Research on ultrasonic non-destructive examination in water immersion of a composite material

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Abstract: Nondestructive Evaluation is important in particularly for the control of composite parts. Critical parts are required more and more to be tested during the manufacturing process by more efficient and accuracy nondestructive evaluation methods (NDE). One of the most suitable method to be automated is the ultrasonic exam. Inspections with this technique over composite parts introduces additional difficulties to the standard inspection, because the acoustic coupling it can’t be done correctly. In this paper, we present a method of examination with ultrasound, for a composite part.

Key words: ultrasound, immersion, probe, higher resolution, defect

1 Introduction

Ultrasounds are widely used in health care for noninvasive diagnostics and in industry for nondestructive testing [1], [2], [3].

In the human body, it generates visual images from inside the test medium: the fetus, malignant tissue, stones, etc. In industrial applications, besides defect detection, ultrasounds are also useful for determining significant material characteristics such as density, thickness, mechanical properties, and level sensing.

Knowledge of ultrasonically analyzed information is important for human health as well as for cost-effective production of quality industrial materials.

1.1 Ultrasonic examination in water immersion

The ultrasonic examination in water immersion is wonderful suitable for automation. Such examination method, “under a column of water”, avoid the direct coupling problems - uncertain in many cases. Also the reproducibility of results obtained by this method are excellent [4], [5], [6].

1.2 Advantages and disadvantage of ultrasonic examination in water immersion

The ultrasonic examination in water immersion presents a number of advantages and disadvantages compared with other nondestructive examination methods. Among the advantages we may include:

- high sensitivity, allowing detection of cracks with an opening of a few microns;
- the high penetration power, modern flaw detectors can be used to control parts with thickness of 5 ... 20 m;
- broad control possibilities, the same device can be used to control the depth of defects of surface cracks, material structure, but also the determination and measurement of thickness;
- the examination does not require complicated and costly preparatory phases and can be done quickly and effectively even in the technological production flow.

The main disadvantage is the high sensitivity of the method, sometimes leading to an uncertain interpretation of results, therefore, to increase safety in the interpretation of results, this method is supplemented sometimes with other methods [1], [12].

1.3 The principal of ultrasonic examination in water immersion

The ultrasonic examination in immersion is a control method in which the test object and the transducer are submerged in a liquid (usually water) that acts as the coupling medium. Usually, the probe
is not in contact with the test specimen (fig 1). The
tank is a device in which the test procedure is
carried out, usually consisting of a multi axis
control. The immersion probes are automated with
motors and encoders for reading the actual probe
position (fig 2).

Fig. 1 The principle scheme of
ultrasonic examination in water
immersion

Fig. 2 Experimental stand of
ultrasonic examination in water
immersion UTwin

The fraction of ultrasound transmission and
energy transferred at the water-material interface is
given by

\[ T = 4 \frac{Z_1 Z_2}{(Z_1 + Z_2)^2} \]  \hspace{1cm} (1)

where: \( T \) is the transmission coefficient in the
propagation medium \( Z_1 \) is the acoustic impedance of
the ultrasound carrier medium (for example, water
for the NCU mode) and \( Z_2 \) is the acoustic impedance
of the test medium.

The transmission coefficient is derived as
the ratio of transmitted acoustical energy \( V \) and the
input energy \( V_0 \) of a plane wave when refracted at
0° incidence on the interface between the two
media:

\[ T \propto \frac{V^2}{V_0^2} \]  \hspace{1cm} (2)

This relationship can also be described by a decibel
scale:

\[ T = 20 \log \frac{V}{V_0} (\text{dB}) \]  \hspace{1cm} (3)

Energy transferred in the propagative medium =

\[ 20 \log T (\text{dB}) \]  \hspace{1cm} (4)

For more details and the significance of
plane wave transmission and reflection at a number
of interfaces in terms of acoustical pressure and
intensity [4], [12], [13].

Ultrasound in noncontact transmission must
propagate from water into the test material and then
again into water so that the transmitted wave can be
detected by a receiving transducer (Fig. 3).

Interface “a” corresponds to water–material
(from acoustic impedance \( Z_a \) to \( Z_m \)) transmission.
Interface “b” corresponds to material–water (from
acoustic impedance \( Z_m \) to \( Z_b \)) transmission.

Fig. 3 Interfaces to be crossed by ultrasound (shown
by arrow) in the immersion mode to propagate
ultrasound through a test material.
The efficiency of an ultrasonic transducer depends on the coupling coefficients and other electromechanical properties of the piezoelectric material. It also depends on the mechanism by which ultrasound is transferred from the piezoelectric material to the medium in which ultrasound needs to be propagated. In the immersion mode, this medium is water [8], [9], [10].

Table 1 provides the transmission coefficients and energy losses in selected test materials in the ultrasonic examination in water immersion calculated by using Eqs. (1) and (4).

