Fyz. čas. SAV 21 (1971), No. 2-3

DISTRIBUTION OF *P*-WAVE AMPLITUDES OVER A QUARTZ SPHERE

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The paper describes the experimental investigation of the distribution of *P*-wave amplitudes over a quartz sphere, using the pulse method. Maps of isolines of the amplitudes of elastic pulses A_{01} and A_{02} and of isolines of the *P*-wave propagation velocity were obtained. The results of the measurements have been compared qualitatively with the deflections of the Poynting vector from the direction of signal propagation. A marked correlation has been found between the direction of the Poynting vector and the amplitude distribution. In order to evaluate the quality of the quartz sample used, the velocities of *P*-wave propagation were computed using the elastic constants of quartz and compared with the observed ones.

I. INTRODUCTION

The ideas concerning the internal structure of the Earth are mostly founded on the interpretation of the kinematic parameters of seismic waves, recorded during earthquakes and explosions. Only lately has attention been devoted to the dynamic properties of seismic waves, which are more sensitive to the changes of the internal structure of the Earth. In interpreting the kinematic and dynamic parameters of seismic waves, one assumes that the internal structure of the Earth is stratified and that the individual layers are homogenous and isotropic.

However, laboratory measurements with various types of rocks have indicated that the velocity of elastic waves depends on the direction of propagation with most rocks, i. e. that the rocks are anisotropic. Also seismic field measurements, carried out between California and the Hawaii [1] and near Hawaii [2], substantiate the fact that elastic anisotropy is not only of local importance, but that it is displayed by whole structure. It follows that the anisotropy of the physical properties of rocks will have to be taken into account in interpreting geophysical data.

* Geofyzikální ústav ČSAV, PRAHA 4, Boční II. č. p. 1401.

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This is the reason why the anisotropy of rocks is being studied systematically in the Geophysical Institute of the Czechoslovak Academy of Sciences [3—11], the main attention having been hitherto devoted to the kinematic parameters of *P*-waves. The present paper is an attempt at evaluating the dynamic parameters of *P*-waves in an anisotropic medium.

II. EXPERIMENTAL METHOD

The measurements were carried out with a spherical sample, the shape of which allows for the signal to be propagated in an arbitrary direction and does not require any assumptions as regards the internal symmetry of the material, which cannot be always predetermined in a polycrystalline aggregate like a rock. The *P*-wave amplitudes were measured by propagating short ultrasonic impulses through the sample; at the same time, the time required for the elastic pulse to propagate through the sample was observed. For reason of method, a mineral of known properties, a quartz singlecrystal, was chosen for the first set of measurements. The spherical sample had a diameter of 75.92 mm and had been ground optically on the surface.

Two methods of recording the wave image from the sample were used during the measurements. The wave image was recorded along discrete directions on the one hand, and the *P*-wave amplitudes were continuously recorded as the sample rotated, on the other.

The experimental equipment, which is shown schematically in Fig. 1, has a revolving table with a sample holder and two mutually perpendicular protractors for setting the sample in the required position. Electro-acoustic

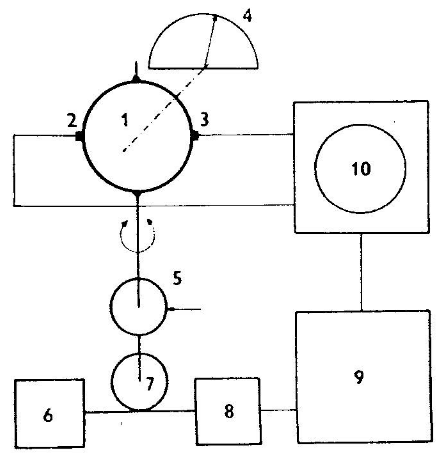

Fig. 1. Diagram of the equipment for investigating the elastic anisotropy of rocks. 1 — spherical rock sample, 2, 3 — piezoelectric transducer, 4 — vertical protractor, 5 — horizontal protractor, 6 — electric motor, 7 — turntable, 8 — precise potentiometer, 9 — *X*-*Y* recorder, 10 — apparatus for measuring the elastic parameters of rocks.

