Ultrasonic Velocity Measurements Used to Assess the Quality Of Iron Castings

A Paper By

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1 Introduction

One of the main problems facing the quality control department in a foundry producing nodular (ductile) cast iron is to make sure that castings that have an unacceptable graphite structure do not leave the foundry.

Ultrasonic testing, although widely used in the steel casting, forging and fabrication industries, has not been applied to iron castings until recent years. The advent of nodular graphite irons, which increased the scope of the iron foundry to such a great extent, particularly in much increased service requirements, resulted in the demand for improved non-destructive testing techniques. One particular area of successful development in ultrasonics is the measurement or comparative assessment of cast irons, especially the nodular graphite types.

The Measurable Properties of material when being tested by ultrasonic methods are the velocity of the sound waves passing through the material and the loss of energy or attenuation of the sound in the material. Most modern techniques of testing for material quality are based on work published in 1957 by Ziegler and Gerstner. These works showed the effect of carbon saturation on the velocity of sound in cast iron as shown in figure 1

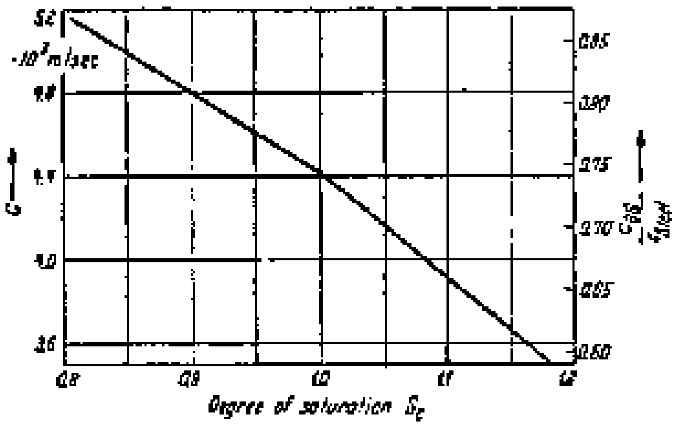

Figure 1 - Relative Velocity vs Degree of Carbon Saturation

The degree of carbon saturation is given by the following formula:

$$Sc = \frac{C}{4.23 - 0.312\,Si - 0.275P}$$

From this relationship it follows that, as the tensile strength of cast iron in the as cast condition decreases with increasing carbon saturation values, a relationship must be present between tensile strength and acoustic velocity.

Ziegler and Gerstner published such a relationship for two types of iron, one cupola melted and one electric melted as shown in figure 2, on the next page.

This relationship, however, indicates only a trend and should not be taken as a practical working value.

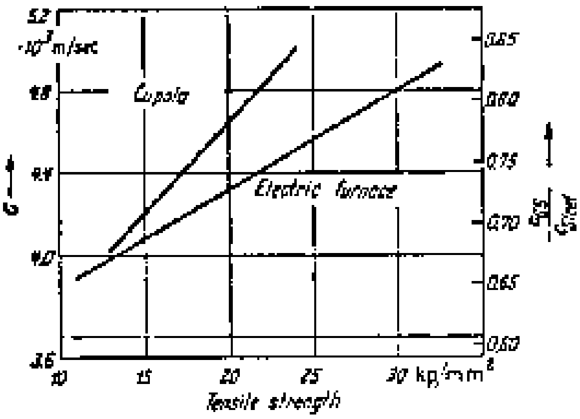

Figure 2 - Relative Velocity vs Tensile Strength for Cupola and Electric Melting

The acoustic velocity may be related more accurately to the elastic modulus and Poisson's Ratio of material according to the following equation.

$$C = \sqrt{\left[\frac{E}{r} X \frac{(1-S)}{(1+S)(1-2S)}\right]}$$

Where C = longitudinal sound wave velocity
E = elastic modulus
r = density
s = Poisson's Ratio (which is proportional to the composition and percentage of free graphite)

From this derivation it can be concluded that flake graphite irons can be sorted according to mechanical properties but it is difficult to predict actual tensile strength. In practice sorting of castings is achieved using known standards as comparators.

It is essential that these standards have been produced under the same conditions as the castings being sorted, thus one standard may not be used to check castings from another foundry with differing production practices.

Testing nodular graphite irons may be achieved using the same technique. The effect of changing degree of nodularity on acoustic velocity of different levels of carbon saturation is shown in figure 3.

