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ULTRASONIC INSPECTION OF ALLOYED TUNGSTEN BARS

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Alloyed tungsten bars made from powdered metals that are compressed, sintered, and swagged can be ultrasonically inspected. Both longitudinal and shear waves were used, the latter being more sensitive. A frequency of 2.25 MHz proved best. One crack was found. The crack was equated to a standard.

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FIGURES

INTRODUCTION

This report describes an ultrasonic inspection process that was developed for use on round alloyed tungsten bars with an as-swagged surface finish. During manufacture, the alloying metals are mixed together in powdered form, compressed, sintered, and swagged. The solid bars are approximately 3 cm (1.2 in.) in diameter by 34 cm (13.4 in.) long. Each bar weighs about 5 kgm (11 lb). The surface finish on the outside diameter is smooth and shiny. Both ends are machined square. One end contains a small centering hole. A picture of an alloyed tungsten bar is shown in figure 1. These bars are to be made into dart-like penetrators. When fired from a gun at supersonic speed, a high density penetrator can pierce thick armor plate. To be effective, the tungsten alloy used in the penetrator must be tough. The presence of any cracks or voids would degrade toughness and would reduce the ability of any dart-like projectile to penetrate.

The purpose of ultrasonic inspection is to detect toughness-reducing defects. Preventing defective material from entering a stockpile guarantees better penetration performance.

Of the hundreds of round bars ultrasonically inspected, only one was found to contain a defect. This bar had a crack near one end (fig. 2).

INVESTIGATION

Variations in Diameter of Tungsten Bars

Swagging has a tendency to taper the ends of bars. The first and last portions that go through the hammers tend to be slightly smaller in diameter. Measurements were made of the diameters of twelve as-swagged tungsten alloy bars. Three measurements, 120 degrees apart, were taken at each of four locations:

- 2 to 3 cm (approx. 1 in.) from the near end
- At approximately 1/3 of the length
- At approximately 2/3 of the length
- 2 to 3 cm (approx. 1 in.) from the far end

For 10 bars of an earlier manufacture (by Kennametal), the range of change in diameter was 0.23 mm (0.009 in.).

For two bars of recent manufacture (by Teledyne), the range of change in diameter was 0.08 mm (0.003 in.). Out-of-roundness averaged about 0.005 mm (0.0002 in.) for all measured locations. For all practical purposes, there was no taper on the ends of these two bars.

Variations in diameter of tenths of a millimeter will not reduce the effectiveness of an ultrasonic inspection.

Frequency Analysis of Ultrasound

Any kind of sintered material made from powdered metal will be noisy during an ultrasonic inspection. For a given material, lower frequency ultrasound generates less noise. A frequency of 2.25 megahertz (MHz) was tried with good results. An immersion 2.25-MHz narrowband, 0.375-inch-diamter flat lens transducer was used to pulse ultrasound through water and down through the length of an alloy tungsten bar. A Hewlitt-Packard Model 8557A Spectrascope revealed the front interface and back echoes which are superimposed in figure 3. The front interface echo contained peak energy at a frequency spread of 2.2 to 2.3 MHz (which was to be expected). The back echo from the far end of the bar (after the pulse went down through the bar and back) contained peak energy between 2 to 4 MHz. This revealed that a substantial portion of the tuned energy in the region of 2.25 MHz was bringing back information about conditions inside the bar.

Transducer diameters of 0.25-inch and 0.5-inch were tried with inferior results. The smaller diameter lacked energy and the larger diameter caused excessive noise on the outside diameter. Transducer frequencies of 3.5 MHz and 5.0 MHz were also tried, but frequency analysis revealed that very little of the energy in the region of the peak frequency returned from the back of the bar; that is, the sintered metal absorbed a greater proportion of the higher frequency ultrasound. Frequency analysis was repeated with shear waves traveling diagonally across the bar. The results for both frequency and size were the same. A narrowband 2.25 MHz transducer, which generates more intense pulses, was compared to a broadband transducer and preferred.

