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DETERMINATION OF VOLUME CHANGES OF PIEZOCERAMICS BY A HOLOGRAPHIC METHOD

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Abstract
In the paper is discussed the application of the holographic interferometry method for determing the properties of piezoceramics excited by an HF voltage source. The method allows the evaluation of the surface form of vibrating piezoelements in relation to the resonant frequencies. On the basis of the changes it is possible to determine the mounting of piezoelements and the non-homogeneity of the material which influences piezostriction, respectively.

Keywords: piezoceramics, piezostriction, holographic interferometry, elastic deformation, vibration of the plate.

1. Introduction

Piezoceramics have a wide utilization in technical practice. In their application it is necessary to take into account various shapes and properties of the employed elements. A knowlegde of the parameters of the individual piezoceramic elements allows an optimum operation and utilization of the equipment. For the determination of the parameters of piezoelectric elements is most suitable the holographic interferometry method.

2. Properties of piezoceramics and their utilization

In piezoelectric substances is set up as a consequence of elastic deformation an electric polarization P which leads to a measurable surface charge between the corresponding parts of the substance surface. Its magnitude is proportional to the deformation and thus also to the force which has caused it. To the piezoelectric phenomenon exists an opposite phenomenon which is called piezostriction when an electric field of the intensity E, applied to the piezoelectric substance, evokes in it a corresponding magnitude of the elastic deformation. Piezostriction is often utilized for fine shifts of subjects, for the drive of vibrating motors or for the excitation of ultrasonic waves.

For a practical many-sided utilization have been developed several types of substances with different properties which exhibit the piezoelectric phenomenon. For the verification of the method was used a sintered powder material on the basis of lead titanate-zirconate $Pb(ZrTi)O_3$ in the form of a circular plate with a diameter of (50,0 ± 0,1)mm and a thickness of (6,00 ± 0,05)mm, made by moulding [1]. This substance with an admixture of silver is denoted by the manufacturer with the code number 841.

There have been measured the properties of the employed piezoceramic plate with regard to the applicability for the excitation of ultrasound or for the fine control of microshifts in optical interference systems. Furthermore was investigated the influence of mounting of the piezoceramic plate onto its deformation upon application in the above mentioned cases. Shifts and deformations of the upper plate surface in the direction of the z-axis have been evaluated by the holographic interferometry Metod.

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3. Employed holographic method

The method is based on the interferometry of mobile objects. Its essence in the continuous exposure of a continuously changing scene. It is possible to monitor the uniform straightline movement and the vibrating harmonic movement. The object under observation has a diffuse reflective surface.

Upon the movement of points of the object with the same velocity depends the intensity of the set up image wave on the overall track, along which the points move. Upon the movement of points at different velocities are set up interference fringes which are dependent on the intensity of the incident light. Since the values of the maximum intensity are rapidly decreasing, the practical utilization of this method is limited to an overall shift of the object in the order 10 μ m. The necessary exposure periods can be from several ns up to several minutes, i.e. that the measurable velocities are within the limits from $10^{-9}\,ms^{-1}$ up to $10^{3}\,ms^{-1}$.

Upon a harmonic vibrating movement of the object, in which all points vibrate with the same amplitude, the overall brightness of the image depends on the intensity of the incident light. The points of the object which vibrate with different amplitudes, cause the formation of interference fringes, from which can be determined the nodal areas and the locations of equal amplitudes.

For comparing the influence of volume changes are presented in Fig.1 patterns of a vibrating membrane [2], determined by the interferometric method. The holographic method gives more detailed results than those provided by the study of Chladni patterns and its advantage lies above all in the fact that it is not limited onto flat areas and does not require polished surfaces.

