Sept. 17, 1968 B. WEINGARTNER ETAL **3,402,371**

DELAY DEVICE FOR PRODUCING ARTIFICIAL REVERBERATION

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FIG. 1

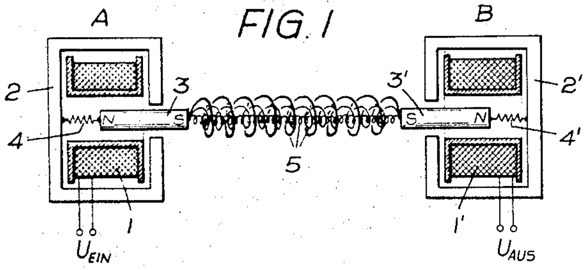


FIG. 2

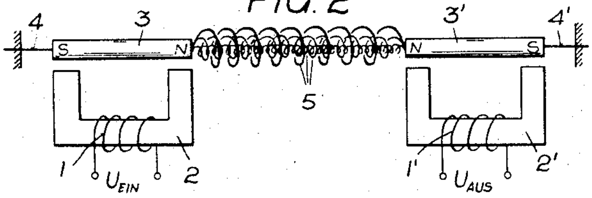


FIG. 3

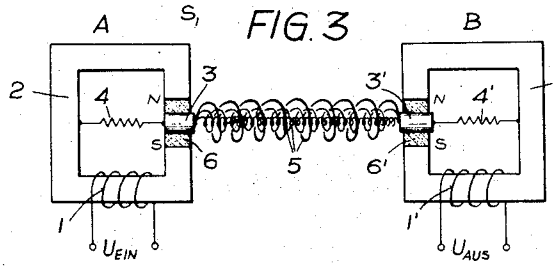


FIG. 3a

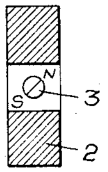
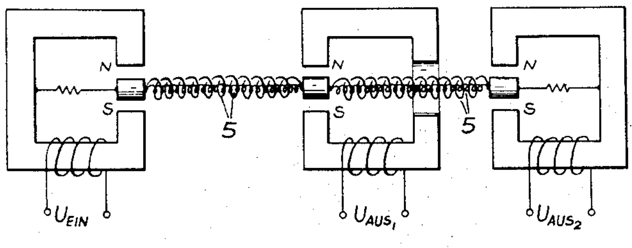


FIG. 4



BERNHARD WEINGARTNER
ERNST KOVACS
OTTO MARSCHALL
INVENTOR.

BY Karl G. Ross
AGENT

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FIG. 5

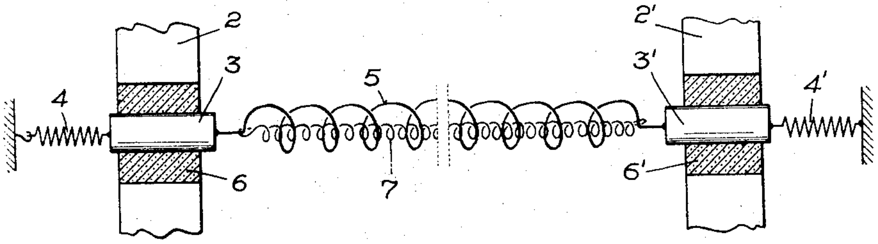
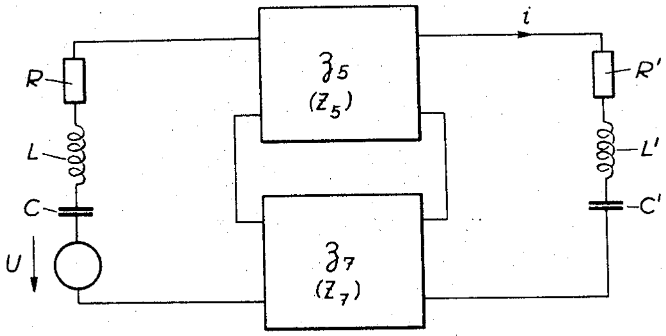


FIG. 6



BERNHARD WEINGARTNER
ERNST KOVACS
OTTO MARSCHALL
INVENTOR.