transducers make contact with the sample at points where the line joining them would pass through the centre of the sample perpendicularly to the axis of rotation of the table. The active elements of the transducers were made of a lead-zirconate-titanate type of ceramic material, with a diameter of 4 mm and an inherent frequency of 3 MHz. An instrument developed in the Geophysical Institute and described in [10, 11], was used to excite and record the ultrasonic signals. In the course of the continuous sampling along a profile, the table with the sample was turned continuously by a motor over a range of 0—360° and back again. The revolving motion of the table was electrically coupled with the X-axis of an $X - Y$ recorder.

The direction of the measurement were determined with respect to a meridian-parallel grid with steps of 15°. With a view to the known symmetry of quartz, the Z-axis determined optically was selected as the axis of the grid.

The discrete measurements were carried out when the sample was stationary at the intersections of the meridians and parallels of the grid mentioned. The wave image, picked up by the electro-acoustic transducer, was recorded photorgaphically (Fig. 2) and for each direction A_{01}, A_{02} amplitudes and the time of propagation of the signal through the sample were determined from the record. The system selected allows for measurements to be made in 133 independent directions.

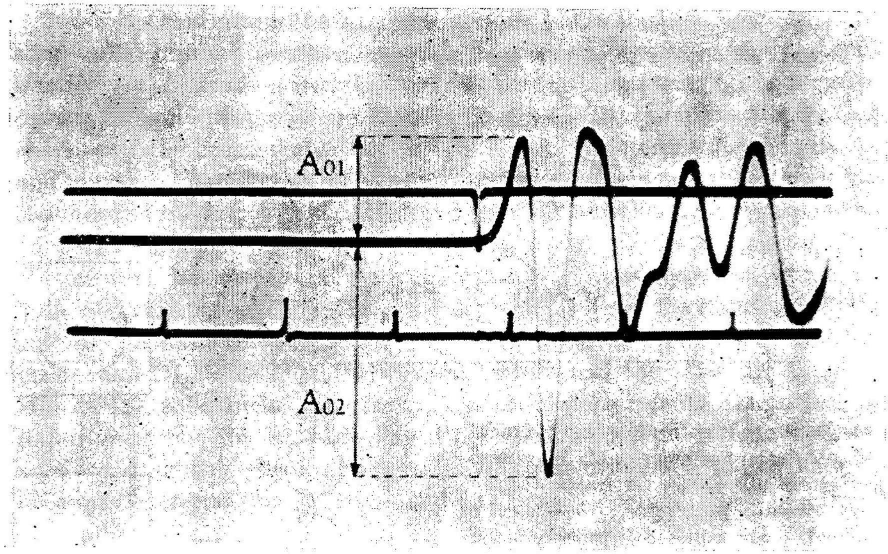

Fig. 2. Example of a record of the ultrasonic signal on the tube screen. Time scale division 1 μs. The arrows indicate the measured A_{01} and A_{02} amplitudes.

Continuous measurements were executed along meridional circle for 12 independent profiles on the whole. All the profiles passed through the Z-axis of the sample. The operator compared the A_{01} or A_{02} amplitude on the screen of the tube with the amplitude of an auxiliary HF signal, which was converted to D. C. voltage and recorded on the Y-axis of the $X - Y$ recorder. An example of a continous record of the A_{01} amplitude is shown in Fig. 3. The circle in the graph indicate the values of amplitudes obtained from discrete measurements.

