Ultrasonic Microstructural Analyzer (UMA):

Breakthrough in Hardness Depth Measurement

The Technology

The Ultrasonic Microstructural Analyzer (UMA) measures the hardness depth of induction hardened steel parts. Its operation is fast, accurate, cost effective, and non-destructive. It has the potential to increase consistency of manufacturing quality for a variety of hardened parts and to save the industry millions of dollars annually. The UMA makes measurements without the need for surface preparation and performs the test on induction hardened cylindrically shaped steel parts (such as axles, shafts, rods, etc.) in less than a minute, making it suitable for near real-time process control applications. Current destructive techniques for a automotive axle may take as long as 30 minutes. Generally, UMA measurements may be made for hardness depths greater than 1.0 mm.

The UMA uses a high frequency (10 MHz to 25 MHz) ultrasonic wave to measure hardness depth. Though presently perfected for measuring case depth in automotive axles, the technology has much wider application. Compared to typical destructive methods of measuring hardness depth, the UMA offers advantages of near real-time control over the heat treatment, as well as reduced costs, the ability to make localized measurements and detect axial changes in hardness depth, and potential adaptability to through-hardened pieces. It can also reduce inspection costs, eliminate the scrap created by destructive tests, and provides a means for 100 percent inspection.

The Process

The UMA system includes a tank containing water in which a steel shaft is submerged and rotated. Water is required as a transmission medium to couple sound into the part. An ultrasonic sensor positioned over the part directs sound waves at the part. The transmitted wave passes through crystalline structures within the steel, which scatters numerous small waves back toward the sensor. The microstructure within the hardened layer back scatters low-amplitude waves. The softer underlying microstructure scatters higher amplitude waves. The point within the material which corresponds with the change in low amplitude to high amplitude back scatter is termed the “transition zone”. The amplitude change detects this amplitude change. The UMA and its corresponding time value for the wave to travel from the sensor to the transition zone (TZ) between hardened and unhardened steel and back to the sensor. Temporal shifts of the transition-zone response correspond to proportional changes in hardness depth. Figure 1 illustrates the process, and shows a typical ultrasonic response from hardened steel axle shafts.

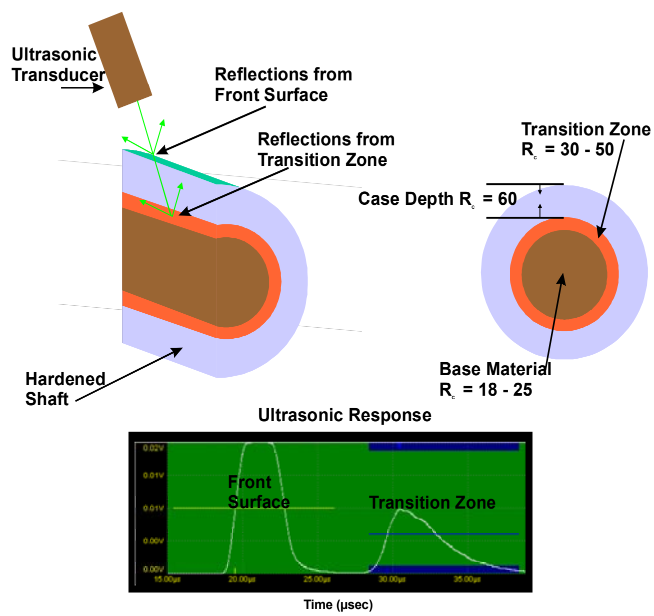

Figure 1: Ultrasonic response from a hardened steel axle shaft.

Conversion to a hardness depth measurement is accomplished with calibration data and reference pieces. The accuracy of the device is dependent on how (rate of change) the transition zone changes between the hardened steel to softer base material. The sharper the transition, the better the accuracy. Accuracy is within 0.2 mm for a set of steel shafts with hardness depths ranging from 1 to 3mm.

The technology was developed by the Pacific Northwest National Laboratory (PNNL) and the Delphi-Saginaw Steering Systems (formerly a division of General Motors Corporation). Sonix holds the license from PNNL for commercializing the technology. In 1994, the UMA was chosen as one of the world’s top 100 technologies by R&D magazine.

Time-of-Flight: The Basic Measurement

The UMA measures the time delay or "Time-of-Flight" (TOF) between the front surface reflection, and the TZ reflection. Consistent and accurate measurement of the TOF between the front surface and the TZ is critical for accurate depth measurements. Figure 2, a typical ultrasonic response, showing the front surface reflection (left lobe), and the transition zone reflection (center lobe) illustrates the TOF measurement. Two gates, represented as horizontal lines on the scope, are used to measure the points at which the two lobes cross a given threshold value. The front surface gate is set at 50% of the screen. The TZ gate is set for 30% screen height. Time delay is measured between these two crossing points. As described below, the TOF measurement is converted to a hardness depth by using a calibration line.