BY Karl G. Ross
AGENT

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DELAY DEVICE FOR PRODUCING ARTIFICIAL REVERBERATION

Bernhard Weingartner, Ernst Kovacs, and Otto Marschall, Vienna, Austria, assignor to Akustische u. Kino-Geräte Gesellschaft m.b.H., Vienna, Austria, a firm

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11 Claims. (Cl. 333—30)

ABSTRACT OF THE DISCLOSURE

A delay device, for producing artificial reverberations, is disclosed as of the type including a driving magnetic system connected to one end of relatively elongated coil spring means for converting electromagnetic oscillations into mechanical vibrations of the coil spring means, and a driven electromagnetic system connected to the opposite end of the coil spring means for converting vibrations of the coil spring means into electromagnetic oscillations to produce an output voltage.

In accordance with the disclosure, the coil spring means comprises two or more concentric coil springs disposed one within the other. Corresponding ends of all of the springs are connected to each other, and one commn end of all of the springs is connected to the electromagnetic driving system and the other common end of all of the springs is connected to the electromagnetic driven system. The ratio of the respective delay times of the springs is preferably an irrational number, and damping means may be provided for modifying the apparent reverberation time and the frequency response.

Background of the invention

It is known to produce artificial reverberations in order to improve the reproduction of sound by electro-acoustic transmitting equipment, particularly in order to enhance the fidelity of the sound pattern which is emitted, and to produce special effects. For this purpose, some methods and apparatus have been disclosed. Of these known methods and apparatus, mainly those using metallic coil springs as delay elements have been successful. The delay devices incorporating such springs are relatively simple and inexpensive. The vibrations to be transmitted are imparted to one end of the helical springs, in the form of slow compression, flexural, or torsional waves, by a suitable, preferably electromagnetic, drive unit, and are picked up at the other end by a similar pick-up unit. The application of torsional vibrations to the helical springs is preferred because of the freedom of dispersion, the ease of excitation and the simple damping. In order to prolong the reverberation time, and to increase the fidelity or reflection, the ends of the springs are suspended from a frame, which is resistant to vibrations and reflects the mechanical waves. For a further increase of the number of reflections per unit of time and of the number of natural frequencies, it has been found suitable to provide a plurality of coil springs, which are connected in parallel in the transmission line.

In a known delay device, each spring has associated with it a separate small permanent magnet at each of the drive and pick-up ends. Each magnet is disposed in an air gap associated with a common drive or pick-up coil. One end of the magnet is connected to the associated coil

spring and the other end of the magnet is connected to a relatively stiff leaf spring. The latter is firmly secured to the carrying frame. An audio-frequency voltage applied to the drive means will cause torsional vibration to be imparted by the common field coil to the permanent magnets. This is similar to the operation of an instrument having a rotary magnet. These torsional vibrations will be transmitted to the associated spring. The vibrations at the pick-up end will impart motion to the associated permanent magnet, and the lines of force of the latter will induce, in the pick-up coil, an alternating voltage, which is properly amplified and then fed as a reverberation voltage to the loudspeaker or loudspeakers. This voltage is a succession of the delayed reflections of the vibrations imparted to the spring, because the vibration reflecting suspension means of the spring cause a vibration wave to travel repeatedly between the two points of support before it has decayed.

The invention relates to a delay device of the type described hereinbefore, which serves for the production of artificial reverberations. It is an object of the invention to simplify this device, and to reduce its cost and increase its reliability in operation. In order to accomplish this object, the invention provides a delay device which comprises delay elements in the form of coil springs, a preferably electromagnetic drive unit for imparting mechanical vibrations to said springs at one end, and an analogous unit for converting said vibrations into electrical oscillations at the other end of the springs. The invention uses coil springs having different diameters and concentrically arranged one inside the other. All the springs are interconnected to each other at both ends and the opposite interconnected ends are connected to drive and pick-up units, respectively, which are comomn to all springs. The ratio of the delay times associated with each of the springs is preferably an irrational number.

According to a further feature of the invention, suitable damping means may be provided for modifying the apparent reverberation time and the frequency response of the arrangement. In a special embodiment of the invention, the damping is effected by damping material, such as felt or the like, which is provided in the air gap of the drive and/or pick-up unit, in which air gap the permanent magnet is movable.

As a feature of the invention, the transmission line may be provided with a plurality of delay devices according to the invention, in a series and/or parallel connection with each other.

The invention will be explained in more detail with reference to the accompanying drawings, in which

FIG. 1 is a diagrammatic view showing a delay device according to the invention, in which longitudinal flexural vibrations are imparted to the springs.

FIG. 2 is a view showing such a device in which the springs are subjected to transverse vibrations.

FIG. 3 shows a device in which torsional vibrations are imparted to the springs.

