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Feb. 22, 1955 J. RABINOW 2,702,472

TRAVELING-WAVE TRANSDUCER

Filed May 29, 1952 3 Sheets-Sheet 1

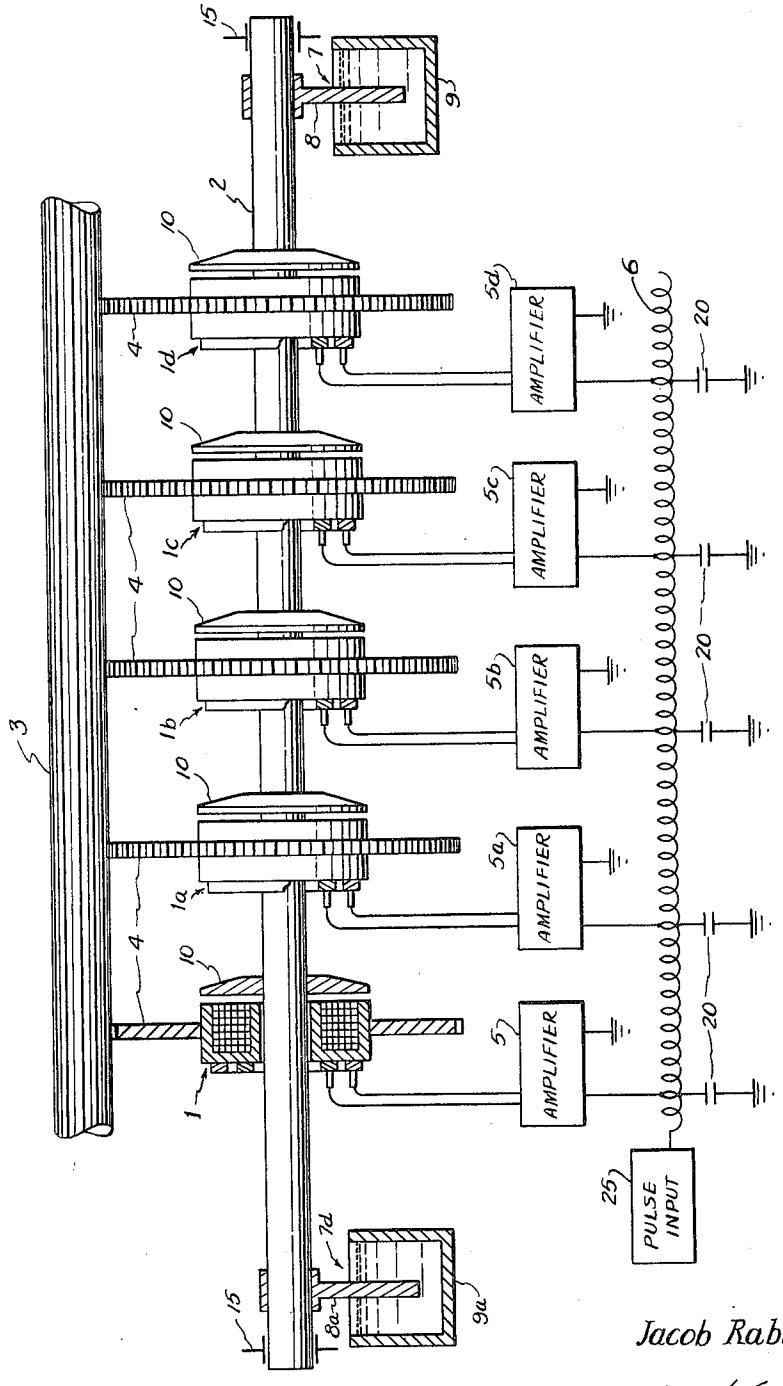


Fig. 1

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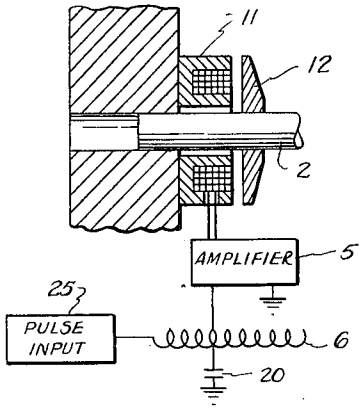


