Ultrasonic Testing adapts to meet the needs of the Automotive Tube Industry

By David Fortin & Mark Palynchuk, Western Instruments Inc.

Mill-Line Ultrasonic Testing (UT) has typically been limited to wall thicknesses above 0.080", with diameters greater than 1.5". The results of a recent development program are presented which will discuss new equipment that will allow tubes, with wall thicknesses of 0.028" and diameters of 0.750", to be tested immediately after welding or during finishing. The traditional testing method for these small tubes, used in hydroforming, has been with Eddy Current inspection techniques, however it's ability to detect short, small weld interface defects that do not break the OD surface is limited. This new development represents a significant advancement in the ability of manufacturers to produce a more reliable weld, to withstand the rigours of hydroforming or other mechanical working. In order to achieve this level of testing, one has to overcome "Traditional" thinking and redefine the UT system in terms of what is most suitable to the Tube Mill. Advancements were required in the area of: mechanical probe suspensions, calibration standards, transducer design, and instrumentation to name a few. These modifications will be discussed below.

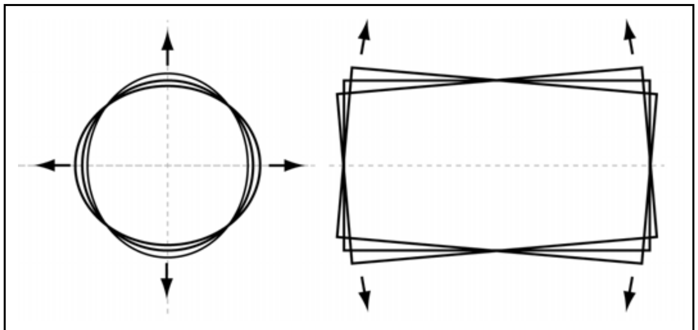
Figure 1: Under actual conditions tube is neither round nor straight.

Ultrasonic systems are available to test 0.070" wall thickness and 0.5" OD sizes during conveyor line testing, however the tube being tested must be rigidly held in place to minimize its motion with respect to the transducer. These existing units utilize the "Immersion" technique, whereby the entire tube is immersed in a "bath". This creates high maintenance and very strict tolerances for alignment of the transducer. In most cases the tube cannot vary more than 0.005" transversely! In addition, one would experience jamming up of these support mechanisms when these tolerances were exceeded. In general, tube is neither straight nor perfectly round and a system should be able to accomodate these dynamic conditions. As shown in Figure 1, the pipe can be tilted or distorted in the local vicinity of the transducer. It may also be translated (not shown) up, down or transversely in the plane perpendicular to the tube axis. To overcome these difficulties requires a paradigm shift from a UT-centric point of

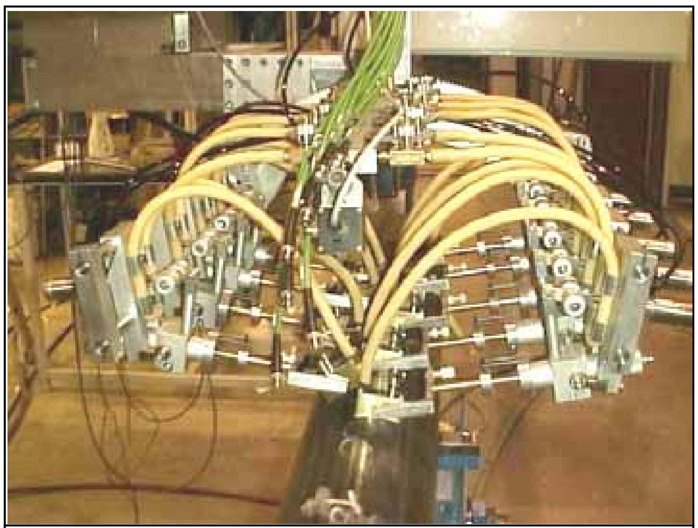
Figure 2: Probes with gliding suspension accomodate changes in tube position and maintain transducer incident angle to nearly zero tolerance.