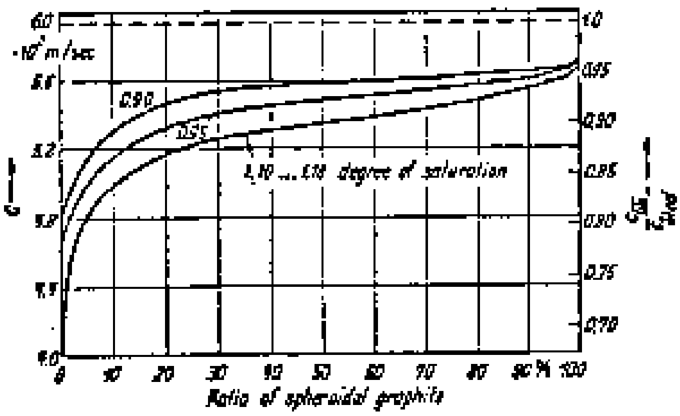

Figure 3 - Relative Velocity vs Nodularity

Mostly nodular graphite irons are produced with carbon saturation values in excess of 1.0 hence the relationship may be taken at the lower line values.

2 Metallurgical Variables

The effect of other metallurgical variables which occur during the production of castings and which affect the acoustic velocity must be taken into consideration. The most important of these variables are matrix condition, any applied heat treatment and shape and distribution of the graphite.

Considering the testing of nodular graphite irons, for which the majority of such tests are currently applied, the effects of changing matrix and heat treatment are shown in figures 4 and 5.

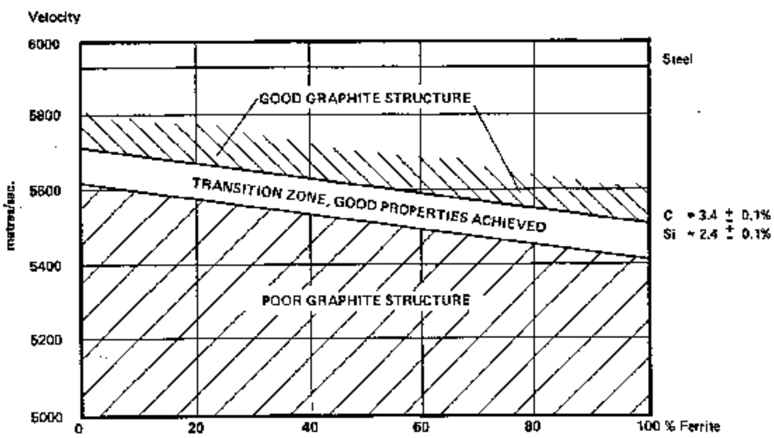

Figure 4 - Effect of Increasing Ferrite Content on Velocity of Sound in Nodular Graphite Irons

Increasing ferrite content causes a decrease in acoustic velocity in the order of 200 metres per second for a complete change from pearlite to ferrite. (Increasing quantities of cementite in the matrix cause an increase in the acoustic velocity).

In practice using standard castings for control a deviation of +15-20% of the matrix type may be tolerated for reasonable testing accuracy

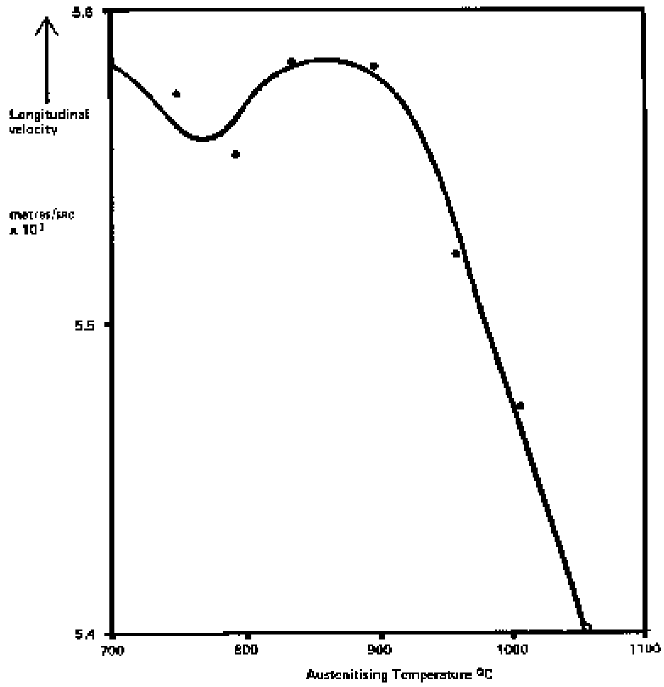

Figure 5 - Effect of Increasing Austenising Temperature on
Velocity of Sound in Nodular Graphite Irons

The effect of heat treatment varies according to the treatment cycle applied. The graph in figure 5 shows how the acoustic velocity changes according to the austenising temperature reached by the castings. Due to these variations caused by heat treatment it is normally good practice to test castings before heat treatment unless large variations of matrix occur in the as cast condition.

