Feb. 4, 1941. L. HAMMOND **2,230,836**

ELECTRICAL MUSICAL INSTRUMENT

Filed July 15, 1939 4 Sheets-Sheet 1

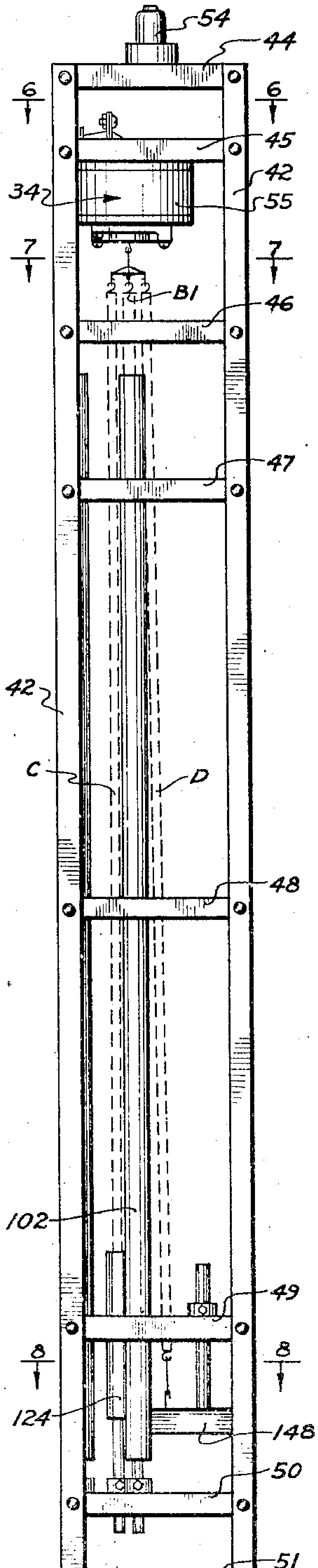

Fig. 2

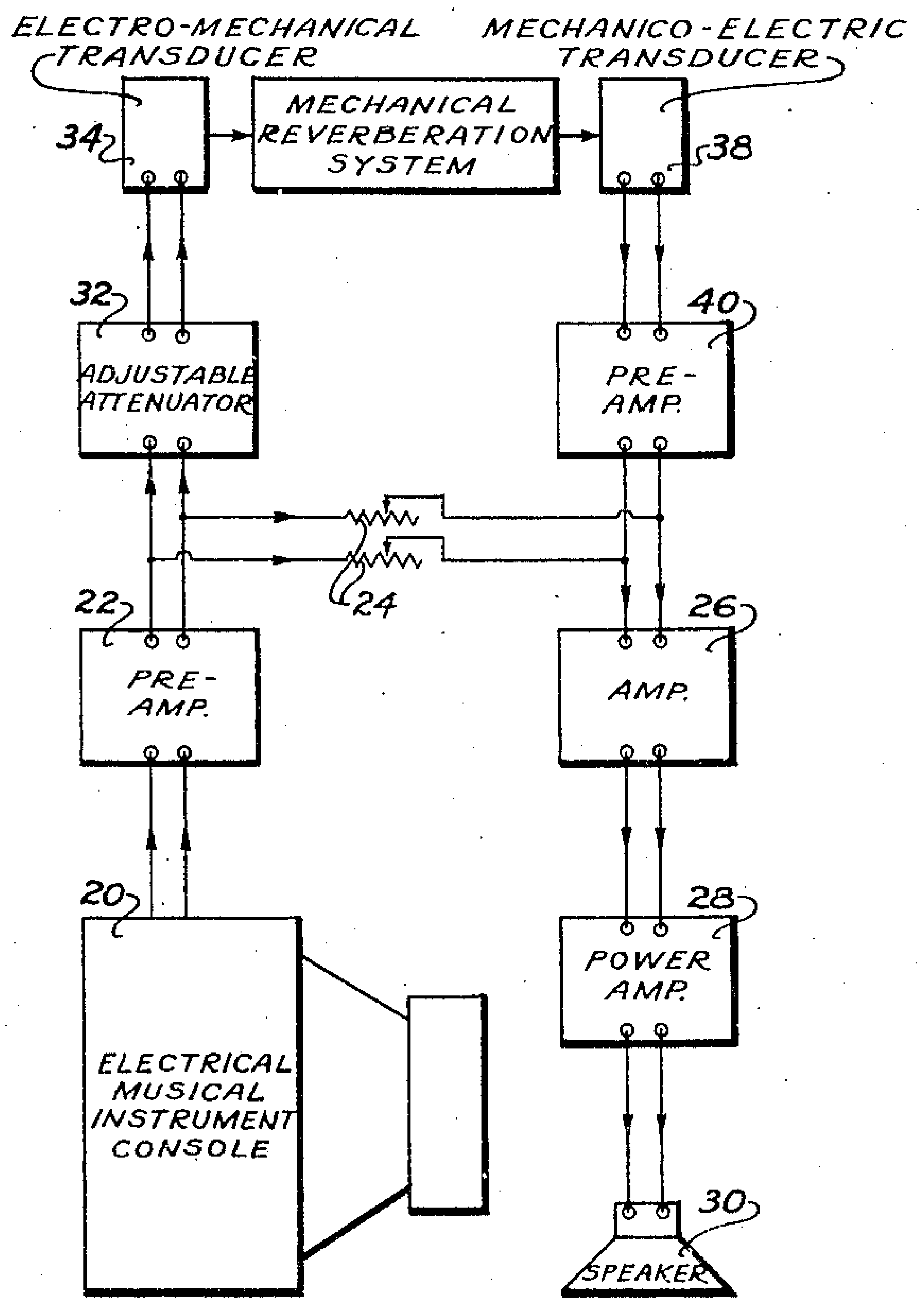

Fig. 1

Inventor