view to an Automotive Tube Manufacturer point of view. Specifically, the new mechanical assembly does not require strict, rigid confinement of the tube. Instead the assembly allows the probe to follow the shape of the tube and adapts itself to changes in position. A new adaptive suspension is shown in Figure 2. This adaptive suspension allows the probe to ride on the tube and can follow the changes in the tubes position to almost zero tolerance. In traditional systems, the probe does not ride on the tube so the relative position of the transducer and tube are not constant. With an adaptive suspension, the probe is always held flush to the surface of the tube. As a consequence, the transducer angle is fixed with respect to the tube. In this way tolerances can easily be maintained even at high speed. Such a system dynamically follows the tube and always maintains the fixed optimum angle of incidence that the transducer requires to pick up the defect signal. Having the probe ride on the tube is a great advantage in that you have reduced the number of mechanical adjustments to only one. That is, you merely set the distance of the probe from the weld. The rest is taken care of by the adaptive suspension. The operator can compensate for weld spiral during production by rotating a motorized ring gear via remote camera, and joy stick. A laser pointer on the ring gear is used as a center line reference for the weld position. Another problem with fixed or immersion systems is if tube damage occurs upstream. The potential for equipment damage is high. With an adaptive suspension, lift-off is easily facilitated by using an upstream proximity sensor that triggers pneumatic cylinders to lift when mechanically injurious conditions occur.

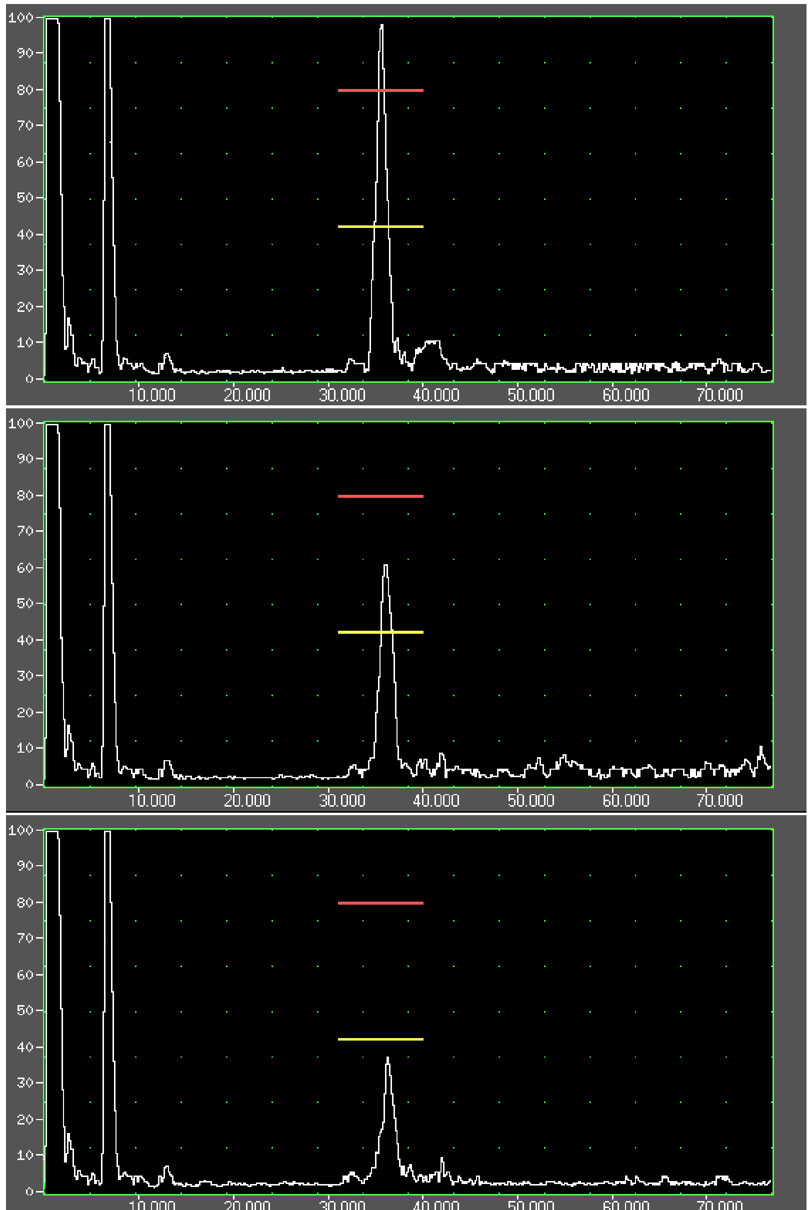

Figure 3: 2.5” Dia. x .034” stainless steel tube with a gain of 11.1 dB. Top - 0.062” hole, Middle – 0.031” hole, Bottom – 0.018” hole