Because of these effects a tight control of the manufacturing processes is desirable and where large deviations of matrix are suspected other tests, such as hardness determination, should be incorporated with the ultrasonic tests.

It must be pointed out that the effect of these variations on the acoustic velocity is not as great as the effect of deteriorating graphite shape as shown in figure 3, on page 5.

% Nodularity	% Ferrite	Longitudinal Velocity m/sec
100	100	5,600
80	100	5,500
50	100	5,300
20	100	5,150
100	50	5,700
100	0	5,800
Relationship: Acoustic Velocity to changing graphite nodularity and ferrite content.		

Figure 6 - Relative Velocity v Degree of Nodularity and Ferrite Content

Figure 6 shows results obtained in practice measuring relative acoustic velocity with changing degree of nodularity and ferrite. The velocity decreases rapidly with reducing degrees of nodularity but the effect of ferrite content is less pronounced, thus a casting with pearlite matrix but with 60-70% nodularity has a lower acoustic velocity value than a ferrite casting with 90% nodularity. The values quoted should not be taken as accept/reject standards for all iron castings.

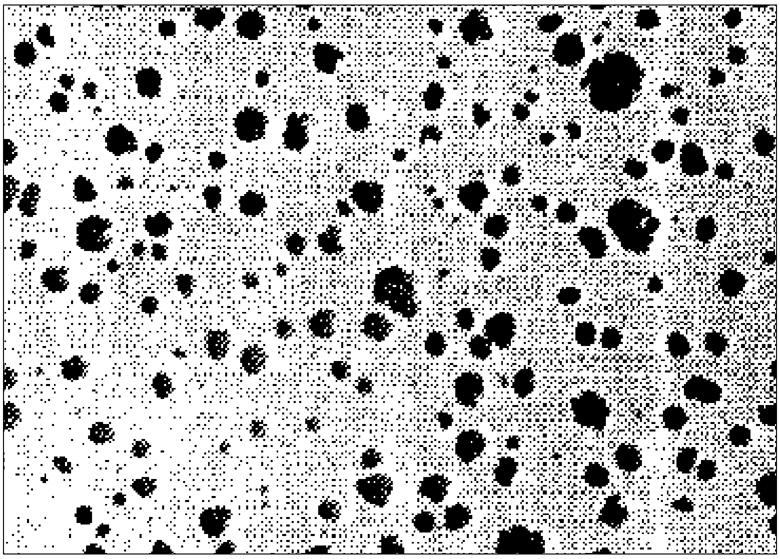

Figure 7 - Acoustic Velocity 5559 m/sec

Figures 7-11 illustrate graphite forms and related velocities.

