Ultrasonic Inspection Equipment for Al-Fin Insert Diesel Pistons

A Paper By

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1 Introduction

The Al-Fin bond is a bond between an aluminium alloy and a ferrous metal. It is this bond that will be inspected using ultrasound. The actual bond area is an alloy of iron and aluminium that has an intermediate chemical composition, of approximately $FeAl_3$.

In diesel engine pistons for the automotive industry, this Al-fin process is used to bond an iron insert in the position where the top piston ring groove will be machined. More recently, this iron insert has been extended to the second ring groove as well. This is necessary because of the high compression ratio of a diesel engine, compared to that of a gasoline engine and therefore the stress on the top ring groove is that much greater.

The areas of interest within a piston having an Al-Fin insert are:

1. The Crown (top) and Skirt (bottom) side bonds

2. The Back bond.

3. The possibility of cracks radiating from the internal corners of the insert groove, known as ‘crater’ cracks

4. Oil cooling gallery position, for offset, tilt and concentricity.

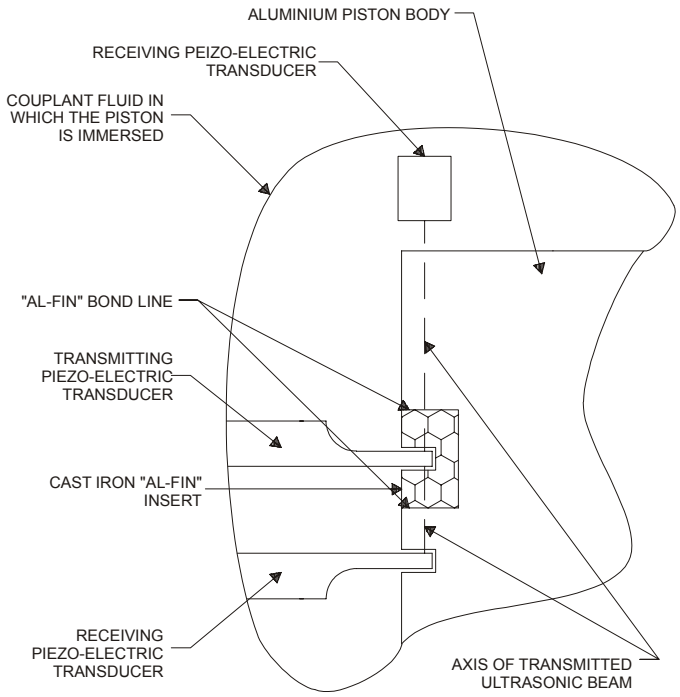
The photograph below shows a de-bonded Al-Fin insert that has been destructively removed from the piston.

An Example of a Typical Crown Side Bond Defect in a Dissected Piston

In order to monitor the quality of this bond, on a 100% basis, ultrasound is used. There are two fundamental techniques for the inspection of the bond with ultrasound.

1.1 The Transmission Technique

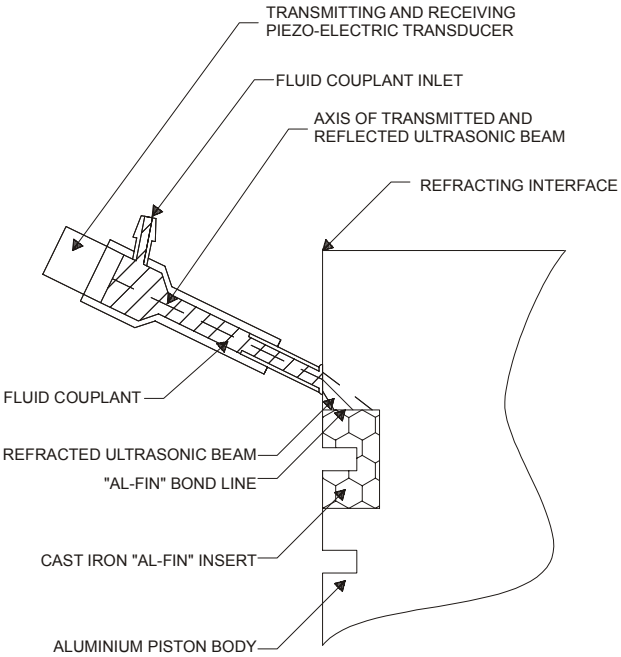
The first is a transmission technique, where a transmitter transducer in the top ring groove generates the ultrasound. In a satisfactory bond the sound passes through the skirt side bond area to the second ring groove on one side and through the crown side bond to the piston crown on the other side. Please refer to the illustration of this technique below.