FIG. 3*a* is a sectional view taken on line S–S_1 of FIG. 3 and shows a drive unit.

FIG. 4 shows a series connection of a plurality of delay devices according to the invention.

FIG. 5 is an enlarged view showing two coil springs arranged one in the other, for an explanation of the advantages of the arrangement with respect to its vibration behavior.

FIG. 6 is an equivalent circuit diagram of FIG. 5 on a four-terminal network basis.

In the embodiment shown in FIG. 1, coil springs **5** having different respective diameters are concentrically arranged one inside the other and have longitudinal compressional vibrations imparted to them. The drive unit is indicated at A. It comprises an exciter coil **1**, which produces lines of force in the magnetic circuit **2** when an audio-frequency voltage U_{ein} is applied to the coil. The circular air gap accommodates a bar magnet **3**, one end of which is connected by a stiff spring **4** to the housing of the drive unit, whereas the other end of the magnet is secured to the interconnected ends of three coil springs. When an exciting voltage U_{ein} is applied to the exciter coil **1**, a corresponding alternating field will be produced in the associated magnetic circuit. This field tends to move the bar magnet **3** in the direction of its longitudinal axis in the rhythm of the applied alternating voltage. The vibration performed by the magnet is propagated in the form of compressional waves in the delay springs and transmitted to the permanent magnet **3'** of the pick-up unit B, which has basically the same design as the drive unit A. The stiff spring **4'** holds the permanent magnet bar **3'** in the housing of the pick-up unit. The mechanical vibration of the magnet **3'**, and the resulting movements of its field of force, induce, in the pick-up coil **1**; a voltage which is available as an output voltage U_{aus}. As the support of the bar magnets **3** and **3'** in their housings is relatively resistant with respect to vibrations, the vibrations imparted to the concentrically arranged springs are reflected repeatedly between the ends of the springs until they decay. In this way, a reverberation voltage is obtained, which simulates the acoustic conditions of a room. To avoid a periodicity in the reverberation waveform (flutter echo), the ratio of the delay times associated with the respective springs should be an irrational number.

FIG. 2 shows a delay device according to the invention, in which concentrically arranged coil springs are caused to perform flexural vibration (transverse waves). The reference characters have the same meanings as in FIG. 1. A difference from the embodiment described hereinbefore resides in that the springs **4** and **4'**, holding the permanent magnet bars **3** and **3'** in the housing, are leaf springs.

A particularly desirable embodiment is shown in FIG. 3, and provides for application of torsional vibrations to the concentrically arranged coil springs. Torsional vibration has the advantage of being free from dispension so that it provides for a delay or transit time which is independent of frequency. A and B are again the drive and pick-up units, respectively. An audio-frequency alternating voltage U_{ein} applied to the exciting coil **1** of the drive unit produces, in the air gap of the magnetic yoke **2**, an alternating magnetic field, which imparts torsional vibrations to the diametrically magnetized permanent magnet **3**, the magnetic axis of which is inclined by approximately 45° from the vertical.

FIG. 3*a* is a sectional view taken on line S–S_1 through the front part of the pick-up unit, and indicates the arrangement of the diametrically magnetized permanent magnet **3** in the air gap. The rotary vibration or oscillation of this magnet bar **3** is propagated in the coil springs **5** as torsional vibrations, the velocity of propagation of each of which varies with the square of the diameter of the helix of the respective spring. The vibrations are transmitted to the magnet **3'** of the pick-up unit B. The movement of this magnet induces a voltage in the pick-up coil **1'**. A part of each vibration is reflected and decays slowly, depending on the inherent damping of the system. In this embodiment, the springs **4** and **4'**, which hold the magnets **3** and **3'** may consist either of leaf springs or of coil springs. To provide for damping, the entire system may be submerged into a viscous liquid, such as oil. Besides, frictional damping material, such as felt, may be used, e.g., in the air gap between the magnet bar and the magnet yoke, as is indicated in FIG. 3 at **6** and **6'**. This material may alternatively extend across only a part of the width of the air gap.

When a particularly close succession of echoes is desired, a plurality of delay devices according to the invention may be arranged in series in the transmission line, as is shown in FIG. 4, and/or in parallel in the transmission line.

Instead of a rotatable permanent magnet and a fixed field coil, the drive or repelling unit for producing torsional waves may comprise a fixed magnet and a movable rotating coil in the field of the magnet yoke, as in a rotating coil instrument.