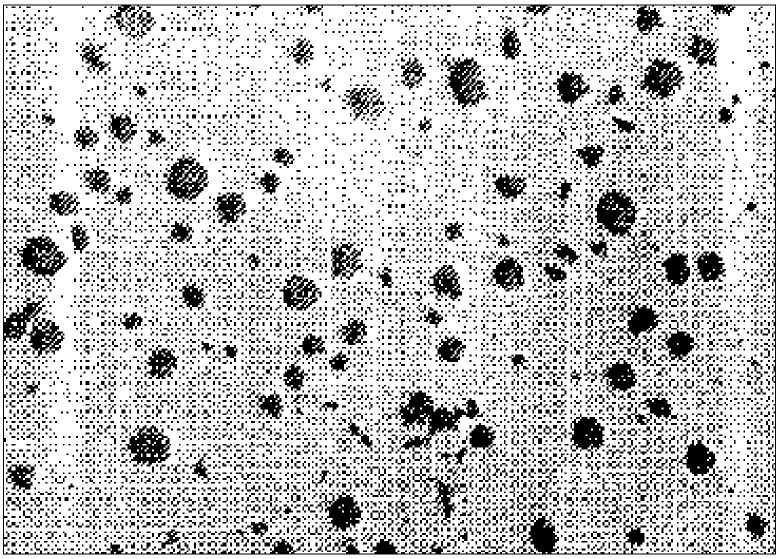

Figure 8 - Acoustic Velocity 5491 m/sec

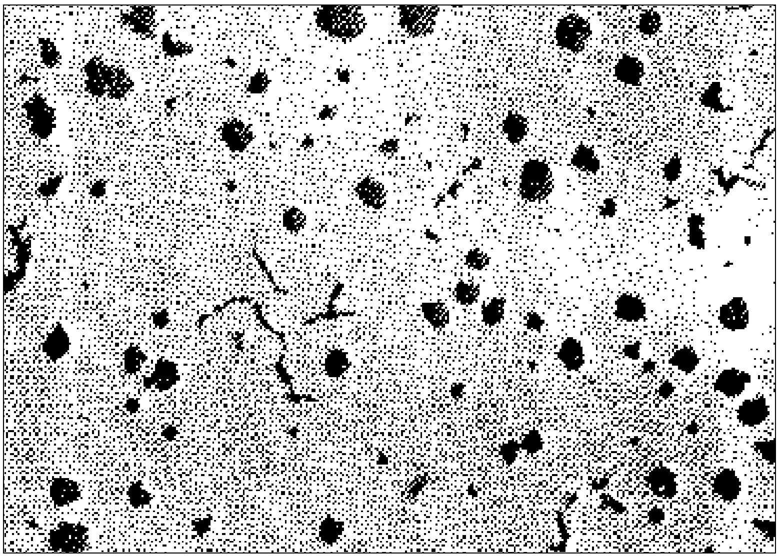

Figure 9 - Acoustic Velocity 5466 m/sec

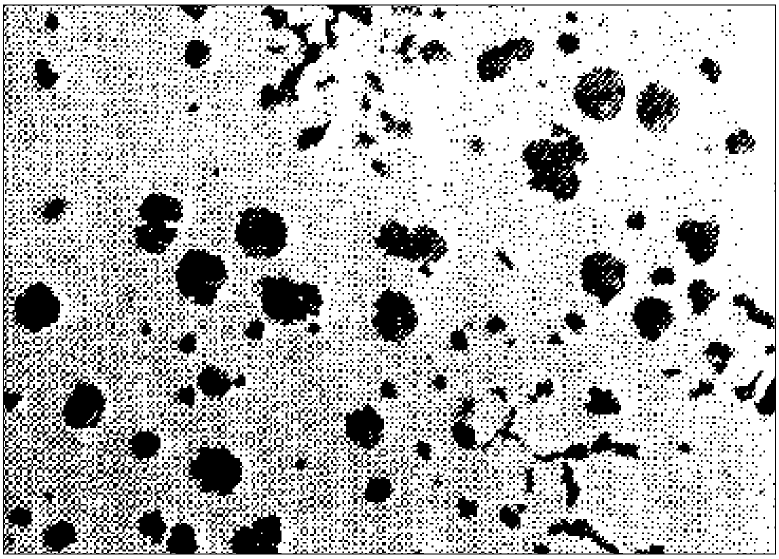

Figure 10 - Acoustic Velocity 5268 m/sec

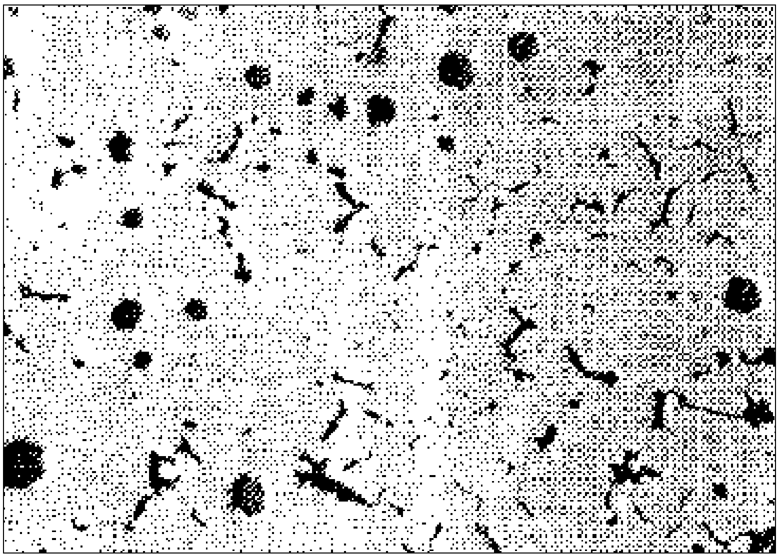

Figure 11 - Acoustic Velocity 5126 m/sec

3 The Qualiron Method of Sound Velocity Determination

To facilitate the production quality control of iron castings in the foundry using the principles described requires the use of a system that has the following attributes.

