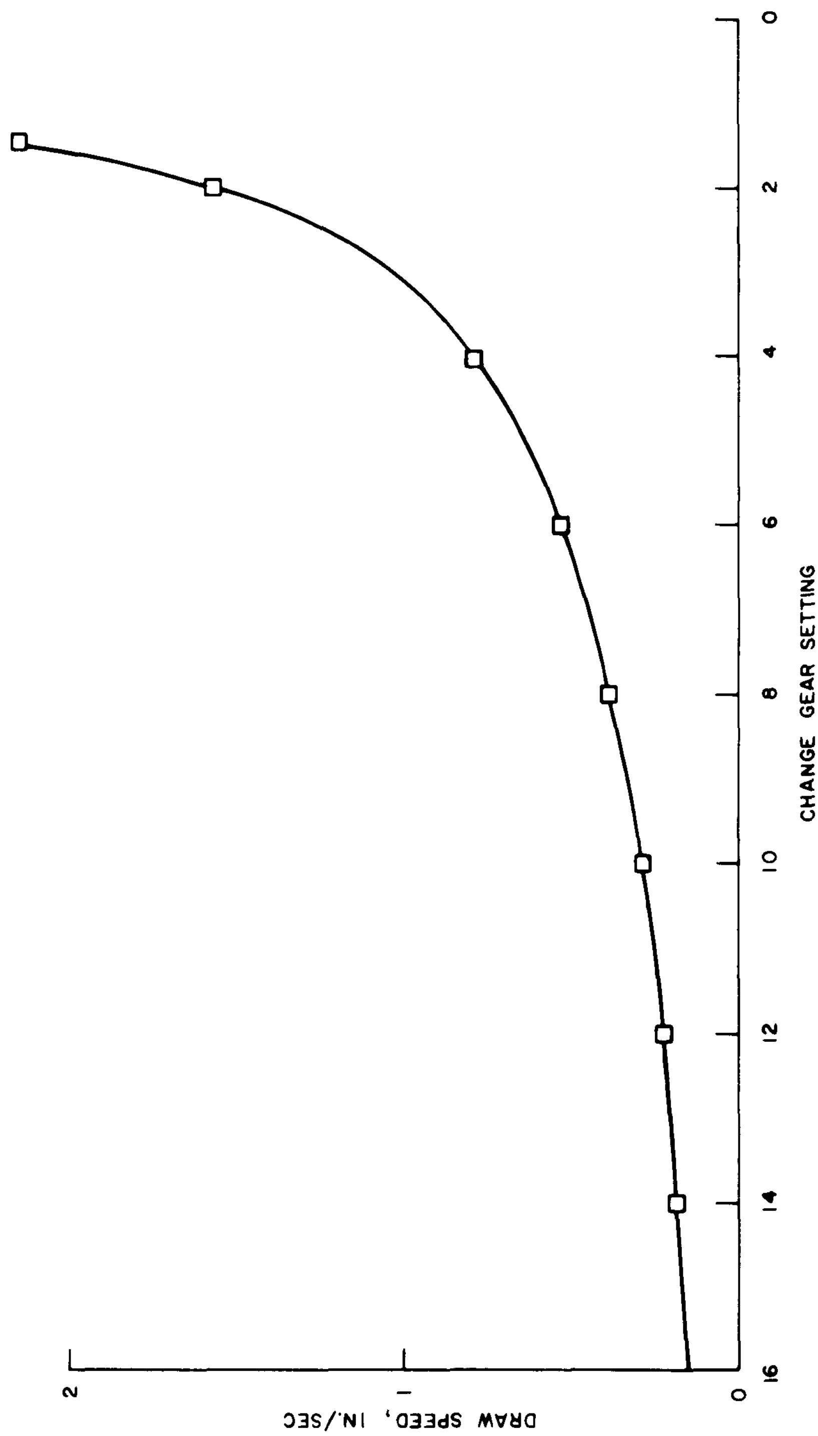

FIG. 8. Draw Speed at Various Gear Box Settings on the LeBlond Lathe.