Principles of Ultrasonic Bond Testing using the Through Transmission Method

1.2 The Pulse Echo Technique

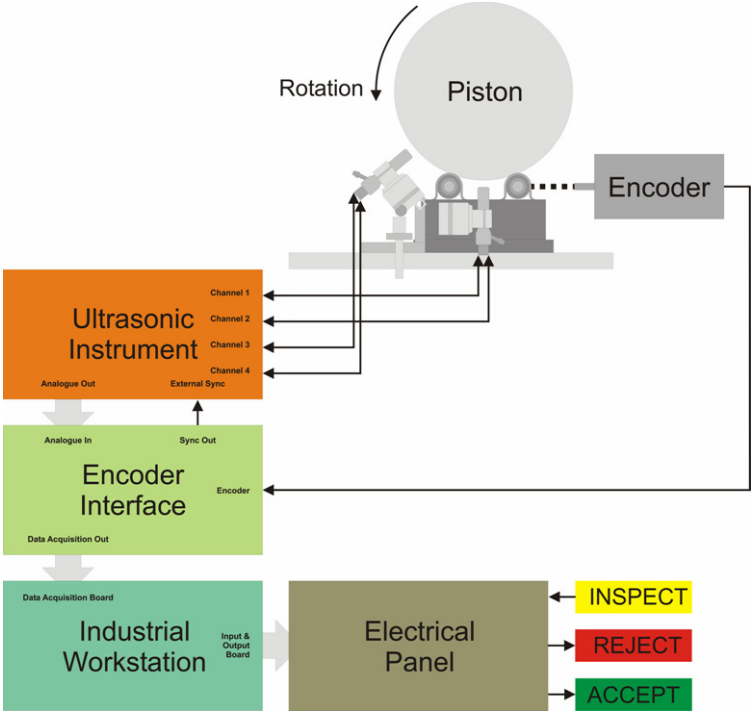
The pulse echo technique may also be used, where the sound is directed at an angle to the bond region and the reflection from the bond obtained. This signal is used to determine bond quality. Please refer to the following illustration of this technique.



Principles of Ultrasonic Bond Testing using the Pulse Echo Method

2 Principle of Operation

With the reinforcement of the top, and more recently, the second groove of heavy-duty diesel engine pistons using a cast iron insert becoming increasingly common. The subsequent reliable performance of the piston depends upon the quality of bonding between the Aluminium alloy and Iron in the foundry process and by avoidance of stresses induced during machining. 100% inspection of pistons determines that the required bond quality has been achieved or otherwise.



Our Piston Inspection Equipment is designed specifically to provide this inspection capability. The system block diagram of the manual version of the machine is shown, each unit being described as follows:

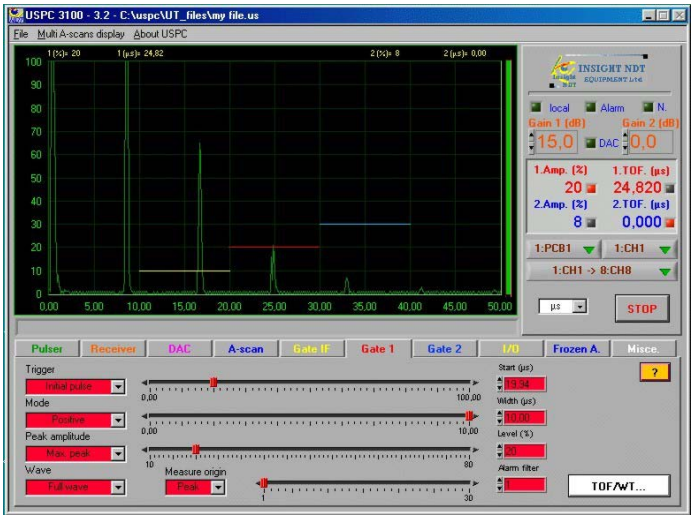
- The Ultrasonic Instrument comprises of a multi-channel transmitter/receiver unit. It provides all the necessary signals to synchronise the transmitter and monitor gate to the rollers when rotating. The monitor gate is provided to allow exclusive monitoring of required ultrasonic signals. The Ultrasonic Instrument is software controlled and is automatically launched from the Piston Inspection Software on the Industrial Workstation.

- The Encoder Interface provides the power for the encoder and also provides the Ultrasonic Instrument with a synchronising signal even when the rolls are not rotating. When the rolls start rotating the Encoder Interface immediately synchronises the Ultrasonic Instrument to the roll speed. The Encoder Interface also provides a direct connection of the analogue signals from the Ultrasonic Instrument to the data acquisition board in the Industrial Workstation.

- The Industrial Workstation reads the flaw amplitude and time of flight information from the Ultrasonic Instrument via the data acquisition board, and stores it in memory. The rate at which this is done and the number of samples taken is dependent on the roller speed and the piston diameter as entered. From this information the defect lengths are calculated and compared with the user-defined and selected inspection standard. The results are displayed and the accept/reject decision is made.

2.1 The Ultrasonic Instrument

The ultrasonic technique is now well established as a method of detecting internal and superficial flaws in a wide range of metallic and non-metallic materials. Not only will the method detect defects but will also provide invaluable information on the location and severity of any flaws detected. The range of applications include, weld testing, crack detection, bond assessment, fatigue and stress damage, metal quality, porosity, thickness measurement together with many other applications on raw materials, partially and fully finished components and on parts following a period in service.



The transmitter pulse from a transmitter in the ultrasonic instrument in the system excites the transducer connected to that channel. The Channels can fire sequentially, which is a multiplexed system, or they fire at the same time, which is a parallel fire system. The type of system depends on the ultrasonic instrument fitted. The resultant signals from the transducers pass through a tuned amplifier and filter arrangement to be displayed as an A-scan on the computer screen, as the above screen illustration.

2.2 The Piston Inspection Software

The piston inspection software is designed to perform several functions critical to the integrity of the overall inspection system. These functions include:

- To provide a user-friendly menu-driven user interface for communication with the piston testing system.
- To process and analyse ultrasonic inspection data provided to the computer by the Ultrasonic Instrument.
- To store sets of user definable acceptance parameters.
- To associate a unique ultrasonic set-up file to each set of user definable acceptance parameters.
- To save the raw inspection data, for future analysis.
- To display the inspection results, after an inspection or when re-loading a saved inspection data file.
- To print the results to a printer or store as a bitmap file.