A common way of producing a calibration standard is to select the most perfect sample. This method is great if the tube under test is perfect. In reality, production of perfect tube is more of the exception than the rule. In fact, if all tubes were perfect there wouldn't be a need for any testing at all! For a Calibration Standard, a tube should be selected that represents a typical tube because it is better to have the calibration standard match the actual conditions of the tube under test. Common sense dictates that if calibration is done on a typical tube, then a defect can be found on a yet another typical tube, since the conditions are the same. Traditionally, notches have been used to simulate weld defects, however drilled holes can be a better alternative. An inch long notch on a calibration standard just doesn't simulate a realistic defect. In fact, a one inch notch is a pretty gross defect. Such gross defects are easily detected and do not in general represent true injurious defects. On the other hand, being able to detect and get a good signal on a calibrated 0.018" drilled hole on a typical tube guarantees the ability to pick up minute defects reliably. The effective area of a drilled hole is less than its cross-sectional area since the surface that presents itself to the ultrasonic signal is curved. Defects are not just flat and they do not just lay perpendicular to the incident rays. Defects can be curved as well. Hook cracks are a good example of this. Drilled holes instead of notches on calibration standards also make economic sense and can considerably reduce machining costs and fabrication times of calibration standards. The three indications in figure 3 show the reflected signal for a 0.062", 0.031" and a 0.018" drilled through hole on a typical 2.5" Dia. x 0.034" thick stainless steel tube with a gain setting of 11.1 dB. Nearly identical results occur for a 1 ¼" Dia. by 0.029" with a gain of 14.3 dB. A defect as small as the one represented by the 0.018" hole is likely smaller than is required by any specification. However, being able to resolve a defect as small as 0.018" allows detection of any size defect larger than this with the utmost reliability because of the high signal to noise ratio. High signal to noise ratio means your signal will not be obscured by random or coherent noise. High signal to noise ratio means there is less information open to interpretation. High signal to

