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Calibration Method Study of Ultrasonic Thickness Gauge

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Abstract

Since the invention of ultrasonic examination technology, the ultrasonic thickness gauge has been widely used and playing an important role in many field, such as service inspection of pipeline and pressure vessel, in the quality control of massive construction project, the dimension measurement of complicated-shaped mechanical components and so on. With the rapid growing of our country economy and the development of technology, the quality control and examination become more and more important. Therefore, the application of this traditional technique becomes more popular in now days. To take full advantage of the high accuracy and easy operation, as well as satisfying various requirement of application, this paper is trying to show the concept of "zero point calibration" which is very important to the measurement accuracy of ultrasonic thickness gauge. the most popular calibration methods used in the ultrasonic thickness gauge will be described and compared.

Keywords Ultrasonic, Pulse echo, Thickness measurement, Ultrasonic thickness gauge

1. General

The ultrasonic thickness gauge has been widely used and playing an important role in many field, such as service inspection of pipeline and pressure vessel, in the quality control of massive construction project, the dimension measurement of complicated-shaped mechanical components and so on. With the rapid growth of our country economy and the development of technology, the quality control and examination become more and more important. Therefore, the application of this traditional technique becomes more popular in now days. To satisfy requirements of different fields and take full advantage of high precision and simple operation, the "zero point calibration" is very important to the measurement accuracy of ultrasonic thickness gauge, and effect of "zero point calibration" by change of temperature or other condition may increase error of specimen measurement. For this moment, most popular "zero point calibration" methods are used in the ultrasonic thickness gauge to improve measurement accuracy by throwing off change of temperature or other factors.

2. Introduction of "zero oint calibration" of ultrasonic thickness gauge

As we all kown, ultrasonic probe without delay block is majority used in the ultrasonic flaw detection, but ultrasonic probe with delay block is always used in the process for measurement of specimen thickness. Therefor, a transducer for an ultrasonic thickness gauge in pulse-echo mode of the pitch and catch type has transmitting and receiving transducer elements on adjoining blocks of delay material separated by an acoustic barrier at certain angle (at 1°~2.5° in average) for requirement of "pseudo focus" (see Figure 1). Increasement of the pulse-echo propagation time is produced by delay block, circuit or program is designed by throwing off this increasement to obtain real measurement of specimen, thus function is named as "zero point calibration". For understanding the theory of "zero point calibration" of ultrasonic thickness gauge, the process of measurement of specimen is introduced firstly.

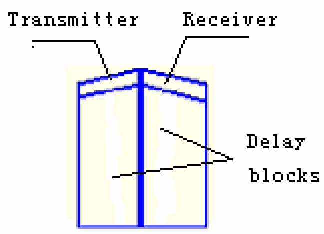

Figure1. A probe comprising

3. Theory of ultrasonic thickness gauge in pulse-echo mode

Pulse echo measurement is most popular method in the many measurement methods of ultrasonic thickness. In pulse echo method, measurement for round-trip time of the propagation of ultrasonic in specimen is equal to specimen thickness by certain conversion and calibration, theory of pulse echo method is shown as figure 2

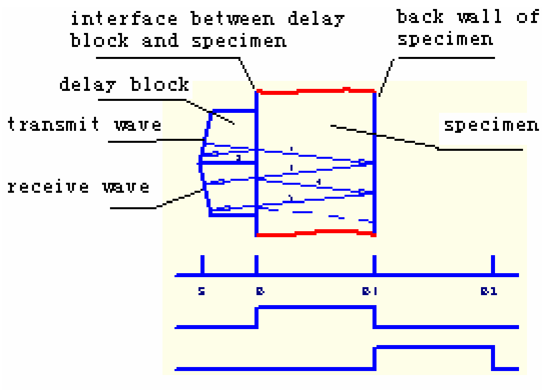

Figure2. Theory of pulse echo method

Where:

1——incident wave S, produced by transmitter and traveling in the specimen through delay block ;

2——echo B, the echo from the interface between the delay block and the specimen, which is also called interface echo;

3——echo B1, the echo from the backwall of specimen, which is also called first bottom echo, could be received by receiver transducer after traveling in the specimen through delay block.;

4——echo F ,the echo from the interface between the delay block and the specimen, which is only traveling in the specimen;

5——echo B2 , the echo from the backwall of specimen, which is also called second bottom echo, could be received by receiver transducer after traveling in the specimen through delay block..

There will be third bottom echo, fourth bottom echo, and so on, untill power of ultrasonic signal is off.

Theory of pulse echo measurement is that: high voltage signal S is given to transmitter transducer firstly, then ultrasonic wave is produced by reverse piezoelectricity, and ultrasonic wave is traveling at speed C_1 in delay block. As reach to interface between delay block and specimen, echo B is produced and other incident wave is traveling at speed C_2 in specimen; As reach to backwall of specimen, echo B1 is produced and could be received by receiver transducer after traveling in the specimen through delay block.. In this process, echo F is produced, thus second bottom echo; third bottom echo, fourth bottom echo, and so on, are also produced and received.