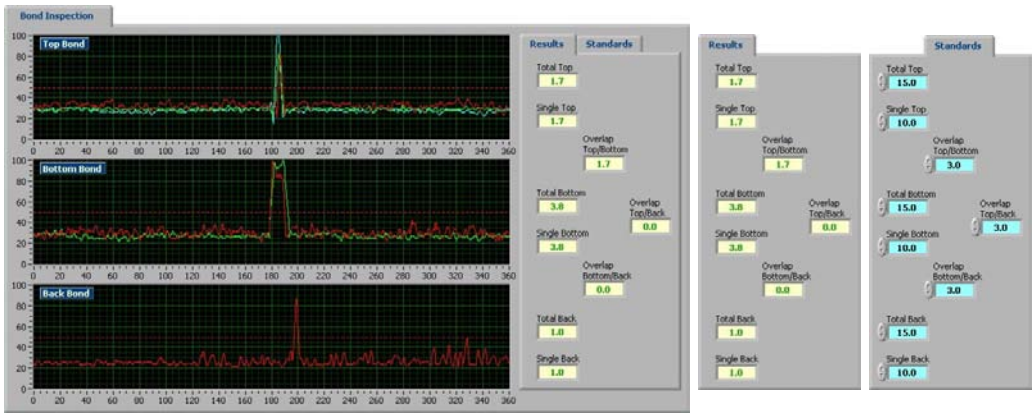
The piston inspection software collates data provided by the Ultrasonic Instrument concerning the ultrasonic flaw detection of pistons. This data is stored analysed and displayed following each piston test, and furthermore, the software will compare the test results with the user definable acceptance parameters, and make an accept/reject decision. Finalised test results are displayed following each test and can be save for future reference.

The Main Screen of the piston inspection software is shown above, allows the use of up to eight Ultrasonic channels to test different features associated with diesel engine pistons that have an Al-Fin insert or oil-cooling gallery.

The data from an inspection is displayed as a B-Scan or C-Scan, and the accurate defect lengths are calculated. This inspection data can be loaded from a saved inspection file or the result of a recently completed inspection.

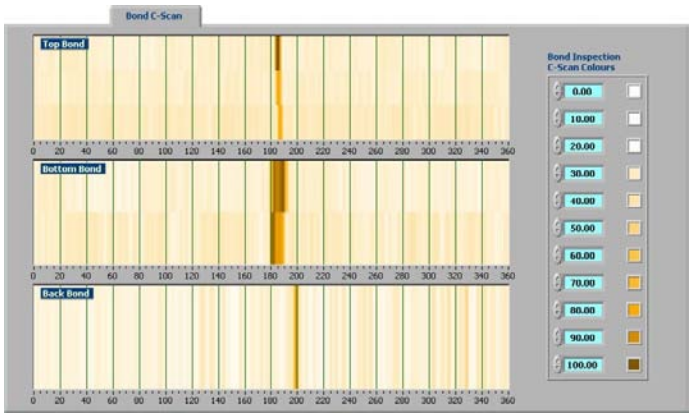
The screen has a number of tab pages, which allow viewing of the data for the desired feature and the setting of the user definable acceptance parameters for that feature, these are:

- ***Bond B-Scan*** page shows the B-Scan charts for the ultrasonic channels that have been assigned to the Top Bond, Bottom Bond or Back Bond features.



In addition to the charts, there are two tab pages that are used to display the inspection results and the user definable acceptance parameters for the Bond inspection features, both shown above.

- ***Bond C-Scan*** page shows the C-Scan charts for the ultrasonic channels that have been assigned to the Top Bond, Bottom Bond or Back Bond features.



In addition to the charts, there is a control that allows the user to assign colours to different signal amplitudes. It is these colours that are used to display the C-Scan for all the Bond features.

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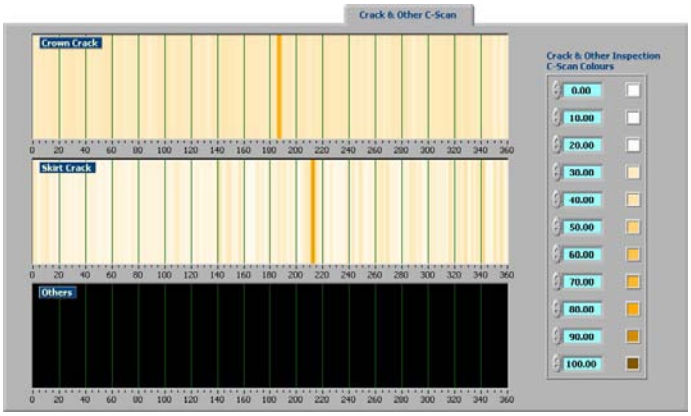
- ***Crack & Other B-Scan*** page shows the B-Scan charts for the ultrasonic channels that have been assigned to the Crown Crack, Skirt Crack or Other features.

