VIBRO-ACOUSTIC APPROACH FOR REGISTRATION AND EVALUATION OF TECHNICAL DEVIATIONS IN ALUMINUM CASTINGS

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Abstract: *Superficially masked internal discontinuities in the aluminium casting during the manufacturing process occurs often. As a result of dynamic loadings in the process of operation, it is possible the occurrence of leakage in the machines. The application of classical methods of non-destructive testing of internal discontinuities in parts with relatively complex geometric dimensions requires a significant resource or is not always possible.*

A vibro-acoustic study for express diagnosis of internal discontinuities in aluminium castings is shown in the work.

The resonance behaviour of a part depends on its specific shape and material properties of the elastic medium. This allows diagnostic approaches for registration of different technical deviations, estimating an equivalent size of internal discontinuities, to be created.

Classical theory of resonance is used for scientific justification of study. It is suitable in spatial parts of complex shape the theoretical results to be obtained for each particular construction by means of the constructive model in CAD environment. The possible technical deviations are created in the geometric model by software. The model is divided into elementary parts and a detailed description of their properties and the elastic connections are described by the Finite Element Method (FEA). This allows diagnostic models for registration of discontinuities, incl. for assessing its equivalent size in a particular section of the casting to be created rapidly.

A study of an aluminium part by a universal acoustic apparatus is shown in this work. The samples are separated into factory conditions of „suitable" and „unsuitable" after machining of the joining dimensions. Typical areas of occurrence of discontinuities in the casting process are defined. The „suitable" samples are divided according to the specific elastic characteristics of the material used. Insignificant scattering (2-6 Hz) of resonant frequencies in the range 20 Hz to 20 kHz is measured. Discontinuities in the typical areas of registration in the real parts are formed successively in the CAD model. The resonances are calculated in FEA. Diagnostic signs for registration and evaluation of an equivalent size of discontinuity according to its disposal are created. Discontinuities of irregular shape are created in part of the „suitable" samples and the resonances are registered again; the changes of resonances are determined. The principle consistency between theory and experiment is assessed. A good compliance is obtained.

The work may be used to assess the technical condition of castings by manufacturers of such parts.

Keywords: ALUMINUM CASTING, INTERNAL I DISCONTINUITIES REGISTRATION AND SIZE EVALUATION

1. Introduction

As a result of technological deviations in the process of aluminum parts casting superficially masked internal discontinuities occurs often[1]. The problem with internal discontinuities is significant for thin-walled details, from which both mechanical strength and tightness are required. As a result of internal discontinuities accidents of product leakage after a certain period of dynamic load during the operation are possible.

Internal discontinuities can be recorded by well established non-destructive methods. For each method a scientifically justified sensitivity threshold is defined, ie. the minimum amount of discontinuities that can be registered. There are also specific requirements for the shape of the parts in order to realize the study.

In parts with relatively complex geometric shapes nonconformities with different locations are possible. For their registration, technical devices have been developed to explore the subject from different sides and make 3D computer images. This makes the application of classical methods for non-destructive testing of internal discontinuities to require a significant resource or is not always applicable.

The resonance behavior of a part depends on its particular shape and material properties of the elastic medium [2]. An opportunity to assess the technical condition, incl. the registration of internal discontinuities in aluminum castings gives the analysis of some characteristic resonant frequencies, excited in the parts. The vibrations are recorded quickly by means universal acoustic equipment and no highly qualified personnel is needed to determine resonant frequencies [3]. The vibro-acoustic method is not universal in terms of diagnostics of machine elements. This defines it as a highly effective method for controlling the technical condition of concrete parts after a specialized procedure to demonstrate its application.

The aim of the work is to show a vibro-acoustic express diagnostic approach of internal discontinuities in aluminum castings.

2. Stages of the study

To clarify the resonance phenomenon in theory, mathematical dependencies are usually presented for simple bodies. For example, the basic (first) critical angular velocity of one shaft is given by the dependence [2]:

$$\omega = \sqrt{\frac{k}{m}} \ . \tag{1}$$

Here k is stiffness on the shaft, m - mass. For each body, resonant modes of a specific nature exist; they are determined by the major deformation in the material, such as: transverse, longitudinal, twisting, etc. In complicated parts, consisting of simple interconnected bodies, there are conditions for the simultaneous stimulation of more resonances. In fact these are systems of elements with elastic connections between them, which make their theoretical description difficult. The shape of complex details is easily described using engineering CAD and strength analysis (FEA) software, widespread in engineering. Once created, the geometric model of a part in a CAD is used for technological purposes, and can also be used for vibro-acoustic control of the productions. In a CAD environment, it is appropriate to work on the model to create some technical deviations that are found experimentally. After translating into FEA environment, the revised geometric variants are separated to elements by software, and the elastic properties of the material are set. Depending on the complexity of the model and the level of computer equipment, the time for calculating the resonant frequencies is 2 - 60 minutes, followed by an analysis of the results obtained with respect to the change of frequencies compared to those of the model without technical deviations.