Fig. 2

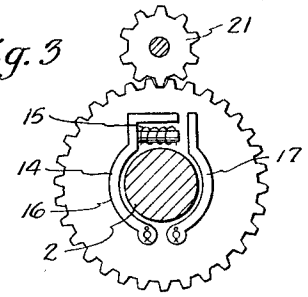


Fig. 3

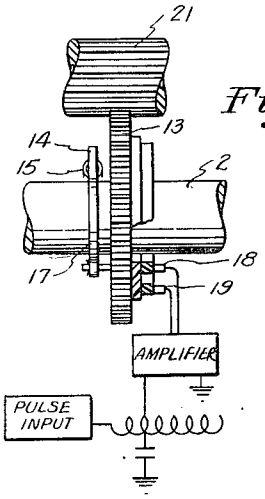


Fig. 4

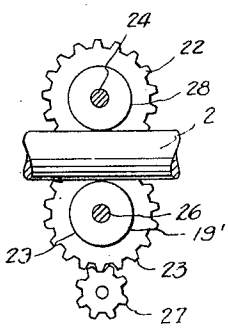


Fig. 5

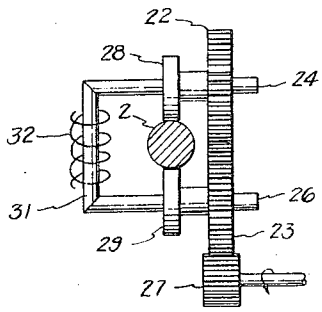


Fig. 6

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TRAVELING-WAVE TRANSDUCER

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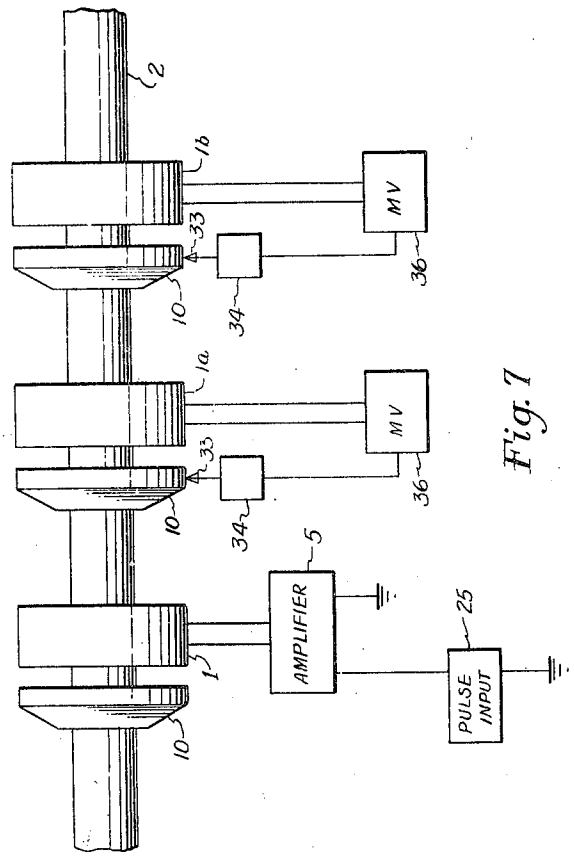


Fig. 7

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2,702,472

TRAVELING-WAVE TRANSDUCER

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Application May 29, 1952, Serial No. 290,841

7 Claims. (Cl. 73—67)

(Granted under Title 35, U. S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States for governmental purposes without the payment to me of any royalty thereon in accordance with the provisions of the act of March 3, 1883, as amended (45 Stat. 467; 35 U. S. C. 45).

This invention relates to the art of setting up vibrations and vibratory waves in bodies and in particular to setting up vibratory waves whose frequencies are not limited to the natural frequency of the body in which the waves are induced.