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle
Attys.

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ELECTRICAL MUSICAL INSTRUMENT

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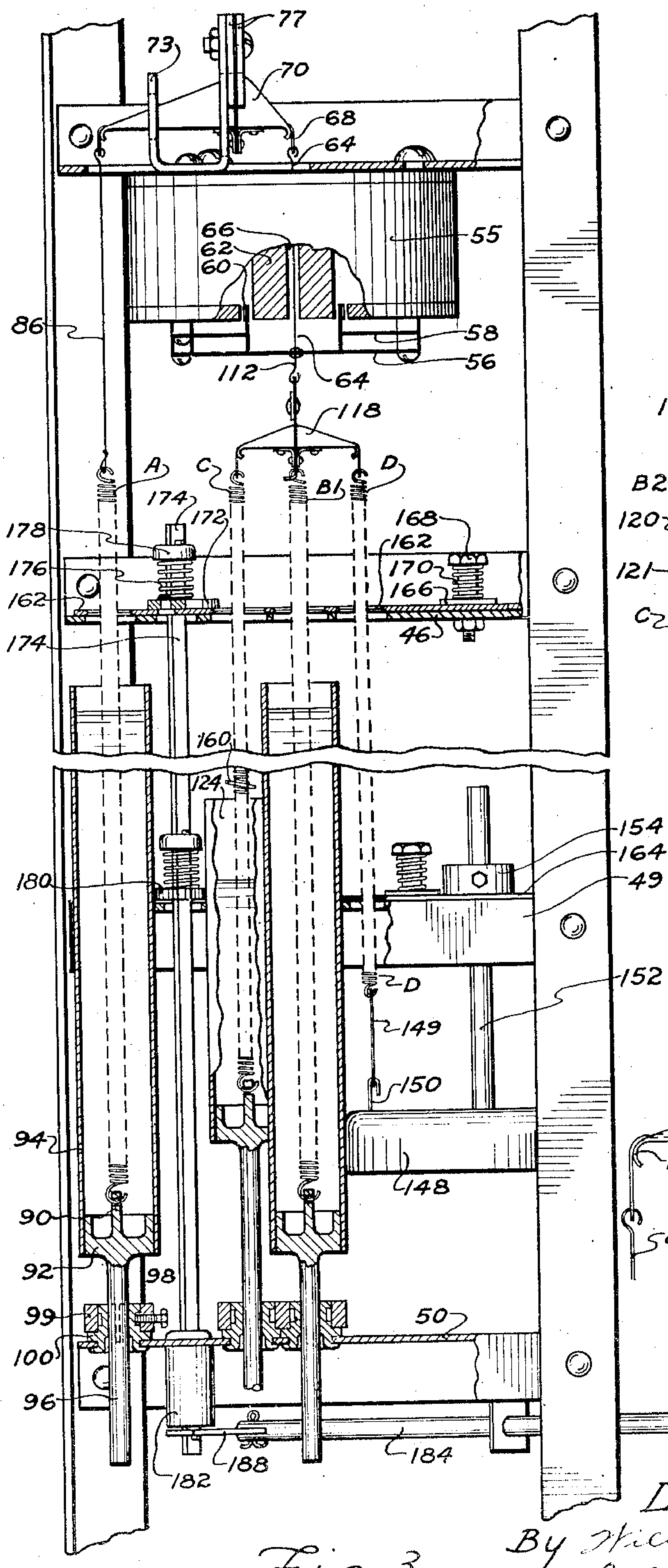