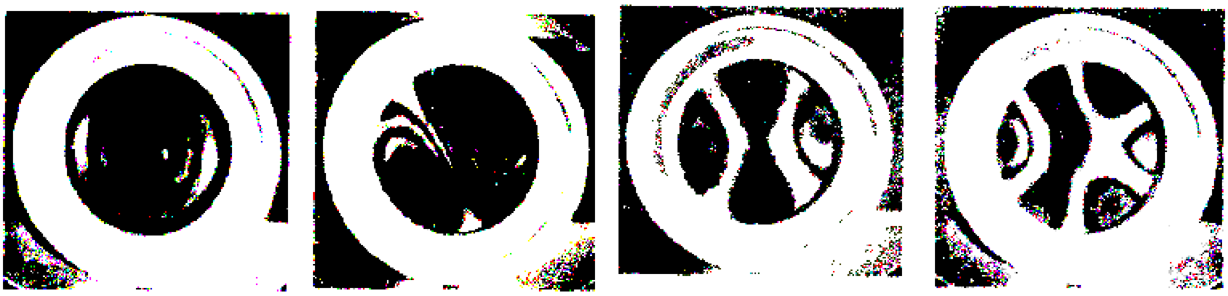

Fig.1 Patterns of a vibrating membrane

This holographic method of a vibratory movement is identical with the double exposure interferometry whan one exposure takes place upon each odd reciprocating position of the object and the second upon each even reciprocating position. The nodal curves are permanently at rest and therefore in these locations the holographic image is most intensive. Apart from these basic interference fringes will appear further fringes which correspond to the magnitude of the volume changes of the measured object.

The vibrating movement of the objects can also be studied by the method of „live“ fringes. The hologram is first of all recorded in the non-vibrating state. After developing it is inserted accurately into its original location. Through an interference of the reconstructed wave with the reflected wave are set up „live“ fringes which have a relatively low contrast.

4. Arrangement of the measuring system (experiment)

The arrangement of the system of the employed holographic method is shown diagramatically in Fig.2 [3]. There was used the He-Ne laser light source with a wave length of the light 632,8 nm. The light from the laser L impinges after passage through the shutter U onto the dividing prism D which separates the laser ray into two beams. The first beam - reference (comparison) beam - passes after passage through the space filter F_1 the objective L_1, by which is formed a parallel beam of rays. Through further optical elements it is deflected onto the holographic plate H. The socond beam - object (measuring) beam - passes through the space filter F_2 and after passage through the objective L_2 forms a parallel beam of rays. After impinging onto the measured object P it is reflected into the plane of the holographic plate H where together with the reference beam of rays interference takes place. In Fig.3 is a photograph of the experimental arrangement.