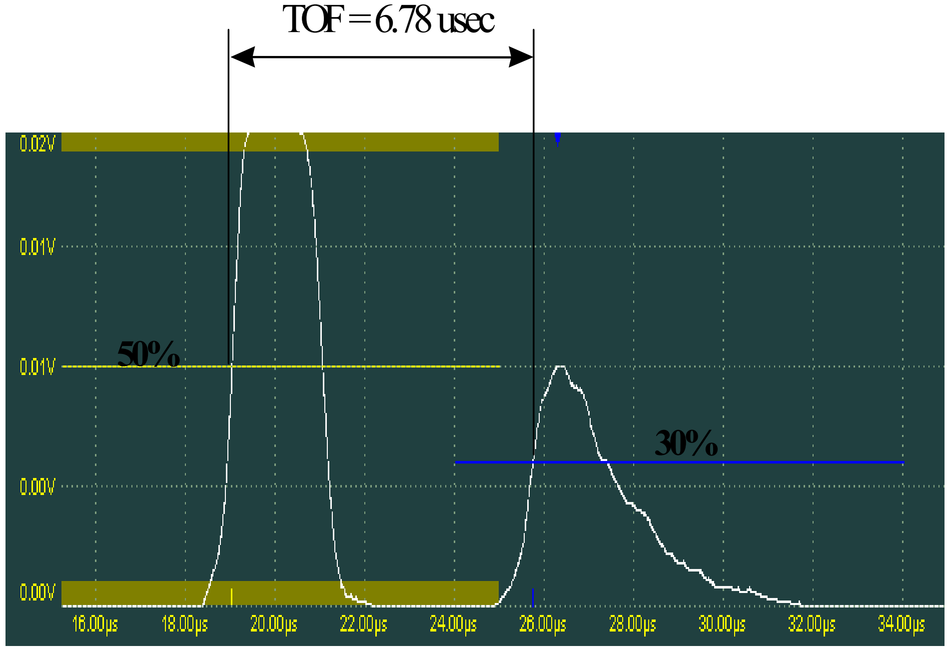

Figure 2: Time-Of-Flight Measurement (TOF) between "Front-Surface" and " Transition Zone" reflections.

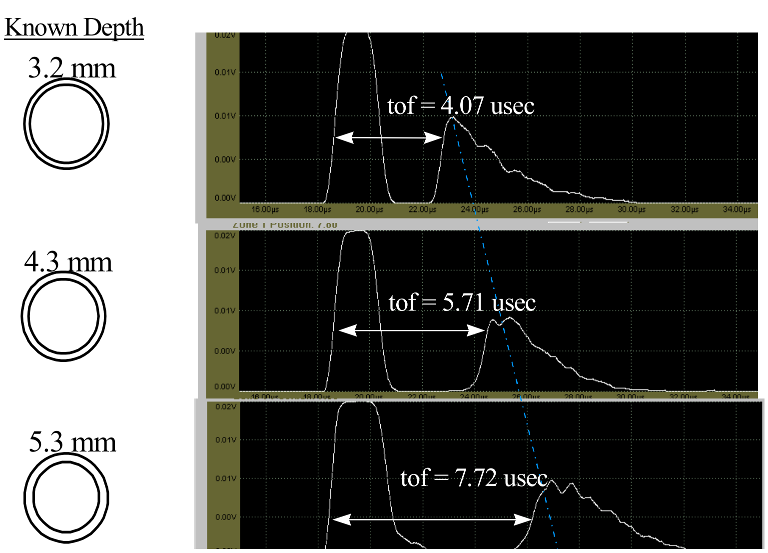

Figure 3 shows the ultrasonic responses from (a) minimum (d=3.2mm), (b) nominal (d=4.3mm), and (c) deep (d=5.3mm) hardened axle shafts. Signal amplitude as a function of time is plotted. The figure shows that as the case depth increases from plot (a) to plot (c), the transition zone lobe moves to the right. The position of this lobe is generally linear with respect to case depth. The main reason for this is that ultrasonic velocity is relatively constant in steel.

Figure 3: Ultrasonic responses from three axle shafts of varying hardness depths.