Design of a Standard

It is difficult to design a standard when the size and type of defect are unknown. The problem is complete lack of experience and lack of data with sintered alloyed tungsten material. No one contacted knew what geometry of defect was expected to cause a problem. The target that was used to simulate a yet-to-be-established defect is illustrated in figure 4. The target consisted of a hemispherically bottomed hole drilled along the axis of a bar. A spherical target provides a uniform reflective surface to any ultrasound pulse coming diagonally across or straight down the bar.

Two standards were made. One contained a 4.75 mm (0.187 in.) hemispherically bottomed hole. The other standard contained a hole half the size--2.39 mm (0.094 in.) in diameter. Both holes were the same length and were covered with tape to prevent entry of water. Drilling these holes was tricky. The drill could easily grab and break off. The hemispherical bottom was a light clean-up finish cut with a new drill to achieve a smooth surface.

In use, the hemispherical target is difficult to detect. High amplification of the reflected signal is needed for longitudinal waves coming down the length of the bar. For diagonally-across-the-bar shear waves, the beginning of the hole where is enters the end of the bar gives a greater signal. This greater signal is from the corner effect. As a result, the beginning of the hole was first detected with shear waves. Then the transducer was moved parallel to the bar to the bottom of the hole where the hemisphere was detected.

Ultrasonic Scans

Approximately 200 tungsten bars manufactured by Teledyne were ultrasonically inspected.

Two ultrasonic scans were used to completely inspect each bar. These scans were:

Longitudinal waves pulsed directly through the length of the bar

Shear waves pulsed diagonally across the bar

Details of these scans follow.

Longitudinal Waves

Arrangement of Ultrasonic Transducer. Figure 5 shows the arrangement of the ultrasonic transducer relative to the bar. The inspection was done under water. Longitudinal waves of ultrasound were used. Ringing of the water-to-metal interface signal was difficult with this arrangement. The problem was that the duration of ringing could last during the entire time that the pulse was in the length of the bar. By shortening the water path; that is, moving the transducer close to the rear end of the bar, the duration of ringing was shortened. Waterpaths of 1 to 2 mm (0.04 to 0.08 in.) permitted ultrasonic inspection of the far half of a bar. As a result, every bar had to be inspected through both ends (one end at a time) so that all of the metal could be ultrasonically interrogated.

Inspection Process. The inspection was accomplished by moving the transducer across the end face while the bar was rotating. Usually, it is adequate to conduct this inspection with the transducer centered on the near end and the bar stationary. Such is not the case with sintered bars. There are so many acoustic paths that turn into dead ends that the transducer must be moved to explore all the paths down through and back out the length of the bar.

The bar is rotated at about three revolutions per second while the transducer moves vertically at about 1 1/2 mm (0.06 in.) per second toward the rim of the end face. As soon as surface signals from the outside diameter build up and trigger an alarm, the inspection is stopped. Then the bar is turned end-for-end, and the process is repeated with the transducer heading towards the center of the end face.

Sensitivity of the Inspection Process. It takes high amplification to detect echos from the far ends of the powdered metal bars. Since the critical defect size is unknown (including the geometry of a critical defect), the alarm threshold was made very sensitive. The threshold was set at a value of 6 decibels (dB) above the peak noise signal. For the Krautkramer-Branson flaw detector model USIP-11 that was used, the gain setting was 52 dB.

On the standards, the large 4.75 mm (0.187 in.)-diameter hemispherical hole triggered at a gain setting of 38 dB whereas the small 2.39 mm (0.044 in.)-diameter hemispherical hole triggered at a gain setting of 46 dB. Therefore, both standards were rejected.

Shear Waves

Arrangement of Ultrasonic Transducer. The arrangement of an ultrasonic transducer relative to a bar is shown in figure 6. Ultrasound pulses emanating from the transducer traveled through the water, converted to shear waves upon entrance into the alloyed tungsten bar, and traveled diagonally across the bar. Dotted lines give a general idea of the path of ultrasound.

