f and F are then found to satisfy

$$(\partial^2F/\partial z^2)+\alpha^2F=0,$$
$$(1/r)(\partial/\partial r)(r(\partial f/\partial r))-(\alpha^2+\beta^2)f=0,$$

where α is an arbitrary constant. The above equations have for solution:

$$F=A\cos\alpha z+B\sin\alpha z,$$
$$f=CJ_0((-(\alpha^2+\beta^2))^{\frac{1}{2}}r)+DY_0((-(\alpha^2+\beta^2))^{\frac{1}{2}}r).$$

By means of the boundary conditions the arbitrary constants are shown to be

$$D=A=0;\quad \alpha=\pi/l;\quad B\cdot C=-\alpha/J_0(-(\pi^2/l^2+\beta^2)^{\frac{1}{2}}r_0),$$

whence

$$T_1=T_2\Big[1-J_0\Big(-\Big(\frac{\pi^2}{l^2}+\beta^2\Big)\Big)^{\frac{1}{2}}r\Big)\sin\pi z/l\Big/ J_0\Big(-\Big(\frac{\pi^2}{l^2}+\beta^2\Big)\Big)^{\frac{1}{2}}r_0\Big)\Big].$$

The average (in space) temperature fluctuation is

$$\bar{T}_1=1/\pi r_0^2 l\int_0^l\int_0^{r_0}2\pi rT_1drdz,$$

which leads to expression 20.

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A New High Speed Level Recorder

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A high speed level recorder of the "potentiometer type" which is useful both for laboratory and field measurements is described. The recording system consists of a moving coil with translational motion, the speed of which can be varied with a maximum value of about 1000 db/sec. Recording is made by a steel stylus on waxed paper of the same kind as that in the usual Neumann recorder.

THE high speed level recorders for acoustic measurements built so far can be divided roughly into two groups, namely, (a) instruments essentially consisting of a usual logarithmic tube voltmeter provided with a recording device, which is generally optical, and (b) recorders which have some kind of electromechanical feedback to regulate the amplifier input voltage to a constant value. The input voltage is taken from the sliding contact of a potentiometer over which the voltage to be recorded is applied. The position of the potentiometer contact varies according to the changes in the voltage level. The response function is generally made logarithmic, but it only depends on the resistance distribution of the potentiometer and can be changed easily. The recorder described here belongs to this second group of instruments.

Even though the same basic principle has been used in the "potentiometer recorders," different methods of driving the moving system have been applied. In a construction presented by Meyer and Keidel,[1,2] a moving coil instrument, which operates in combination with a liquid potentiometer and an optical system, is used. The construction is simple and the recording is made with high speed and good accuracy, but the disadvantage with this type of instrument is in the necessity of photographic recording and the sensitivity of the liquid potentiometer.[3]

In the best-known instrument, the Neumann recorder,[4] the driving force is obtained by friction between a rotating cylinder and a steel fork which is pushed alternatively to the both sides of the cylinder, giving a backwards and forwards motion of the moving system. The maximum recording speed is about 300 mm/sec., corresponding to 300 db/sec. when a 50-db potentiometer is used.

Another similar recorder using magnetic clutches in the drive was constructed about the same time, but in contradiction to the Neumann recorder, a rotary instead of translational motion was given to

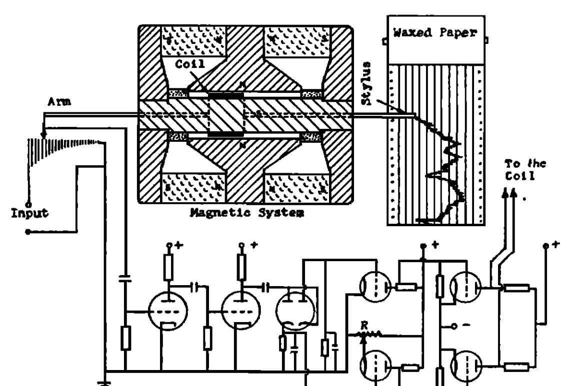

FIG. 1. Schematic drawing of the level recorder.