The concentric arrangement of the springs and the use of only one drive unit and one pick-up unit is not only simpler and less expensive in structure but has also advantages with respect to the vibrational and acoustic behavior, as will be explained with reference to FIGS. 5 and 6.

FIG. 5 is an enlarged view showing an arrangement of the type illustrated in FIG. 3, comprising two concentric springs **5** and **7**. FIG. 6 is an equivalent electric circuit diagram, in which U represents the driving force P acting on the magnet **3**. i represents the mechanical velocity v of the magnet **3'** at the pick-up end resulting in the induction of the voltage $U_{aus}=B\times 1\times v$. The masses of the magnets **3**, **3'** are represented by the inductances L, L'. The compliance of the suspension springs or strips **4**, **4'** is represented by the capacitances C, C'. The damping resistances **6**, **6'** are represented by the ohmic resistances R, R'. The two springs **5** and **7** are represented by the series-connected four-terminal networks having the resistance matrix z_5 or z_7 and the characteristic impedance of each spring Z_5 or Z_7. Thus, each four-terminal network (each spring) is terminated at each end by the total of the input impedance of the other spring in series with the impedance of the drive or pick-up units. Hence, the reflection of a wave propagated in one spring decreases as the difference between the characteristics impedance and the terminating impedance increases. The characteristic impedance of the springs being proportional to their diameter for the same thickness of wire, and proportional to the third power of the thickness of the wire for the same diameter, an optimum approach to the characteristics of a natural reverberation can be achieved by the selection of springs having appropriate dimensions in relation to the impedance of the drive and pick-up units without need for additional, individual damping means which can be adjusted only with difficulty.

The characteristic impedance of a spring is calculated as:

$$Z_i=\sqrt{\frac{\pi R_i a_i^3}{2}}\sqrt{E\rho}\left[\mathrm{cm.}^2\,\frac{g}{s}\right]$$

where:

$2R_i$=diameter of a turn of the springs
$2a_i$=wire diameter of the springs
E=Young's modulus of elasticity
ρ=density of the material

The characteristic resistance Z_0 of the drive and pick up system is derived from the square root of the ratio of the moment of inertia of the magnet to the compliance of the support wire, and this is expressed as follows:

$$Z_0=\frac{\pi}{2}\sqrt{\frac{a_1^4 a_2^4 g_1 l_1 G_2}{l_2}}\left[\mathrm{cm.}^2\,\frac{g}{s}\right]$$

where:

$2a_1$=diameter of the magnet
g_1=specific mass of the magnet
l_1=length of the magnet
$2a_2$=diameter of the support wire

G_2=sheer modulus of the wire
l_2=length of the wire

The torsion waves, which are generally used, have a velocity of propagation of:

$$V_w=\frac{a}{4\pi R^2}\sqrt{\frac{E}{\rho}}\text{ [turns/sec.]}$$

where:
$2a$=wire diameter
2R=diameter of one turn
E=Young's modulus of elasticity
ρ=specific mass

$$T_n=\frac{4\pi R^2}{a}\sqrt{\frac{\rho}{E}}\cdot n\text{ [sec.]}$$

The upper limiting frequency of transmission is defined, if the wavelength is shorter than 4 turns, because above this frequency torsion-waves cannot exist. That means

$$f_{gr}=\frac{v}{\lambda_{gr}}=\frac{v}{4}=\frac{a}{16\pi R^2}\sqrt{\frac{E}{\rho}}\text{ [1/s]}$$

For the mechanical-electrical analogy, this is used the following:

Moment of inertia (rotating mass)—1 g. cm.^{2} is corresponding 1H
Compliance—1 cm./dyn. is corresponding 1F
Torsion resistance—1 g./s. cm.^{2} is corresponding 1Ω

A delay device as shown in FIG. 5 has actually been constructed with the following dimensions:

Magnet bars **3** and **3′** of barium ferrite, 2 mm. in diameter, 10 mm. long, specific gravity 6 grams per cubic centimeter. The combination of each magnet bar **3** or **3′** with its suspension spring **4** or **4′** had a resonant frequency of 800 cycles per second.

With reference to the electrical equivalent circuit shown in FIG. 6, the rotatable mass was equivalent to an inductance $L=L'=0.95$ millihenry. The torsional rigidity of the suspension spring **4** or **4′** was equivalent to a capacitance $C=C'=42$ microfarads. This resulted in a charactedistic impedance $Z=\sqrt{L/C}=15$ ohms. The friction in the air gap of each of the drive and pick-up units was equivalent to approximately 30 ohms.