Inspection Process. Each bar was scanned while rotating. The rotational speed could be fast. Approximately five revolutions per second was used with a scan movement of 1 to 1.5 mm (0.04 to 0.06 in.) per revolution. Then the bar was turned end-for-end and the ultrasonic scan was repeated.

It was essential to locate the supporting cradle wheels all the way out beneath both ends of the bar. Initially, when the wheels were located closer together, they generated false defect signals as the ultrasonic scan passed over them.

Sensitivity of the Inspection Process. This shear wave inspection is inherently more sensitive than the longitudinal wave (down-through-the-length) inspection. During calibration, the 4.75 mm (0.187 in.) hemispherically-bottomed hole in the standard triggered the alarm at 30 dB. The smaller 2.39 mm (0.094 in.) hemispherically-bottomed hole triggered the alarm at 37 dB. This is 8 to 9 dB more sensitive than the longitudinal wave inspection.

The gain setting for this diagonal inspection was 36 dB. This is substantially lower than the 52 dB gain setting used for the longitudinal wave. This lower amplification setting gave reasonable control over false alarms from noise. At this amplification setting, the 4.75-mm standard was rejected, but the 2.39-mm standard was accepted.

Complete Process Inspection

A complete process for ultrasonically inspecting alloyed tungsten bars has been documented.* The process description includes equipment and detailed procedures for setup, calibration, and inspection.

Detection of a Crack

Of the approximately 200 Teledyne made alloyed tungsten bars that were ultrasonically inspected, only one bar was encountered that had an alarm-ringing flaw. A longitudinal wave scan of the bar had failed to detect a flaw, but the diagonal shear waves located a flaw 23 mm (0.9 in.) in from one of the ends of the bar. The flaw behaved like a crack, exhibiting unidirectional reflectivity. Careful machining revealed that the flaw was a crack approximately 2 mm (0.08 in.) long (shown in fig. 2). Note that the crack did not go through any of the powdered metal particles. The crack skirted the round particles.

When compared to the size of detection signals from the two standards, the maximum detection signal from this crack fell in between. Interpolation reveals that a 2.7 mm (0.106 in.) diameter hemispherically-bottomed hole in a third standard would echo the same amplitude of detection signal as the peak signal received from the crack.

The crack lies approximately one-third of the way into the bar and faces the ends of the bar.

Figure 2 shows more than a crack. Notice all the void space between the metal particles. This region has a low density and is weak. So weak that a crack occurred during swagging.

CONCLUSIONS

Bars made from powdered metal (mainly tungsten) by compressing, sintering, and swagging, can be ultrasonically inspected for the presence of flaws.

An ultrasound frequency of 2.25 MHz works best.

Both longitudinal (down-the-length) and shear (diagonally-across) ultrasound waves can be used for complete coverage of all the material in the bar.

One design of a simple standard worked well for both modes of ultrasonic inspection.

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* Copy is available from the author.

One small crack was found. Its peak signal was equivalent to the echo from a 2.7 mm (0.106 in.)-diameter sphere centered on the axis of a standard bar.

Only one crack was encountered in about 200 alloyed tungsten bars that were ultrasonically inspected.

RECOMMENDATION

Determine the critical crack size in alloyed tungsten metal so that proper ultrasonic inspection standards can be used.

