MAGNETIC TAPE RECORDING AND PROCESSING OF STRONG-MOTION DATA

by

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SYNOPSIS

Because of the increasingly widespread interest in the acquisition of data from strong local earthquakes, a new family of instruments for measuring, recording and processing such information has been developed. This paper discusses the characteristics of the major components of a complete strong motion magnetic-tape data acquisition system.

Among the components discussed are: the acceleration transducers, magnetic tape recorder, tape playback system, and data processor, which converts the records into digital form on computer compatible tape.

DESCRIPTION

Beginning with the acceleration transducer, two alternative devices have been designed. Both produce an electrical signal which is proportional to acceleration. The first is a spring-mass system with electromagnetic transduction; it is illustrated in Figure 1. When the accelerometer is vibrated, the coil moves in the magnetic field, generating a voltage. This voltage is used for damping the accelerometer, and also forms the electrical output. The signal is amplified and integrated, producing an output of 2.50 volts/G. The frequency response is flat with respect to acceleration from the corner frequency of the integrator (0.1 Hz) to the natural frequency of the spring-mass system (25 Hz).

The second transducer is a force-balance accelerometer. It is also a spring-mass device but uses variable capacitance transduction, as shown in Figure 2. A portion of the output is fed back to a torquer which is an integral part of the mass. This has the effect of stiffening the system, increasing the natural frequency to 50 Hz. Another portion of the output is fed back to the torquer after passing through a differentiating (phase-lead) filter. This controls the accelerometer damping which is normally adjusted to 0.7 critical. The system block diagram is shown in Figure 3 and the closed loop transfer function is:

$$\frac{\text{output voltage}}{\text{input acceleration}} = \frac{E_c}{A}(S) = \frac{K_c K_a}{S^2 + 2\zeta\omega_o S + \omega_o^2 + K_c K_a \frac{G}{R_f M} + K_c K_a \frac{G}{R_h M} K_h \frac{S}{S+\omega_h}}$$

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In order to achieve the proper damping, it is desired to have the phase-lead circuit act as a pure differentiator in the region of the system natural frequency. Thus ω_h is set at a high value (3141 radians/sec) making $\omega_h \gg j\omega$ for frequencies in the range of interest, i.e., below the system natural frequency. With this simplification, the transfer function is reduced to:

$$\frac{E_c}{A}(S) = \frac{K_c K_a}{S^2 + 2\zeta\omega_o S + \omega_o^2 + K_c K_a \frac{G}{R_f M} + K_c K_a \frac{G}{R_h M} \frac{K_h}{\omega_h} S}$$

In the actual force-balance system, $\zeta \approx 0$, and $\omega_o^2 \ll K_c K_a \frac{G}{R_f M}$ so the final closed loop transfer function becomes:

$$\frac{E_c}{A}(S) = \frac{K_c K_a}{S^2 + K_c K_a \frac{G}{R_h M} \frac{K_h}{\omega_h} S + K_c K_a \frac{G}{R_f M}}$$

which has the form of the transfer function for a simple second order differential equation. Thus, the system natural frequency, ω_n, will be:

$$\omega_n = \sqrt{K_c K_a \frac{G}{R_f M}}$$

and the system damping,h,will be:

$$2h\omega_n = K_c K_a \frac{G}{R_h M} \frac{K_h}{\omega_h} \; ; \; h = \frac{1}{2} \frac{\omega_n}{\omega_h} \frac{R_f}{R_h} K_h$$

The complete force-balance system, and each of the elements comprising it, has been studied in detail on an IBM 360 computer using CSMP (Continuous System Modeling Program). The experimental results from actual force-balance accelerometers are in very close agreement with the theoretical results predicted by the computer analysis.

Both types of accelerometers can be packaged in various kinds of housings. A typical type of housing is a cubical cast aluminum box, 8 inches x 8 inches x 6 inches containing three accelerometers, and sealed to prevent the entrance of moisture. This device is designed for surface mounting and has been widely used in nuclear power plants. Another configuration for a triaxial set of accelerometers was designed for down-hole applications. It is 3 inches in diameter by 19 inches long, and has an integral electrical cable. Designed for holes as deep as 500 feet, it has been used on off-shore oil platforms.