Fig. 3

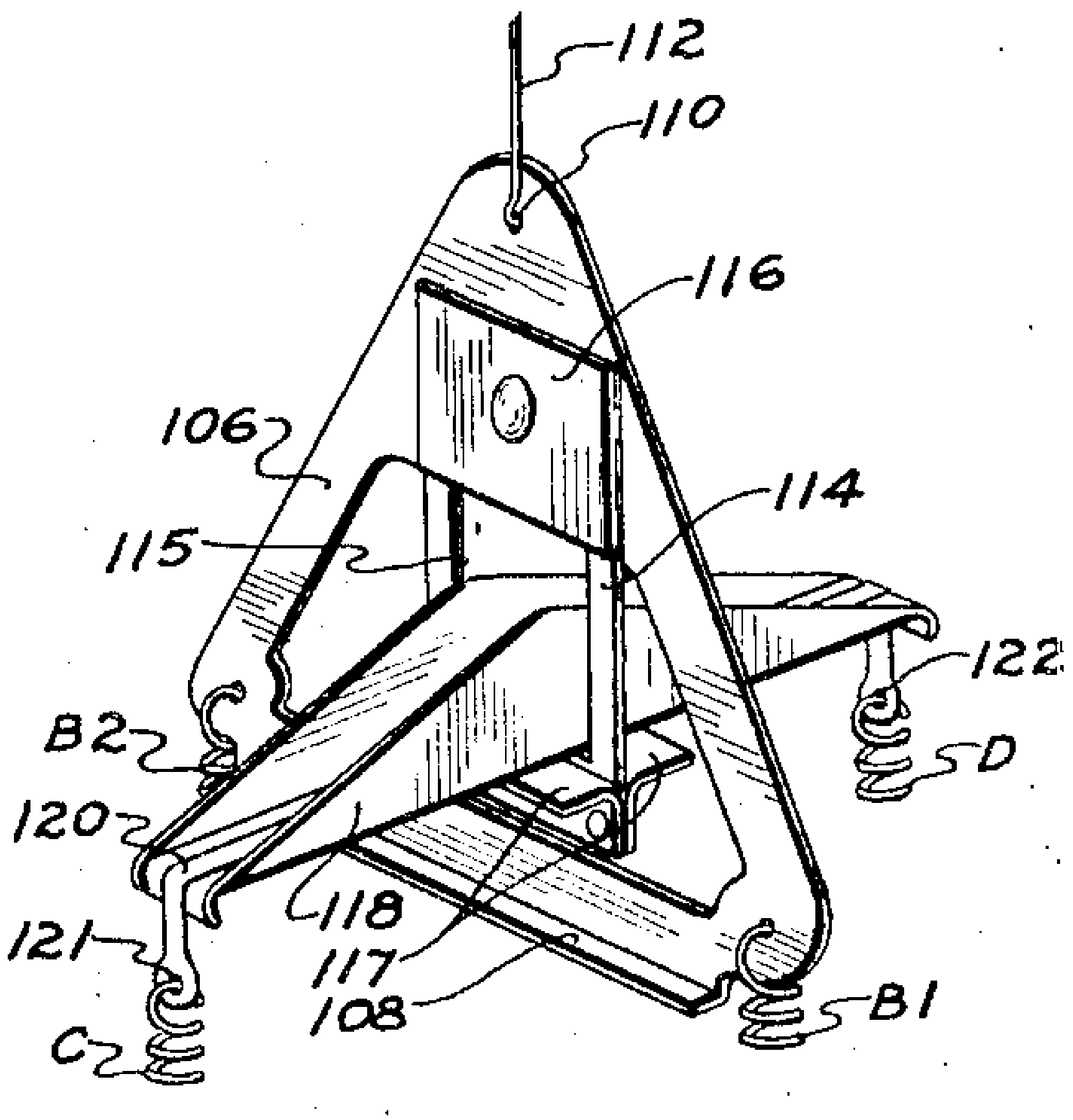

Fig. 4

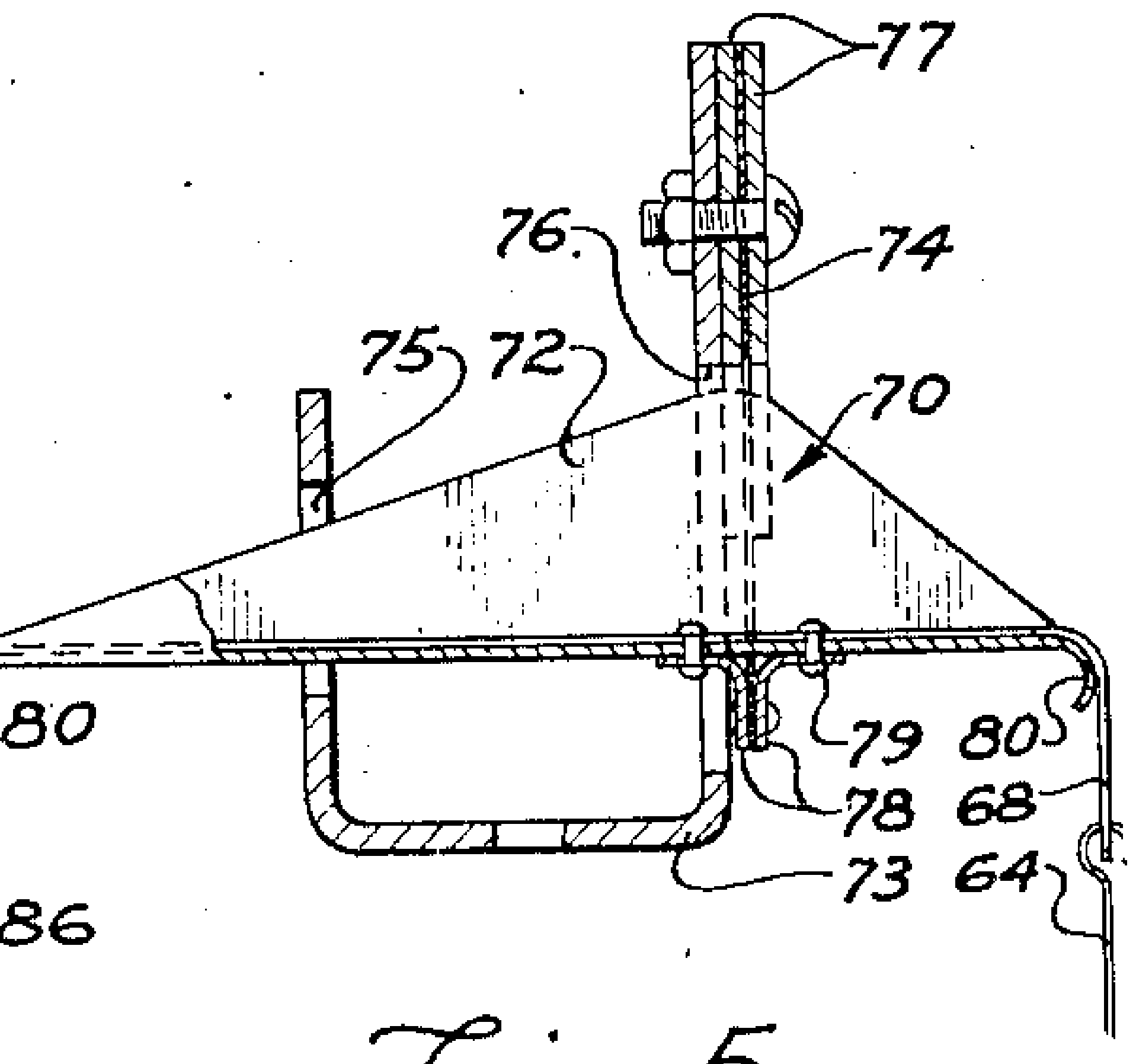

Fig. 5

Inventor