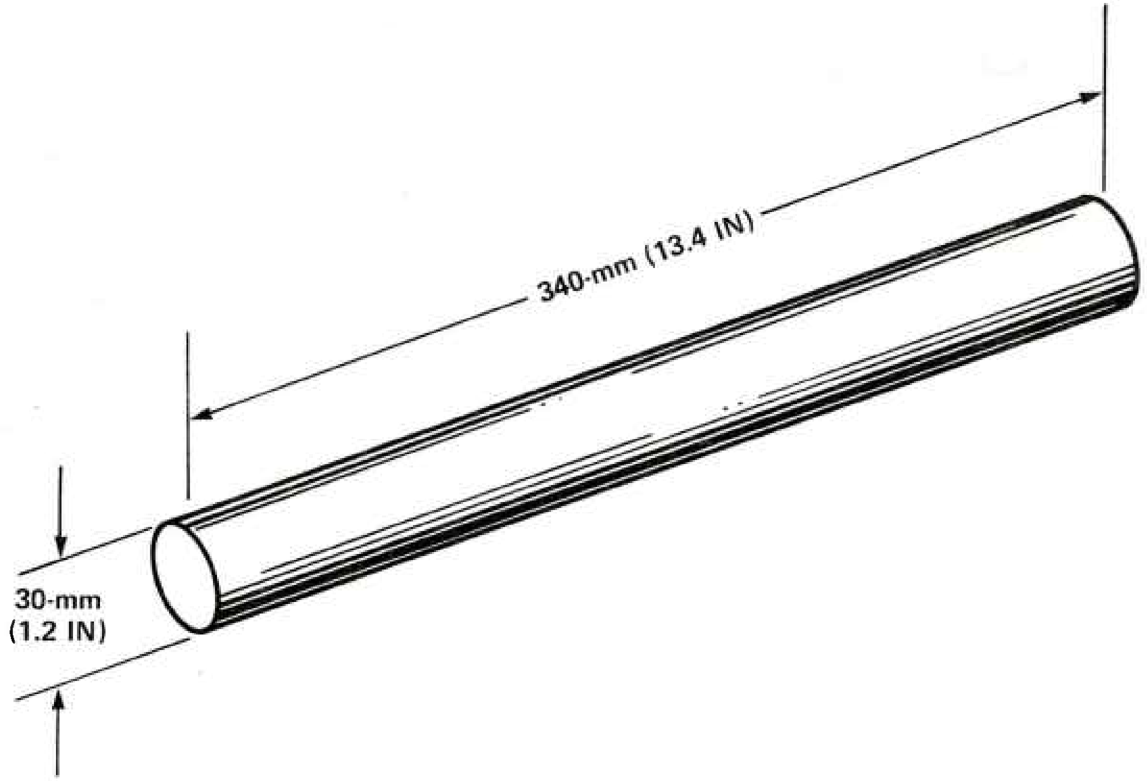
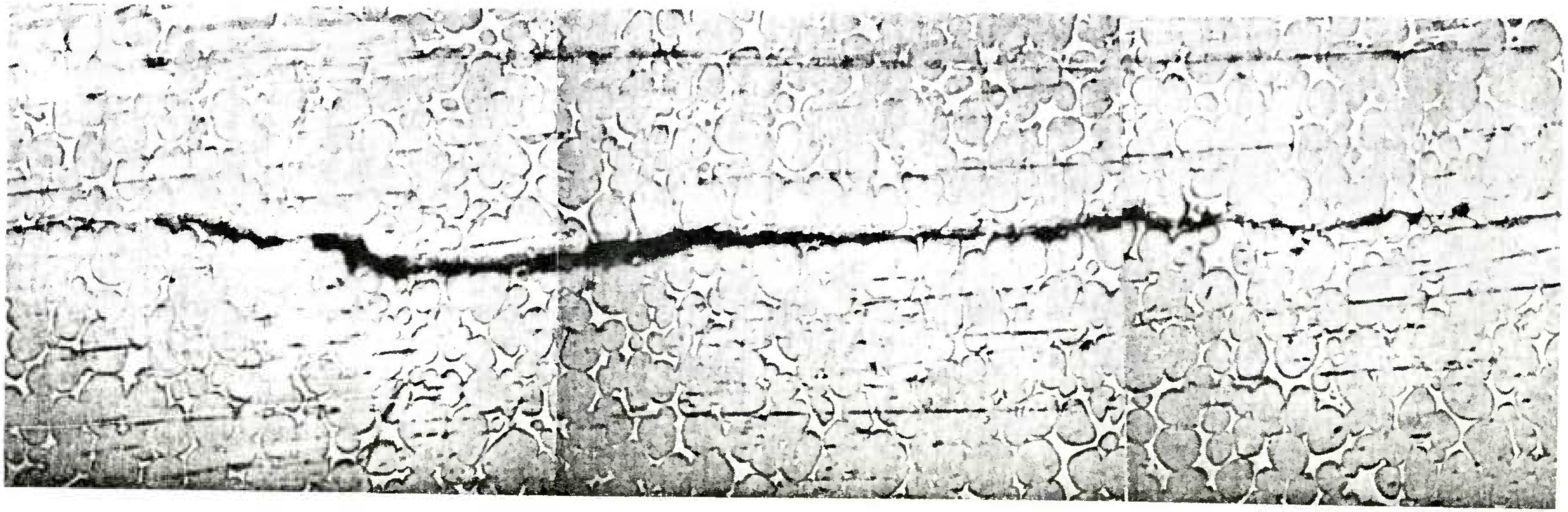