In the prior art, when it was desired to produce oscillations or elastic deformation in a body, the body was stressed by some type of mechanism which produced compression, elongation, or some form of strain in the body. Such prior art mechanisms were of a unitary character and in order to produce large stresses large mechanisms, or a multiplicity of mechanisms actuated in unison, were used. If desired, oscillations of large magnitude could also be obtained by applying successive shocks phased accurately for the natural oscillation frequency of the body. This system limits the frequencies of oscillation to the resonant frequencies of the bodies and prevents such systems from being applicable to wide-band use.

The restriction to the use of the resonant frequencies of the vibrating body is undesirable in the field of material testing, where it is desirable to subject the material under test to wide ranges of vibration. Also in this field it would be desirable to be able to control the wave shape of the pulse applied to the material under test, but in a resonant system the wave shape is necessarily fixed. The limitation as to bandwidth and shape of the output pulse would also impose severe limitations in the field where this type of vibrating body is used to apply mechanical blows as distinguished from continuously applied, though possibly variable, forces.

Vibration body transducers as normally employed in the field of underwater sound rely on the resonant frequency of the body and the band widths are therefore characteristically small. The narrow band width of such resonant transducers is unfortunately disadvantageous since it permits only single side band transmission when employed in an amplitude modulated system. The narrow band width characteristic of such transducer also makes a frequency modulator system impracticable because of the required large frequency deviation. In accordance with the present invention, the vibrating frequency is not limited to the resonant period and the desired range of frequencies is easily obtainable.

Moreover, in fatigue testing of materials, in applying ultrasonic techniques to abrasive drilling and cutting and in testing the performance of electronic equipment under torsional vibration stresses, it is important to have a vibration source which will cover a wide range of frequencies.

It is the primary object of this invention to provide a system for producing stresses in bodies in which the frequency of vibration is not limited by the natural frequency of the vibrating body.

Another object of this invention is to provide a system for vibrating bodies in which the body may be caused to vibrate over a very wide range of frequencies.

Another object of this invention is to provide transducers for use in the field of ultrasonics, which transducers may be used in frequency-modulation systems.

Another object of this invention is to provide for vibrating bodies in which the wave shape of the vibrations may be controlled.

Another object of the invention is to provide for vibrating bodies where the heat dissipation of the system is spread over the large body.

In accordance with the preferred embodiment of the present invention a number of electromechanical transducers are situated at spaced intervals along the body to be vibrated. Each transducer may be arranged to receive the output of an electronic amplifier. The amplifiers are excited sequentially by means of an electrical impulse traveling along an electrical delay line. The pulse sent out by a signal input mechanism energizes the first amplifier, which in turn energizes the first electromechanical transducer. The mechanical disturbance created in the body to be vibrated travels in both directions along the body. By the time this disturbance has reached the second electromechanical transducer, the electrical signal has reached the second amplifier. The output of the amplifier energizes the second transducer. The disturbance created by the second transducer is added arithmetically to the disturbance this portion of the body from the first transducer. The delay line between the amplifiers must be such that the electrical pulse traveling from the first to the second amplifier reaches the second amplifier at such a time that the second transducer is caused to stress the body just when the stress produced by the first transducer has reached that part of the body affected by the second transducer. Any number of transducers may be employed depending upon the amplitude of the vibration desired.

Other uses and advantages of the invention will become apparent upon reference to the specifications and drawings.

Figure 1 shows schematically a simple form of the invention where a series of electromechanical clutches are used to produce a torsional wave through a long bar.

Figure 2 is a schematic diagram of another form of the invention where longitudinal oscillations are set up in a bar.

Figures 3 and 4 are schematic diagrams of another form of the invention used to create torsional disturbances in a bar.

Figures 5 and 6 are schematic diagrams showing another embodiment of the invention for producing longitudinal oscillations.

Figure 7 is a schematic diagram of another embodiment of the invention.

Referring to Figure 1, a series of clutches **1**, **1***a*, **1***b*, etc. are mounted on shaft **2** and are driven by a common pinion rod **3** through gears **4**. The rod **2** is mounted for rotation in the bearings **15**. Cooperating with each clutch is a clutch follower plate **10**, which is rigidly fixed on the shaft **2**. The clutches are excited in sequence by a series of amplifiers **5**, **5***a*, **5***b*, etc., which are in turn energized from a delay line **6**, having a propagation velocity equal to the propagational velocity of the torsional oscillations in the rod **2**. The rod has mounted on each of its ends energy-absorbing devices **7**, **7***a*, which may consist of paddle wheels **8** and **8***a*, immersed in containers **9** and **9***a*, of an energy-absorbing liquid, like oil. A signal input device **25** is connected to the input of the delay line as shown.