- The testing system is rapid.
- Skilled operation is not required.
- It is very sensitive.
- Takes account of normal casting dilation.

In a single process, non-technical personnel can measure the velocity, in absolute terms, at the rate of 700 castings per hour, on castings of different section and thickness.

The principle of ultrasonics is that a pulse of mechanical vibrations of a high frequency (typically 2-4 MHz) is generated in a piezo electric crystal probe and is transmitted into the casting via a thin layer of couplant, such as oil or grease. The pulse propagates through the thickness until it reaches the back wall. At the back wall (or any other interface in the way of the beam) the pulse is reflected back to the probe, which receives it and converts it into an electrical pulse suitable for electronic processing.

The time taken from the pulse leaving the probe and returning to it depends on two factors - the distance travelled and the velocity of sound in the material. Velocity is the product of time taken x distance travelled. The velocity of sound, as previously mentioned, characterises a material and is independent of frequency of the vibrations.

Since typical velocities of sound in cast iron can be in excess of 5000 metres per second, and 10 metres per second can mean the difference acceptable and unacceptable metals, it follows that an extremely accurate device is necessary to measure the time between the pulse leaving the probe and its return and also measure precisely the thickness between the front and back surfaces.

Such equipment is the Qualiron, which comprises the two functions of measurement of thickness and time taken for the pulse to travel through the section in a single operation. See figure 12 for a picture of the Qualiron.