Laurens Hammond
By Williams, Bradbury,
McCaleb & Hinkle
Attys.

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ELECTRICAL MUSICAL INSTRUMENT

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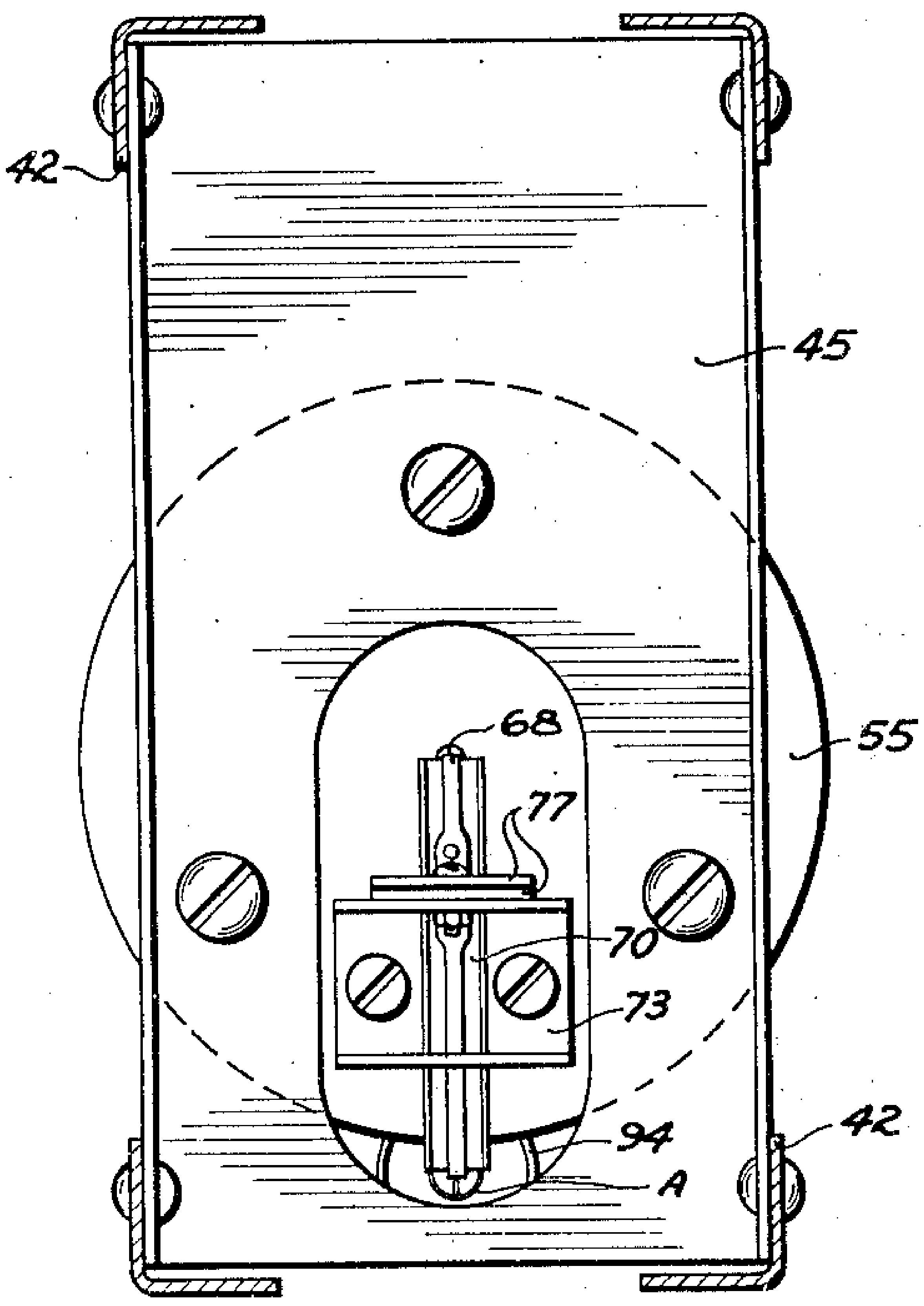