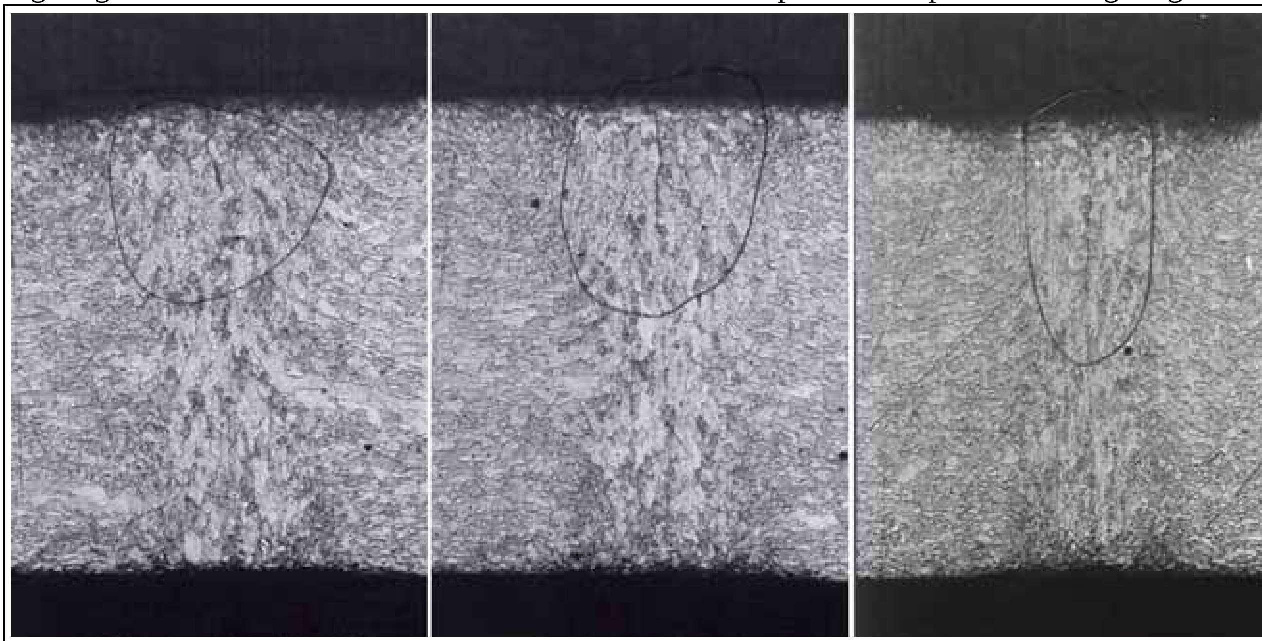

Figure 4: Defects detected on 2" Dia. x 0.054" tube are approximately 19 - 46% of wall thickness.
Left – Defect 0.010" deep, Middle – Defect 0.018" deep, Right – Defect 0.025" deep
Photo Courtesy of Tenneco Automotive – Walker Manufacturing Metallography Department

noise ratio means a PHd isn't required to sort out the results. The desired size defect to detect is found by simply adjusting the warning and reject levels, and by adjusting the gain and position (delay) settings. Figure 4 shows an example of the size of defect one can detect that is on the order of a 0.018" to a 0.031" hole. These three defects were detected on a 2" Dia. x 0.054" thick tube. The penetration depth of the first defect was 0.010", the second was 0.018" and the third was 0.025". Close examination reveals that the defects are along the grain boundary of the material. These defects were 19 - 46% of wall thickness with no readily detectable length according to the Metallography Department at Tenneco Automotive – Walker Manufacturing.

Steel making practices have been steadily improving quality over the past 20 years and have reduced the amount of body defects to obscurity. It is the weld area where most defects occur and similarly this is where most of your UT inspection should occur. Clearly, conveyor-line testing is not the most efficient means for testing weld interface defects. The primary reason is that conveyor-line testing doesn't lend itself that well to tracking the weld for inspection. However, full body testing is routinely implemented in the conveyor line. Full body testing involves testing more of the tube than is really necessary. The solution to this problem is to have the ability to test right after the weld (hot testing) or right after the sizing section. Right after the weld area, the weld has minimal spiral and rests for the most part in the 12:00 position. Probes must be designed to handle the higher temperatures and have a built in mechanism that allows the operator to compensate for changes in weld spiral. Figure 2 shows a 10 Channel system, for larger sizes of tube, designed to check for laminations on either side of the weld, transverse cracks and longitudinal ID and OD cracks. Testing right after the weld has many advantages over testing in the finishing or conveyor-line area. Mill-line testing allows you to find and remove any defects early in the process to avoid wasting time and money processing defective product. In addition, a mill-line system allows the operator to respond to and correct defects early in the process that are due to adverse forming and welding conditions. This is a huge advantage over conveyor-line testing as by the time the process problem is discovered it is too late to alter. Several hundred