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[1] E. Meyer and L. Keidel, E. N. T. 12, 37 (1935).
[2] L. Keidel, Akustische Zeits. 4, 169 (1939) (Review by L. Beranek, J. Acous. Soc. Am. 11, 366 (1940).
[3] I. O. Nielsen, Ingenioren 2, 1 (1937).
[4] H. J. Braunmuhl and W. Weber, 12, 223 (1935).

the recording stylus arm.[5] The speed can be made as high as 850 db/sec. and can be varied by changing the speed of the rotating cylinder. This instrument is rather large and is built mainly for the laboratory. It should be mentioned that in a commercial version of this recorder[6] the motion is made translational, but the speed is not higher than about 60 db/sec.

The recorder described here was constructed in order to get an instrument for the laboratory as well as for field work, suitable for measuring, for example, short reverberation times and for making extended measurements covering long periods of time. Instead of frictional or magnetic driving forces, a pure electromagnetic system was introduced similar to that in a loudspeaker.

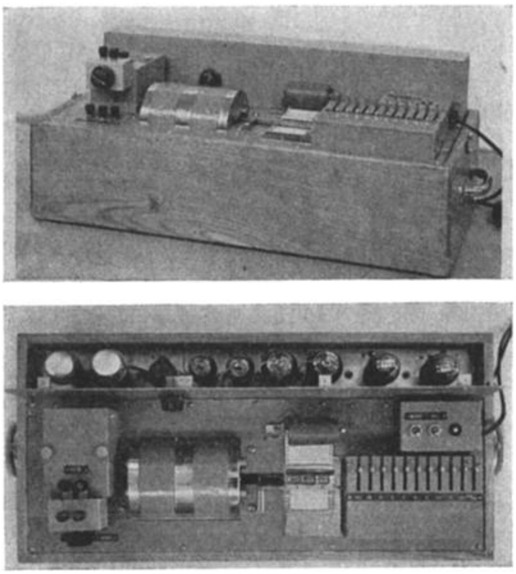

FIG. 2.

The schematic drawing in Fig. 1 and the photographs in Fig. 2 show the essential features of the recorder. The electromagnetic system consists of a moving coil inserted in a radial magnetic field produced by two permanent magnets indicated on the drawing. The coil, shown in Fig. 3, has an air core and is carried by two light brass tubes which slide on tightly drawn steel wires. Figure 1 shows the moving system firmly connected to the potentiometer contact on one side, thus producing the feedback, and on the other side to the recording stylus.

Other elements of the recorder consist essentially of a preamplifier, a duo-diode rectifier, a balanced d.c. amplifier, and a power stage feeding the coil. The voltages of opposite polarity from the rectifier stage are connected to the grids of the tubes in the d.c. amplifier, which is balanced when the input voltage on the preamplifier, which is the voltage on the slide contact, is about 5 mv. Any change of the voltage applied to the terminals of the potentiometer causes unbalance, and the coil is pushed to a new position of equilibrium where the voltage again is 5 mv.

The potentiometer has about 100 contacts, which corresponds to $\frac{1}{2}$-db steps in the case of a 50-db potentiometer. In addition to this, the recorder is supplied with two more logarithmic potentiometers of 25 and 75 db and also a linear one with a range of 5 mv to 55 mv.

The "stiffness" of the system is expressed by the strength of the restoring force on the moving coil when removed from the equilibrium position. The maximum restoring force is obtained when the coil is moved a distance corresponding to one contact on the potentiometer or when the voltage change is at least as large as the level difference between two adjacent contacts. Since this holds in the static case, it is almost true even under normal conditions when the coil is in full speed, because the inductance of the coil is too small to cause any serious effects. When recording a sudden step of the voltage level as shown in Fig. 4, the coil current almost immediately rises to its maximum value and is kept constant until the coil reaches its new equilibrium position where the current changes to a maximum

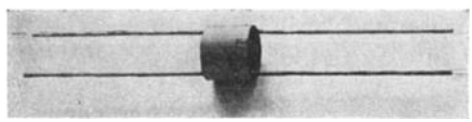

FIG. 3. The moving coil, which is the fundamental part of the moving system.