The acceleration signals are recorded by means of the tape recorder module. This module contains signal conditioners for three channels of acceleration data, as well as a tape transport. It can be assembled integrally with the accelerometers or on a standard 19 inch panel for rack mounting at a central recording station. The signals from a triaxial set of accelerometers are fed through buffer amplifiers, then frequency modulated (FM), and recorded on magnetic tape. The modulation is accomplished by means of three voltage controlled oscillators each having a center frequency of 1000 Hz and full scale deviation of ±50%. The tape recorder uses a high quality Phillips cassette, and has a 4-track head. Each of the three acceleration signals is recorded on its own separate track. A timing reference signal is recorded on the fourth trace. No multiplexing is used, which greatly simplifies the recording and retrieval of data. Unlike commercially available cassette recorders, the tape transport was carefully designed to perform properly after long periods of time and then to record faithfully within 0.1 seconds after turn-on by the earthquake. While waiting for an earthquake, the recording system is in a quiescent mode. The arrival of an event is signalled by a seismic trigger so that the system turns on and records when the trigger is actuated by an acceleration of 0.01 G or more.

After an earthquake has been recorded, the data can be retrieved by means of the playback unit. This unit demodulates the three FM acceleration signals. In addition, it divides the 1024 timing reference down to 2 Hz. These processed signals are available in two forms. In one of the modes, the demodulated FM signal is compensated for tape speed variations and outputed onto a strip chart recorder. This process is accomplished, one channel at a time, by means of circuitry and a recorder which are integral parts of the playback unit. The other playout mode is direct output of the electrical acceleration signals. The playback unit produces both the FM signals and the demodulated signals, as well as the reference timing signal. All of these are produced simultaneously for processing onto computer-compatible tape. The playback unit, like the tape recorder, accelerometers, and seismic trigger, is powered by its own internal batteries. Thus a loss of AC power during an earthquake in no way impairs the faithful collection and playout of the acceleration data.

The last step is accomplished by the digital data processor. It accepts the three acceleration data signals and the time signal and simultaneously digitizes them. It uses a 12 binary bit analog to digital converter, and has a nominal data rate of 2,000 samples per second. However, it scans across multiple channels at a 40,000 Hz rate. Thus, the phase relationships between channels are well preserved. The system utilizes a synchronous tape transport, as opposed to an incremental recorder. The data are collected in memory, and then transferred to tape at the maximum transport rate. The final result is digital acceleration data stored on a 9-track, 12-1/2 inches per second, 800 bits per inch computer compatible tape.