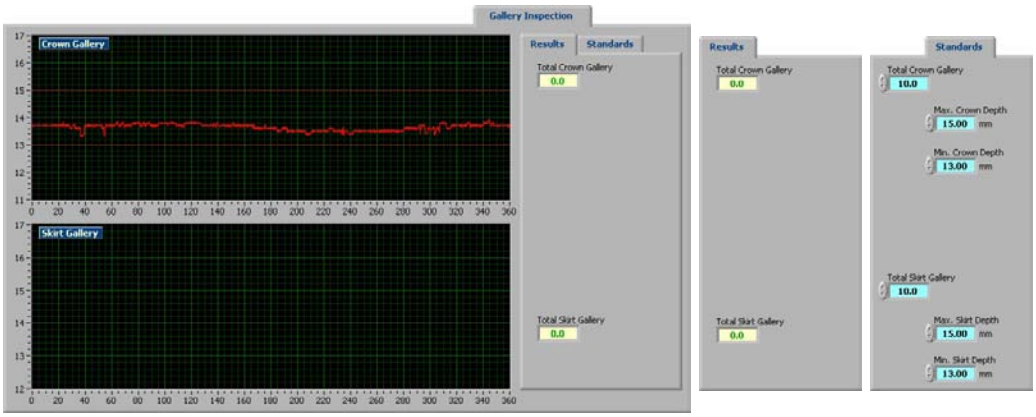
In addition to these charts, there are two tab pages that are used to display the inspection results and the user definable acceptance parameters for the Crater Crack and Other inspection features, both shown above.

- ***Crack & Other C-Scan*** page shows the C-Scan charts for the ultrasonic channels that have been assigned to the Crown Crack, Skirt Crack or Other features.



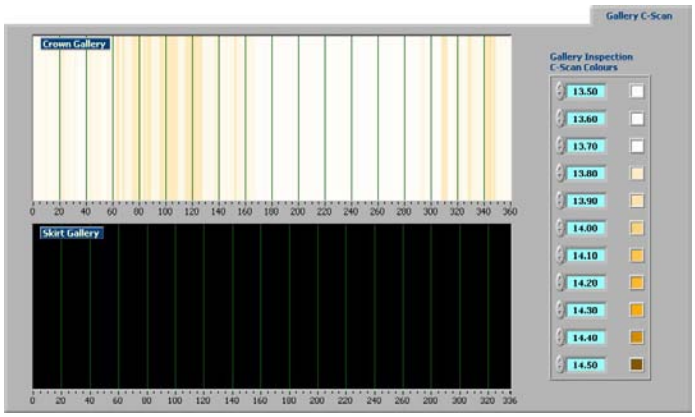
In addition to the charts, there is a control that allows the user to assign colours to different signal amplitudes. It is these colours that are used to display the C-Scan for all the Crater Crack and Other features.

- ***Gallery B-Scan*** page shows the B-Scan charts for the ultrasonic channels that have been assigned to the Crown or Skirt Gallery features.



In addition to these charts, there are two tab pages that are used to display the inspection results and the user definable acceptance parameters for the gallery inspection features, both shown above.

- ***Gallery C-Scan*** page shows the C-Scan charts for the ultrasonic channels that have been assigned to the Crown or Skirt Gallery features.



In addition to these charts, there is also a control that allows the user to assign colours to different gallery depths. It is these colours that are used to display the C-Scan for both gallery features

