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TEMPERATURE DISTRIBUTION ALONG A CYLINDER SURFACE WITH A NON-LINEAR ULTRASONIC WAVE

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In the present paper the experimental apparatus and some results connected with the measurement of temperature distribution along the surface of a solid sample, across which an ultrasonic wave with a high amplitude is passed, are described. The sample is in the shape of a cylinder, the used ultrasonics frequency is 21.2 kHz.

INTRODUCTION

The problem of non-linear waves propagation has lately come to the fore mainly due to the fact that intensive ultrasonic waves have been used more frequently. Non-linear phenomena which appear at such waves propagation are of basic importance in non-linear acoustics, the results of which have been lucidly elaborated by Zarembo, Krasiľnikov [1] and Ostroumov [2]. The present paper deals with the phenomenon which creates a maximum temperature on the surface of a solid sample, across which an ultrasonic wave with a high amplitude is passed. This phenomenon has not been described yet in literature. It can be supposed that there are more mechanisms contributing to its existence.

EXPERIMENTAL METHOD

A magnetostrictive transducer [1] operating within the range of low limit ultrasonic frequencies, i. e. about 20 kHz, is suitable for the generation of longitudinal ultrasonic waves in a solid material. With regard to fixing, the transducer should be completed by a half-wave resonator, fixed in the nodal plane of the acoustic particle velocity. To obtain intensive ultrasonic fields, an ultrasonic horn must be used [3], which works as an acoustic particle velocity transformer. The used magnetostrictive transducer completed by the half-wave resonator and cathenoidal horn is in Fig. 1.

The dimensions of the half-wave resonator as well the ultrasonic horn were calculated for the frequency of 21.2 kHz, corresponding to the resonant frequency of the used transducer. The radiating area of the magnetostrictive transducer is square with the sides of 2.5×10^{-2} m, the height of the sheets of the magnetostrictive core being 1.15×10^{-1} m. The ultrasonic horn has a circular section, the input area diameter is 3.5×10^{-2} m, the output area diameter is 5×10^{-3} m. The core of the transducer is made from permendur CV 49, the half-wave resonator and ultrasonic horn are from brass. With regard to the lowering of acoustic energy losses on junctions the individual components are silversoldered together over the whole areas.

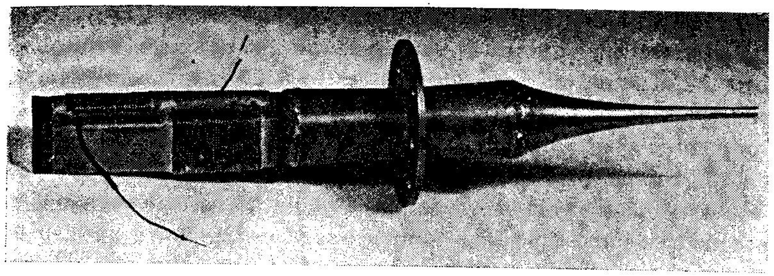

Fig. 1. A magnetostrictive transducer with a half-wave resonator and horn.

For transducer feeding an ultrasonic generator VUMA-UG 250 with the following parameters was used: power input 750 W, power output 250 W and the frequency 18—26 kHz.

The resonance state and particle amplitude of an acoustic wave were determined optically, by means of a microscope (magnification 80×) with a measuring eyepiece. At the beginning of measurement, when the ultrasonic generator was switched off, a mark on the horn output was determined. After the ultrasound excitement instead of the mark a small surface was observed, the width of which corresponded to the double value of the particle

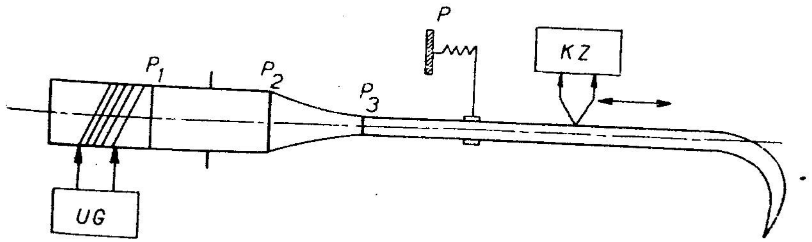

Fig. 2. Block scheme measurement. UG — ultrasonic generator; KZ — recorder; P — spring; P_1, P_2, P_3 — acoustic couplers.

amplitude of the acoustic wave. The resonance state was determined by such a frequency at which the width of the measured mark was a maximum one.

For surface temperature measurement a thermocouple of the constantan-iron type was used. The thermocouple was connected by mechanical transmission with an electrical motor enabling a uniform shift of the thermocouple along the surface of the investigated material. The thermocouple was moved along a surface moistened with a suitable liquid, which secured its thermal contact with the studied sample. The thermocouple data were registered by a recorder of the type ekBT 1 EX. The measurement of temperature distribution is represented by the block scheme in Fig. 2.