The operation is as follows: The clutches are revolving continuously but are deenergized so that clutch **1** is in the released condition. When in this condition there is still some contact between the clutch and the follower plate. This is necessary since, in order that the system may be responsive to high frequencies, the relative movement between these two parts must be kept small so as to reduce time lag. When the clutch is energized the friction between these two components is increased causing a large friction increase. This method of operation is known as friction modulation and is well known in the art.

When a pulse is applied by the signal input mechanism, amplifier **5** amplifies this pulse and energizes clutch **1**, engaging the clutch and the clutch follower

plate 10, thereby causing the plate to rotate. As the relative axial motion between the clutch and follower plate is negligible, allowance for this motion can be made by permitting the usual axial play in the bearings between the clutch and the rod 2. The rotational motion thus established in the follower plate causes the rod 2 to be twisted and sets up a torsional disturbance in the rod which travels in both directions. The duration of this disturbance depends generally upon the duration of the electrical pulse. The same trigger pulse which was fed to the amplifier 5 is also supplied to the first section of the delay line 6. Just before the disturbance set up in the rod by the clutch 1 reaches clutch 1*a*, the electrical signal has reached the amplifier 5*a*. This synchronism needs to be only approximate to cause the energies to add. The clutch 1*a* is energized by the output of the amplifier and the disturbance created by clutch 1*a* is added arithmetically to the amplitude of the disturbance created by the clutch 1. This action continues until the clutch member 1*d* is reached, each clutch adding its disturbance to the total of the disturbances created by the preceding clutches. The disturbance then proceeds to the right-hand end of the shaft where its energy is finally dissipated, or made use of, in the energy-absorbing device 7. It will be seen that the proper additive relationship between the disturbances of the various clutches will be maintained only for those disturbances travelling in the same direction as the controlling signal in the input delay line. The pulses from each stage which travel in the opposite direction serve no useful purpose. These disturbances must ultimately be disposed of and are eliminated by a suitable characteristic termination 7*a* on the end of rod 2.

It can be seen from the above that the frequency of vibration of the bar 2 is independent of its length, it being possible to transmit a large number of disturbances of short wavelength along the bar without the disturbances interfering with each other. The only timing problem involved is concerned with the necessity that each clutch add its torque increment when the sum of previously produced torques reaches the place in the rod affected by the clutch in question. It should be noted that the actuators need not all act in a single direction as long as they are properly "phased" to add energy to the traveling disturbance. As previously stated, the wave shape of the disturbance set up in the rod is controllable, it being possible to vary the shape in accordance with the particular application for which the transducer is to be used. Factors which may be varied so as to control the wave shape are the inductance-to-resistance ratio in the amplifier output circuit, the shape of the electrical input pulse, the nature of the materials used, the gap in the electromagnet, and many others.

Although the clutches are shown spaced equally along the length of the rod 2, it should not be inferred that this is necessary to the operation of the device, since unequal spacing can be taken care of by using delay lines with unequal time delays.

It should be noted that since the mechanical stresses in the body occur over the entire length of the body, the resulting heat generated in the system is distributed over a large area and therefore the problem of heat dissipation is greatly minimized.

It must also be observed at this point that a rigid structure, as represented by the shaft 2, acts like a flexible medium in respect to its response to applied pulsed forces as is well known in mechanics. In considering the operation of the embodiment shown in Fig. 1, as well as the remaining disclosed modifications, it is important to consider only the transient effects and phenomena as compared to gross effects, such as the bodily displacement of the rod 2 which would occur only upon the application of a relatively steady magnetic field or a magnetic field which occurs at a very low frequency. At the frequency spectrum with which this invention is concerned, the gross effects may be ignored since only the transient effects are manifested. Thus, the application of a transient pulse to the rod 2 through a respective clutch, results in a real disturbance of an incremental portion of the rod and the propagation effects described.