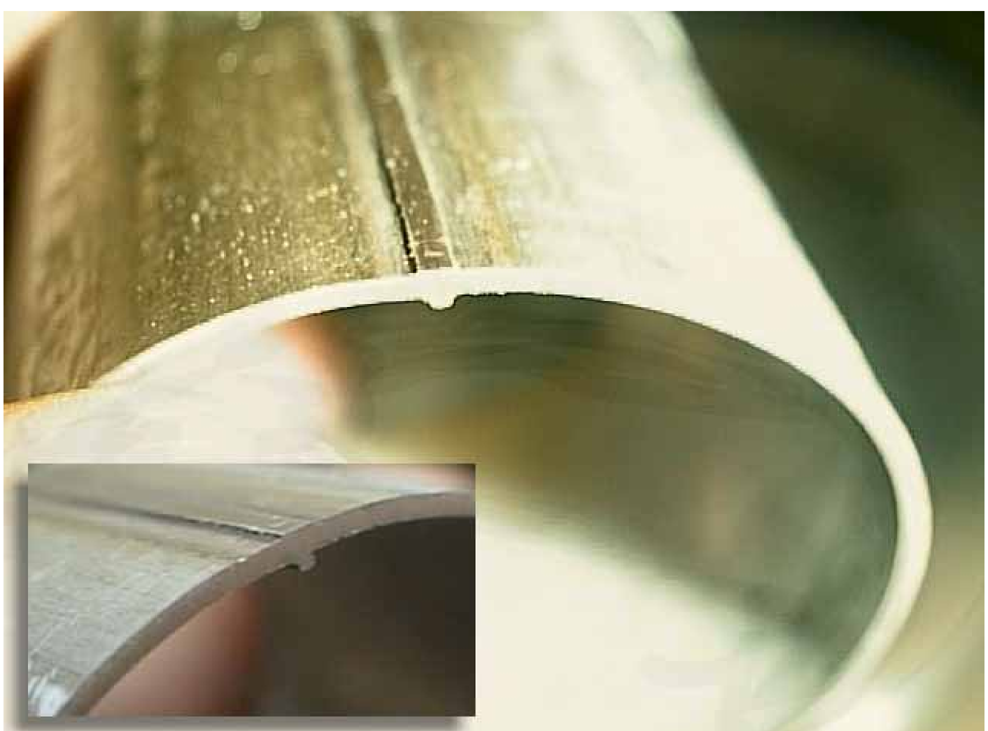

Figure 5: 1.25" Dia. x 0.028" with poor trim conditions

feet or more of tube can be rendered useless just because of minor adjustments in the set-up. Conversely, the mill-line system allows you to respond dynamically to adverse conditions and correct them with a minimum of material loss and downtime.

Another requirement that has been demanded of UT in the past has been the need for near perfect ID and OD trim. In most cases a minor distortion of the weld area does not affect the outcome of an application, so why adhere to these demands. Luckily, by using advanced techniques in transducer design and mathematical simulation, it is possible to minimize the effects of poor trim condition. Figure 5 shows a 1 ¼" Dia. x 0.029" ERW stainless tube with a sizeable ID and OD flash. One needs to keep in mind that it is not the absolute height of the flash that poses a problem but the ratio of the height of the flash to the wall thickness as well as how the signal is aimed. While the trim conditions in figure 5 would normally be unacceptable, with the right equipment one can reduce their effect on signal quality. Figure 6 shows a profile of a 1.25" Dia. x 0.028" tube with acceptable trim (top). The middle profile is the same tube with good OD trim but ID flash in. The bottom profile is the same tube with ID trim but with OD flash in. The gain was set at 15.9 dB. The initial indication to the left of the gate is a return signal off the surface where the signal enters the tube. As can be seen the OD trim in this case is more critical than the ID trim. In fact the ID trim contributes very little to the background noise. A good probe manufacturer designs a probe around the requirements of the individual Tube Manufacturer. Off-the-shelf transducers are fine for standard applications, but when it comes to small diameter tubing and small wall thicknesses, a probe must be designed to meet the specific needs of the application. This is the best way to ensure the optimum signal quality, performance and repeatability in a mill testing environment. Where ideal trim conditions are a requirement, a Flash Gauge can be utilized. A Flash Gauge gives a continuous cross-section of the weld area. That is, the Flash Gauge draws an ID and OD profile of the weld area and gives instant feedback of trim conditions. This is highly desirable as corrective action can be taken without delay.