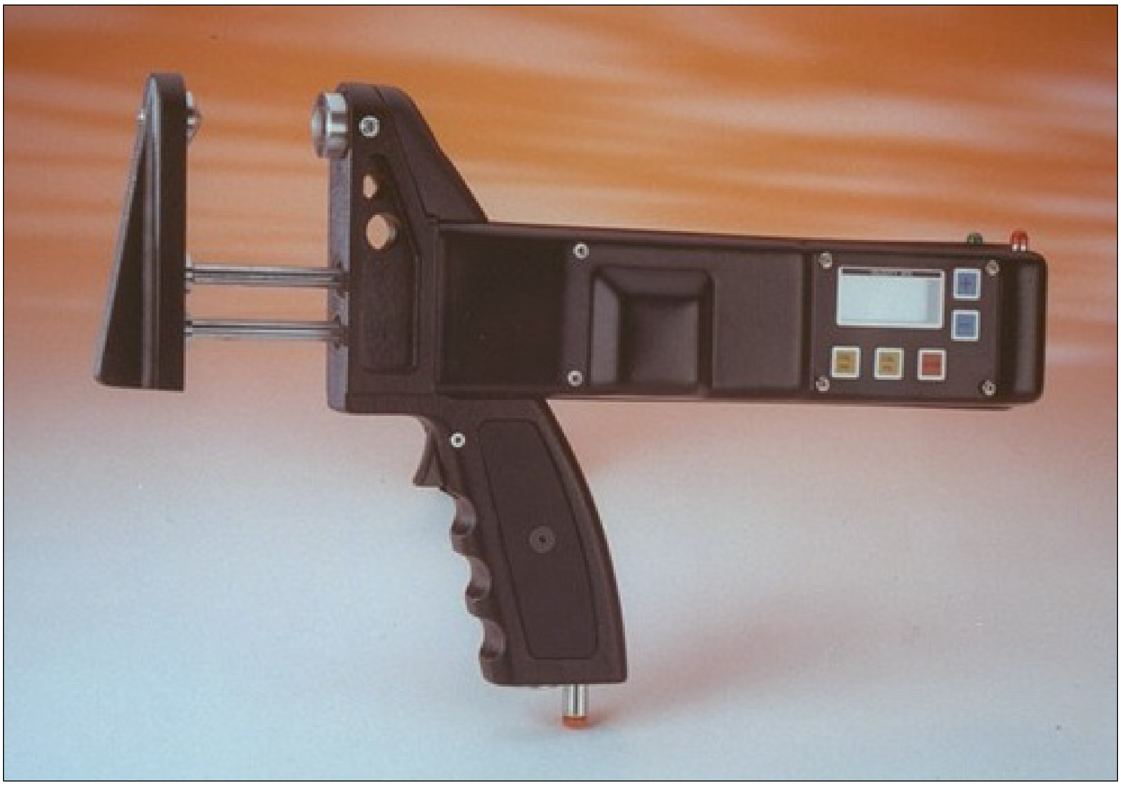

Figure 12 - Qualiron Cast Iron Quality Assessment Caliper

Consisting of hand held caliper the body of which accommodates the adjustment controls, digital indicator showing velocity of material and green *Accept* and red *Reject* indicator lamps. Integral with this unit is a sliding twin rod arrangement with an anvil. Slight pressure of the trigger of the caliper unit withdraws, by a pneumatic system, the anvil towards the body of the caliper. Associated with the rods within the caliper is a high precision potentiometer. This system when applied to a casting provides an accurate measurement of the casting thickness and feeds this data into the processing system. In line with the anvil is the integral ultrasonic probe which generates the ultrasonic pulse to be transmitted into the casting. The time taken for the pulse to travel through the section and back again to the probe is again accurately determined by the electronics system. Therefore by applying the caliper over the edge of the casting and squeezing the trigger the anvil will retract toward the body clamping the casting section between the anvil and the probe face so that both are in firm contact.

As in all manual ultrasonic techniques it is necessary that a coupling medium, which is usually a viscous liquid - grease, oil or similar should be applied to the probe surface. This medium transmits the high frequency vibrations from the probe to the casting surface.

The two sets of data are processed immediately and the velocity in metres per second is shown on the display. The process is quick and simple.

Since it is not possible, as discussed above, to allocate a particular absolute velocity to the degree of graphite in the nodular form the Accept/Reject threshold are variable. This facility also allows for castings to be tested to varying standards. The controls on the caliper body permit the threshold to be varied to suit the Acceptance Standard required.

To carry out this adjustment requires a section of cast iron of known minimum acceptable characteristics (of nodularity - proof strength) preferably from the same design of casting to be tested and, also preferably (if access of the caliper allows) near the in-gate of the casting. The caliper is then applied to the section. The velocity will be displayed and by means of press buttons on the body the threshold can be set at the indicated velocity. When the velocity is below this value the red reject light illuminates when above this value the green accept light illuminates. There are thus positive indications of both conditions.

There are, in fact, two thresholds possible, one in which the reject indication illuminates when the velocity is below a velocity value, and one which indicates when the velocity is greater than a higher value. In practice this allows application of the Qualiron to compacted graphite irons in which an excessively high velocity is just as much a reason for rejection as is low velocity.

If, when the Qualiron is clamped on the casting, neither of the lamps show then this is an indication that the test is not valid (lack of coupling - broken cable etc).

***NOTE:* Calibration for nodularity percentage by using photomicrographs of polished samples in which nodularity has been assessed visually.**

This method is acceptable and convenient but it should be remembered that assessment by eye varies from viewer to viewer of the same sample and is in any case only done in steps of 5%. Also the visual method is only done on one plane whilst ultrasonics examines the total section between the probe and the anvil. Tests have shown that the mechanical properties of cast iron can be more closely related to ultrasonics than assessment of nodularity by eye.

4 Non-contact Methods of Sound Velocity Determination

The Qualiron calliper method of metal quality determination is ideal for larger castings e.g. man access covers but can be tedious and too slow for routine checking of mass produced small castings such as automotive brake callipers. Further in thin sections it is more important that the physical distance travelled by the ultrasonic beam is measured accurately.

To permit a more rapid test sequence and improve thickness measurement accuracy we have developed a method in which contact with the casting (other than support) is not necessary.

In this method the casting is immersed in the couplant between two ultrasonic transducers, each transmitting and receiving.

With the distance between the transducer faces being known and the velocity of sound in the water couplant being also known (1450 m/s) it is possible to measure ultrasonically from each transducer the distance to the nearest surface of the casting. Adding these and subtracting the result from the known distance between the transducers gives the casting section thickness. The length of time taken for a pulse of ultrasound to travel from transducer to transducer without a casting section will be shortened by the presence of the casting. The degree of time reduction is the time taken through the casting. Thus we know the thickness and the time travelled, therefore the velocity can be calculated.

The mechanical arrangement can be designed to suit the casting's geometry and a considerable degree of automation and data analysis can be included as required.