As figure 1 shown, time from generation of incident wave S to receive of echo B is equal to traveling time between delay block surfaces, this is called t_{SB}; for similar reason, traveling time between specimen is called t_{BB1}, or t_{B1B2}、t_{B2B3}、t_{B3B4}……and so on。

Pulse echo measurement could calculate thickness of specimen by traveling time between specimen surfaces, and express is given as followed:

$$h = (t \times C) / 2 \ldots\ldots\ldots\ldots\ldots (1)$$ [1]

h——Thickness of specimen;

t ——Traveling time between specimen surfaces, which is also called time-of -flight

C——sound velocity of material

Based on pulse echo measurement, "zero point calibration" methods could get real measurement of specimen by throwing off increasement of time-of –flight produced by delay block, several most popular calibration methods used in the ultrasonic thickness gauge will be described and compared to show their advantages and disadvantages.

4. Ddetails of "zero point calibration" methods

4.1 Introduction of five "Zero point calibration" methods

Methods 1: As figure 3 shown, time–of–flight t_{SB} (round-trip time in delay block) and time–of–flight t_{SB1} (round-trip time in the specimen and delay block) are measured, then time–of–flight t_{BB1} (round-trip time in the specimen) could be calculated by express (2)

$$t_{BB1} = t_{SB1} - t_{SB} \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

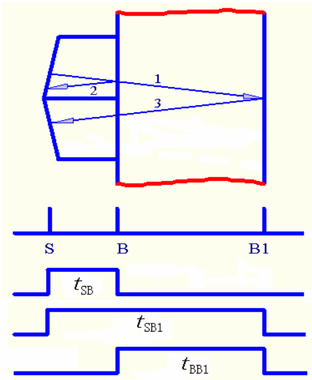

Figure 3. Theory of method 1

Therefor, real measurement of specimen could be obtained by express (1).

Methods 2: time–of–flight t_{SBt} (round-trip time in transmitter delay block), time–of–flight t_{SBr} (round-trip time in receiver delay block) and time–of–flight t_{SB1} (round-trip time in the specimen and delay block) are measured, then time–of–flight t_{BB1} (round-trip time in the specimen) could be calculated by express (3)

$$t_{BB1} = t_{SB1} - (t_{SBt} + t_{SBr}) /2 \ldots\ldots (3)$$

Therefore, real measurement of specimen could be obtained by express (1)

Methods 3: As figure 4 shown, a certain thickness sample is choosen as applied sample, firstly time–of–flight t_{BB1} (between applied sample surfaces) is pre-stored in gauge, then time–of–flight t_{SB1} (between incident wave S and echo B1) are measured by applied sample, so time–of–flight t_{SB} (between delay block surfaces) could be calculated by express (4)

$$t_{SB} = t_{SB1} - t_{BB1} \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

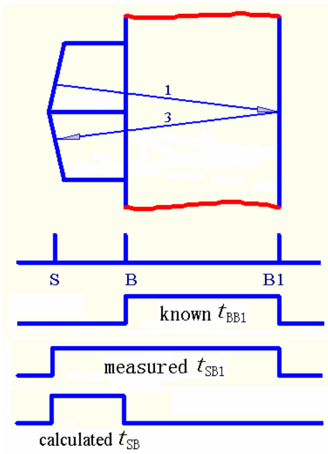

Figure 4. Theory of method 3

Therefor, real measurement of specimen could be obtained by express (2).

Methods 4: As figure 5 shown, this method is different from above methods, time–of–flight t_{BB1} (between echo B and echo B1) is measured, instead of measuring time–of–flight t_{SB1} (between t incident wave S and echo B1). Therefor, real measurement of specimen could be obtained by express (1). So this method is also called as auto calibration method.

Methods 5: This method is to obtain t_{B1B2} (time–of–flight between bottom echo B1 and bottom echo B2). Therefor, real measurement of specimen could be obtained by express (1). So this method is also called as echo-echo method.

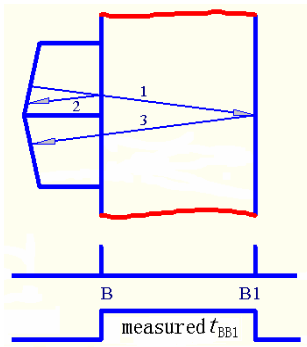

Figure 5. Theory of method 4

From above calibration methods, we find that t_{SB} (time–of–flight between delay block surfaces) should be measured in methods 1, methods 2 and methods3. Meterial of delay block is always made by organic glass (OG), Polysulphone, Polyimide or other materials, and sound velocity is different as traveling in these materials at changeable temperature. As a result, measurement of specimen would be effected, and temperature coefficients of materials in theory are shown as Table1:

Table 1 Temperature coefficients of materials in theory

Material	Temperature coefficients（m/s/℃）
Organic glass	-4.02
Polysulphone	-2.08
Polyimide	-2.55