Converting Time-of-Flight Into a Depth Measurement

In order to convert the time-of-flight (TOF) measurement into an actual case depth, a calibration line is needed. An arbitrary line is represented by the equation: "y = mx + b". Where m is the slope, b is the y-intercept value, x is the time of flight measurement, and y is the estimated case depth. The user has three options for generating this calibration line:

1) The line can be produced from two parts having known case depths of different values. For example, one having a minimum case depth, and one having a near maximum case depth. By collecting TOF measurements from the known parts, both the slope (m), and intercept (b) values for the equation of the line are calculated automatically.

2) The user may want to use a single "nominal" production part (of known depth) as a calibration sample. In this case, the user must enter a reasonable slope, and the system will automatically calculate the intercept (b) value.

3) The user can enter both the slope and y-intercept values manually. This may be desirable when a number of parts having a range of depths are available, and the user wishes to create a table of known depths and TOF values for the parts. Using a spreadsheet program such as Microsoft Excel, a trend line can be produced which "best-fit" through the points.

This third case is illustrated in Figure 4. The plot shows the actual case depth versus the measured TOF value for 13 size 23.automotive axle shafts. A best-fitting straight line has been plotted through the points using Excel. Note that the slope is 0.5522 and the intercept is 1.1515. These values could be directly entered into the UMA machine for size 23 axles.

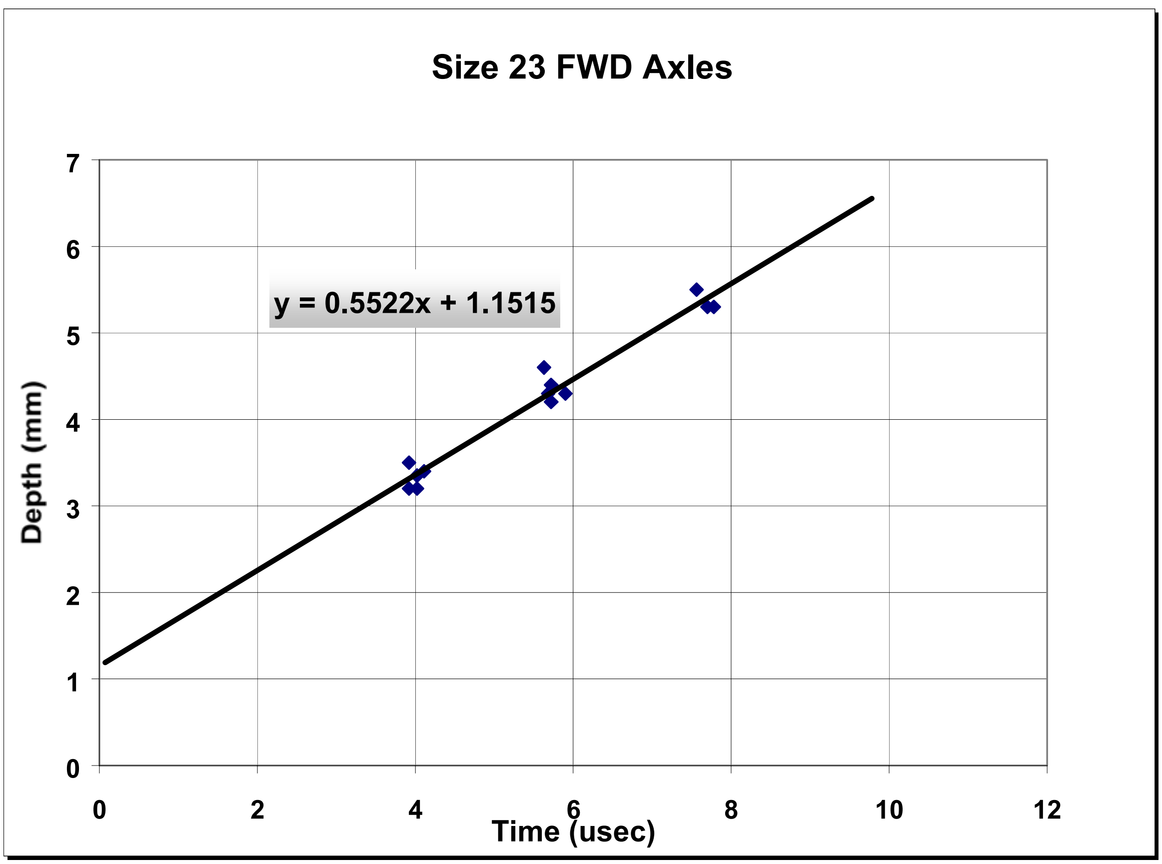

Figure 4: Hardness Depth vs. Time-of-Flight for 13 size 23 axles. Note the trend line which has been "best-fit" to the data.

