

Preface

The development of various branches of modern natural sciences is closely related to the theoretical and applied problems of interaction between different media and fields. Interaction problems are fundamental in the new, rapidly progressing field of mechanics of deformable solid bodies in the context of the theory of magnetoelasticity, which is the study of complex fields and processes in deformable bodies under the influence of external electromagnetic fields. The interest in investigations in this scientific field is due to the importance of quantitative study and evaluation of the effects of interaction between mechanical and electromagnetic processes as well as their practical application. An important consideration in the theory of magnetoelasticity is the issue of vibrations and the stability of thin elastic conductive plates and shells in electromagnetic fields. A good understanding of these issues can lead to truly integrated structures that are able to perform multiple structural as well as electromagnetic and electromechanical functionalities. Structures featuring multiple functionalities are likely to revolutionize the concepts used in design including that of the next generation of aerospace vehicles. These interactions generate new important physical and mechanical phenomena that can affect advanced technology in a beneficial way. For example, these include the generation of different types of resonant vibrations; the noncontact transfer of disturbances; and the design of the next generation of magneto/electro material structures used in active controls. Obtaining the best possible knowledge of the phenomena generated by magneto-elastic interactions and their investigation constitute an important task of modern mechanics. A number of results generated by these phenomena will contribute dramatically to the development of advanced technology, such as the design of electromechanical converters, which can be widely used in important and prospective branches of the economy as well as the medical industry, material science, the instrument-making industry, radio engineering, electronics as a part of selective devices, automatic, telemechanics, and the measurement of technology such as parametric converters. The results of the proposed research can be used also in seismology to design devices for seismic observation.

The purpose of this book is (1) to acquaint the reader with the methods, mathematical modeling techniques, and solutions of nonstationary dynamic problems in the theory of magnetoelasticity; and (2) give the reader an idea of the wealth of physical effects caused by the interaction of electromagnetic and mechanical phenomena in conductive thin elastic bodies. The study is limited by the model of an elastic body under the assumption of small deformations.

In the first part of the book (Chaps 1–6), the basis of the main nonlinear equations and relations of mechanics and quasi-static electrodynamics of continuous media, linearization of the system of equations of magnetoelasticity, surface conditions, and constitutive equations are obtained as is describing the behavior of disturbances in a nonferromagnetic conducting medium interacting with an external magnetic field. On this basis, using the generalized hypothesis of magnetoelasticity of thin bodies, the two-dimensional linearized equations and relations of magnetoelastic vibrations and stability of plates, as well as cylindrical and spherical shells, are derived. The mathematical modeling of examined processes is presented, according to which the problem of magnetoelastic vibrations of thin bodies (plates and shells) is reduced to the solution of a two-dimensional system of singular integral-differential equations under the usual fixing conditions of the plate's (shell's) edges and the conditions of attenuation of perturbations at infinity. On this basis, and solving certain problems, a number of qualitative and quantitative results is identified that are conditioned by the interaction of mechanical and magnetic phenomena in conductive thin bodies. Here some of the most characteristic effects of interaction are identified in the study of various problems in the dynamic theory of the magnetoelasticity.

- When investigating the natural vibrations of thin conductive bodies in a magnetic field, the following characteristics have been established:
 - There is a strong damping effect of the magnetic field exist, e.g., for a magnetic field of 1 T, the damping coefficient of magnetic origin can exceed by several tens of times the structural damping coefficient.
 - There is a substantial dependence of natural frequencies on the magnetic field, and the following character of this dependence is shown: For relatively thick plates (or shells), the frequency of vibrations increases with the increasing intensity of the external magnetic field. For very thin plates (or shells), the character essentially changes. In this case, with the increasing intensity of the external magnetic field, the frequency of vibrations decreases rapidly, reaching a zero value, which saves in the certain range of external magnetic field (i.e., the possibility of damping perturbations without vibrations). A further increase of intensity leads to a sharp increase of frequency of vibrations of the plate (or shell). For a plate of medium thickness, the dependence of frequency of vibrations on the external magnetic field intensity has an extreme character (there is a minimum point).

- When studying the problem of dynamic stability (parametric vibrations) of conducting plates and shells in a magnetic field, it has been established that due to the magnetoelastic interaction there exists the following:
 - a minimum value of the given magnetic field intensity, above which the possibility of parametric resonance under the influence of external harmonic force is eliminated;
 - the possibility of generation of resonant vibrations of the parametric type in a thin plate with the help of a time-harmonic magnetic field. Moreover, compared with the previous case, where resonance occurring near the frequency of the external magnetic field is equal to the first frequency of free vibrations, resonant vibrations can also occur that are close to the twice of frequency of natural vibrations.
- In studying the problem of forced vibrations of conductive plates caused by external forces of nonelectromagnetic origin, including the effect of a time-harmonic magnetic field, the following has been established:
 - When varying the intensity of the external magnetic field, one can either eliminate the possibility of dangerous unusual resonant vibrations or cause violent vibrations in those cases when, in the absence of a magnetic field, the system is outside of the region of resonance. It was also found that if the frequency of the driving force is less than the frequency of the natural vibrations of the plate in the absence of a magnetic field, then the dependence of the amplitude of forced vibrations on the intensity of magnetic field decreases monotonic function. Moreover, by making an appropriate choice of constant magnetic field of medium intensity, the amplitude of the vibrations can be reduced by many hundreds of times (especially in the case of resonance without a magnetic field). If there is an inverse ratio between the natural frequency and the frequency of a given mechanical force, then the noted monotonic dependence is broken (there is a maximum point), and the presence of the moderate magnetic field can lead to a substantial increase of the amplitude of the forced vibrations.
 - There exists the possibility of generating resonant vibrations in the plate (or shell) with the help of a nonstationary harmonic magnetic field. It has been shown that the rapid increase in the amplitude of vibrations occurs as closely as possible to the frequency of the external magnetic field, equal to the natural frequency of the magnetoelastic vibrations of the plate, as well as near the frequency of the magnetic field, which is equal to the half of the natural frequency of the plate (shell).
- The above-mentioned points are conditioned by the interaction of mechanical and electromagnetic processes in oscillating thin bodies.
- A quantitative study was performed to explore the effects of observed interaction.