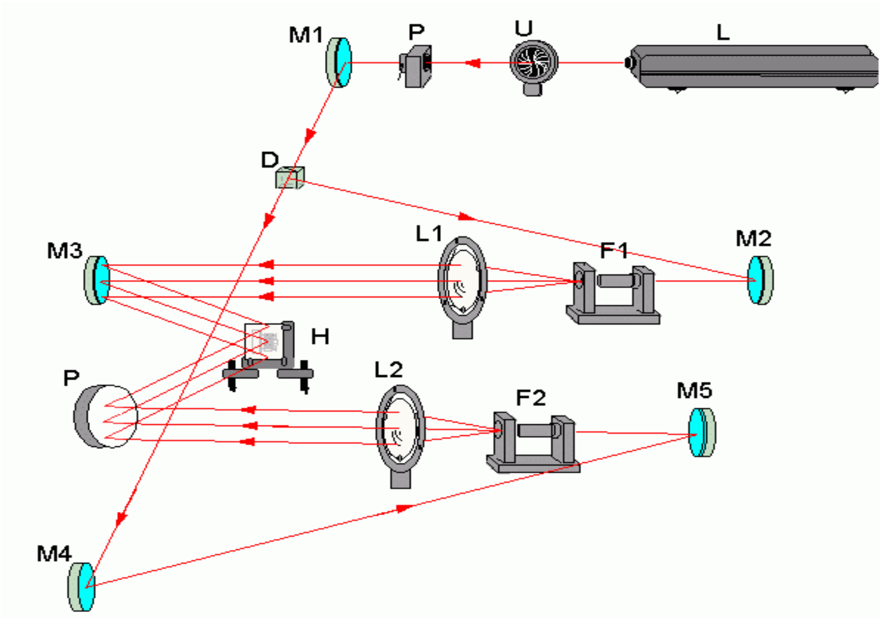

Fig.2 Diagramatic arrangement of the holographic method

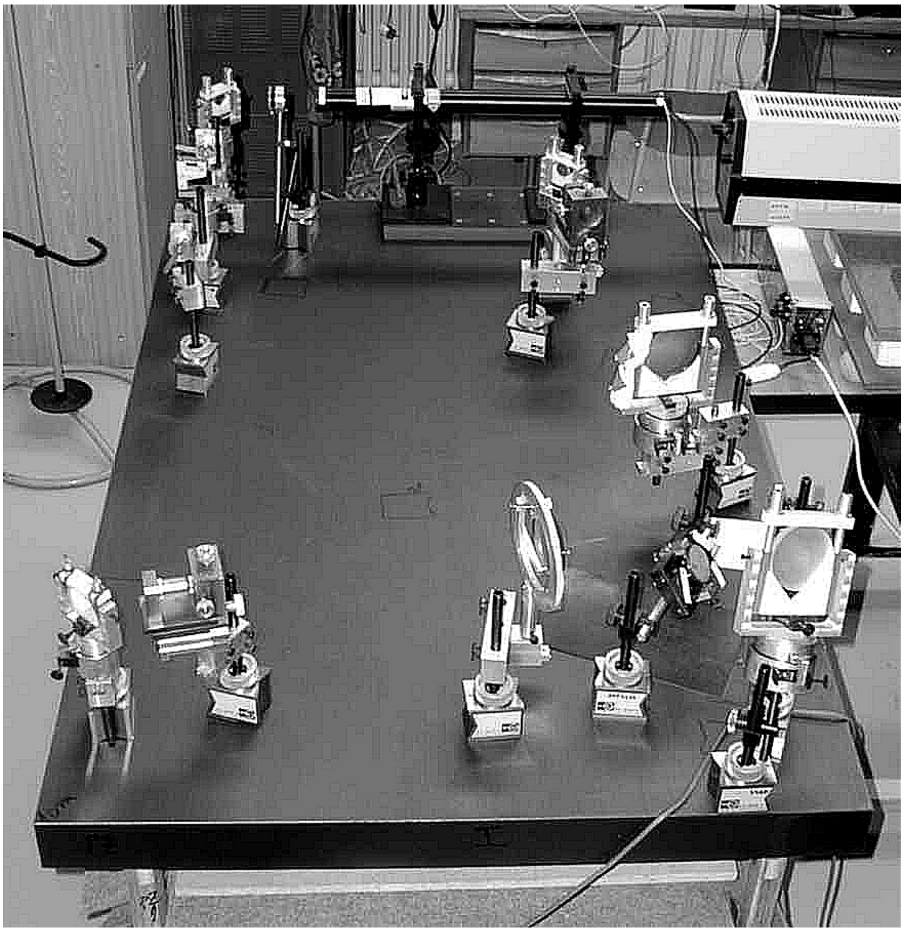

Fig.3 Photograph of the arrangement of the measuring system

5. Recordings of the measurements

In Fig.4 are presented eleven interference recordings of vibrations of a piezoceramic plate by the finite fringe width method for various frequencies of the alternating voltage excitation source.

