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Investigation of Ultrasonic Calibration using Steel Standard Reference Blocks

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Abstract

The equipment used in standardization must be adjusted in order that both the receiver amplifier and video display are linear over the range of distance and flaw size to be used. The failure to do that would result in different block-to-block response ratios because of the measurements depending on the scope reading or attenuator setting. In this paper, using two sets of steel reference blocks (area-amplitude and distance-amplitude) to modified method to verify the linearity of the system of instruments used in the ultrasonic inspection. This method depends on the response from reference blocks with different hole diameters at constant gain and ratio between the figures slope at different gains. The linearity of the ultrasonic instruments can be measured with high precision. The results can be used effectively for determining resolution and sensitivity capabilities.

Keywords: Ultrasonic calibration, steel, standard reference blocks, area-amplitude, distance-amplitude

Introduction

Calibration refers to the act of evaluating and adjusting the precision and accuracy of measurement equipment. In ultrasonic testing, there is also a need for reference standards. Reference standards are used to establish a general level of consistency in measurements and to help interpret and quantify the information contained in the received signal [1,2]. Reference standards also help the inspector to estimate the size of flaws [3]. In a pulse-echo type setup, signal strength depends on both the size of the flaw and the distance between the flaw and the transducer [4]. The inspector can use a reference standard with an artificially induced flaw of known size and at approximately the same distance away for the transducer to produce a signal. By comparing the signal from the reference standard to that received from the actual flaw, the inspector can estimate the flaw size [5]. Design, maintenance and calibration of ultrasonic reference blocks are some activities of the many tasks of the ultrasonic laboratory at the National Institute of Standards (NIS) [6]. The effects of certain dimensional variables on ultrasonic reference blocks response has been investigated by Eitzen *et al.* [7]. Blessing [8] concluded that there were several variables affecting the amplitude variation of the nominally identical blocks as, block material, transducer, instruments (pulser/receiver), identical reference standard, operator judgment and procedures and block geometry. He suggested that it is reasonable to develop a specification with a net system tolerance values identified and/or estimate them. The net system tolerance could be expected to meet a value of ±8 % of full scale (less than ±1dB) for the shortest blocks and ±3dB for the longest blocks. Mundry [9] used the standard reference blocks to evaluate the defect by direct comparison of real flaws echoes with those of an artificial test reflector such as cylindrical bore holes or notches of similar geometric configuration. But the problem with the reference block is when using the same ultrasonic measuring system; the ultrasonic response from nominally identical reference block varies unacceptably, this causes different levels of acceptability. Whittaker [10] introduced what is called a traverse technique or 6 dB drop technique to estimate size and extent of a flaw with dynamic scanning. The size of small flaws (area of flaw smaller than cross-section of sound beam) can be determined only by measuring the maximum echo amplitude produced by the flaw (static determination of size of the flaw). If the probe is moved from the unaffected zone over the flaw, the echo rises from zero to a constant maximum value, if the area of the flaw is normal to the sound beam; the echo height reaches half its maximum value when the axis of the beam touches the edge of the flaw. This technique is also called the 6 dB drop method [10,11].

This paper is concerned with the fabrication and checking of steel flat-bottom-hole reference blocks which are used to establish performance characteristics of ultrasonic flaw detection systems. They are also used to standardize and control the adjustment. Artificial defects of flat bottom surface are fabricated inside the blocks. The material of the blocks is the low carbon steel, which is used in Egypt in many products. These two sets are Area-Amplitude (5 blocks) and Distance-Amplitude (12 blocks). The blocks are fabricated from the same raw material of low carbon steel rod. Immersion and contact techniques are used to establish the Area-Amplitude and Distance-Amplitude calibration curves using a frequency of 5 MHz. The Area-Amplitude calibration curves are used to verify the linearity of the amplifier of the receiver of the flaw detector instrument. In these measurements an improvement approach is achieved by means of measuring the hole area versus the response on the screen at certain gain setting and its double. This method allows us to calculate the linearity of the attenuator with very high precision of less than 0.5 % within the used range.