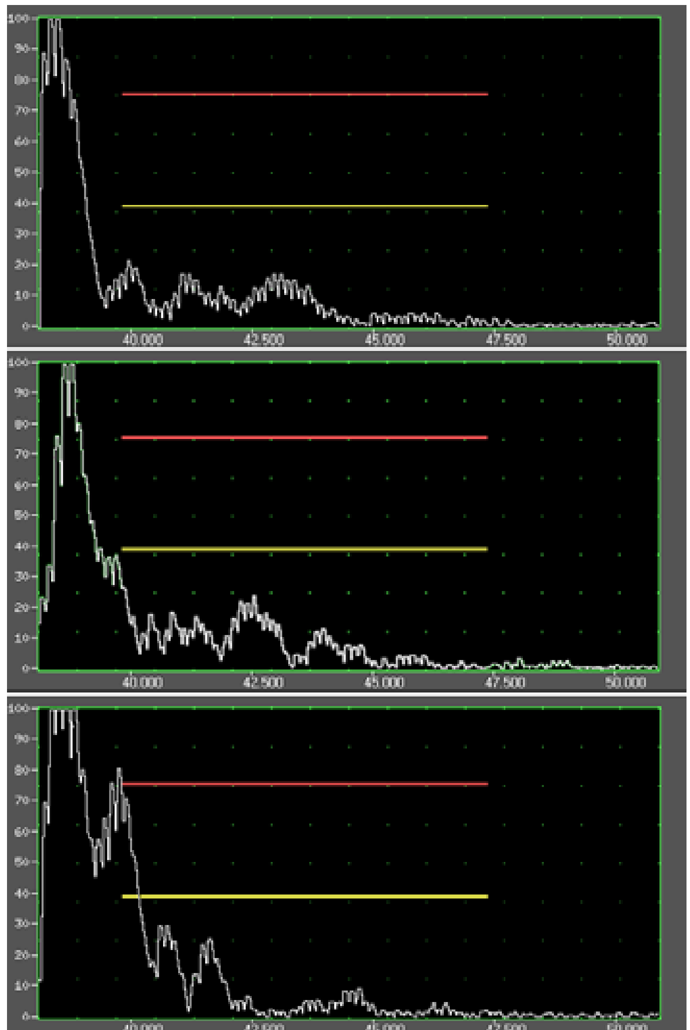

Figure 6: Indication for good trim condition (top), poor ID (middle), poor OD (bottom)

Instrumentation has evolved over the years to meet the demands required of it. It used to be that a separate monitor was required for each channel/probe that was in the system. Older systems were also large and cumbersome. The tube industries demands have risen over the years and have insisted that the instrumentation have more flexibility at a lower price. The UT industry rose to the challenge. New computer based instrumentation can now display 10 channels simultaneously, and has more features than it's analog predecessors. For example, each channel can be set with