One of the frequent reasons for changing the resonant frequencies in serially produced parts is the permissible deviation of the elastic characteristics of the metal. These deviations are difficult to record by non-destructive methods, such as an ultrasonic method, but they change the resonant frequencies of the part. It is appropriate for the "elastic medium" factor to be read in advance so as to achieve a good recognition of unacceptable technical deviations.

The theoretical results are evidenced by comparing theoretical results with experiments with details with artificial discontinuities, which repeat the CAD deviations, as well as with details with proven discontinuities. Difficulties in proving the theoretical results create the possibility in a part with the recognized discontinuities by leakage to exist other inconsistencies / deviations.

2.1. Preparation for Vibro-Acoustic Control:

- Demonstration of the metrological accuracy of finished products in one series - this activity is performed by comparing the deviation of resonant frequencies in a series;

- Analysis of typical sections with a discontinuity in the parts;

- Modeling of the dependence between the resonance frequency deviation and an equivalent degree of discontinuities in the way $\Delta f_i = F(\delta)$, i - the number of the resonance, Δf_i - its frequency deviation from the technical variance; or reverse function - $\delta = F(\Delta f_i)$;

- Creating samples with artificial discontinuities and verifying the theoretical results;

- Setting standards to control for registration and diagnosis of inconsistencies.

2.2. Control procedure

- Distribution of parts in batches, e.g. by mass measurement or reference resonance frequencies;

- Recording resonance frequencies and analysis by comparing with selected standards for recording inconsistencies in typical sections;

- In case of suspected frequency deviations, conclusions are drawn about the location and the extent of the discontinuities.

This sequence helps to quickly create diagnostic signs for registration of technical deviations, such as geometric deviations, deviations in product density.

3. Example of illustrating the approach

An example of a study of an aluminum piece shown in Fig. 1 a) with a universal vibration-acoustic apparatus is shown in this paper. In factory conditions the samples are processed to the exact size, after which they were tested for leakage. The typical areas of discontinuities in the casting process are selected [5]. The good samples are separated into groups according to the specific elastic characteristics of the material used. Insignificant scattering (2-6 Hz) of resonant frequencies in the range 20 Hz to 20 kHz is determined and higher resonances have greater scatter. In addition, higher-frequency resonances require extra attention on excitation and analysis.

The mass of samples was examined and a change of 2.8% was found.

3.1. Preparation of the test sample

In the constructive model of the sample are formed consecutive irregularities in the typical areas of registration in real details. Part of the sample models are modified by

irregularities in the sections established by practical studies, established by practical research and changes Δf of some resonance frequencies are registered $\Delta f = f - f_{def}$; f - frequency of sample with normal quality, f_{def} - frequency of sample with discontinuities. Frequency variation Δf depends on the equivalent depth δ of discontinuities and on the particular disposition of the discontinuities. For the specific detail, four sections are found [5]. They are shown in Fig. 1 b). In the first stretch the possibility of double-sided leakage, indicated as I and I ', is established. When the depth of discontinuities ranges from 0 to 3 (6) mm, some resonant frequencies change significantly (above 10 Hz). They are shown in Table 1. It is appropriate to use them as informative it is appropriate to use them as informative features for registration of discontinuity and for determine its equivalent depth.
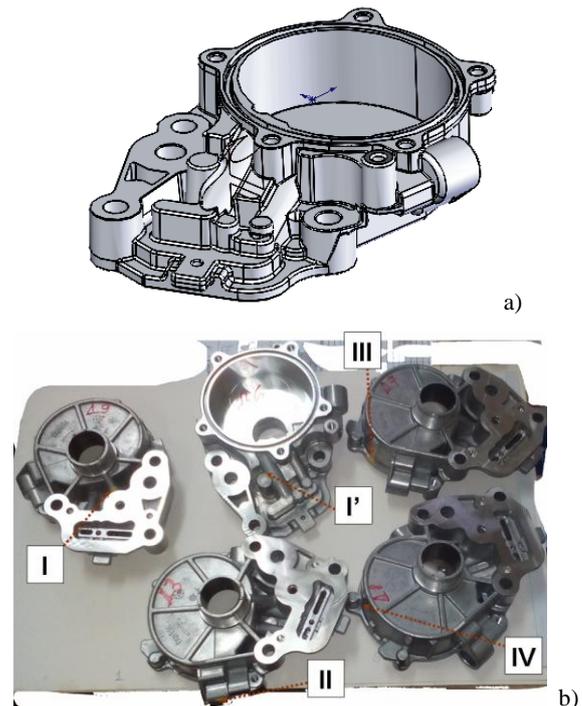

a)

b)

Fig. 1. *3D model of research example (a) and typical sections with discontinuity in the real samples (b).*

Resonance 4 changes insignificantly (up to 10 Hz) in case of discontinuities in section IV, and otherwise does not change and is suitable to be selected as a benchmark for assessing the quality of the parts.