Figure 1. Alloyed tungsten bar



100X MAGNIFICATION

Figure 2. Crack in an alloyed tungsten bar

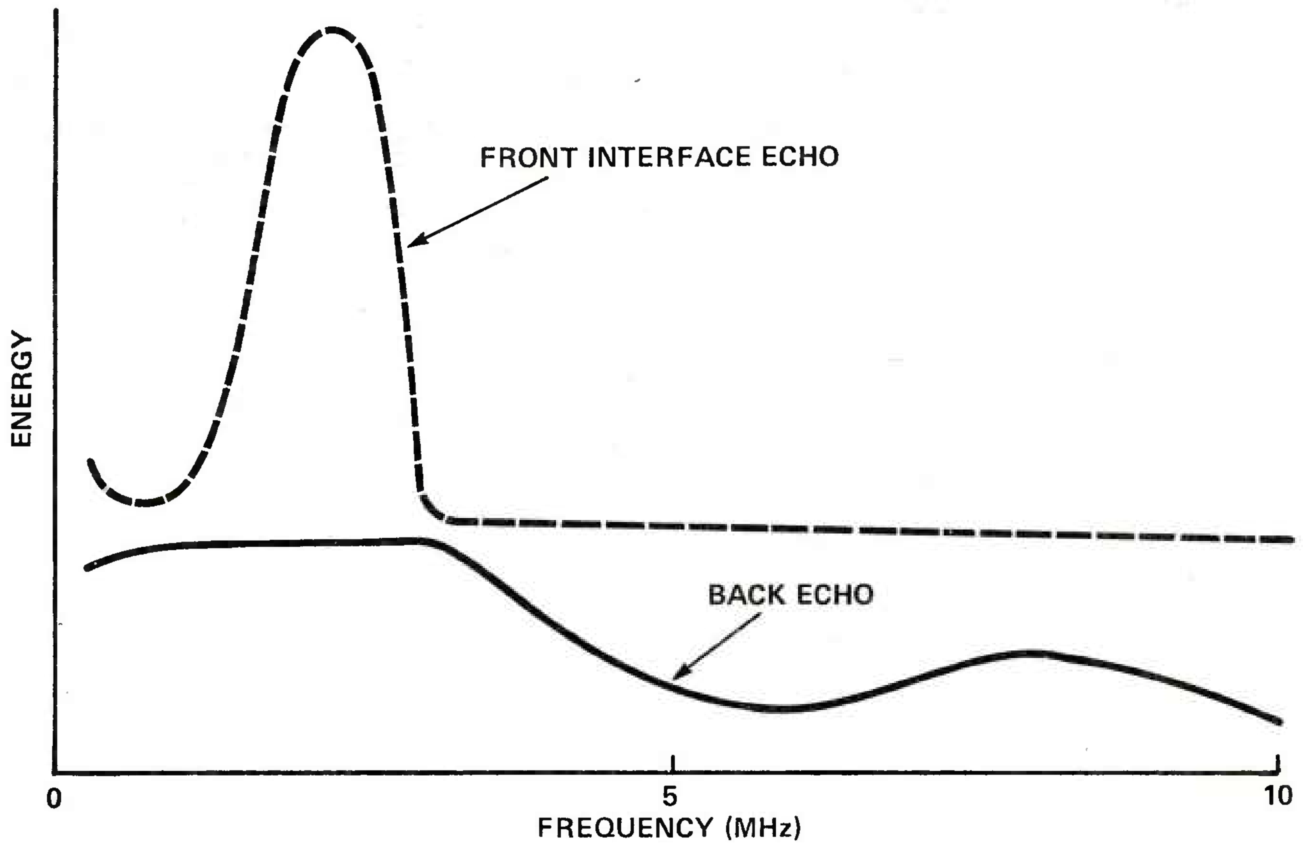


Figure 3. Frequency distribution of a 2.25 MHz pulse going into and coming out of an alloyed tungsten bar