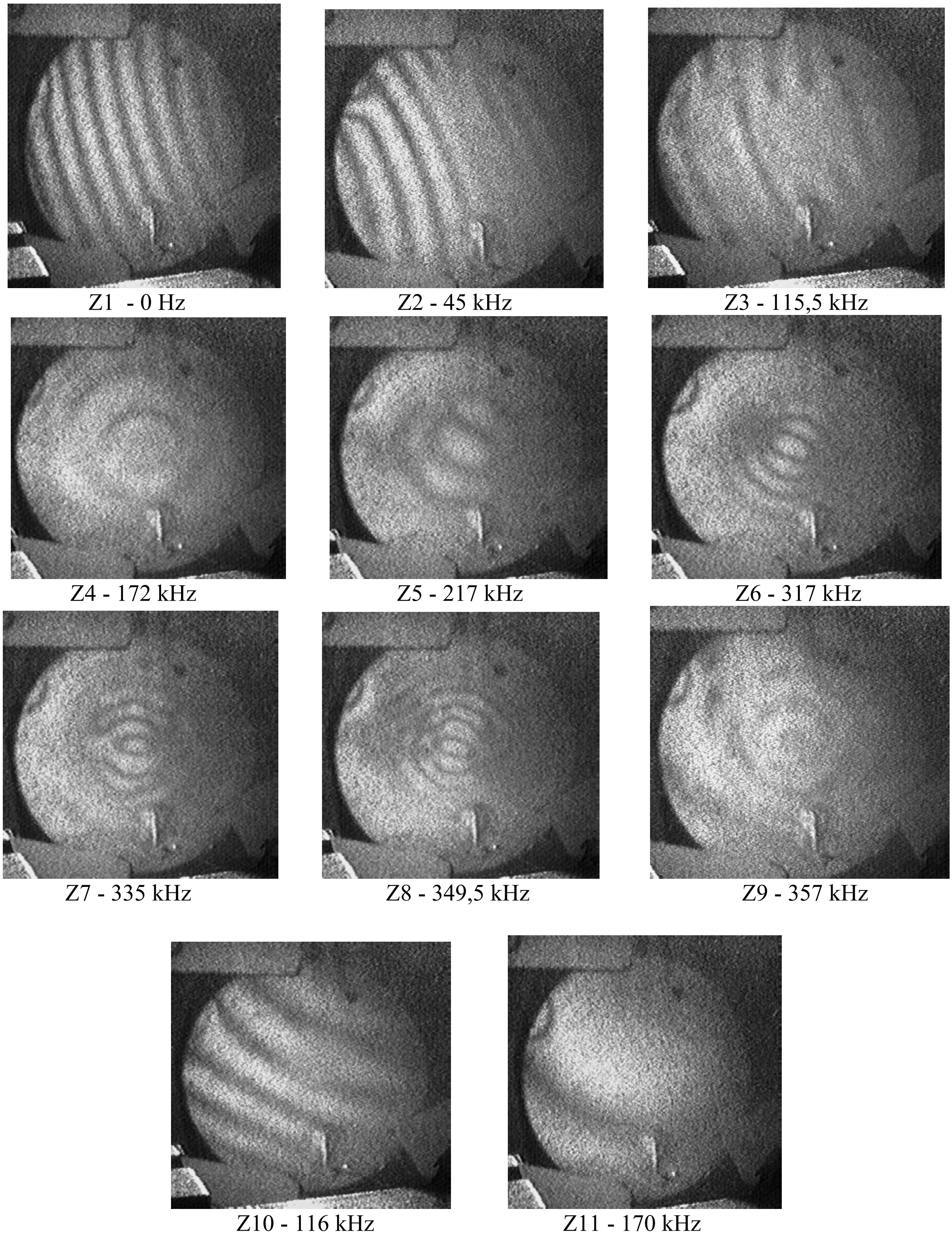

Fig.4 Interference recordings of vibrations of a piezoceramic plate for different frequencies of the supply source

6. Evaluation of the measuremets

The reason for measuring the expansion of a ceramic plate with a perovskite structure (e.g. mixed systém $PbZrO_3$ - $PbTiO_3$) was to monitor the complicated behaviour of possible occurances of transitions between para-, ferro- and antiferroelectric states; these phenomena can be influenced also by admixtures of other substances which during production enter into the resultant specimen in an uncotrolled manner. The properties of the produced ceramic plates can therefore have, upon a mutual comparison, different properties. For the practical application of ceramic plates is of greater importance the knowlegde of the dependence of expansion on electric voltage and the thus caused change of the intensity of the electric field *E* in the plate.

During the measument the investigated plates must be in a vertical position, in which they are pressed by a steel spring to the foundation plate. The pressure of the spring causes a piezoelectric phenomenon and the magnitude of the polarization in the substance must be corrected by the relationship [4]

$$P = Z\,d + E\,\varepsilon_0\,\kappa\,, \qquad (1)$$

where *Z* is the mechanical tension, *d* the thickness of the piezoelement, *E* the intensity of the electric field, ε_0 the vacuum permitivity and κ is the electric susceptibility.

The elastic deformation δ is determined by the relationship

$$\delta = Z\,s + E\,d_{33}, \qquad (2)$$

where *s* is coefficient of elastic compliance and d_{33} the piezoelectric constant.

The image of the vibrating plate formed by the holographic method was by a change of the reference ray inclined by a small angle in such a way with regard that the upper area of the plate image was with regard to the real area of the plate inclined by an angle $1{,}0.10^{-4}$ radians. This so called method of finite fringes forms on the plate interference fringes. The recording Z1 depicts the situation before the application of a voltage onto the plate electrodes. Eight fringes have been formed which have a direction perpendicular to the inclination of the plate image with regard to the real position of the plate position. The evaluation of the recordings is more difficult than in the infinite fringe method and does not allow in the majority of cases the execution of a quantitative evaluation of the shifts, but it is very sensitive onto the magnitude of the shifts, i.e. onto the magnitude of the voltage applied onto the plate.