System Components

The UMA consists of a industrial (Intel based) computer used as a system controller, software, ultrasonic electronics, a multiplexer for electronically switching the transducers, and an immersion tank containing a mechanical scanner for rotating parts.

Figure 5 shows a simplified block diagram of the UMA system. The computer chassis contains a Pentium PC processor board, SVGA monitor, and sealed keypad with a multiplexer, pulser/receiver, and analog-to-digital (A/D) converter boards plugged into the computer's expansion slots. A modem (for use with a telephone line) and remote diagnostic software are optionally provided for remotely communicating with the system.

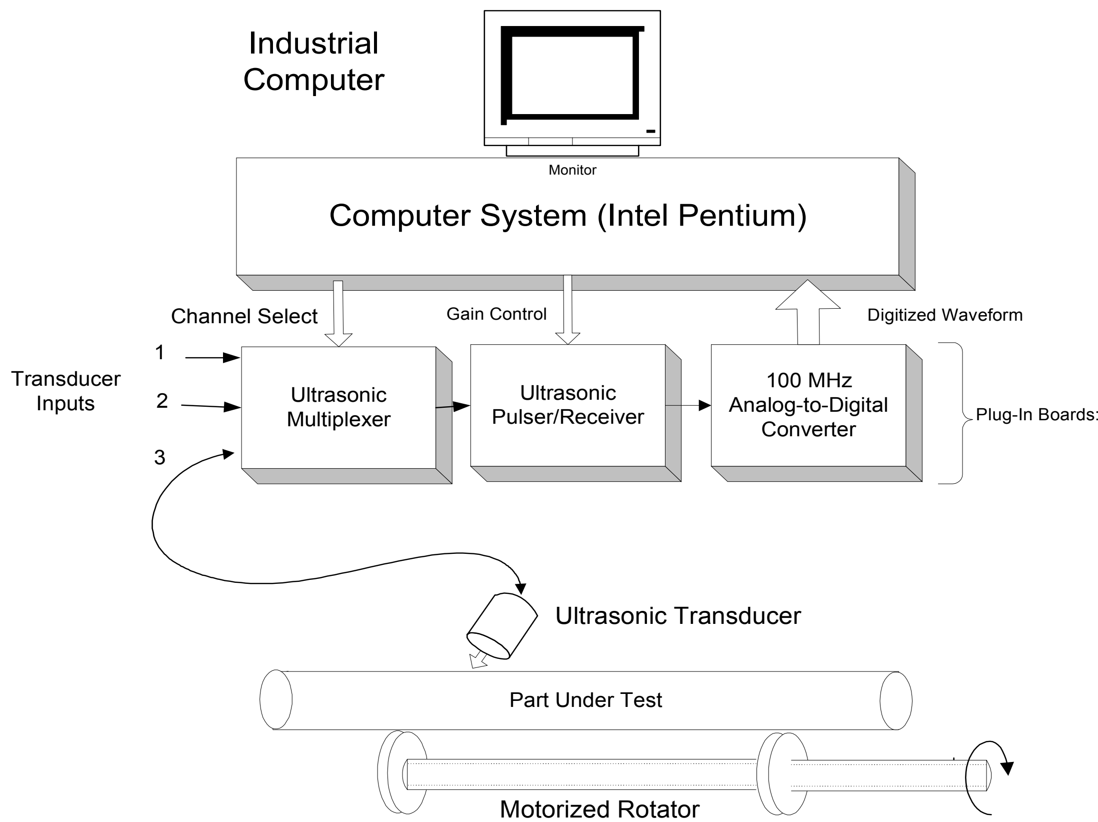

Figure 5: Simplified Block Diagram of UMA System.

A typical scanner system includes 1-3 sensor bridges, mechanical rollers with motor, motion power unit, sensor fixture(s) and a water filtration system. Vertical and horizontal slides and an ultrasonic transducer is mounted on each sensor bridge. Because of part eccentricity, the slides are free to move up and down and side to side. The mechanical rollers are adjustable for a large array of cylindrical parts such as axles, pump shafts and steering linkage rods. Each sensor fixture houses the ultrasonic transducer for interrogating the part microstructure and may be repositioned by sliding the bridge to an axial position of the part. The ultrasonic electronics board contains a pulser and preamplifier for generating and receiving ultrasonic waves. System software includes data acquisition, signal processing, operator interface and general system control. The software operated in three distinct modes: system setup, calibration and test.