Experimental methods

The flaw detector Echo-graph USIP 20 Krautkramer-Germany was used as the basic data capture instrument [12]. Also, Karl Deutsch-Echo-graph 1080 flaw detector with range (1 - 40 MHz) was used with the immersion system to determine the calibration curves of the reference blocks. For the calibration purposes, the immersion system was used which consists of a tank with dimensions of (95×53×46 cm), it is equipped with a bridge of sufficient strength to support the manipulator rigidly and allow smooth, accurate positioning of the search unit. The manipulator provides precision control of search unit positioning in the x-y and z directions as well as positioning in two vertical planes normal to the tank bottom within an angle of 1°. **Figure 1** illustrates the arrangement of the equipments used. The transducer used in this paper is a zero degree incidence, broad band 5 MHz center frequency compression wave transducer. The transducer was held in a clamp attached to a micromanipulator assembly. Echo signals can be peaked by the movement of the probe. The steel reference block is actually placed in a tank and the transducer is moved vertically across the surface of the target with the use of a manipulator. Two parameters must be considered in the immersion technique, the length of the near zone and the minimum water distance between the transducer and the sample being tested. The length of the near zone must be in water and the far zone in the sample to avoid the interference of acoustic pressure in the near zone [13]. Any defect falling within the far zone can only be detected, if it lies in a point of maximum acoustic pressure and in this case the size of the flaw could be highly erroneous [14]. **Figure 2** shows the various echoes from a test piece in ultrasonic immersion testing.

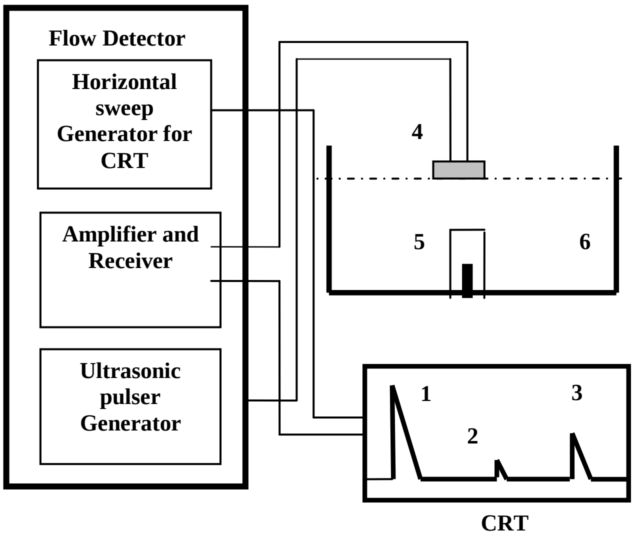

Figure 1 Schematic diagram for the immersion system. (1) Initial pulse, (2) Echo from the defect, (3) Echo from the back surface, (4) Transducer, (5) Steel Reference block with artificial defect and (6) Immersion tank filled with water.

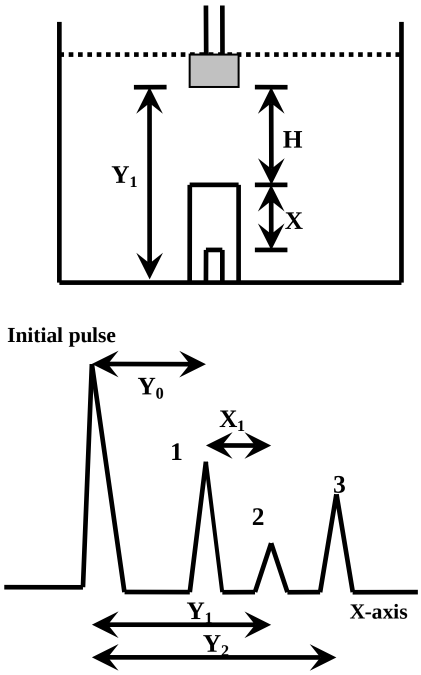

Figure 2 Various echoes from a test piece in ultrasonic immersion testing, 1 is the first front surface echo, 2 is the back wall echo, 3 is the second front surface echo.

Table 1 Dimensions and identification of reference block in the Area-Amplitude set.

Block ID number	Hole diameter in (mm)	Metal distance in (mm)	Overall length in (mm)
AA1	3.2	75	95
AA2	2.8	75	95
AA3	2.4	75	95
AA4	2.0	75	95
AA5	1.6	75	95

Table 2 Dimensions and identification of reference block in the Distance-Amplitude set.

Block ID number	Hole diameter in (mm)	Metal distance in (mm)	Overall length in (mm)
DA1	2	12.5	32.5
DA2	2	25	45
DA3	2	37.5	57.5
DA4	2	50	70
DA5	2	62.5	82.5
DA6	2	75	95
DA7	2	87.5	107.5
DA8	2	100	120
DA9	2	112.5	132.5
DA10	2	125	145
DA11	2	137.5	127.5
DA12	2	150	170

Results and discussion

Block sets of steel were fabricated in two sets as listed in **Tables 1** and **2**:

1. The area-amplitude set contains blocks of different hole sizes and equal metal distances [15].
2. The distance-amplitude set contains blocks with equal hole size and different metal distances.