Fig. 6

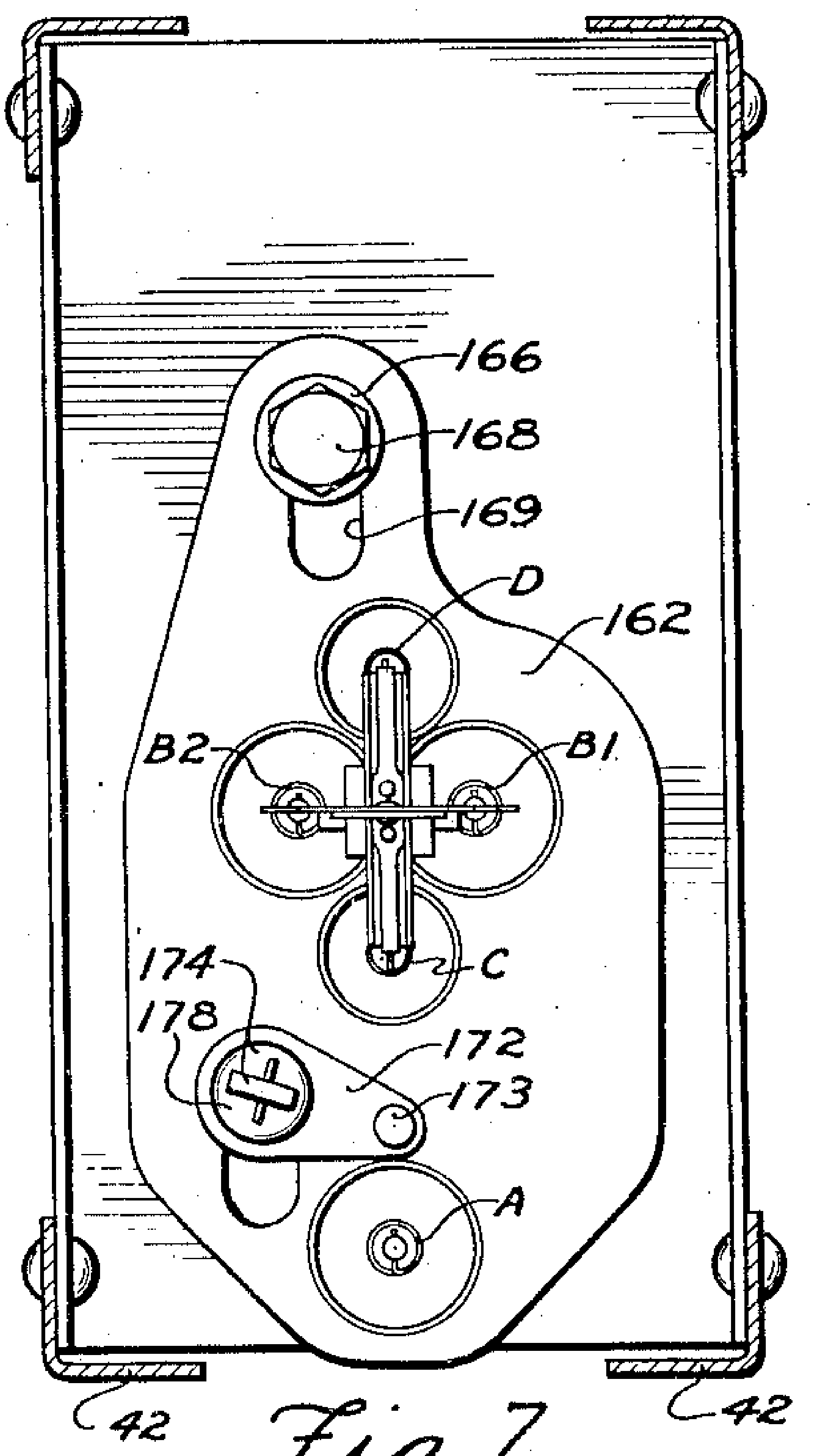