Figure 6 shows a screen display of the "Test Screen". Signal processing includes signal enveloping, signal averaging, and waveform smoothing with a moving average filter to generate a stable profile of backscatter amplitude versus arrival time, determining the arrival time of the transition zone response, and converting to hardness depth by means of calibration data. The operator interface provides the means to change, save, and recall system parameters for different types of parts.

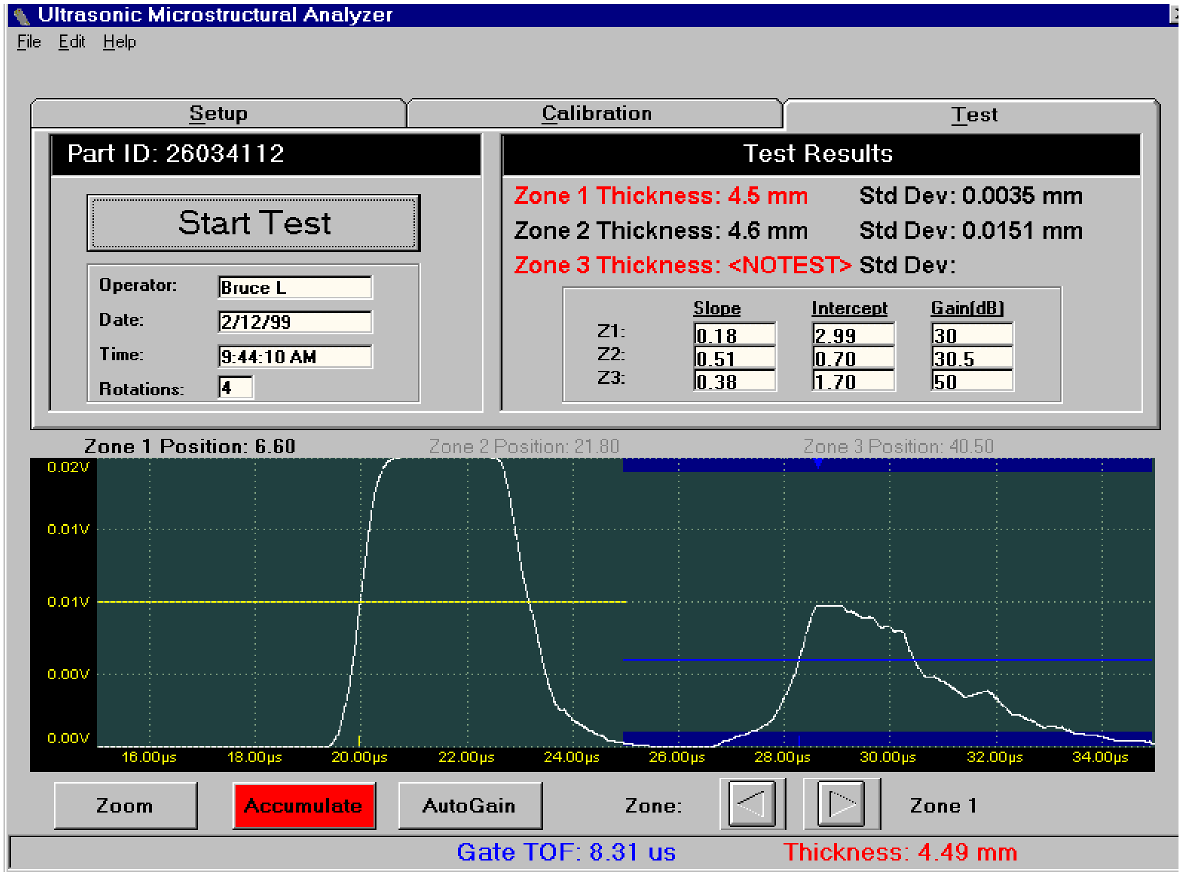

Figure 6: Operating Screen for the UMA

Core Hardening

Axles that have sharp transition zones will produce the best accuracy in case depth measurement. Quickly cooling the part after it has been heated produces the best results. However, if the quenching process is delayed or diminished, the heat will conduct toward the part center. This is an undesirable effect since some degree of core hardening may result. When this happens, the ultrasonic response from the transition zone is greatly reduced, or in the worst case, eliminated entirely.

Although it is difficult to make an accurate case depth measurement with a diminished TZ, it is easy to identify when this condition exists. If the amount of gain needed to bring the signal level up to 50% screen height is too great, chances are the core may be over hardened. In order to detect this condition, a "Max-Gain" setting is provided in the setup procedure. If the system needs more gain than the value set in "Max-Gain", then a "No Test" reading will be displayed. This advanced analysis feature provides a safeguard against making erroneous depth measurements.