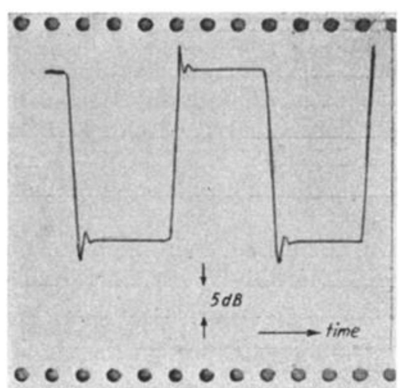

FIG. 4. Recordings of sudden steps of voltage level; the paper speed is 30 mm/sec.

[5] E. C. Wente, E. H. Bedell and K. D. Swartzel, J. Acous. Soc. Am. 6, 121 (1935).
[6] (No author given), Electronics 16, 100 (July, 1943).

in the opposite direction. Small oscillations are present, which are unavoidable in this extreme case, but their effects are unimportant in usual acoustic measurements.

If friction were negligible the coil would move with constant acceleration because of the constant driving force. The step function would be recorded with a parabolic path instead of a linear one. The presence of friction, however, produces a constant velocity so that straight recordings result as seen in Fig. 4.

The maximum recording speed, defined by the slope of the curve when recording a sudden step of the voltage level, is about 750 mm/sec. or 750 db/sec. with a 50-db potentiometer for the experimental model described here. However, in the commercial version of the recorder this value has been brought up to 1000 db/sec. The speed can be varied by the resistance in parallel with the coil and also to some degree by the resistance R shown in Fig. 1. An example of the effect of reduced velocity is shown in Fig. 5, where a reverberation curve is recorded at different speeds. The elimination of some of the oscillations at the lower velocity is an advantage if only the slope of the curve is of interest. The recording speed is proportional to the strength of the magnetic field in the air space between the magnet poles, but is, of course, limited by the time constant of the electrical circuit which is mainly determined by the rectifier. A compromise selection of the time constant must be made so that optimum condition of recorder speed and lower frequency limit of the instrument can be obtained.

The recording paper used is the same as that used in the Neumann recorder, i.e., waxed paper of 50-mm effective recording width. In order to meet the requirements regarding paper speed in different kinds of measurements, 10 different speeds are available: 100, 30, 10, 3, 1, 0.3, 0.1, 0.03, 0.01, and 0.003 mm/sec.

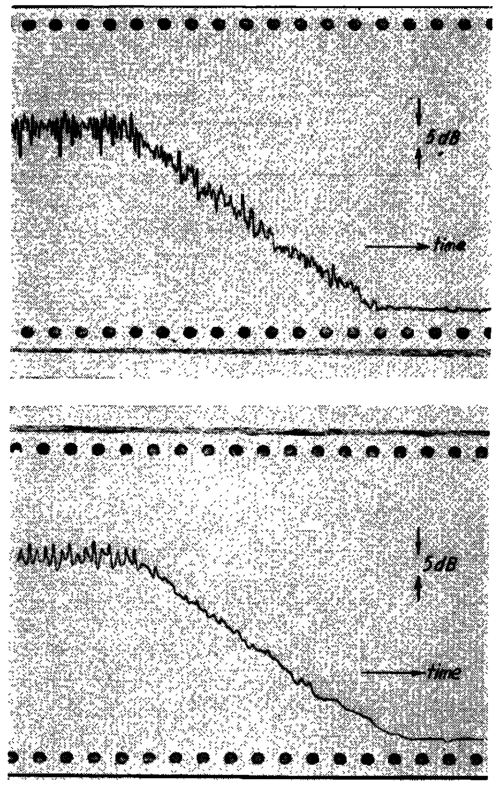

FIG. 5. Reverberation curves taken at full and reduced recording speed.

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