In the two sets, the hole diameter was fabricated at 20 mm from one face of the block. One of the key factors in the successful use of reference blocks in the procedures for the evaluation of materials is matching within the limits specified in the practice of the ultrasonic response from the reference blocks to the ultrasonic response from the materials under test. This is accomplished by: (1) preparing reference blocks from a grade of materials with the required acoustic response in relation to the material to be inspected, or by (2) determining significant ultrasonic differences between reference blocks and the material to be inspected compensating for the differences by adjusting the instrument [16]. The reference blocks were made from one cold rod with 59 mm diameter low carbon steel. Its chemical composition is shown in **Table 3**. To obtain a fine-grain and uniform structure, the low carbon steel was heated up to 920 °C for 30 min then quenched in water, then heated up to 650 °C for 3 h and left to cool slowly in air. The heat treatment condition was chosen referring to DIN 54120 [17]. A slice of 10 mm thick was cut from the surface of the block; a circular saw blade was used for this work. The slice was sectioned into sixteen small parts that were examined before, in order to examine the uniformity of the metallurgical microstructure of the material of the blocks.

Table 3 Chemical composition of the used carbon steel.

Constituent	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Weight %	0.23	0.23	0.76	0.01	0.018	0.44	0.168	0.42	0.025

Figure 3 represents the area-amplitude curves for the steel reference blocks using the immersion technique with a frequency 5 MHz transducer. It shows a linear relationship between the hole size and the signal (echo height) as a percentage of the full screen at different gains. In this procedure, the reference standard 3.2 mm hole diameter is set to read 100 % of the vertical linear limit, and then the other blocks are read. We notice that, as the hole diameter decreased, the signal height decreased consistent with linear behavior. It is the upper straight line in **Figure 3**. The gain was then reduced by 6 dB, the signal height of the standard reference block read 50 % of the full screen. We noticed also, that, the signal heights of all blocks decreased linearly as the size of its flat bottom holes decreased. This is represented by the lower straight line in **Figure 3**. From the results, it is noticed that, as the gain decreased by 6 dB, the heights of the echoes from the holes decreases to half its value. Then in the ideal case, the ratios of the slopes must be equal to 2. The ratio between the two slopes in **Figure 3** is equal to 1.966. This means that, the deviation from the ideal slope is 0.004 and this represents a deviation of 0.005 dB from the 6 dB drop, then it is concluded that, the accuracy of measuring the linearity of the system is 0.0009. This indicates that the amplifier-attenuator of the system is linear within about 0.01 % with the attenuator range.

The system sensitivity with the transducer of 5 MHz and of nominal diameter 6.35 mm is set using a DA1 block of metal distance 12.5 mm as a reference standard. After beam normalization to the block's front surface, the transducer is moved laterally, in a transverse plane, until a maximum-amplitude reflection from this block's is detected [18]. The system gain is then adjusted until the reflected amplitude is 80 % of the full-scale. **Figure 4** represents the area-amplitude relationship using direct the contact technique with 5 MHz of 12.5 mm effective diameters transducers. The relationship is linear between the hole size and the echo height percentage of the full screen of the flaw detector instrument. The direct contact method is valid only for checking the performance of the ultrasonic inspection and not to verify the accuracy of the linearity of the receiver. It is clear from **Figures 3** and **4** that the echo heights are proportional to the square of their hole diameter. The amplitude height is related to the amount of reflected sound energy. Large hole diameters, causing a total reflection of sound, produce signal responses of higher amplitude than smaller hole diameters. **Figure 5** shows the distance-amplitude curve with a 5 MHz transducer. The gain controls of the flaw detector are then adjusted until the peak amplitude of signal reads 80 % full screen for DA5 block of 62.5 mm metal distance and 40 % of the full screen with DA3 block of 37.5 mm metal distance. It can be seen that the distance between the echo from the face of the block and the echo from the flaw varies according to the variation of the metal distance and the echo heights reduce to the square of their distance. Thus the horizontal sweep is a function of the defect locations. The horizontal sweep of the screen of the flaw detector instrument may be considered as a base to locate defects and flaws in metals bodies from the entry or back surfaces. Also, the distance between the echo from the defect and echo from the back surface of the block is constant since the distance between the defect and the back surface of the block is a constant 20 mm. It is clear from all of these results that the measurement using the technique proposed in this paper can be used for determining resolution and sensitivity capabilities and the results are in good agreement with previously published data [19].