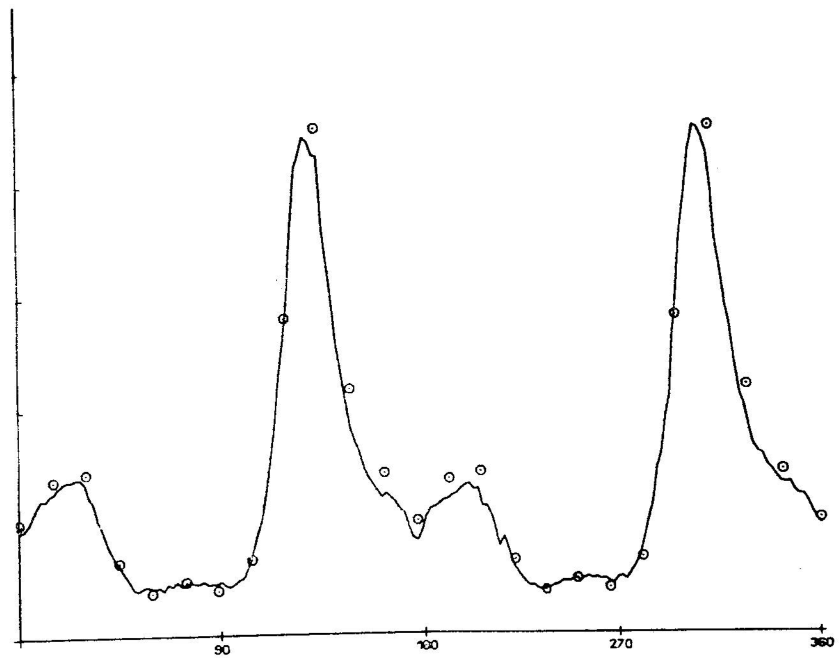

Fig. 3. Example of a continuous record of the A_{01} amplitude along a profile in the Y-Z plane. The circles in the graph indicate the corresponding measurements of the A_{01} amplitudes in discrete directions.

An acoustic contact of the transducers with the sample was achieved in both cases by a thin layer of transformer oil. In the case of discrete measurements the contact is stationary and in the case of continous profile measurements it is sliding. The comparison of the results pertaining two both methods of measurement is shown in Fig. 3 and it indicates that the change in the nature of the contact does not affect the magnitude of the amplitude substantially.

III. RESULTS

So far, from the obtained data the amplitude and velocity measurements in discrete directions have been treated. The time of propagation of the signal through the sample was used to determine the P-wave velocities [13], which were plotted with the help of a system of isolines in a cylindrical grid (Fig. 4). In order to evaluate the quality of the samples used, the isolines of P-wave velocities were also calculated using the elastic constants mentioned in A. J. de Witte's paper [14], see Fig. 5. The comparison of both figures shows that the observed velocity distribution agrees well with the computed one.

In the same way, i. e. using isolines, the sets of values of A_{01} and A_{02} amplitudes were treated (Figs. 6 and 7). The A_{01} and A_{02} isolines have a compatible hcaracter and also the position of the extremes agree, so that one may assume that the A_{01} and A_{02} amplitudes both belong to the P-wave group. The only difference is represented by the more marked local extremes of the A_{02} amplitudes in the equatorial regions.

Owing to the known fact that in an anisotropic medium the energy flux does not in general agree with the direction of propagation of the wave, the direction of the Poynting vector [12] was determined for all points investigated. In Fig. 8 each of the vectors computed is marked by a point towards which it is directed. By joining these points, a deformed grid is obtained, the densifications and rarifications of which correspond to the particular amplitude

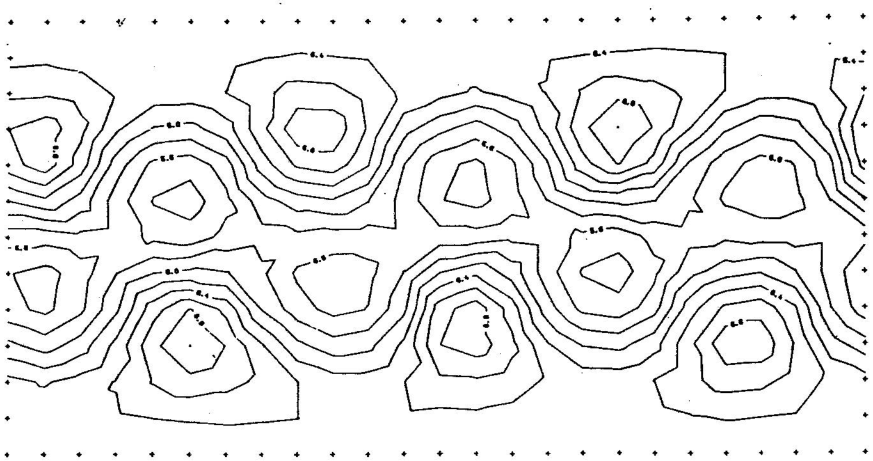

Fig. 4. Isolines of observed P-wave velocities in cylindrical projection. The isolines were constructed for values of 5.6 km/s to 7.0 km/s in steps of 0.2 km/s.