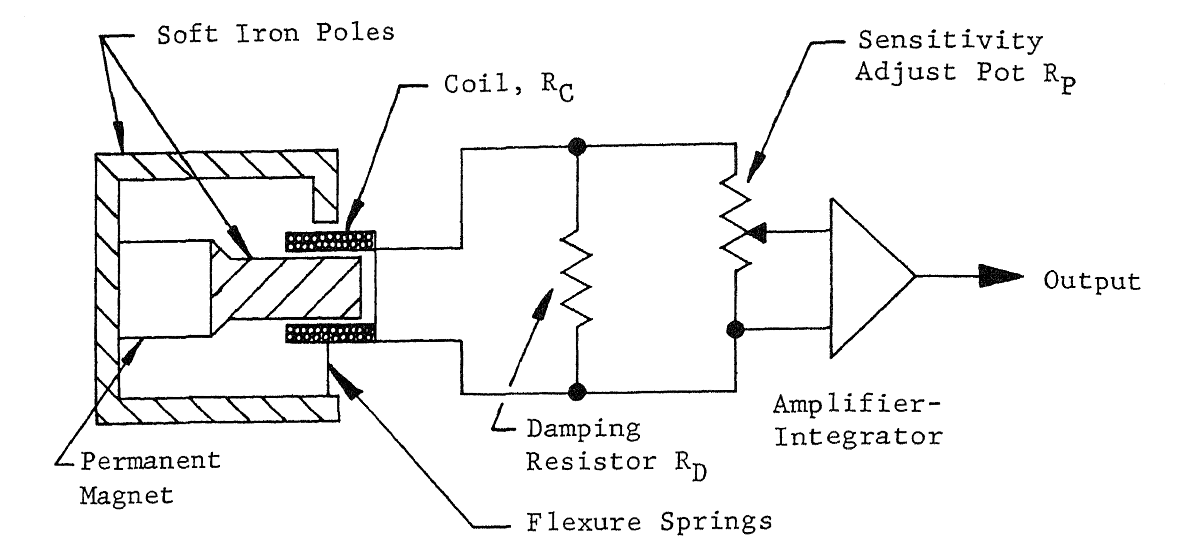


Figure 1 Electromagnetic Accelerometer

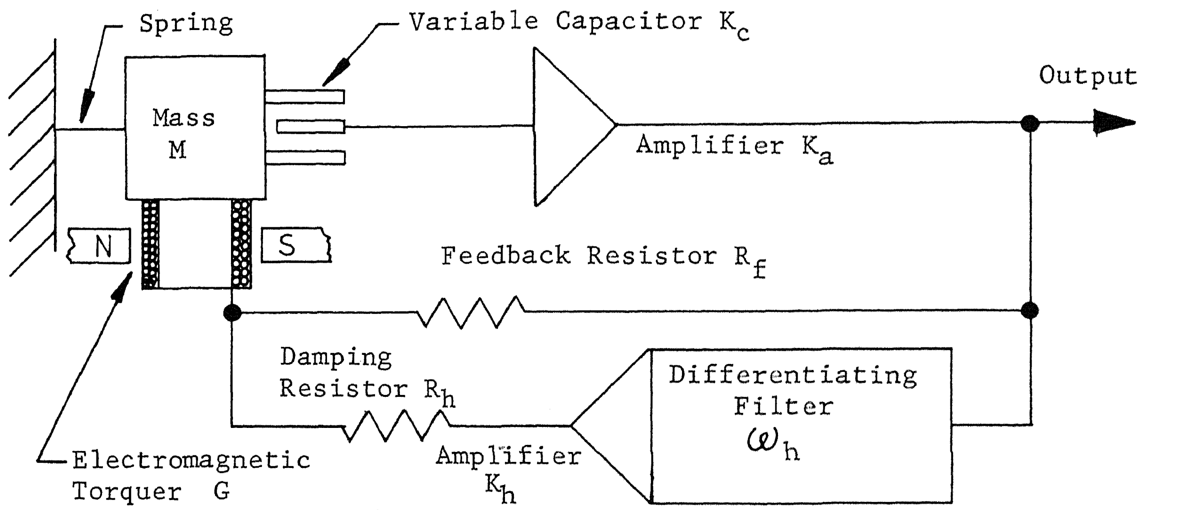
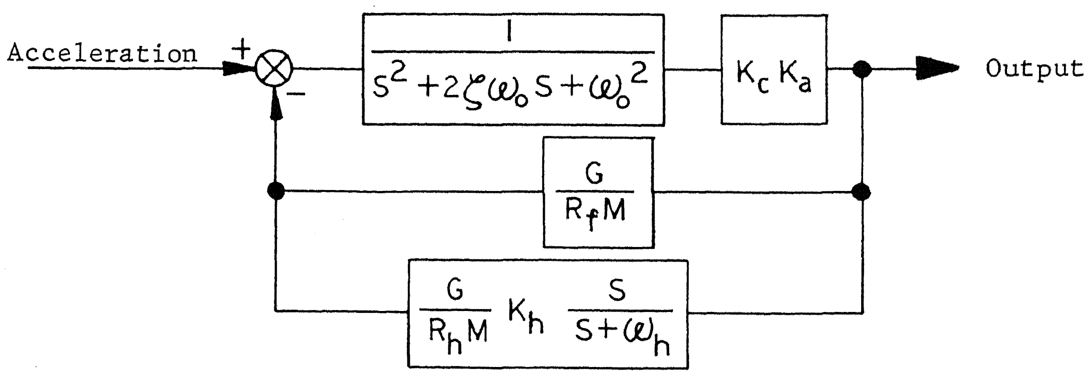


Figure 2 Schematic - Force Balance Accelerometer



$\zeta =$ intrinsic damping of spring mass

$\omega_o =$ natural frequency of spring mass

Figure 3 Block Diagram - Force Balance Accelerometer