Tab. 1. *List of resonant frequencies up to 10 kHz, which changes in case of discontinuity according to the section.*

Section №	Significant change in the resonant frequencies, №	Minor change in resonant frequencies, №
I	1, 3, 10, 11, 12	5
II	26*, 37*	-
III	2, 7, 8	3, 5, 12
IV	2, 3, 5 – 10, 12, 13	1, 4, 11
Note: * Resonances specified are only informative and are outside the frequency range.		

A statistical analysis of the frequency of occurrence of discontinuities in the different sections of the sample is done. The most common cases of leakage (about 60%) are recorded in section I. Sections I and IV are used here as examples of creating

diagnostic signs for registration and evaluation of equivalent discontinuity dept.

Theoretical results for the frequency variation Δf of resonances with conditional serial number (№) in sections I (a) and IV (b) depending on their serial number are shown in Fig. 2.
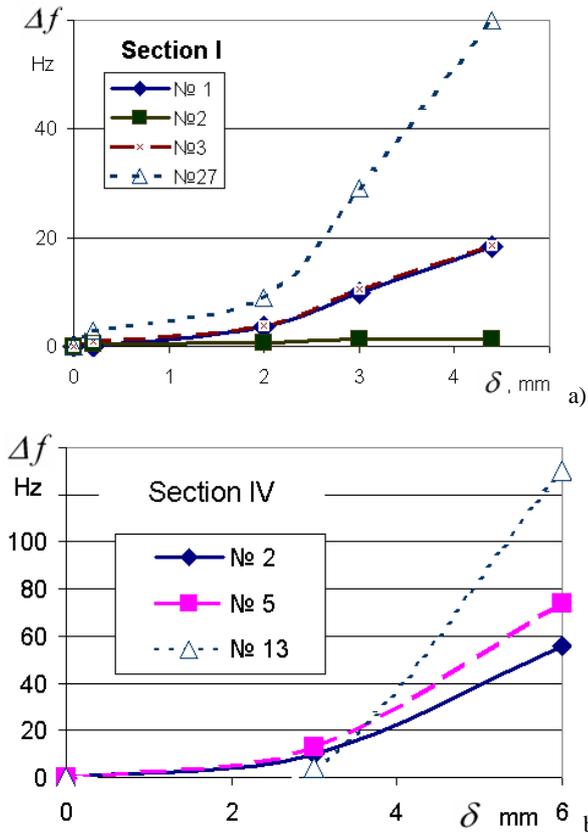

Fig. 2. *Results for variation of Δf in section I (a) and IV (b) depending on the serial number (No) of the resonant frequency.*

Diagnostic signs for registration and assessment of an equivalent depth δ of discontinuity according to its location were created on the so-called nomograms as follows:

For section I

$\Delta f = = -0,1288.\delta^4 + 0,8485.\delta^3 - 0,2947.\delta^2 + 0,026.\delta + 6.10^{-11}$
for resonance № 1

$\Delta f = -1,1666.\delta^4 + 9,9951.\delta^3 - 22,643.\delta^2 + 19,138.\delta + 2.10^{-10}$
for resonance № 27

For section IV

$\Delta f = 2.\delta^2 - 2,6667.\delta + 6.10^{-14}$ - for resonance № 2

$\Delta f = 2,6667.\delta^2 - 3,6667.\delta + 6.10^{-14}$ - for resonance № 5

Here Δf is in Hz, and δ - in mm. These equations are processed to the following:

For section I

$\delta = 0,002.\Delta f^3 - 0,0649.\Delta f^2 + 0.735.\Delta f + 0,1$ - for resonance № 1

For section IV

$\delta = -0,0042.\Delta f^2 - 0,3419.\Delta f + 3.10^{-14}$ - for resonance № 2

$\delta = -0,0025.\Delta f^2 - 0,2627.\Delta f + 1.10^{-14}$ - for resonance № 5

The main criteria for selection of informative resonance frequencies are:

- Target sensitivity of the analysis, which determines the minimum recognizable value of Δf and is related to the scattering of the results for one batch of parts;

- Recognition of resonance; this problem is typical for close-to-order resonances for which overlapping is possible. In this case, the inspection body may make a wrong conclusion. The results of processing multiple experiments show that lower frequency resonances are easier to analyze. For example, the resonance change № 27 of depth incoherence δ in section I shown in Fig. 2 (a) has a theoretical meaning due to difficulties with its registration.

The main factors of scattering for a batch are related to:

- Variations in geometric dimensions of the parts due to technological reasons;

- Non-metal inclusions and porosity of the material (in case the study does not have a purpose for their registration).