At the end of the first part, the results of the experiment are presented, confirming, in particular, the possibility of generation of resonant vibrations with the help of nonstationary magnetic field. A comparative analysis of theoretical and experimental results is then provided.

The second part of the book (Chaps. 7–9) discusses magnetoelastic processes in superconducting thin plates and shells placed in both stationary and nonstationary magnetic fields. Here the following specific circumstances associated with superconductivity have been taken into account: (1) When placing the superconducting body in a magnetic field, in its thin surface layer appears an undamped electric current (screening current), which fully compensates induction inside the body by its field. (2) Because inside the superconductor the magnetic induction is zero, then on its surface the normal component of the external field is zero, i.e., the field outside the superconductor is everywhere tangential to the surface (i.e., magnetic field lines encircle the superconductor). (3) The tangential component of the magnetic field intensity at the surface of the superconductor is discontinuous; therefore, on this surface the components of the Maxwell tensor will also be discontinuous. Due to this discontinuity, magnetic pressure appears at the surface of the superconductor. Consequently, the body forces of magnetic origin are zero, and the effect of magnetic field on the superconducting body takes place by way of the noted pressure. Taking this into account, and using the equations and surface conditions of the theory of magnetoelasticity for small deformations, similar to the first part of the book, the problems of vibrations and the stability of elastic superconducting bodies in magnetic fields are addressed. On this basis, and using the hypothesis on nondeformable normal (Kirchhoff or Kirchhoff-Love hypotheses) of two-dimensional linearized equations and related conditions, the behavior of disturbances in superconducting thin plates and shells is described. In solving the formulated boundary-value problems, the qualitative and quantitative aspects of the interaction of deformable superconducting bodies and the magnetic fields are explored.

Following are some of the most significant new effects conditioned by magnetoelastic interaction:

- The presence of a magnetic field can lead to a significant increase in the frequencies of vibrations of lower modes (magnetic induction of order $0.1Tl$ increases by approximately ten times the first frequency of thin plates), and this influence is much enhanced with a decrease in the relative thickness of the plate.
- Under the influence of magnetic pressure, a superconducting plate will bend, and the magnetic induction of average intensity can cause plastic deformations in the plate. Moreover, the noted bending makes it possible for the nonstationary longitudinal force to act as an (additional) generator of transverse vibrations (accompanying forced vibrations arising solely in superconducting plate in the presence of an external magnetic field).
- In the case of magnetoelastic system of parallel plates, it has been shown that with the help of a constant magnetic field, the forced and parametric type vibrations of one plate, on which disturbing force acts, can be transmitted to another plate that is free from external mechanical loads.

- There exists a possibility of loss of both static and dynamical stability of thin bodies under the action of only an external magnetic field. The critical parameters of magnetic field are defined, at which static stability is lost and there occur resonant vibrations of both the usual and the parametric type.
- It has been established that when a magnetic field is present, and with a further increase of its intensity, the width of any area of dynamical instability (established in a thin superconducting body under the action of longitudinal harmonic in the time-mechanical load) decreases and tends to become zero at a certain value of magnetic field intensity.
- It is important to note here the appearance of parametric resonance in superconducting cylindrical shells carrying surface nonstationary electric current.

The addressed boundary-value problems are solved exactly, as well as approximately, by applying the asymptotic method, which was formulated by G.Y. Bagdasaryan.

From the above-mentioned points, it can be concluded that this book is useful not only for students, graduate students, and scientific researchers working in the fields of mechanics and electrodynamics of continuum media, but it should also of interest for professionals in the field of physics and its various applications.

The generalized hypothesis of the magnetoelasticity of thin bodies, which is based on the results obtained in the first part of this book, were formulated and proven on the basis of a hypothesis of the magnetoelasticity of thin bodies. The latter were proposed and proven in the joint works of S.A. Ambartsumian, G.Y. Bagdasaryan, and M.V. Belubekyan.

It should be emphasized that numerical calculations were performed using the Gaussian system of measurement in the first part of this book; in the second part of the book, the SI international system was used.

The main part of the book comprises the results of G.Y. Bagdasaryan and his students (Z.N. Danoyan, D.J. Hasanyan, M.A. Mikilyan, P.A. Mkrtchyan, G.T. Piliposyan, and A.A. Sanoyan). A great deal of work associated with the preparation of the manuscript was performed M.A. Mikilyan. The authors express sincere gratitude to all of the listed persons.

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