The studied material had the shape of a cylinder with the diameter of 5×10^{-3} m and the length of 1 m. Such a shape of the sample is suitable with regard to the horn output area and enables to realize situations close to the one dimensional case. The end of the sample had the function of an absorber which prevented the formation of a standing ultrasonic wave. The coupler P_3 between the sample and the ultrasonic horn (Fig. 2) could not be devised in the same way as the couplers P_1, P_2 because in this case an exchange of the sample would be impossible. The sample was therefore losely applied to the output area of the ultrasonic horn and pressed to it by the spring P.

EXPERIMENTAL RESULTS

The measurements were made at room temperature 24 °C. After adjustment of both the resonance frequency and the power output, the temperature distribution along the surface of the studied sample was observed. The samples were made of some metals (brass, steel) and some synthetic materials (novodur, texgumoid). The sample material was chosen at random since it was not the properties of the concrete material which were studied, but the experimental verification of some theoretical results of the calculation of temperature distribution along a cylinder was performed with a non-negligible ultrasound absorption.

When the metals were investigated, no temperature deviations were found along the sample exceeding measurement errors. During the investigation of the synthetic materials the measured sample showed a temperature maximum. The scanning of the temperature distribution showed a practically constant temperature of the sample surface along the longitudinal direction except in the place with the maximum of temperature, which was rather conspicuous. The temperature maximum shape is represented in Fig. 3. At the ultrasound, whose amplitude of the acoustic wave had reached the value 2.5×10^{-5} m on the horn output, this maximum was evidenced by the melting (novodur) or carbonization (texgumoid) of the sample. That enabled to look for a maximum temperature position by means of a heat effect on the sample material. After the ultrasound switching off, the heated place remained apparently deformed or carbonized (Fig. 4). The width of the overheated place was about 3×10^{-3} m. At the maximally possible particle amplitude of the acoustic wave 3.5×10^{-5} m another temperature maximum, more distant from the beginning of the rod, was formed. The temperature of the second maximum was lower than that of the first.

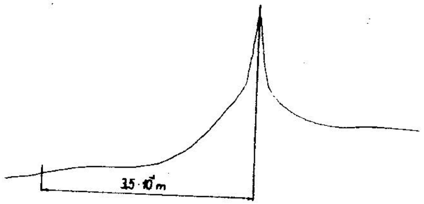

Fig. 3. The shape of the temperature maximum.

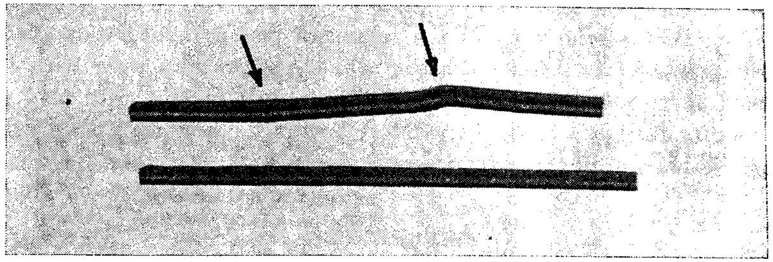

Fig. 4. A part of the novodur sample before and after deformation. Arrows pointing at temperature maxima.

A set of measurements was made for novodur, the measuring density of which is 3.8×10^3 kg m^{-3}. The first temperature maximum arose at a distance of about 3.5×10^{-2} m, the second at a distance of about 9×10^{-2} m from the beginning of the sample. The temperature of the first maximum exceeded the temperature of the surroundings by about 50 °C. Under the same conditions the maxima position was reproducible. With the use of more samples, even when of the same material, the maxima were shifted by about $\pm 10^{-2}$ m. However, this fact can be explained by the apparatus not guaranteeing ideal reproducibility of acoustic conditions on the boundary between the sample and the ultrasonic horn.

CONCLUSIONS

The experimental results obtained so far do not enable a thorough theoretical explanation of the studied phenomenon. The temperature maximum is probably due to more mechanisms related to the rise of the shock ultrasonic wave as well as to the internal friction in solid materials. The theory of internal friction in solid materials has not been elaborated for the case of nonlinear waves to such an extent that the amount of the internal friction influence on the considered effect [4] could be determined. However, some results can be obtained on the assumption that the origin of the temperature maximum is connected with the origin of the shock ultrasonic wave in the solid material [2]. Supposing this fact, however, it is possible to explain the different behaviour of metals and synthetic materials since, according to [2], the heat quantity associated with the rise of the shock wave is in an inverse proportion to the density of the material. Synthetic materials have an advantage because of their small heat conductivity, due to which the generated, arising heat is spent for a temperature increase in the close neighbourhood of the place of its origin only. The temperature maximum position can be calculated on the assumption that a solid body in the region of plastic deformations behaves similarly as a compressible liquid across which an ultrasonic wave with a final amplitude is propagated [4]. The results obtained in this way may serve as a basis for further investigations. More accurate conclusions can be drawn only on the basis of further experimental results.*

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