3.2. Experimental results

The experimental results were obtained by universal acoustic equipment and were realized in a soundproofed room. Audio signals are recorded in the 20 Hz - 20 kHz range and they are they are entered and saved on a computer via a USB. The samples are suspended on a perfectly flexible and unstretchable thread and are dynamically excited by impulse. Attention is paid to the relatively uniform amplitude excitation of resonant frequencies over a wide frequency range. Registration and frequency analysis of signals is done in digital form by software for a recording time range 0.5 s.

In Fig. 3. a typical experimental result of the resonance recording is shown. By software the exact measured values of the resonant frequencies are determined and the values of Δf are determined according to the depth of discontinuities.
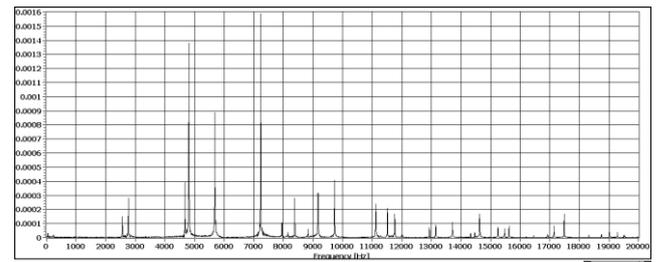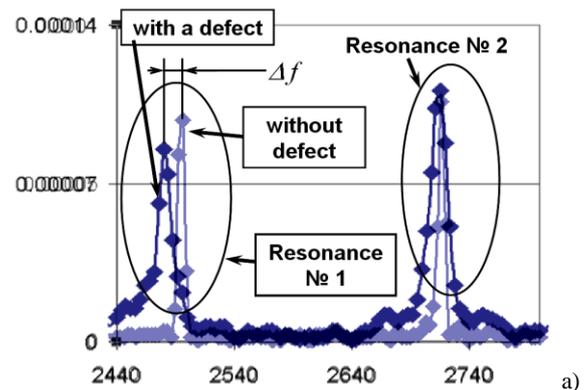

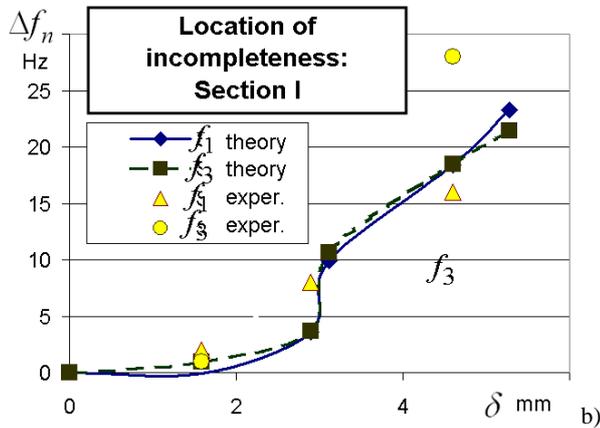**Fig. 3.** *A typical result obtained by experimental study of resonant frequencies.*

Fig. 4. *Stages of the study; a) - to determine the frequency resonance change, b) - to confirm the theoretical results.*

A comparison of the resonance frequencies №1 and №2 obtained for detail without deviation (used as etalon) and for detail with discontinuity 2.5 mm depth in section I is shown in Fig. 4 (a). The figure is shown for illustrative purposes and it is obtained by overlaying screen images of recorded signals and formatted for the same frequency range (2440 to 2780 Hz). It is noted that for the part with discontinuity the first resonance is lower (13 Hz is reading) from the etalon and for the second resonance the both frequencies are equal. Basically, these results correspond to the theoretical values shown in FIG. 2 (a).

A quantitative comparison between theoretical and experimental results in case of discontinuities in section I is made. For this purpose discontinuities with different depth δ are formed in the section of a series part and the frequency difference Δf for each modified part has been measured. The results of the comparison of resonance frequencies № 1 and № 3 are shown in Fig. 4 (b). Principal coincidence between theoretical and experimental results is observed. This allows resonances 1 and 3 to be used for registration and determination of equivalent depth of discontinuities in section I.

4. Conclusion

The approach described above for vibro-acoustic assessment of internal incompleteness in aluminum castings is illustrative and object-oriented. For its application, no specialized knowledge and further continuing training in non-destructive testing is required. The approach is based on general engineering fundamental knowledge in the field of defectology and software products widely used in engineering. It can be applied using affordable acoustic equipment. The assessment of the technical condition of the products is made by comparing the reference resonance frequencies of the studied parts with those obtained for good quality products.

The approach is not universal and requires considerable theoretical and experimental work to demonstrate its validity. But it provides an opportunity for an express assessment of the technical condition of the parts and is cost-effective.

The work may be used for self-assessment by manufacturers of technical condition of cast parts.

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