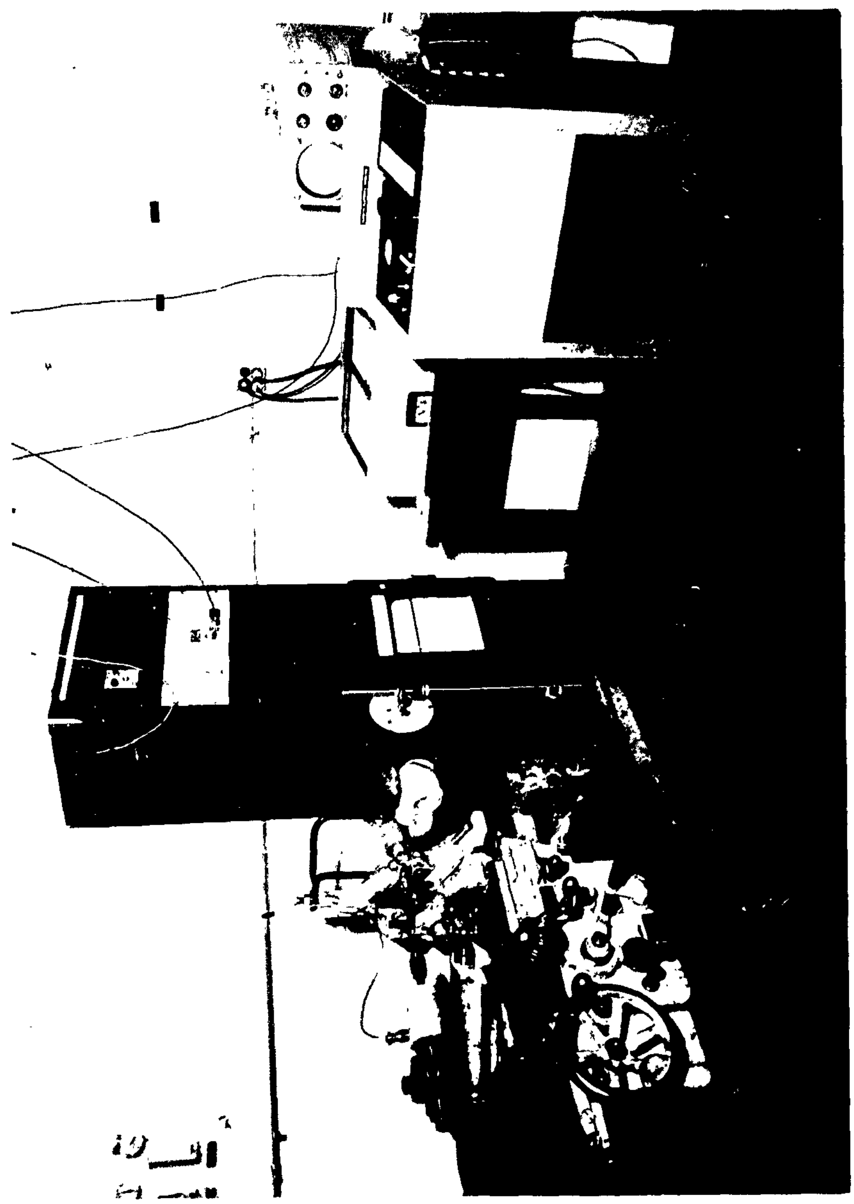

FIG. 9. Instrumentation and Wire-Drawing Test Setup.

