Ultrasonic tomography of pressure couplings

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Abstract. The article tells of the method of pressure coupling fit area research with ultrasonic tomography, which was set up on the basis of the proprietary technology of quantitative estimation of press-fit joints quality with the ultrasonic echo-impulse method. The possibility of 3D - images receiving of the press-fit joint strain-stress state area is shown. On the basis of the study of the characteristics of ultrasound reflection from the pressure coupling fit area, it is shown that the ultrasonic signal reflection coefficient is the general characteristics of press-fit joint quality because it is bound with the normal stresses appearing on the joint surfaces. Considerable attention is paid by the authors to the possibility of optimization of the research process: the possibility of automation of joint quality control by the described method is realized.

The possibility of automation of the process of control as applied to the ultrasonic echo-tomography of metal structures using echo-impulse sensing is pointed out in [1]. The ultrasonic tomograph operating principle is described in [1] as following. On the surface of the object for research (metal, plastic, ceramic, fluid, etc.) an impulse ultrasonic field is excited by piezoelectric transducers (PET). The ultrasound propagates in the object reflecting from internal discontinuities. The reflected impulse signals are received by PET and visualized on the screen in the form of pulses, figure 1,a (image A-type, ultrasonic scan). On the screen (figure 1,a) a series of clear pulses reflected from the object defects is viewed. If you continuously move the PET over the surface of the object and use the ultrasonic scan for the modulation of signal intensity in brightness, you will receive on the screen an object section plan on which the defects images are observed. They are shown in black, figure 1,b (image B-type). As a result during the building up of the image heterogeneities in the object of control will be displayed in the form of dots of different brightness levels or colors. It is obvious that using a scan, as well as the image of B-type, we can estimate the size of the defective area and the depth of its occurrence under the surface. If you move the PET along the surface of the object, capturing different sections, you can obtain on the screen of the device transverse projection of defects images, figure 1,c (image C-type) which allows determining the transverse dimensions and shape of the defects. Thus, in...
these studies, the image of some cross-section of the object is received, so the images of B- or C-type can be considered as tomographic since they represent 2D-tomograms.

![Tomographic Images](image_url)

Figure 1. Schemes of the building up of tomographic images by different methods of scanning a controlled object [3].

So the tomographic image (3D-tomogram) can be obtained only by three-dimensional reconstruction of the study object on the bases of B- and C-type images synthesis, and it is stated in [1] as the prospects of the method development. And this is true taking into consideration the fact that the "tomography" term appeared in X-ray radiography first [2]. In particular, it was found that the tomographic effect is achieved in three cases: 1) stationary object and moving source and receiver of radiation; 2) stationary source and moving object and the receiver; 3) fixed receiver and moving object and the radiation source. This method is the multi-angle sensing and recording of data about the object in intersecting directions with the subsequent solving of the inverse problem. The solving of the inverse problem allows first to synthesize the layer image (2D-tomogram) in the cross-section of the object subjected to the multi-angle sensing. Then we can obtain a three-dimensional image of the object (3D-tomogram) using a three-dimensional reconstruction of the study object based on the synthesis of images of specific layers (2D-tomograms).

Unfortunately, in [1] there are no data of the possibility of applying the developed method of study of the internal structure of objects and materials for obtaining quantitative estimates of any manufacturing parameters characterizing the study object quality. Also, it can’t simply be implemented for the research of press fits. However, this does not mean that echo-sounding cannot be used as a method of ultrasonic imaging of pressure couplings [3]. The 2D-and 3D-tomograms are firstly two- or three-dimensional images of the distribution of some physical characteristics. It includes cases when there is a possibility to reconstruct a three-dimensional image of the object studied area using the points of weakening of the measured signal without any additional mathematical processing of data, using measurement results directly.

Unlike the research method, described in [1], in our studies, the ultrasonic "tomographic effect" is implemented exactly according to the first variant, with the only difference that the radiation source and receiver are stationary and the object of study can rotate and move steadily relative to the radiation source and the receiver.

The scheme of the measuring experiment and analysis of the obtained measurement data is as follows:
- in each object cross-section the ultrasonic wave is brought in through the contact liquid in the outer side surface of the female ring of the pressure coupling at different directions intersecting in the center of the object;
- building up of the image of a pressure coupling interface in each object cross-section is performed by points of attenuation of the measured reflected signal for each sounding direction.
Figure 2. Diagram of attenuation of the ultrasonic pulse for 8 cross-sections at different distances from the end ($\Delta l$) in length of the assembly $l$: $\bullet$ interference of 140 µm; $\circ$ interference of 100 µm.