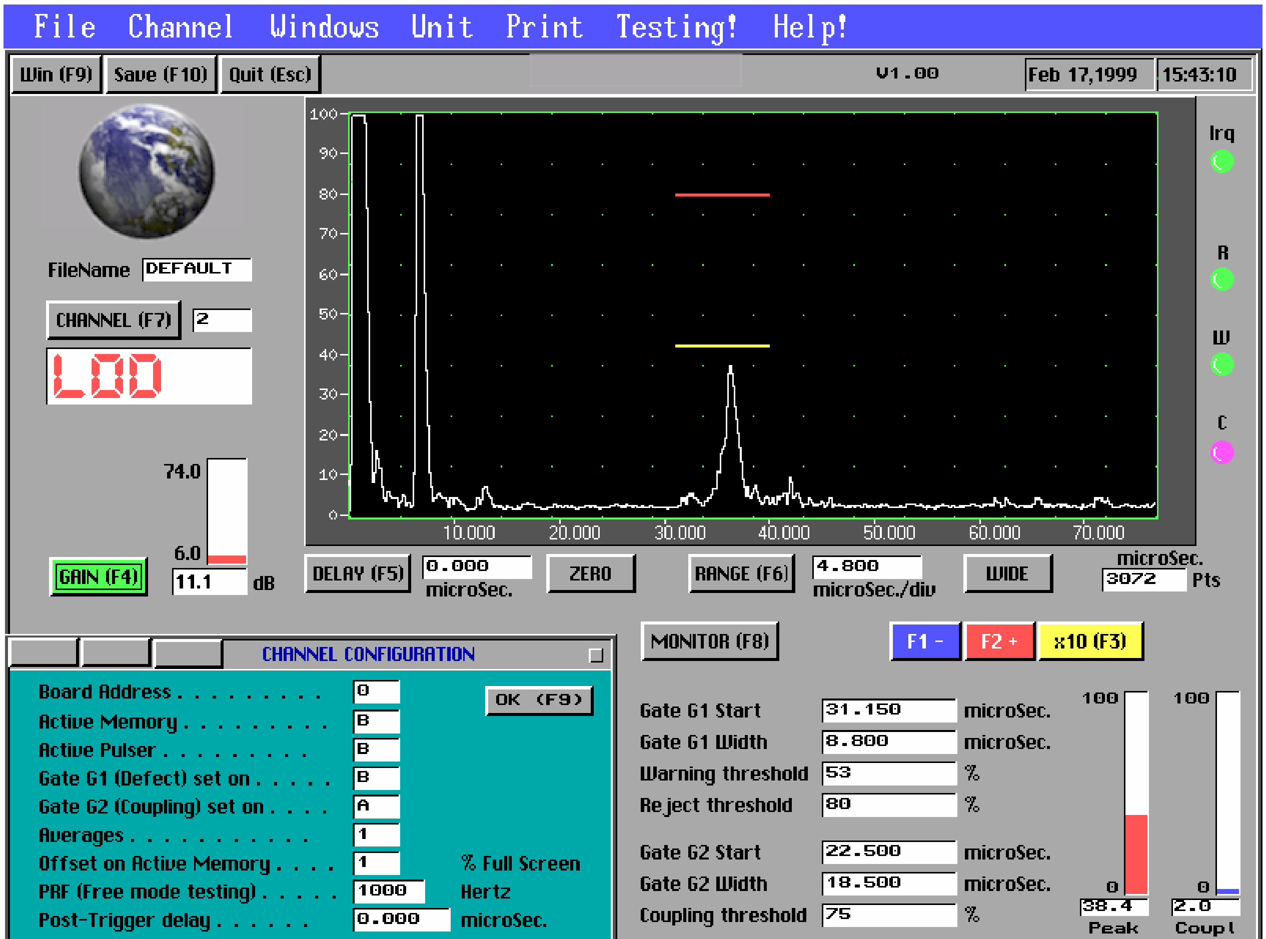

Figure 7: Set-up screen on modern instrumentation

separate controls to adjust the gate, the gain, the delay, and the range. Modern instruments now boast such features as storage of settings, pulser settings and event envelopes. A set-up screen can be seen in Figure 7. Storage settings are beneficial in that they allow the user to input settings for each size of tube being tested to be retrieved at a later time. This decreases set-up time for the operator since all that is required is to load in the relevant settings. The pulser settings allow the user to change the pulse width and voltage to suit the application, further optimizing the setup. Event envelopes give the user a chart recorder like view of defects, which when coupled to the mill-line encoder, provides the length and relative position of the defects. Sometimes the defect indication occurs faster than is discernable on a display, but the chart recorder faithfully captures the event for operator evaluation. Figure 8 shows an event envelope at the bottom and two channels at the top. The signals, that are in groups of three on the chart recorder, are holes 0.062", 0.031", and 0.018" in diameter on a 2.25" Dia. x 0.034" thick stainless steel tube. The largest amplitude signal is the 0.062" hole followed by the next largest which is the 0.031" hole followed by the smallest hole which is, obviously, the 0.018". The probe is scanned back and forth across the three holes at an increased rate. Notice how the holes become grouped closer together as you move from right to left. Another feature of newer instrumentation is the ability to store this data for logging and retrieval at a future date.