Z2 depits the situation at a supply voltage frequency of 45 kHz when the vibration amplitude of the upper plate surface has the magnitude $\lambda/2$ ($\lambda = 632{,}8$ nm). This proves a shift of the interference fringes into the locations of the previous light fringes. Simultaneously the fringes attain a curved shape and in the middle section they are smeared. The curvature proves that the plate does not raise its surface uniformly in the course of vibrations, but it forms a saddle. Clearly visible are the first four fringes, the following two are smeared in the middle, because their amplitude is not a multiple of $\lambda/2$. With regard to the curvature of the fringes the amplitude in this section will not be larger than $\lambda/2$, but smaller.

More complicated is the vibration waveform on Z3 which was recorded at a frequency of 115,5 kHz. The locations with distinct dark or light fringes correspond to an amplitude which is a multiple of $\lambda/2$, the grey locations vibrate with different amplitudes.

Simpler is the situation on Z4 where at a frequency of 172 kHz the vibrating plate will form at the moment of the largest deflection a spherical cap. The horizontal fringe (dark or light) was transformed onto an ellipse that differs only very little from a circle which is a point of intersection of a plane parallel with the plate of a holographicaly created pattern of the upper plate surface and the real upper surface of the plane on its margin cambered by vibrations. The numbers of fringes in the form of a circular ring in the recording allows the determination of the deviation of the peak from its original position. Here can by seen two dark fringes from which follows that the peak has spaced itself by $2\lambda/2 = 0{,}632\,\mu$m. If the upper surface is considired as a spherical cap, than the radius of the corresponding spherical surface is 178 m.

In the recording Z5 the cap does not form part a sphere, but of an ellipsoid. In the direction from the bottom left-hand corner to the top right-hand corner the curvature of the cap is slightly larger than in Z4. In this recording at right angles onto the previous direction the radius of the curvature is more than twice as large and its magnitude can no longer be estimated. The recording Z5 was made at the alternating voltage frequency of 217 kHz.

In the recording Z6 at a frequency of 317 kHz the situation is similar, but the curvature radius is half, i.e. approximately 89 m, because the number of fringed is twice as large. In a perpendicular direction the curvature radius is again unmeasurable and larger than 350 m.

In Z7 and Z8 is the largest curvature approximately the same as in Z6, but the plane of incliation of the original plate surface formed by a moderate deflection of the reference ray has shifted into the vertical direction. The curvature in the horizontal direction can be approximately estimated as 350 m, since the rise of the cap centre with regard to the left-hand disk margin is roughly one fringe, i.e. $\lambda /2$. The recording Z7 was made at a resonant frequency of 335 kHz and Z8 at a frequency of 349,5 kHz.

The vibrations of the plate in Z9 do not differ too much from Z4 and were recorded at a frequency of 357 kHz. The deviation has manifested itself through the influence of a magnification of the marginal stain which is located in the left-hand top part. The influence of this stain manifests itself on all the recordings. It was probably caused by a non-homogeneity of the material at the location of the stain on the plate. Since the centre of non-homogeneity is always white, it is not influenced by the applied voltage. Therefore at the given location there occurs no piezostriction and this part of the plate does not vibrate. A pit is forme which on Z9 reaches furthest, approximately up to a distance of 8 mm.

On the recordings Z10 at a frequency of 116 kHz (close to the frequency on Z3) and Z11 at a frequency of 170 kHz (close to the frequency of the recording Z4) has occured a change in the inclination of the plate surface with regard to the initial state.

7. Conclusions

The method of holographic interferometry is a contactless and non-destructive method which allows the evaluation of the surface shape of a vibrating plate excited by an alternating voltage source of resonant frequencies. The individual resonant frequencies influence the shape of vibrations of the plate surface, and this allows to select a suitable resonant frequency for a concetrate application. Furthermore from these changes can be determined the influence of the mounting of piezoelements on their vibrations and thus can be optimated the construction of equipments, jigs and fixtures. A further positive contribution of this method is the nonambiguous determination of the shape of possible non-homogeneities as well as their position in the plate material which influence piezostriction.

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