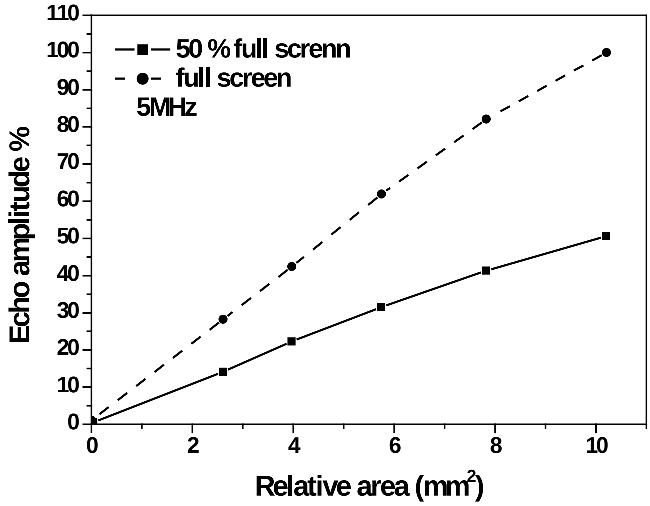

Figure 3 The area-amplitude curves for the steel reference blocks using the immersion technique with a 5 MHz transducer.

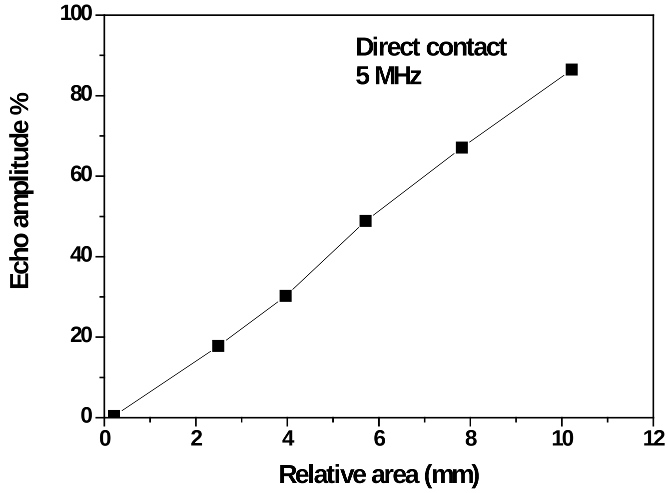

Figure 4 The area-amplitude curves for the steel reference blocks using the direct contact technique with a 5 MHz transducer.

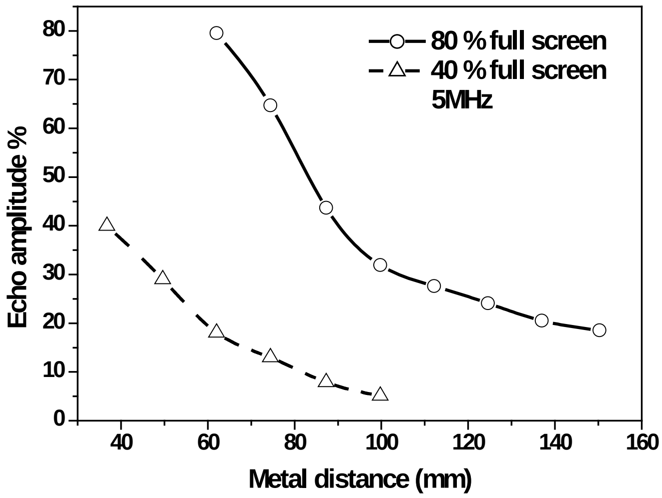

Figure 5 The distance-amplitude curves for the steel reference blocks using the immersion technique with a 5 MHz transducer.

Conclusions

The calibration curves established using the distance-amplitude reference blocks can provide a basis for estimating flaw severity and possible material rejections for low carbon cooled roll steel. Also, the area-amplitude blocks set can be used to estimate the size of defect in metals and solid bodies. The blocks used in this work had a 2 mm hole diameter using different sets of standard blocks of 1.2 mm and 3.2 mm hole diameter. They provide a wide range of difference amplitude curves for defect evaluation. The relationship between the ultrasonic response and hole size indicated that the display of flaw detector instrument is linear within the range of the measurements. The measurements have been used to evaluate the size of the defects inside the samples under test. The results obtained in this study could be used in the future to establish accept-reject criteria for many worked steel products.

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