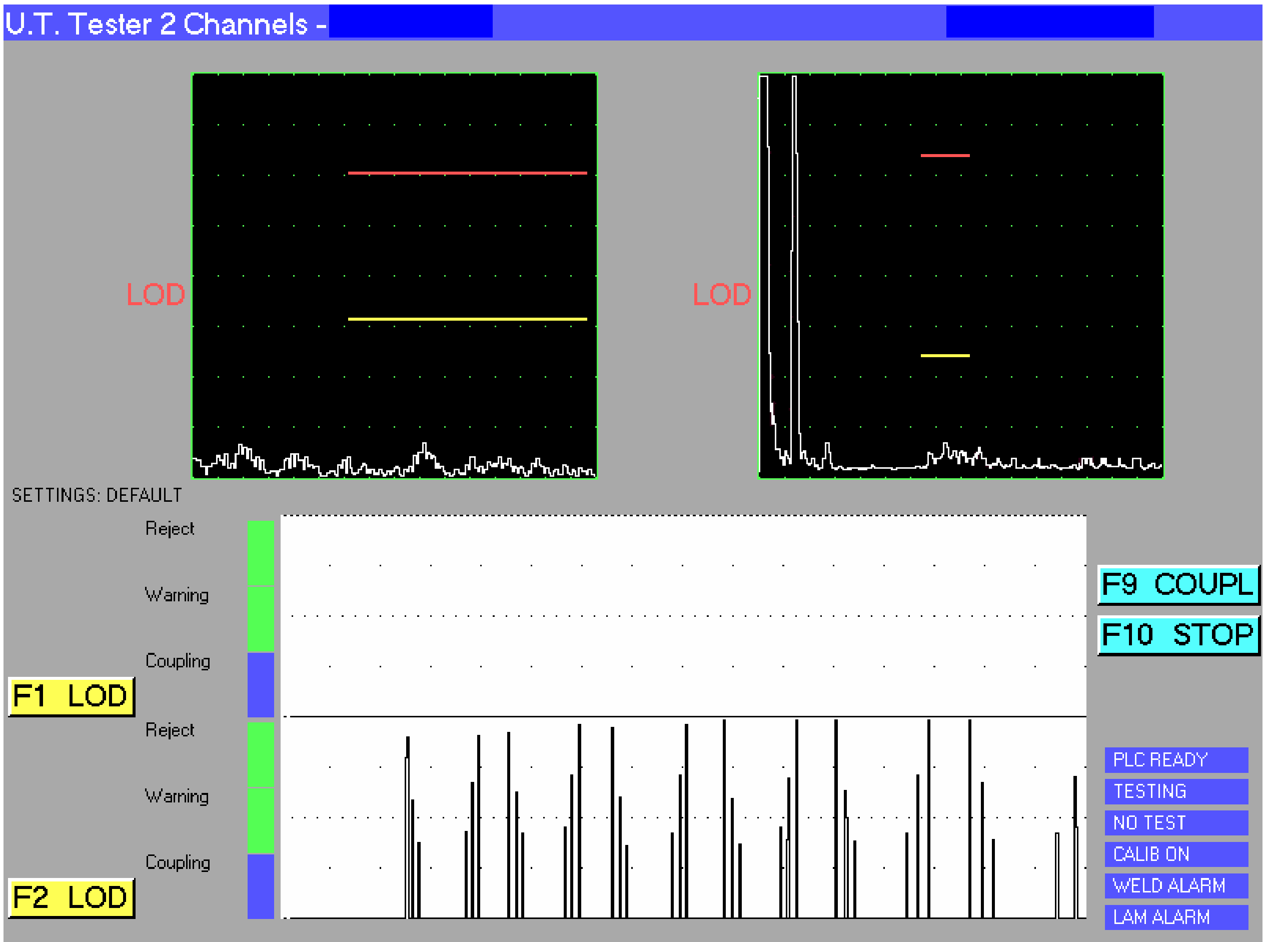

Figure 8: Testing screen display of modern instrumentation showing two channel display and event recorder

Ultrasonic testing has responded to changes in industry requirements by improving all aspects in the equipment design. Adaptive mechanical suspensions have been designed to conform dynamically to tube position while simultaneously removing the tolerance problems associated with changing incident angle. In addition, adaptive mechanical suspensions provide safety by detecting tube damage and lifting off probes thereby negating damage to equipment. Better ways of calibration have been developed that simulate more closely actual conditions. Probe designs have been improved to de-emphasize the effects of poor ID and OD trim. Finally, instrumentation has become more flexible and useful by allowing adjustment of additional parameters, the storage of settings and data, the display of multiple channels on one monitor and charting of the event envelope. These innovations have aided in the ability to detect small defects in small diameter tubing of varying wall thickness.

Acknowledgements: Many thanks go out to Tenneco Automotive – Walker Manufacturing for creating and supplying as many known samples as needed and for coming to our facitilities twice during the development process. This included the preparation and photomicrography of defects found, in the samples provided, during their visit. Special thanks to Terry Martin at Tenneco Automotive North American O.E. and Joe Heppner at Tenneco Automotive Walker Exhaust Division.