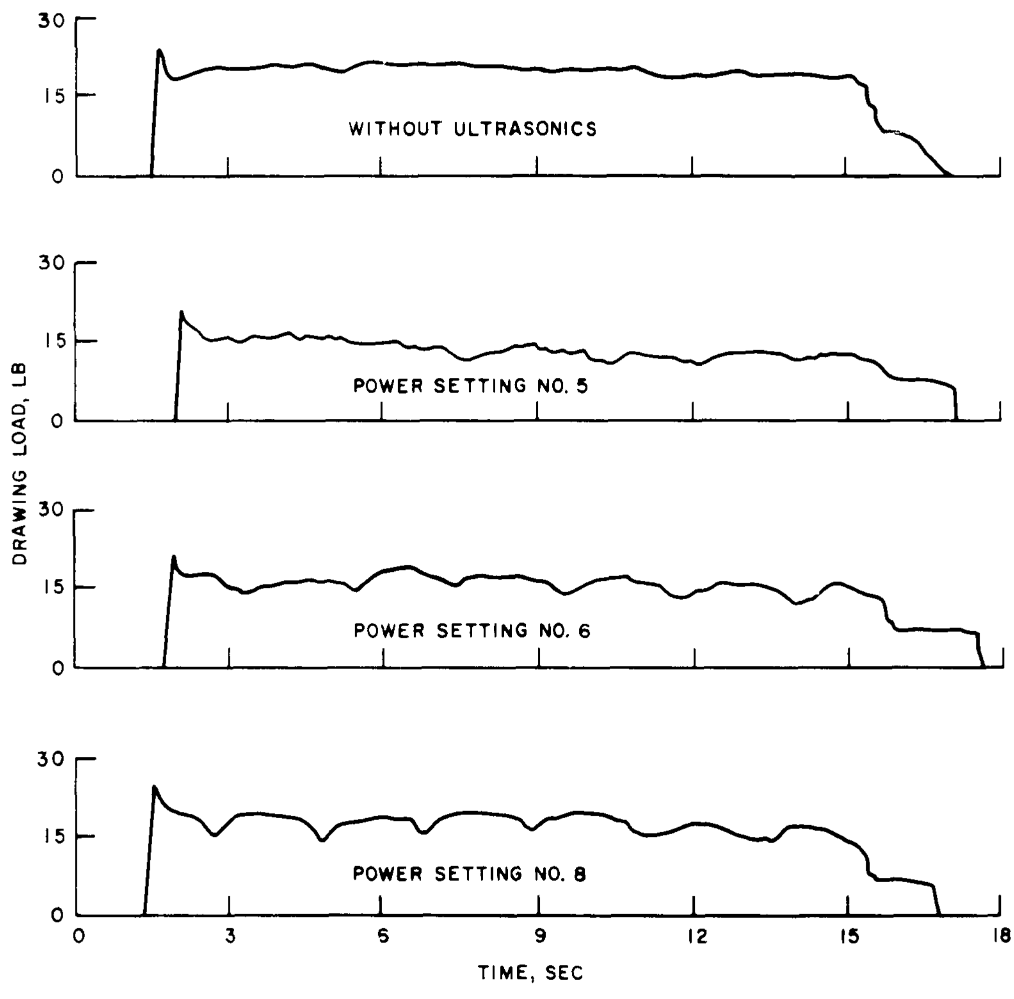

FIG. 10. Load Versus Time Curves for the Drawing of Copper Wire. Draw speed: 1.56 in/sec, D_o: 0.0403 in., D_f: 0.0365 in., Area reduction: 18%.

TABLE 1. Relationship Between Striation Interval and Draw Speed for Copper Wire Coated With Tin

Draw speed, in/sec	Striation interval, in.	Ratio of draw speed/interval
0.25	0.0023	108
1.00	0.0091	110
1.56	0.0145	108
2.00	0.019	105

After approximately 20 draws of 22 in.-wire lengths the dies were removed and examined under a microscope. There was considerable loading of the tin coating in the die and visual evidence of internal die erosion.

Draw loads for copper wire were so low that even at maximum sensitivity on the X-Y plotter (30 lb/in), it was difficult to obtain data on the effects of power level and draw speed. It was believed that more reliable information on these two variables could best be obtained by drawing materials of a greater yield strength.

DRAWING OF STAINLESS STEEL

Stainless steel wire, type 321, having an original diameter of 0.0453 in. was drawn through an 0.0395 steel die obtaining area reductions of 36 percent. Different draw speeds and ultrasonic power intensities were examined to obtain information on these variables. No correlation in load with either of the two variables was evident, but it was noted that there was a slight increase in load as the tests continued. After eight total draws the dies were removed and examined. It was found that stainless steel welded to the die throat; and continual metal build-up required that the pulling force be increased, thereby masking the effects of other variables. Possible causes of the welding is believed to be due to one or more of the following:

1. Die design
2. Lack of lubrication
3. Dirty wire
4. Ultrasonic welding

It was decided that further drawing of stainless steel be curtailed until dies of harder material and proper design could be obtained.

DRAWING OF ALUMINUM

Aluminum wire (1100-0) 0.065 in.-diameter was drawn through an 0.052 in. die resulting in area reductions of 34 percent. The wire was coated with soap prior to drawing in an attempt to prevent welding between wire and die. Two draws were made without the use of ultrasonic radiation. After this, several draws were made under various ultrasonic intensities. The loads during ultrasonic radiation were higher and erratic. Manual adjustment of frequency control was ineffective in obtaining optimum power matching between wire and transducer. After seven draws the die was removed and examined under the microscope. There was considerable aluminum build-up on the die throat in spite of the rather heavy covering of the soap before drawing.

DRAWING OF IRON

The negative results obtained with stainless steel and aluminum indicated that examination of the controls of the 75 watt frequency generator (Branson) was needed. A sound intensity instrument was used to measure the power amplitude of the transducer under different conditions. It was found that the range of frequency control was too limited and manual adjustment during drawing operations too sluggish to maintain optimum coupling. Therefore a Glennite Ultrasonic generator, capable of manual frequency adjustments over a wider spectrum, was used for drawing low purity iron wire, 0. 0485-in. diameter. The wire had a coating of black mill scale which was left on to decrease the possibility of pickup on the die. The wire was cleaned with solvent prior to drawing to remove dirt and grime.

