AN ELECTROMECHANICAL TRANSDUCER FOR THE TRANSIENT TESTING OF SEISMOGRAPHS

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INTRODUCTION

The Applications of Seismography. — The modern station seismograph, which provides the written record of earthquakes and earth vibrations, is a complex device and has been the subject of extensive theoretical and experimental research. This is principally due to its importance in purely scientific studies. These studies include the measurement and identification of the various modes of propagation of transient earthquake waves in the earth and the seas; the determination of earthquake foci; the nature and origin of microseismic vibrations in the earth; and the evaluation of the physical and geological constitution of the earth's crust and interior.

The transportable seismograph is also of scientific importance for the localized delineation of geological structures in the crust of the earth and studies of overburdens such as glaciers. The economic importance of this type of seismograph in the exploration for oil and other possible mineral-bearing geological structures, and in similar engineering applications, is of course well known.

At the present time (1949) these instruments have also become important in matters of national defense and diplomacy. Disclosures[1] in the press indicate that seismographs have been included in the array of instruments for the surveillance and detection of man-made "atomic" explosions by foreign powers.

Finally, the technique of measurement of mechanical vibrations in artificial structures, vehicles, ships and airplanes, is of extreme importance in technology. The devices utilized in these applications are variously identified as accelerometers or vibration meters; together with their associated recording mechanisms, they are in many cases entirely analogous to seismographs. In the interest of conciseness, mention will be made henceforth only of seismographs. It is to be understood that the discussions will also pertain in most instances to vibrographs unless definitely stated otherwise.

The Need for Testing Seismographs. — In all the instruments previously mentioned, the data obtained are a written output record as a precise function of time. Since the true movements of the earth or structure, or the exact time of arrival of wavelets, are the desired data in most applications, it is necessary to deduce this information from the written record. It follows, therefore, that the functional relationship between the actual input vibrations and the written output record is of fundamental

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[1] See for example "U.S. Detects Atomic Blast in Russia", Life, Volume 27, Number 14, October 3, 1949, pp. 17-21.

importance and must be precisely determined. This relationship is a measure of the deviation in the recorded seismogram from the true motions, and also a measure of the time delay in the recording apparatus between the true arrival times of wavelets and the recorded event.

This functional relationship may be derived on theoretical grounds, if the physical system is sufficiently simplified. Under these conditions, the response of the seismograph to impressed forces and motions may be computed; the converse is also possible but much more difficult.[a]

There is, however, no guarantee that the mathematical analysis will be valid for any _given_ physical apparatus. Recourse to a physical measurement is therefore ultimately required to validate theoretical expectations for any specified instruments.

Furthermore, experience with even the simplest of physical devices of precision demonstrates the advisability of a standardizing test procedure. The reliability of the reading of as simple a device as a micrometer, for example, is greatly enhanced by the availability of a standard gage block. For the infinitely more complex seismograph, a standardizing test is doubly necessary.

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[a]See, for instance, Dr. Florence Robertson, "A Mathematical Analysis of Numerical Integration and its Application to Electromagnetic Seismograms" (Ph. D. dissertation, Dept. of Geophysics, Saint Louis University, 1945).

To sum up, methods of testing seismographs are useful: (1) to determine or validate the functional relation between impressed forces or motions, and the seismograph record; (2) to evaluate the working "constants" used in the mathematical analysis of the physical system; and (3) to provide a standard of comparison for rapidly ascertaining the operational status of the device.

Seismograph Testing Techniques. — The techniques of testing seismographs[3] may be placed broadly in two categories, depending upon whether the seismometer framework and moving mass or pendulum is rigidly mounted upon a pier; or, the framework is moveable and may be placed upon a testing apparatus known as a "shaking" table or platform. Tests have been devised for both categories which provide transient motions and sustained motions.

It is clear that testing techniques in the first category produce motions of the seismometer mass or pendulum relative to the fixed framework of the seismometer framework and pier. In the second category, the seismometer framework is set into motion, and this in turn influences the seismometer sprung mass or pendulum into a resultant motion. In both methods, the relative motion between the seismometer mass or pendulum and the seismometer framework serves to actuate the recording (or

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[3]For a list of references on the testing of seismographs, see Section 2 of the Bibliography.

indicating) mechanism. Since earthquakes are irresistible movements of the earth's surface and objects attached thereto, it is clear that the use of the moving platform category of test more closely simulates the actual operation of the devices.

The testing of permanently mounted seismographs may be performed by injecting a minute quantity of energy into the physical system which will result in a motion of the suspended mass or pendulum, and actuate the recording mechanism. This is a convenient method, particularly if the damping of the device can be varied over wide limits, and furnishes a means whereby many of the intrinsic "constants" of the device may be deduced. For this type of test, reference may be made to Golitsyn (1.8), and Macelwane[4] and Sohon (3.30).

For seismographs provided with galvanometric registration, the addition of a mechanical, or preferably optical, lever system will provide a means of determining the seismometer parameters when the electromagnetic coil system is energized by a suitable oscillator or source of electromotive force of variable frequency. This is similar to the procedure followed in calibrating the galvanometer recorder associated with the seismometer and has been described briefly by Heiland (2.9).

Finally, it is possible to deduce the seismometer

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[4]Numbers in parentheses are bibliographical references in the sections indicated by the leading digit of the symbol.

and galvanometer "constants" by means of purely electrical tests, using an impedance bridge measurement of what is known as the motional impedance. This is a method which may be adapted from techniques originally used by Kennelly (4.16) and more recently by Goodwin (4.9) and Gilbert (4.8) in work on permanent-magnet, movable-coil instruments.

While these techniques in the first category are in many ways very useful in practice, particularly due to their simplicity, they are not entirely satisfactory because of their inflexibility, and the limited information they usually provide.

The superiority of the moving platform or shaking table techniques of testing seismographs was recognized very early in the development of the science of seismography, as will be seen from the historical survey in the next chapter.

The research described in this dissertation was directed towards improving the versatility and extending the scientific usefulness of mechanical oscillators or shaking tables for testing seismographs and vibrographs. The complete transient testing transducer or shaking table devised and constructed during the course of this research is illustrated in Figure 1.

The exact objectives and the results achieved in this research will be more clearly understood from the perspective of the historical development of these devices.

An exact statement of the objectives is therefore deferred until after the sections on the historical survey and the brief summary of the possible classifications of shaking tables.