The large spring **5** had a mean turn diameter of 10 mm. The small spring **7** had a mean turn diameter of 3.4 mm. The wire of both springs **5** and **7** had a diameter of 0.3 mm. The characteristic impedance Z_5 was equivalent to 10.5 ohms. The characteristic impedance Z_7 was equivalent to 3.5 ohms.

The large spring had 220 turns and a delay time of approximately 90 milliseconds. The small spring had 260 turns and a delay time of about 12.4 milliseconds.

The dimensions indicated above resulted in a fairly uniform, rapid succession of gradually decaying echoes. Up to the limiting frequency of 5 kilocycles per second, the frequency response consisted of resonance peaks having approximately the same height and spaced approximately 10 kilocycles per second apart.

As similar results are obtained with proportionately changed impedances, arrangements in which components providing for proportionally changed impedances are used for design reasons are considered equivalent to the example described hereinbefore. The invention is not restricted, however, to any particular theory regarding the electrical equivalent circuit.

What is claimed is:

1. In a delay system for producing artificial reverberations, of the type including at least one delay device having helical spring means as a delay element, an electromagnetic drive system connected to one end of the spring means to convert electrical oscillations into mechanical vibrations of the spring means, and an electromagnetic driven system connected to the opposite end of the spring means to convert vibrations of the spring means into electrical oscillations: the improvement in which said spring means comprises relatively elongated helical springs, of different respective diameters, arranged coaxially one inside the other; corresponding first ends of all of the springs being connected in common to said electromagnetic drive system, and corresponding opposite ends of all of the springs being connected in common to said electromagnetic driven system; whereby all of said springs are connected in parallel with each other between said electromagnetic drive and driven systems.

2. In a delay system, the improvement claimed in claim **1**, in which said electromagnetic drive system vibrates said springs in a direction transversely of the lengths thereof.

3. In a delay system, the improvement claimed in claim **1**, in which said electromagnetic drive system vibrates said springs in a direction longitudinally of said springs.

4. In a delay system, the improvement claimed in claim **1**, in which said electromagnetic drive means imparts torsional vibrations to said springs about the axes thereof.

5. In a delay system, the improvement claimed in claim **1**, in which at least one of the said electromagnetic systems includes damping means operable to at least partially dampen vibration of said spring.

6. In a delay system for producing artificial reverberations, of the type including at least one delay device having helical spring means as a delay element, an electromagnetic drive system connected to one end of the spring means to convert electrical oscillation into mechanical vibrations of the spring means, and an electromagnetic driven system connected to the opposite end of the spring means to convert vibrations of the spring means into electrical oscillations; the improvement in which said spring means comprises relatively elongated helical springs, of different respective diameters, arranged coaxially one inside the other; corresponding ends of all of the springs being connected to each other; one common interconnection of all of the springs being connected to said electromagnetic drive system, and the opposite common interconnection of all of the springs being connected to said electromagnetic driven system; each of said electromagnetic systems including an air gap and at least one of said electromagnetic systems including damping means disposed in the air gap thereof and damping vibrations of said springs.

7. In a delay system, the improvement claimed in claim **6**, in which each of said electromagnetic systems includes said damping means in the air gap thereof.

8. In a delay system, the improvement claimed in claim **1**, including plural delay devices connected in sereis with each other.

9. In a delay system, the improvement claimed in claim **1**, including plural delay devices connected in parallel with each other.

10. In a delay system, the improvement claimed in claim **4**, in which at least one of said electromagnetic systems comprises a stationary magnetic field means and a moving coil system operatively associated with said magnetic field means.

11. In a delay system for producing artificial reverberations, of the type including at least one delay device having helical spring means as a delay element, an electromagnetic drive system connected to one end of the spring means to convert electrical oscillations into mechanical vibrations of the spring means, and an electromagnetic driven system connected to the opposite end of the spring means to convert vibrations of the spring means into electrical oscillations: the improvement in which said spring means comprises relatively elongated helical springs, of different respective diameters, arranged coaxially one inside the other; corresponding ends of all of the springs being connected to each other; one common interconnection of all of the springs being connected to said electromagnetic drive system, and the opposite common interconnection of all of the springs being connected to said electromagnetic driven system; at least one of said electromagnetic systems including a movable permanent magnet connected to a common interconnection of all of the springs.

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HERMAN KARL SAALBACH, *Primary Examiner.*

C. BARAFF, *Assistant Examiner.*