Using a die size of 0. 046 in. diameter, equivalent to 13 percent area reduction, there was a decrease of 50 percent (42 to 21 lb) in the draw force under an ultrasonic environment. Under these conditions, load values remained relatively constant during the draw except for periodic drops which occurred every 21.6 seconds. By changing die size to 0. 039 in., the drawing load without ultrasonics was 75 lb for 35 percent area reduction. With ultrasonics the load dropped to minimum values of 39 lb and average loads could be sustained at 54 lb. Typical load-time curves shown in Fig. 11 indicate that the generator could not be regulated for optimum coupling. The trace made under ultrasonic environment shows definite perturbations every 7. 5 seconds which is equivalent to distance intervals of 1. 4 in. on the wire. No annular striations similar to ones produced on the copper could be observed on the iron wire after drawing. During the time that optimum coupling was in evidence, it was noted that the die and die retainer had a tendency to loosen and become very warm. After 10 draws the die was removed and found to have excessive build-up. Some scoring of the die was also in evidence. The amount of welding, however, was less than that obtained with copper, aluminum and stainless steel for the same number of draws.

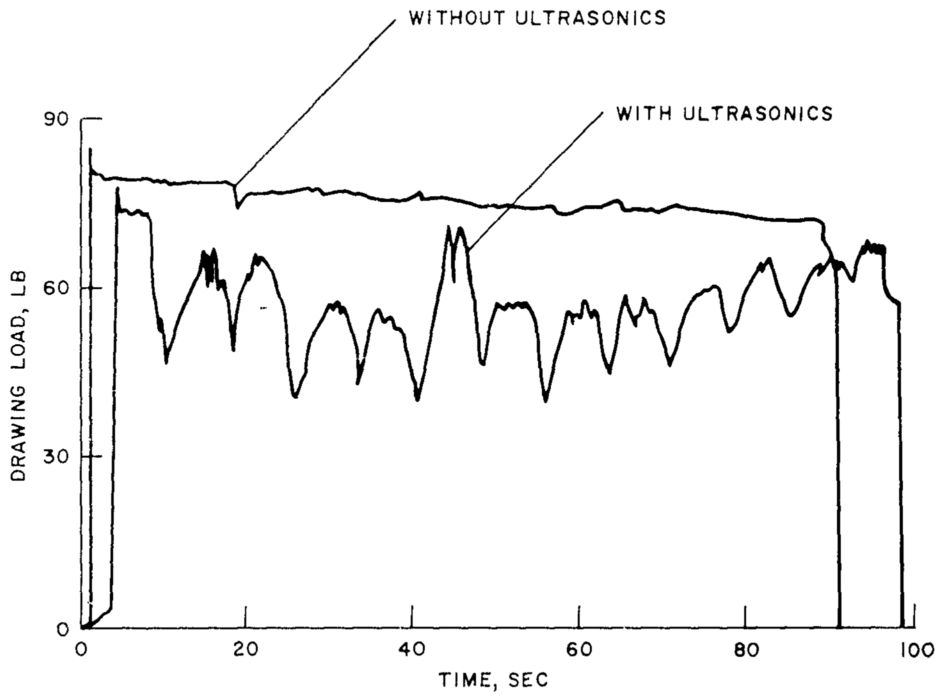

FIG. 11. Load Versus Time Curves for the Drawing of Iron Wire. Draw speed: 0.187 in/sec, D_o: 0.0485 in., D_f: 0.039 in., Area reduction: 35%.

RESULTS AND CONCLUSIONS

The carbon steel dies used in these experiments showed evidence of welded metal after a minimum number of draws; and after cleaning there was evidence of erosion on the throat. The load-time curves in many instances showed erratic behavior which is believed due to the combination of improper coupling and metal build-up on the die.

The use of an ultrasonic radiation environment is influential in decreasing the force necessary for drawing copper and iron wire even at low power intensities of about 23 watts/cm^2. It is believed that the effect would also be shown for aluminum and stainless steel if frequency adjustment were of sufficient range and could have been regulated for optimum coupling between die and wire. In order to obtain reliable data which may be used to clarify the material and processing variables, it is believed necessary to do the following:

1. Obtain dies of harder composition which will resist erosion and scoring.

2. Replace manual frequency control with an automatic device to insure continuous optimum coupling.

3. Continuously monitor power intensities of the transducer so that quantitative values may be obtained

4. Use a draw lubricant to prevent ultrasonic welding and excessive build-up on the die.

ABSTRACT CARD

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