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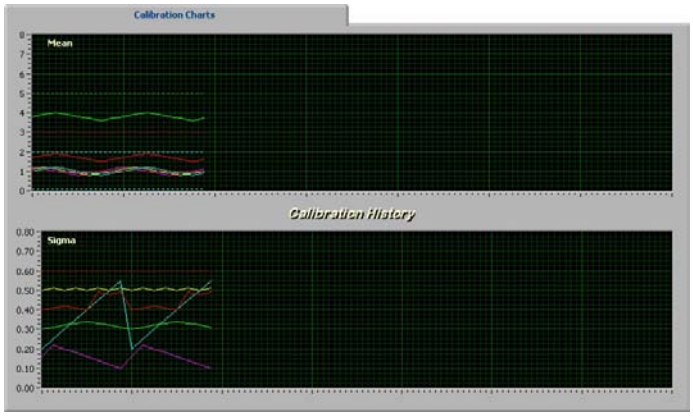
- ***Calibration Charts*** page shows the history of the system calibration, using a master piston as the calibration master. Two charts are displayed, one showing the mean of the results from the master test piston, and the other showing the standard deviation of these results.



- ***Inspection Set-Up*** page allows the set-up of all the remaining user definable acceptance parameters.

The main screen also has three buttons and an indicator, which allow the user to:

- Initiate and inspection cycle, by pressing the 

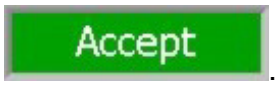
button.

- Save the results of the inspection to a text file, by pressing 

button.

- Exit the Piston Inspection Software, by pressing 

button.

- View the result from the inspection, press 

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3 System Configuration

The machine console contains the ultrasonic transducers and carriage, piston drive mechanism and couplant recirculation system. There are three different type of consoles.

A manual load, parallel roller drive system, (right) using pulse echo inspection only, which is mostly used to inspect the proof turned casting.

A manual load, crown down system using either pulse echo or through transmission inspection, mostly used on finished pistons.

A custom designed fully automatic system.

3.1 Roller Type Manual Hand Load Console

The operations involved in the inspection of a piston on the hand load machine, having set up the system, include placing the piston to be checked on the rollers, pressing the inspection start buttons, and waiting for the verdict, which is displayed on illuminated indicators as either ‘accept’ or ‘reject’.

Parallel horizontal rollers that serve to support the piston are driven by a three-phase motor. An encoder is directly linked to these rollers providing synchronisation of the data acquisition electronics and the ultrasonic instrument. Neoprene tired rollers are used to minimise surface damage to the pistons and prevent slippage.

Couplant fluid is pumped from a 55-litre reservoir, to each transducer. The term ‘couplant’ is used to describe the function of the fluid; to provide a coupling medium through which the ultrasound is transmitted between the transducer and the piston surface. A valve controls the couplant flow rate to each transducer.

The transducer carriage assembly (shown below) facilitates correct positioning of the transducers for the type of piston to be checked. Adjustments provided for this are:

- Angle, from the normal to the piston axis, of each transducer.
- Distance between transducer probe tips for different widths of inserts.

3.2 Crown Down Type Manual Hand Load Console

The operations involved in the inspection of a piston on the hand load machine, having set up the system, include placing the piston to be checked on its crown, and sliding it down in to the immersion tank. Pressing the inspection start buttons pneumatically clamps the piston and rotates it through at least 360^0 causes the piston to be clamped by a pneumatic cylinder, and the drive to the piston to start. Having completed the inspection the piston is automatically un-clamped and the verdict, either accept or reject, displayed.

The motor driven rollers are inclined at an angle to support the piston. An encoder is directly linked to these rollers providing synchronisation of the data acquisition electronics and the ultrasonic instrument. Neoprene tired rollers are used to minimise surface damage to the pistons and prevent slippage.

Couplant fluid is contained in a 10-litre immersion tank. It is necessary to ensure that the fluid in this tank covers the area of the piston to be inspected

The transducer assembly, is mounted below the couplant level in the immersion tank, and allows the transducers to be correctly positioned for the type of inspection to be carried out. Adjustments provided are:

- Angle, from the normal to the piston axis, of each transducer.
- Distance between transducer probe tips for different width inserts.

Testing fixture in ‘Load’ position

4 Fully Automatic Console

Generally the Automatic console is designed to meet customers' exact requirements; we have supplied a number of different fully automatic systems, an example of which is shown below: