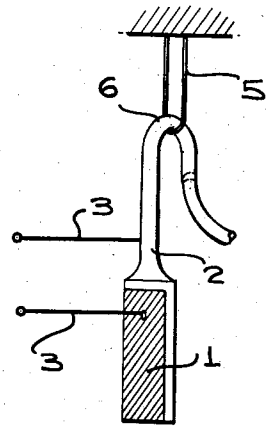
June 15, 1965 J. B. BROMBAUGH 3,189,686

TRANSDUCER AND MOUNTING FOR MECHANICAL DELAY LINES

Filed Aug. 18, 1961

FIG. 1



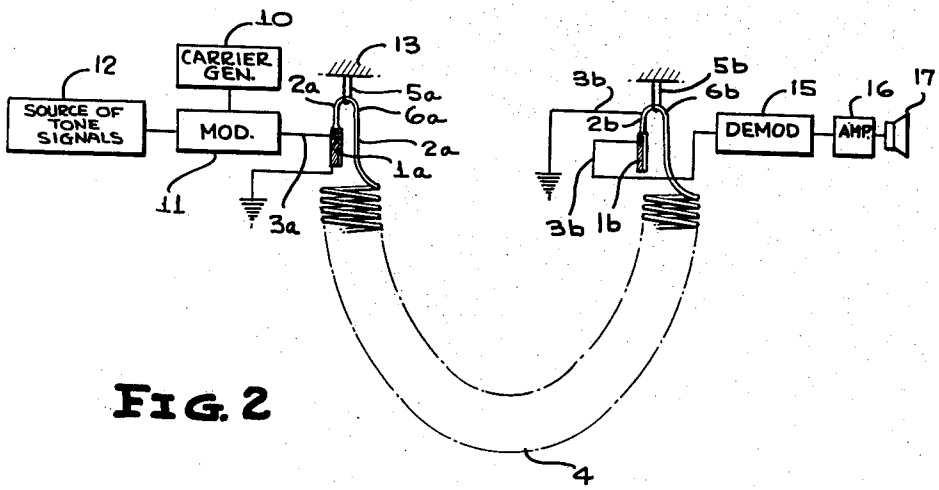


FIG. 2

INVENTOR
JOHN B. BROMBAUGH

BY Hurwitz and Rose

ATTORNEYS

United States Patent Office 3,189,686 Patented June 15, 1965

3,189,686

TRANSDUCER AND MOUNTING FOR MECHANICAL DELAY LINES

John B. Brombaugh, Cincinnati, Ohio, assignor to D. H. Baldwin Company, a corporation of Ohio

Filed Aug. 18, 1961, Ser. No. 132,329
16 Claims. (Cl. 179—1)

The present invention relates generally to electro-mechanical and to mechanico-electrical transduction in delay lines and reverberators, and more particularly to devices and methods for coupling transducers to long wire mechanical delay lines, for mechanically mounting the delay lines, for effective generation of transverse mechanical waves on the delay lines and for effective translation of the mechanical waves into electrical signals.

Long wires, preferably in the form of helical springs, are useful for generating reverberation effects, in music, approximating acoustic reverberations produced by the acoustic properties of large reverberant spaces. Such reverberation generators may be operative at sonic frequencies or at ultra-sonic frequencies. In the former case the output of an electrical musical instrument, such as an electronic organ, or of a phonograph, tape recorder, or other source of electrical signals representative of music, is directly coupled to a driver electro-mechanical transducer which provides mechanical vibrations in the wire. A mechanico-electrical transducer is coupled to the wire at a point remote from the driver for translating the vibrations into electrical signals suitable for subsequent electro-acoustic transduction. The structural arrangement of the system is such that multiple reflections occur at the transducers or at other selected points along the wire.

In the alternative, electrical signals representative of music are modulated on an ultrasonic carrier, or are heterodyned to fall in the ultrasonic range, and the converted signals are employed to generate reverberative mechanical vibrations on a wire at one point of the wire. The vibrations are transduced to electrical signals at a remote point along the wire and the electrical signals, with reverberative effects now added, are derived from the carrier by frequency conversion.

The present invention concerns itself primarily with ultrasonic reverberation systems, in terms of a preferred application. The invention, however, finds further application to sonic reverberators, to mechanical filters, to mechanical delay lines, and the like.

Briefly describing a preferred embodiment of the invention, elongated transducers are cemented to a wire delay line, ends of the transducers coinciding with the ends of the wire, and the transducers being one half wave length long or less at all operating frequencies and bonded lengthwise along the length of the wire. One of the transducers operates as a driver and one as a pick-up, but in other respects they may be duplicates. Preferably the transducers operate in the longitudinally vibrating mode, causing and sensing transverse vibrations in the wire. Leads for the transducers and suspensions for the wire are secured to velocity nodes along the transducer and the wire, to avoid reflections and attenuation. The suspensions may be fabricated of organic material, rather than metallic material.

Since the transducers vibrate longitudinally, either piezo-electric or magneto-strictive transducers can be employed. The latter type possesses low impedance and therefore is particularly suitable in conjunction with transistor circuitry.

The transducer mounting system of the present invention is particularly applicable to ultrasonic reverberator systems because for such systems the transducers can be small and the velocity nodes separated by slight distances.

Wire delay lines have resonances, due to reflections

from the ends of the wire. The fact that the transducers are bonded to the wire along their length implies that they are mechanically integral with the wire, or are seen as a thickening thereof by the mechanical wave motion of the wire. The transducers do not appreciably disturb the resonance characteristics of the wire, because of the mode of association of the transducers and the wire and high efficiency of transduction exists.

It is, accordingly, a primary object of the present invention to provide a novel reverberator.

It is another object of the invention to provide a novel electro-mechanical transducer system.

A further object of the invention resides in the provision of a novel mechanico-electrical transducer system.

A further object of the invention resides in the provision of a transducer capable of transducing mechanical waves to and from an elongated wire, having resonance characteristics due to its length, without materially affecting these resonance characteristics.

It is another object of the invention to provide a transducer having two leads, for generating and sensing traveling wave mechanical vibrations, wherein the leads are located at velocity nodes of the vibrations.

Another object of the invention is to provide a mounting for an elongated mechanically vibrating rod or wire, the mounting consisting of one or more suspensions secured to the rod or wire at velocity nodes.

A further object of the invention is to provide an organic fiber (nylon) suspension for wire having vibrations traveling along its length, the suspension contacting the wire only at a velocity node of the vibrations.

It is still a further object of the invention to provide a transducer for transverse vibrations in a wire, the transducer operating in the longitudinal vibrational mode and being not longer than one half wave length at the operating frequency.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a view in plan of a piezo-electric transducer secured to a wire and including wire leads for the transducer and a mounting element for the wire.

FIGURE 2 is a schematized view of a reverberation system according to the invention, incorporating the structure of FIGURE 1.

Referring now to the accompanying drawings, FIGURE 1 illustrates in general fashion a mode of coupling a transducer 1 to an elongated element 2, such as a long wire, for the purpose of inducing mechanical vibrations therein, and sensing such vibrations. The transducer may be electro-mechanical or mechanico-electrical. Further, the transducer is preferably piezo-electric (but magneto-strictive transducers can also be employed). Its length is $\lambda/2$ or less at its operating frequency. Its mode of vibration is preferably longitudinal, although piezo-electric transducers operating in the bending or flexural mode are usable. Leads 3 may be secured, in the case of a piezo-electric transducer, one to the transducer at a point occupied by a velocity node and the other to the wire 3, also at a velocity node. Thereby, the leads do not adversely affect the operation of the system. The transducer 1 may be bonded along its entire length to the wire 2 by means of a conductive epoxy resin or by soldering. It is then found that the epoxy provides better acoustical and mechanical properties than the solder, for reasons which are not well understood.

If the transducer 1 is considered as a driver operating in the bending or flexing mode, transverse waves are directly generated in the wire 2 and are coupled into the wire by

the bond between the wire and the transducer. If the transducer 1 is operating as a pick-up, in the bending or flexing mode, transverse vibrations in the wire 2 are communicated to the transducer via the epoxy bond and generate voltage therein.

It is found that superior results can be attained by employing a transducer operating in the longitudinal mode. Moreover, it is this mode of operation which enables magnetostrictive transducers to be employed, having low impedance, with consequent advantages in conjunction with transistor circuitry. The transducer, operating as a driver, and the wire 2, bonded to the transducer along the entire length of the transducer, provide a structure in which one element, transducer 1, expands lengthwise, in response to a signal, while the other, the wire 2, does not expand length-wise. The result is a bending action. The action is similar to that which takes place in a bi-metallic thermostat. Operation of the transducer in the longitudinal extension mode provides more output than transducers operating in the flexural mode, for a given transducer material, by a factor of about 10–13 db, in systems which have been tested. When operating as a driver, the transducer is required to be $\lambda/2$ or less in length, at the operating wave-length, in order that all points of the transducer shall contribute to bending of the wire in the same direction, since the bending constitutes or generates a transverse mechanical vibration which travels down the wire. Were the transducer longer than $\lambda/2$ there would exist points along the wire, within the bonded area, which were attempting to vibrate in phase opposition to the motion of the transducer, thus reducing the efficiency of transduction.

Alternatively, when the transducer operates as a pick-up the transverse mechanical vibrations of the wires elongate the transducer in bending it. Maximum output occurs, per unit length of transducer, if the transducer is $\lambda/2$ or less in length at the operating frequency.

The mechanical thickness of the wire at the bond affects the mechanical impedance of the wire 4 and thus the coupling to the driver. This impedance is high, for usual wire sizes, in comparison with the impedance of the driver, so that system resonance is not strongly affected by the properties of the driver, constituting an important advantage of the system. System resonance is very broad and occurs where the driver is a half wave length long of the wave in the combination of driver and wire. One velocity node will occur along the driver, or at its end when it is half a wave length long. A lead wire 3 is attached at this point, so that the lead wire will have minimum damping effect and therefore generate minimum reduction of reverberation time. The wire itself, being bonded to an electrode of the transducers employed, forms a common ground for the driver and pick-up transducers. A ground connection to the wire may be soldered to the wire at a node, to avoid damping.

In a practical reverberator, the wire takes the form of a helical spring 4, but solely to conserve space for a given length of wire. Vibration does not take place in the spring, as a spring, but in the wire as a wire. The turns of wire are non-contiguous, to avoid frictional damping. The spring 4 requires mounting, in any practical reverberator. It is entirely feasible to effect mounting at one end of the spring, but greater mechanical stability is achieved by mounting the spring at both ends and permitting the spring to hang free. In order to minimize effects of the mountings on reverberation time, the mountings are in the form of loops of organic fiber 5 e.g. nylon, from which the spring is suspended at velocity nodes closest to the transducers. It has been found that use of organic fiber suspensions, rather than metallic suspensions, provides superior acoustic effects, although reasons for this are not certainly known. Nevertheless, metallic wire suspensions are operative. It is believed that the effect may be due to high acoustic damping in the fiber, i.e. the organic fiber does not respond to impact. The wire itself is

bent, as at 6, to establish the velocity nodal point on the wire, and to assure that the suspension will occur at such a point. If metallic suspensions are employed they may be soldered to the wire, in which case the bend 6 is no longer necessary.

In an effective reverberator it is essential that repeated reflections occur from both ends of the spring, i.e. that the vibrations travel back and forth along the spring and are reflected from the pick-up end of the spring to the driver end, and back to the pick-up end. A considerable number of two-way traverses may take place. This implies that the transducers do not unduly interfere with reflections from the ends of the wires.

Construction of a transducer according to the present invention provides maximum reverberation time, and minimum damping due to transducers, leads and suspensions, the major part of the damping occurring in the spring itself. By proper choice of spring material, wire size and wire diameter attenuation along the wire of the spring can be minimized. This subject has been dealt with in a copending application, Serial No. 102,443, Bissonette et al., filed April 12, 1961, now Patent No. 3,136,853, and entitled Music Enhancing System, the contents of which are incorporated herein by reference.

In a practical application of the present invention to a supersonic reverberator, of the types described more in detail in the above-mentioned application for U.S. patent, a carrier generator 10 provides carrier at about 20 kc. to a modulator 11. The carrier is modulated, preferably in amplitude, by the tonal input of an electrical music source 12, such as an electronic organ, a phonograph, a radio, or the like. The modulator 11 may be any one of the types referred to in the above-mentioned application for U.S. patent, or any other type known to the art which is capable of translating a band of frequencies in the audio range to a band of frequencies displaced into the supersonic range.

The output of modulator 11 is applied to a transducer 1*a*, preferably a ceramic piezo-electric transducer vibrating in the longitudinal mode. The transducer 1*a* is cemented by means of conductive epoxy resin to a flat formed at the end of a wire transducer. A lead 3*a* is secured to one electrode of the transducer, at a velocity node, and a ground connection is provided on the wire itself, either at the velocity node nearest to the transducer 1*a*, or to the end of the wire. A bend 6*a* is formed in the wire, at a velocity node, and the wire is supported from the bend 6*a* by means of a nylon loop 5*a*, secured to a rigid member 13.

At the remote end of the spring, the structure and arrangement is a mirror image of those at the driver end, numerals of reference employing, however, the subscript *b*. The pick-up 1*b* is connected to a suitable demodulator, 15, for detecting the modulation present in the modulated carrier traveling along the delay line 4, and the detected output is suitably amplified by amplifier 16 and radiated acoustically by loudspeaker 17.

The delay line 4 is designed to have adequate delay time to produce reverberative effects, due to repeated reflections along the delay line. The transducers 1*a* and 1*b* do not introduce material attenuations, and reflections effectively occur from the ends of the wire, which are of zero acoustic impedances. Therefore, reflection is substantially complete. However, there is sufficient internal attenuation in the delay line to accomplish the requisite decay of signal, as a function of time, to simulate true acoustic reverberation as it ocurs in a reverberative space.

A supersonic reverberator employing a long wire delay line possesses very many resonances, which are desirable in enhancing music. The system of the present invention, and the various features thereof, have been found to leave all resonances in the delay line substantially unaffected. Neither the presence of the transducers, nor the leads to and from the transducer, nor the suspensions, introduce damping or reflections. All reflections occur

from the ends of the wires, which represent zero acoustic impedances, so that reflections are essentially total. Moreover, the many operational features of the invention are accomplished by means of a structure which serves to protect the transducers, which are quite small and fragile, from shock, impact, and mechanical strains, deriving from any source or cause.

What we claim is:

1. A reverberation system for electrically generated musical tones, comprising a source of electrical tone signals, a modulator, a supersonic carrier generator coupled to said modulator, said modulator generating a modulated carrier including said tone signals superposed on said carrier, a reverberator having a driver, a long mechanical delay line and a pick-up, a demodulator coupled to said pick-up, said demodulator being responsive to said modulated carrier to recover said tone signals, and means for acoustically transducing said tone signals, said driver and said pick-up each including an elongated transducer, said delay line including a long wire, and means providing a direct bond between said transducers and said wire along at least a major part of the transducers, said transducers being adapted to vibrate along the bond.

2. The combination according to claim 1 wherein said transducers are piezo-electric transducers including electrodes, an electrode of each of said transducers being bonded along its entire length to said wire, whereby said wire constitutes a common ground for said transducers.

3. The combination according to claim 2 wherein said transducers are mounted end to end with said wire and are not greater than one half wave length long along the wire.

4. The combination according to claim 3 wherein wire leads for said transducers are secured to nodal points of said transducers and of said wire.

5. The combination according to claim 4 wherein said wire forms a helical coil, and wherein said helical coil is suspended, at least some of said suspensions being located at nodal points along said wire.

6. A reverberatory system for introducing into music reverberatory effects simulating those of a large enclosure, said system including a flexible wire delay line, said delay line having free ends to provide substantially zero acoustic impedance and therefore maximum wave reflections from said ends, a first transducer for inducing transverse acoustic vibrations of said flexible wire, a second transducer responsive to said transverse acoustic vibrations for generating electrical signals, means providing a direct bond between said transducers and said wire along at least a major part of the transducers, said transducers being adapted to vibrate along the bond, each of said transducers being elongated and having two free ends, a free end of each transducer substantially coinciding with a free end of said wire and the remaining ends of said transducers coinciding with points along said wire substantially displaced from the free ends of said wires.

7. The combination according to claim 6 wherein said means providing a direct bond is conductive epoxy resin.

8. The combination according to claim 7 wherein is provided a supersonic carrier generator, modulating means responsive to said music for modulating said carrier, means connecting said modulating means to said first transducer in driving relation thereto, said last means comprising a lead connected to said transducer at a velocity node of its vibrations.

9. The combination according to claim 8 wherein is further provided a lead connecting said modulating means to said wire at a velocity node of the vibrations of said wire.

10. The combination according to claim 9 wherein are provided suspensions for said wire located at velocity nodes of the vibrations of said wire.

11. The combination according to claim 10 wherein said wire is provided with bends at said last mentioned velocity nodes, said suspensions being organic fibers suspending said bends, said wire hanging free between said bends.

12. The combination according to claim 11 wherein said bends are located between said transducers along said wires.

13. The combination according to claim 12 wherein said suspensions are located at the nodes located nearest to said transducers.

14. The combination according to claim 13 wherein said transducers are each not greater than one half wave length long at the wave length of said carrier along said wire.

15. The combination according to claim 14 wherein said transducers are arranged and adapted respectively to vibrate longitudinally in the direction of the length of said wire in response to a driving signal whereby said first transducer vibrates said wire in the transverse mode and said second transducer responds to said transverse vibrations.

16. The combination according to claim 15 wherein the lengths of said wire adjacent the ends of said wire include flats and wherein said transducers are ceramic piezo-electric transducers bonded to said flats.

References Cited by the Examiner

UNITED STATES PATENTS

1,852,795	4/32	Wegel	333—30
2,318,417	5/43	Phelps	179—1
2,375,004	5/45	Knowles	179—1
2,421,424	6/47	Kreuzer	179—1
2,767,336	10/56	Arenberg	333—30
2,967,447	1/61	Hanert	179—1
2,982,819	5/61	Meinema et al.	179—1
3,012,211	12/61	Mason	333—30
3,025,479	3/62	Wolfshill	333—30
3,041,556	6/62	Meitzler	333—30
3,051,915	8/62	Hoover et al.	333—30
3,064,241	11/62	Schneider	333—30 X
3,070,761	12/62	Rankin	333—30
3,136,853	6/64	Bissonette et al.	179—1

FOREIGN PATENTS

512,067	1/53	Italy.

ROBERT H. ROSE, *Primary Examiner.*

THOMAS B. HABECKER, WILLIAM C. COOPER, *Examiners.*