Referring to Figure 2, means are shown for creating longitudinal oscillations in the rod instead of the torsional disturbances created by the device shown in Figure 1.

In this modification an electromagnet 11 is substituted for each of the rotary clutches 1. The end of rod 2 is freely mounted as shown. Associated with each electromagnet is an armature 12, which is rigidly secured to the shaft 2. The electromagnet 11 need rest only lightly on the shaft 2, a slight gap being inherently provided between the electromagnet and armature 12 as is conventional in connection with transducers of this type. When the electromagnet 11 is energized by the amplifier 5, it pulls the armature 12 and, because of the above-discussed transient pulse effects, a longitudinal disturbance will be set up in the shaft. This disturbance travels to the right and left as formerly described, and is intensified by each electromagnet in turn.

In Figures 3 and 4, an arrangeemnt for a rotational clutch system is shown in which the rod 2 needs no plates attached to it, as was done in the device shown in Figure 1. Here a gear 13 is continuously driven by a pinion 21. Each gear is provided with clutches 14 of the drum type operated by electromagnetic structure 15. The clutch is composed of two brake shoes 16 and 17 which are pivotally mounted on the gear 13, the rod 2 being located between the shoes. Each electromagnet is connected with its associated amplifier through two slip rings 18 and 19. When the electromagnet is energized, the brake shoes 16 and 17 clamp the rod 2 and impart a torque disturbance to the rod that is propagated as in the case of the device of Figure 1. The differences between these two devices is that the mass of the rod itself has no discontinuities caused by the plates as in Figure 1.

Figures 5 and 6 show a friction means for creating longitudinal oscillations. Gears 22 and 23 are rotatably mounted on the shafts 24 and 26, respectively, and are driven by a pinion 27. Connected to each of the gears are friction wheels 28 and 29 which rub against the rod 2. Normally the wheels touch the rod only lightly. As is apparent in Fig. 6, the articulation among the gears 22, 23, and 27 are such as to cause the friction wheels 28 and 29 to rotate oppositely to each other so that their peripheries will provide a longitudinal acceleration to the rod 2 in the same direction when the rollers are forced against the surface of the rod at diametrically opposed points. It will be appreciated that since the magnetizing force applied by the coil 32 emanates from a pulse source such as 25, the applied force is not continuous but occurs in an instantaneous manner in the nature of a transient impact. A shock wave is thereby caused to be transmitted through the rod in accordance with the principles already described. The axles 24 and 26 and rod 31 form a U-shaped member with a coil 32 wound around the rod 31, the entire structure forming an electromagnet. When the coil 32 is energized by its amplifier, the wheels 28 and 29, which are made of magnetic material, are pulled against the rod 2 and produce in it a longitudinal oscillation which is then amplified by other similar friction wheel sets in succession as described before. Enough vertical play is provided between the gears 22 and 23 so that the friction wheels 28 and 29 can be pulled against the rod 2.

Figure 7 shows a means for obtaining the proper phasing between the traveling wave and the subsequent reinforcements without using an electrical delay line. A self-excited system may be used as described below.

Again the pulse source 25 feeds the amplifier 5, the output of which is connected to the electromagnet 1. A sensing device, such as a stylus, 33, which is operatively associated with a piezoelectric crystal 34, is positioned so as to contact the armature plate 10 of the electromagnet 1*a*. The output of the crystal is connected to a single-shot multivibrator 36, the output of which is connected to the electromagnet 1*a*. The same arrangement is used in conjunction with electromagnet 1*b* and any others that may be positioned along the shaft.

The operation of this modification is the same as the device shown in Figure 2 except that the electrical delay line has been eliminated. Timing is obtained by sensing with the stylus and crystal the instant when the traveling wave has reached the armature plate. The mechanical disturbance created by the traveling wave will impart motion to the stylus, which in turn will cause the crystal to send an electrical impulse to the single-shot multivibrator. This impulse will trigger the multivibrator causing it to actuate its output electro-

magnet. After a predetermined time the multivibrator will flip back to its initial condition and be ready to handle the next input signal.

This system of obtaining proper phasing is not limited to use with the type of device shown in Figure 2 but may be used with any of the systems shown in Figures 1 to 6, inclusive. Also this method has the advantage that it is not necessary to determine the propagation velocity of the wave in the body 2 and then match the electrical delay line to the mechanical system. This eliminates difficulties encountered when the body 2 is not uniform throughout its length.

Purely mechanical input devices, such as a series of hammer blows, or mechanical clutches actuated in proper sequence, as for example by cams, may also be used.

It should be understood that the oscillations need not be confined to solid bodies but can be produced in gases and liquids as well. In fact, any device that behaves as a delay line for mechanical (as distinguished from electrical) waves can be excited in this manner.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of my invention as defined in the appended claims.

I claim:

1. A device for the generation of traveling waves in a medium, comprising a body in which traveling waves are to be induced, transducers arranged at intervals along one dimension of said body for inducing mechanical disturbances in said body, means for actuating said transducers when said means are energized comprising a pulse input source and means coupling said source to each of said transducers comprising a section of delay line connected between said pulse input source and each of said means, the time delay in each of said sections of delay line being equal to the time of travel of said mechanical disturbances between the transducers with which each of said sections of delay line is associated.

2. A device for the production of traveling waves in a medium in which traveling waves are to be induced, comprising means for inducing mechanical disturbances in said body, a pulse input source, an amplifier coupling said pulse source to each of said inducing means for actuating said means when said amplifiers are energized, a delay line connected between the input and each of said amplifiers, the propagation velocity of said delay line being such that the mechanical disturbances induced by each of said means reinforce said traveling waves as they are passing each of said means.

3. A device for the generation of traveling waves in a medium, comprising a body in which traveling waves are to be induced, electromechanical transducers arranged at intervals along the length of said body for inducing mechanical disturbances in said body, an amplifier associated with each of the transducers, each transducer being connected in the output of its associated amplifier, and an electrical delay line connected between the inputs of each of said amplifiers, the propagation velocity of said delay line being matched to the propagation velocity of the mechanical disturbances between the transducers with which the delay line is associated.

4. A device for the production of traveling waves in a medium, comprising a body in which torsional waves are to be induced, a series of rotary electromechanical clutches arranged at intervals along the length of said body for inducing torsional disturbances in said body, said clutches being rotatably mounted on said body, an input gear on each of said clutches, a common pinion for driving said input gears, an amplifier associated with each of said clutches, said clutch being connected in the output of said amplifiers, and an electrical delay line connected between the inputs of each of said amplifiers, the time delay of each intervening section of said delay line being equal to the time of travel of the torsional disturbances between the clutches.

5. A device for the generation of traveling waves in a medium, comprising a body in which longitudinal waves are to be induced, a series of electromagnets arranged at intervals along the length of said body for inducing longitudinal disturbances in said body, an amplifier associated with each of said electromagnets each of said electromagnets being connected in the output circuit of its associated amplifier and an electrical delay line connected between the inputs of each of said amplifiers, the time delay of each intervening section of said delay line being equal to the time of travel of said longitudinal disturbances between the electromagnets.

6. A device for the transmission of mechanical vibrations in a medium, comprising a body in which vibrations are to be induced, a plurality of transducers disposed along the path of propagation of the vibrations in said body, means for actuating said transducers, comprising an input pulse source connected to one of said transducers, means for actuating the remainder of said transducers comprising, energizable means each having an output connected respectively to each of said remaining transducers and sensing means connecting each transducer to the input of a subsequent energizable means for energizing the actuating means at such a time as to reinforce said mechanical vibrations as they are passing each of the said remaining transducers.

7. The invention according to claim 6 in which said energizable means comprises a single-slot multivibrator and said sensing means comprises a stylus positioned with respect to said body so as to pick up the mechanical vibrations just prior to the time the transducer, with which said stylus is associated, is to be actuated, a piezoelectric crystal associated with said stylus and actuated thereby, the electrical output circuit of said crystal being connected to the input of said multivibrator for triggering the latter.

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