### Table 1 Transmission Coefficients and Energy Transfer in Selected Materials at Various Interfaces in the Ultrasonic Examination in Water Immersion Z(water); 1,5 Mrayl; 1 Rayl = 1 kg/m²s

<table>
<thead>
<tr>
<th>Material Zm Mrayl</th>
<th>Interface (Fig 1)</th>
<th>Transmission Coefficient eq (1)</th>
<th>Energy Transfer eq (4) (dB)</th>
<th>Total Energy Loss at Interfaces a+b (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel 51,0</td>
<td>Water-Steel, a</td>
<td>0,11</td>
<td>-19</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Steel-Water, b</td>
<td>0,11</td>
<td>-19</td>
<td></td>
</tr>
<tr>
<td>Aluminium 17,0</td>
<td>Water-aluminium, a</td>
<td>0,3</td>
<td>-10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Aluminium - water, b</td>
<td>0,3</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>acrylic 3,5</td>
<td>water-acrylic, a</td>
<td>0,84</td>
<td>-1,5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Acrylic-water, b</td>
<td>0,84</td>
<td>-1,5</td>
<td></td>
</tr>
<tr>
<td>Silicone Rubber 1,0</td>
<td>water-rubber, a</td>
<td>0,96</td>
<td>-0,35</td>
<td>&lt;1</td>
</tr>
<tr>
<td></td>
<td>Rubber-water, b</td>
<td>0,96</td>
<td>-0,35</td>
<td></td>
</tr>
</tbody>
</table>

**2. Ultrasonic transducers for immersion examination mode**

The transducers used for noncontact scanning methods using water as contact medium, are applied in immersion tanks, so they must be waterproof. Many other scanning techniques use them as well, e.g., gap scanning, probe fixtures acting with a water column or water jet. The transducers, which are invariably of the compression-wave type, are mostly in a range of 6 mm up to 25 mm in diameter and operate mostly over a frequency range of 1…25 MHz. The beam from the probe can be focused to a point using a spherical lens and to a line by means of a cylindrical lens [3], [4], [5].

![Fig. 4 Principle design of ultrasonic immersion probe](image)

**3. The technology of ultrasonic examination in water immersion**

An ultrasonic pulse is transmitted through the specimen perpendicular to the surface using separate transmitter and receiver transducers opposite to each other. The signal obtained from the receiver transducer is a measure of the total ultrasonic damping in the material [6], [7], [8].

The ultrasonic damping is influenced by the existing of defects in the material such as high level of porosity or delaminations. Pores will cause the ultrasound to be reflected due to the high difference between acoustic impedance in the material and in air. The porosity are normally much smaller that the focal diameter and cannot be detected one by one.

However, the sum of a large number of pores results in higher total damping and thus a smaller transmitted signal. The ultrasonic equipment
is capable of measuring the peak amplitude of the transmitted signal.

The scans are performed in a rectangular raster pattern. In each point the amplitude of the transmitted ultrasonic signal is measured. The result of the scanning is presented in a color or grey-tone plot where the color scale is in dB, which gives a high dynamic range.

In order to locate the depths of the defects immersion pulse-echo has been used as a supplementary technique. Only one transducers that works as both as sender and receiver are used in this technique [8], [9], [10].

In order to inspect the whole section the ultrasonic signal has to travel twice through the specimen – down to the backside of the specimen and back to the upper surface.

If there are defects (i.e. pores or delaminations) present somewhere in the transversal section the ultrasonic wave will be reflected by the defects and will be measured by the transducer. For the thick laminates (50 mm) it is difficult to examine the whole transversal section because a small echo is received from the back surface.

The applications shall be made on experimental stand UTwin, in the laboratory of IMST faculty.

3.1 Some of the graphics capabilities of the UTwin equipment
- Exceptional 2D and 3D graphing capabilities;
- Display multiple graphs on a screen, limited only by the resolution of the screen itself (fig. 5);
- Graphs are individually sizable on a screen, making for a very flexible arrangement;
- Set up one or more large graphs for visualization with multiple supporting small graphs alongside or around the main graph;
- Arrange multiple graphs on a screen. Set up multiple screens and access each by selecting a user-labeled tab (fig. 6);
- Set up themes for screen layout (e.g. A-Scan, feature monitoring B-Scan, real-time C-Scan, replay analysis, themes, etc.).

Fig. 6 Display any combination of A, B and C-Scans.

4. Experimental results

Textolite plate was used, which were given 6 holes of different sizes and depths.

Textolite plates are used mainly to manufacture parts in applications that require mechanical and electrical insulating properties, such as switching mechanisms. Textolite is also used in applications such as gears and wheels of friction or friction surfaces. Because of fine fabric which has a composition, this material is recommended and manufacturing of small parts. These materials are observed by good machinability, high wear resistance and a good resistance to water, oils and lubricants.

Textolite plates are manufactured in thicknesses from 0.13 to 300 mm of 2000 x 1000 mm formats [11], [12], [13], [14].
If there are no interface delaminations or other discontinuities within the laminate, then the traction and displacement components must be continuous across the interfaces parallel to the $x_1$-$x_2$ plane, i.e.:

$$
\phi_1^{(n-1)} = \phi_2^{(n-1)}, \quad \phi_3^{(n-1)} = \phi_3^{(n-2)},
$$

$$
x_3 = x_3^{(n-2)}
$$

(4)

The textolite plate is controlled by immersion (Fig. 8), presents reflections of disc. Examination results show reflections defects. By measuring the propagation time we determined the depth of defects, as we see occurring in the image obtained by scanning C.

The textolite plate, reflector disk type, 9.5 mm diameter and 6 mm deep
Fig. 10 Ultrasonic examination in water immersion of the textolite plate, reflector disk type, 7 mm diameter and 3 mm deep

Fig. 11 Ultrasonic examination in water immersion of the textolite plate, reflector disk type, 7 mm diameter and 3 mm deep, TOF

4. CONCLUSIONS

The method of examination by ultrasonic immersion is the only nondestructive control method which does not require direct contact between the transducer and the test object;

The method of examination by ultrasonic immersion has a better resolution due to higher frequency and lower focal point of the immersion transducers;

The method allows the examination of multilayered composite laminate

References:

[10] Ultrasonic signal processing methods for detection of defects in composite materials - D.Pagodinas