4.2 Advantage and disvantage of above five "zero point calibration" methods

(1) From temperature experiments, we could get that sound velocity become slower as temperature increasement Take 12mm organic glass delay block as example, sound velocity is changalbe as 40m/s per 10℃, sound velocity is 2379(m/s)at 26℃, but sound velocity is2339(m/s)at 36℃, so delay time-of –flight is 10.09μs at 26℃, and delay time-of –flight is 10.26μs at 36℃, therefore difference of these two delay time is

$$\Delta t = t(36℃) - t(26℃) = 10.26\ \mu s - 10.09\ \mu s = 0.17\ \mu s \ldots (5)$$

Difference time is equal to error of measurement by expression (13)

$$\delta = \Delta t \div 2 \times C_{钢} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(6)$$

we could get

$$\delta = 0.17\mu s \div 2 \times 5.9(mm/\mu s) \cong 0.5mm$$

From above analysis, error of measurement will be increased in methods from 1 to 3, if there no new adjusted at new temperarure; but error of measurement as such could be avoid in methods 4 or 5.

Ultrasonic probe with low sensitivity to temperature should be choosen in methods from 1 to 3, another way is always adjusted at new temperarure, but this method is not suit to high temperature measurement because temperature is changeable quickly.

Methods 4 or 5 could get rid off effect of delay time-of –flight by changeable temperature, so these calibration methods are suit to high temperature measurement or other field with quick changeable temperature.

(2) $t_{SB发}$ (time–of–flight between transmitter delay block surfaces) and $t_{SB收}$(time–of–flight between receiver delay block surfaces) is almost same in theory, but demision of transmitter and receiver are not same actually, so transmitter and receiver could not be changed in method 1 to avoid error caused by different of $t_{SB发}$ and $t_{SB收}$, but transmitter and receiver could be changed in method 2 for $t_{SB发}$ and $t_{SB收}$ are obtained respectively.

(3) t_{SB1} (time–of–flight between incident wave S and echo B1) include delay time of transmitter and receiver in method 3, thus is different from method 1and 2, so transmitter and receiver could be changed in many cases, but temperature effect and probes abrasion could not avoid, always adjusted gauge could keep precesion.

(4) Compared to method1,2, 3, method 4 have more advantage such as temperature effect and probes abrasion could not increase error of measurement, because change of interface signal is consistent with change of

delay block, so calibration is automatic and self-driven.

On the other hand, amplitude of interface signal is related to coupling condition and material of specimen. As we all known, if ultrasonic wave put into interface vertically, echo signal (interface signal) is only decided by material on two sides of interface. For example, delay block is organic glass, and specimen is steel, ultrasonic wave put into interface vertically from organic glass to steel, which shown as figure 6.

Where:

Z_1-- sound impedance of organic glass;

Z_2-- sound impedance of steel;

P_i-- transmitter sound press;

P_r --echo sound press;

P_n –transmission sound press;

If $Z_1= 3.3\times10^5 (g/cm^2.s)$ and $Z_2= 245.3\times10^5 (g/cm^2.s)$

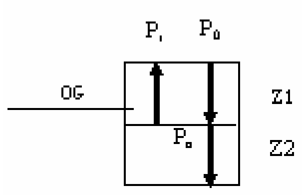

Figure 6. ultrasonic wave put into interface vertically from organic glass to steel

Reflectivity of interface from organic glass to steel is

$$r = P_r/P_i =(Z_2-Z_1)/(Z_2+Z_1) \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$ [1]

$$r = (45.3-3.3) / (45.3+3.3) = 0.86 \ldots\ldots\ldots\ldots (8)$$

$$P_r = 0.86\, P_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

If delay block is organic glass, and specimen is also organic glass or other material similar to organic glass, at that time, reflectivity of interface is nearly equal to zero by expression (14), thus means little echo sound press, so method 4 could bot be applied on the condition of delay block and specimen with similar material, to make interface signal is too small to measure.

(5) method 5 with echo-echo measurement is almost perfect method for specimen with certain range and average material, for its advantage of avoid temperature effect and acoustical impedance or other question, but it is very hard in measuring specimen with very thickness, because second or other bottom echo signal are lost , only except for first bottom echo.When materials of specimen and materials of delay block are the same or are similar, possible not to have second bottom echo, is also unable to measurement.

(6) From implement of circuit design, method 3 is most simpleand low cost; method 1 and 2 are bitter complex with higher cost, method 4 and 5 are most complex with highest cost, proction designed by method 4 and 5 may be higher price.

5. Conclution

“zero point calibration” is very important to the measurement accuracy of ultrasonic thickness gauge, as discussed in the paper, ultrasonic probe with delay block is always used in the process for measurement of specimen, Increasement of the transfer time is produced by delay block, change of sound velocity accoid with change of temperature can change, thus will affect of precesion of measurement. Circuit is designed to take off this increasement to get true thickness of specimen. Five most popular “zero point calibration” methods used in the ultrasonic thickness gauge are introduced in this paper, and effect of each calibration method under different temperature, different coupling condition, different material, are also analyzed, moreover, advantages and disadvantages of each calibration method are detailed. Compared to first three methods, methods 4 and 5 may get better result and improve veracity of measurement for avoid effect of delay block.

Reference

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