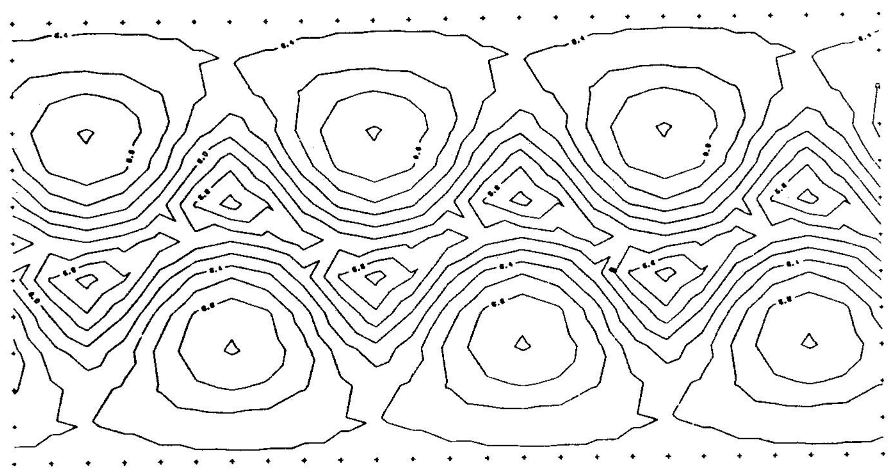

Fig. 5. Isolines of computed P-wave velocities in cylindrical projection The isolines were constructed for values of 5.4 km/s to 7.0 km/s in steps of 0.2 km/s.

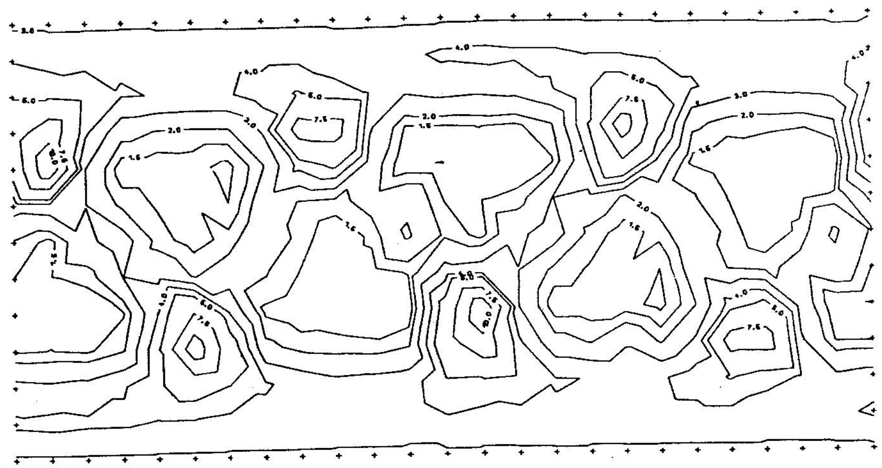

Fig. 6. Isolines of A_{01} amplitudes in cylindrical projection. The isolines were constructed for values of 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 7.5, and 10.0 (arbitrary units).

extremes, as can be seen by comparison with Figs. 6 and 7. Furthermore, bold lines were used in Fig. 8 to indicate isolines of the deviation of the Poynting vector from the direction of the wave propagation. The Poynting vector displays zero deviations in loci of maximum densification and rarification