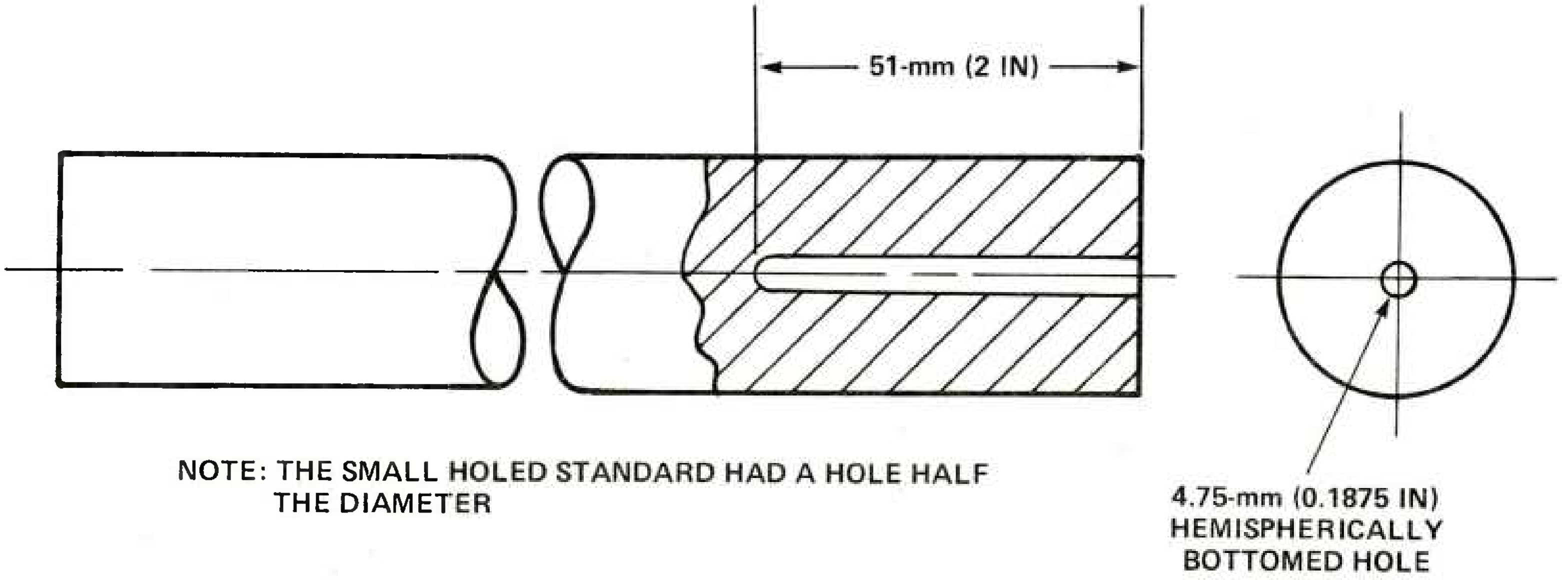


Figure 4. The large holed standard

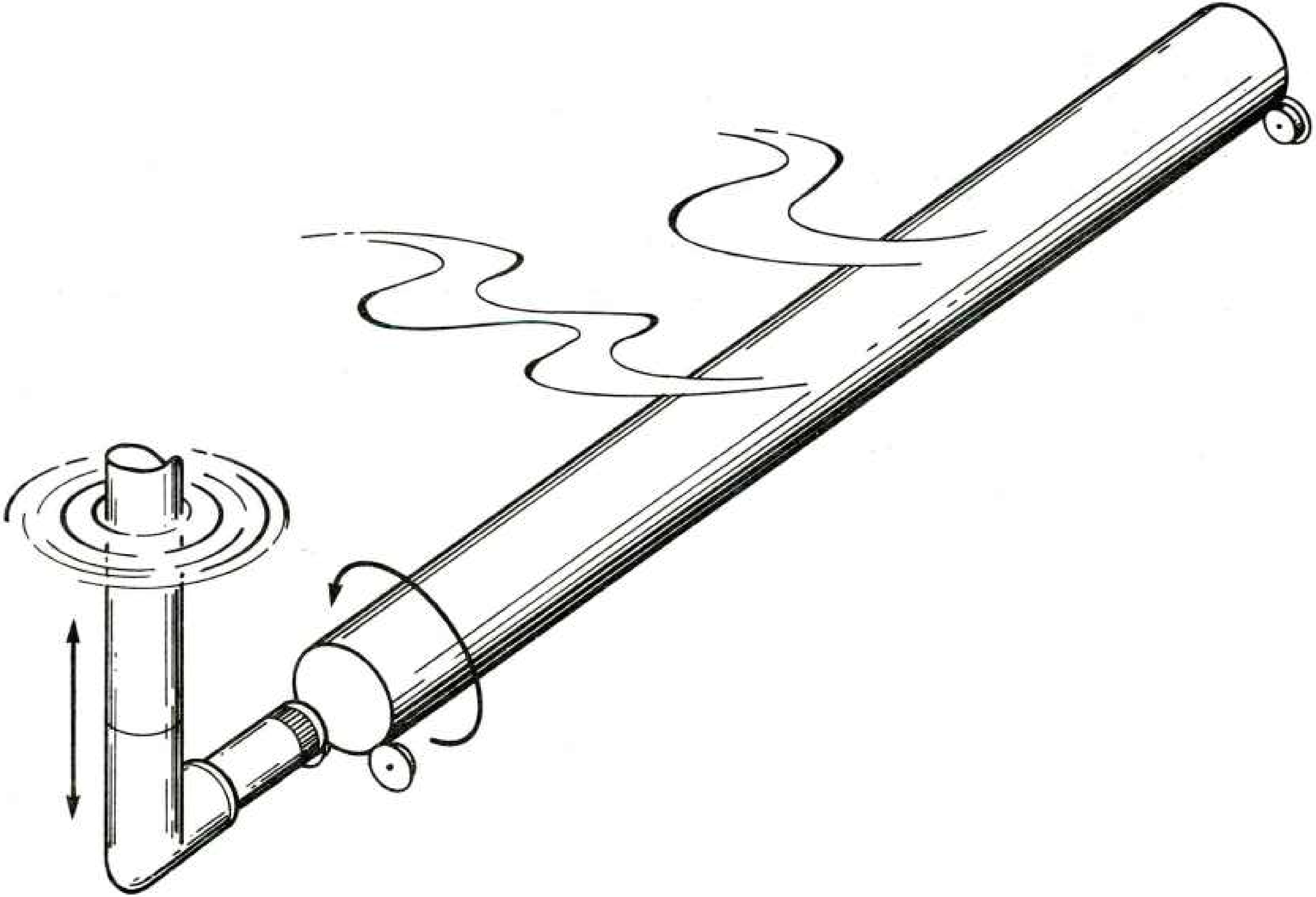


Figure 5. Ultrasonic inspection directly down the length of an alloyed tungsten bar