Figure 2 shows the diagrams of attenuation of echo-pulse for 8 cross-sections at different distances from the end ($\Delta l$) in length of the assembly $l$, which are obtained as described above for two pressure couplings with 100 and 140 µm of interferences. Diagrams of attenuation of the acoustic signal obtained this way for different sections of the pressure coupling are in fact the sets of multi-angle
study of the object in these planes. They are 2D images of the stress-strain state of a joint zone in a given cross-section, as mathematical data processing is implemented in the defect detector by electronic means. Therefore, in this case, to obtain three-dimensional tomography image of the pressure coupling joint (3D tomogram) there is no need in some special mathematical processing of measurement data as the ultrasonic transducer sends ultrasonic wave into the object which partially reflects from the joint zone and returns to the same ultrasonic transmitter, where it is recorded. Then, with the help of a computer, by the ratio of the amplitudes of the first and the second reflections from each point of the studied coupling region, the calculation of attenuation characteristics of the ultrasonic wave is implemented [4]. So, on the display screen, the mathematical reconstruction (three-dimensional image construction) of the mating surface is performed.

Since the dispersion of the results of multi-angle shooting in intersecting directions is large enough, and the interference probably changes relatively smoothly, the data obtained in the experiment should be subjected to mathematical averaging. For this purpose, the following steps about the array are performed.

First and foremost, the standardization of the data by the maximum value is realized. It will allow not to control the interpolated data by the value in the future. The next step will be the linear interpolation of the data set and choice of interpolation datum points (grid) that ensures correct results of mapping. After that, for each of the sections piecewise polynomial interpolation of the given accuracy and then interpolation by the length are produced. After interpolation, the map of intensities is built up and the resulting texture is imposed on the three-dimensional image of the controlled object.

The implementation of this algorithm is made in the same development framework as it is used for calculating program - in Delphi. The program includes two windows: the first is for data entry and specification of the related settings and the second is directly for the derivation of the resulting tomogram.

The dialog windows are shown in figure 3 and obtained using the program tomograms of pressure coupling are shown in figure 4.

Figure 3 shows an example of a model of local stress concentration in the area of interference. Shown in figure 3,b an example of three-dimensional reconstruction of the local stress concentration field structure in the interference zone(figure 3,a) corresponds to the case of step scanning of the object around the joint female part surface. On the bases of the received data characterizing the change
of nature of ultrasonic 2D-diagrams (projections) from cross-section to cross-section, the specified algorithm helps to provide the reconstruction of the 3D-image of the interface.

The algorithm of reconstruction of images is received on the bases of linear interpolation of the data array and specification of the datum points (interpolation grid) that ensures the correct outcome of the transformation. The algorithm also allows solving the problem of building up an ultrasonic 3D-tomogram at a given relative motion of the source and the object of measurement.

In this method, using a small acoustic transducer with a wide beam pattern the shooting of the acoustic field is produced by a circular scanning with the step of 22°30' in eight sections of a pressure coupling and then joint data processing is performed.

![Figure 4. Tomograms of pressure couplings with 100 µm and 140 µm interference: turned to 0°, 120° and 240°](image)

Ultrasonic tomography combines safety, cheapness and efficiency of the ultrasonic method with high informative value and reliability. It allows visualizing the image of the joint area of the pressure coupling. Also, it allows evaluating the real value of the load capacity of the produced assembly, by calculating the total area of the contact surface of the assembly for which the local pressure matches the specified load capacity.

As an advanced technical solution and to exclude mechanical movements of the ultrasonic emitter and receiver it’s possible to use the ultrasonic phased antenna array (PAA). It consists of a set of independently controlled converters. It makes possible to control the acoustic field emitted into the controlled object and "sound-throw" it at the necessary angles. Modern antenna arrays are made as an
ordered set of rectangular items, generally from composite piezoelectric ceramics, which are either placed directly to a controlled object (to use longitudinal waves) or to a prism for angular input of beams to work using cross over waves. The use of the prism limits the ability of the PAA due to losses of ultrasonic energy in the material of the prism and to the transformation of waves at the boundary of prism-controlled metal and also limits the scanning sector.

Main conclusions
1. Quality control of cylindrical pressure couplings obtained by the thermal method of assembly is possible with the use of the ultrasonic tomography.
2. The quality control of other types of pressure coupling and also obtained using other methods of assembly is also possible after the development of the full technological cycle of control, including:
   a) testability evaluation;
   b) selection or development of special control equipment;
   c) development and manufacturing of standard samples of press-fit joints of each type;
   g) determining the levels of rejection and criteria of an estimation of joints quality using ultrasonic tomography.
3. Automation of the process of pressure couplings quality control with the application of ultrasonic tomography is possible and up-to-date because it allows us to get rid of the influence the control result by the human factor and significantly improves the efficiency of the control based on the proposed method.

References
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