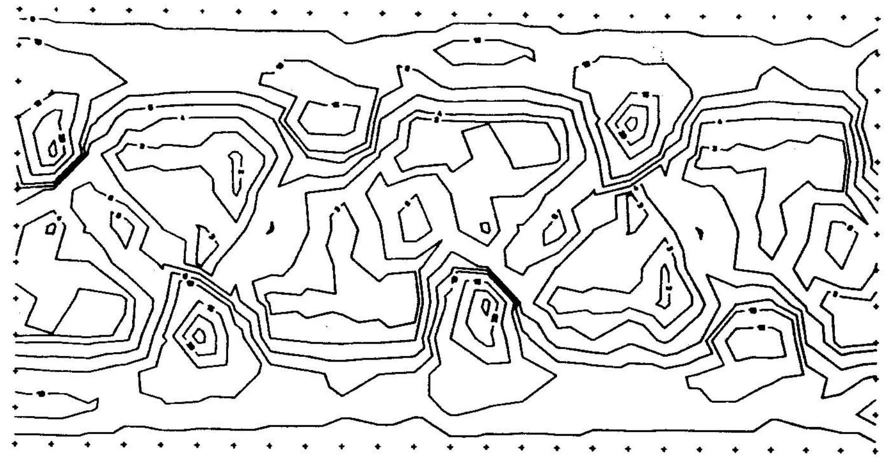

Fig. 7. Isolines of A_{02} amplitudes in cylindrical projection. The isolines were constructed for values of 2.0, 3.0, 4.0, 6.0, 8.0, 10.0, 15.0, 20.0 and 25.0 (arbitrary units.)

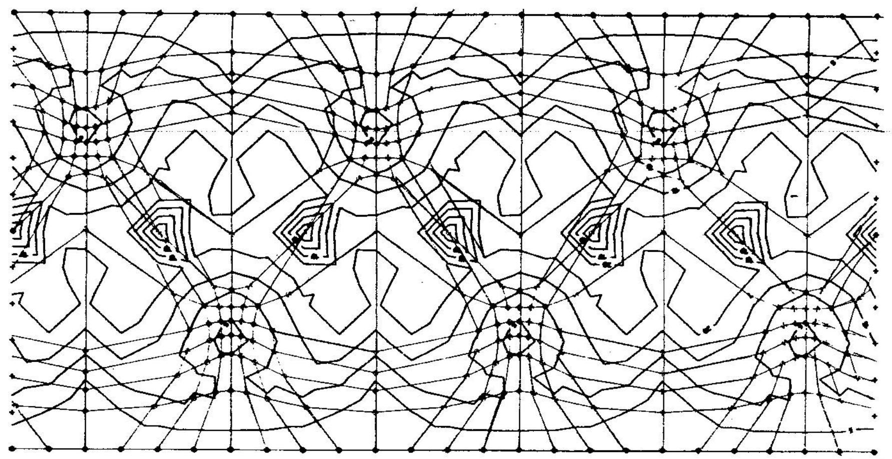

Fig. 8. Orientation of the Poynting vector and the isolines of its deviation from the direction of propagation of the P-waves in cylindrical projection. The circles indicate the points to which the computed Poynting vectors are directed for the directions of propagation of the waves in a regular meridian-parallel grid with steps of 15°. The deformed grid has been included by thin lines. The system of isolines is shown by bold lines. The isolines were constructed for values of the deviation of the Poynting vector from the direction of wave propagation of 5, 10, 15 and 20°.

of the deformed grid, which corresponds to the position of maximum and minimum amplitudes. There are also six points of zero deviation in the $X - Y$ plane, the position of which agree with the local amplitude maxima. A zero deviation of the Poynting vector may also be observed along the Z-axis. This corresponds to a local minimum in the maps of amplitude isolines.

There are other hitherto uninvestigated factors, which have an effect on the amplitude of the observed P-waves. This includes the change in the transmission coefficient between the transducer and the sample due to the anisotropy of acoustic resistance and the inherent dissipative attenuation. Although these factors were not investigated, the expressive correlation between the orientation of the Poynting vector and the observed amplitudes leads one to assume that the orientation of the Poynting vector in dependence on the direction of the propagation of the signal through the sample affects the dynamics of elastic wave propagation in anisotropic media in a substantial way.

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Received November 10th, 1970