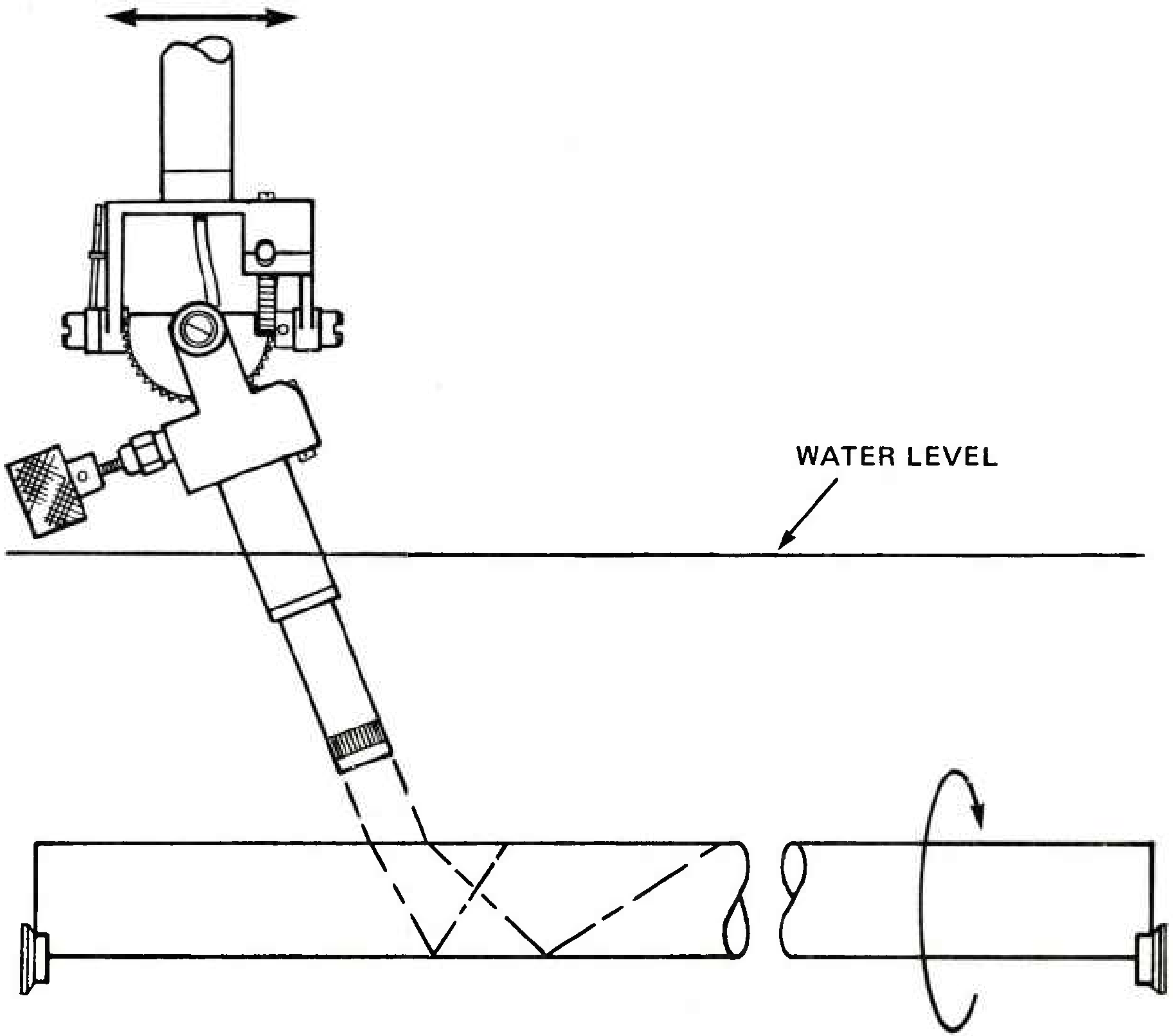


Figure 6. Ultrasonic inspection diagonally across an alloyed tungsten bar

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