Fig. 7

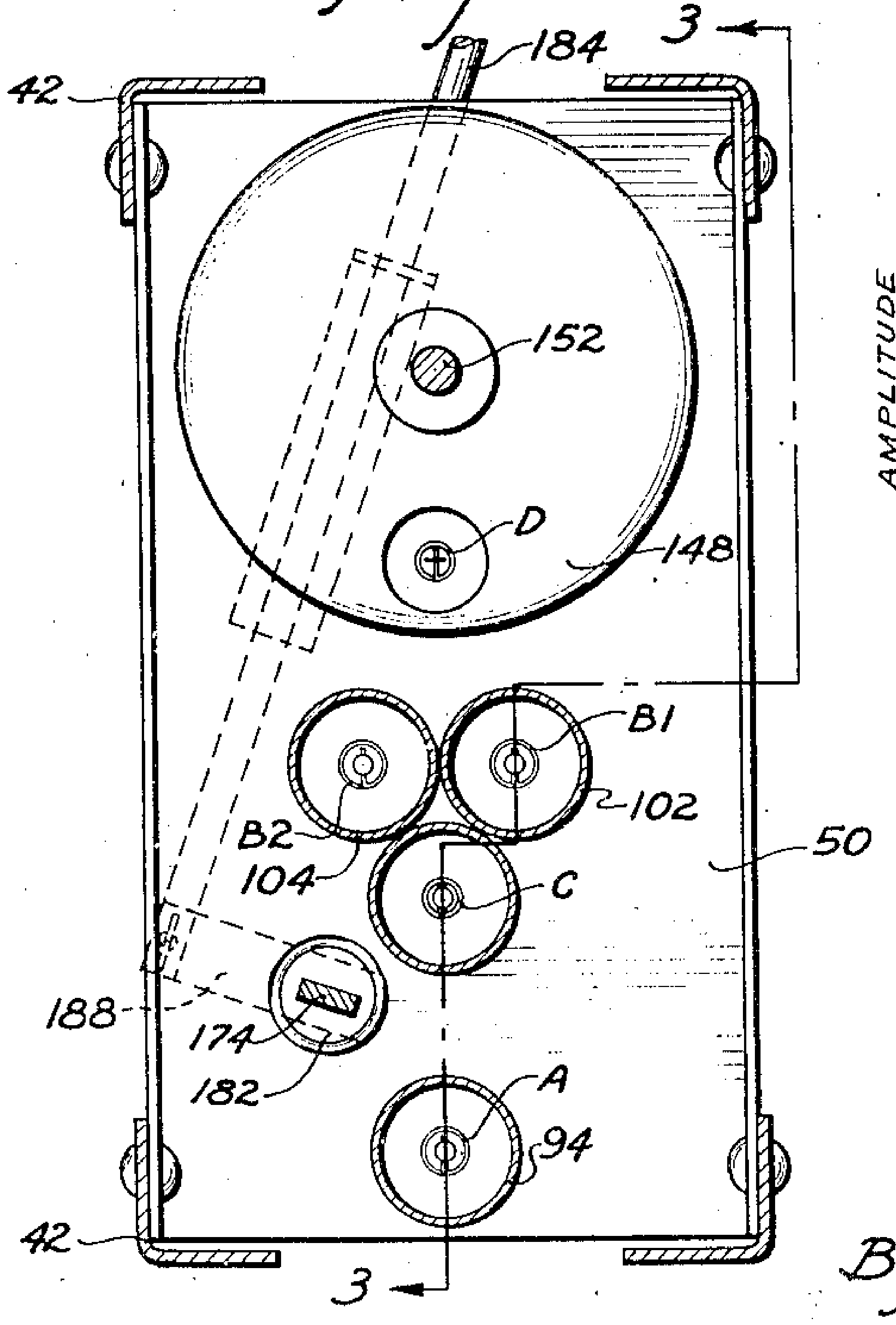

Fig. 8

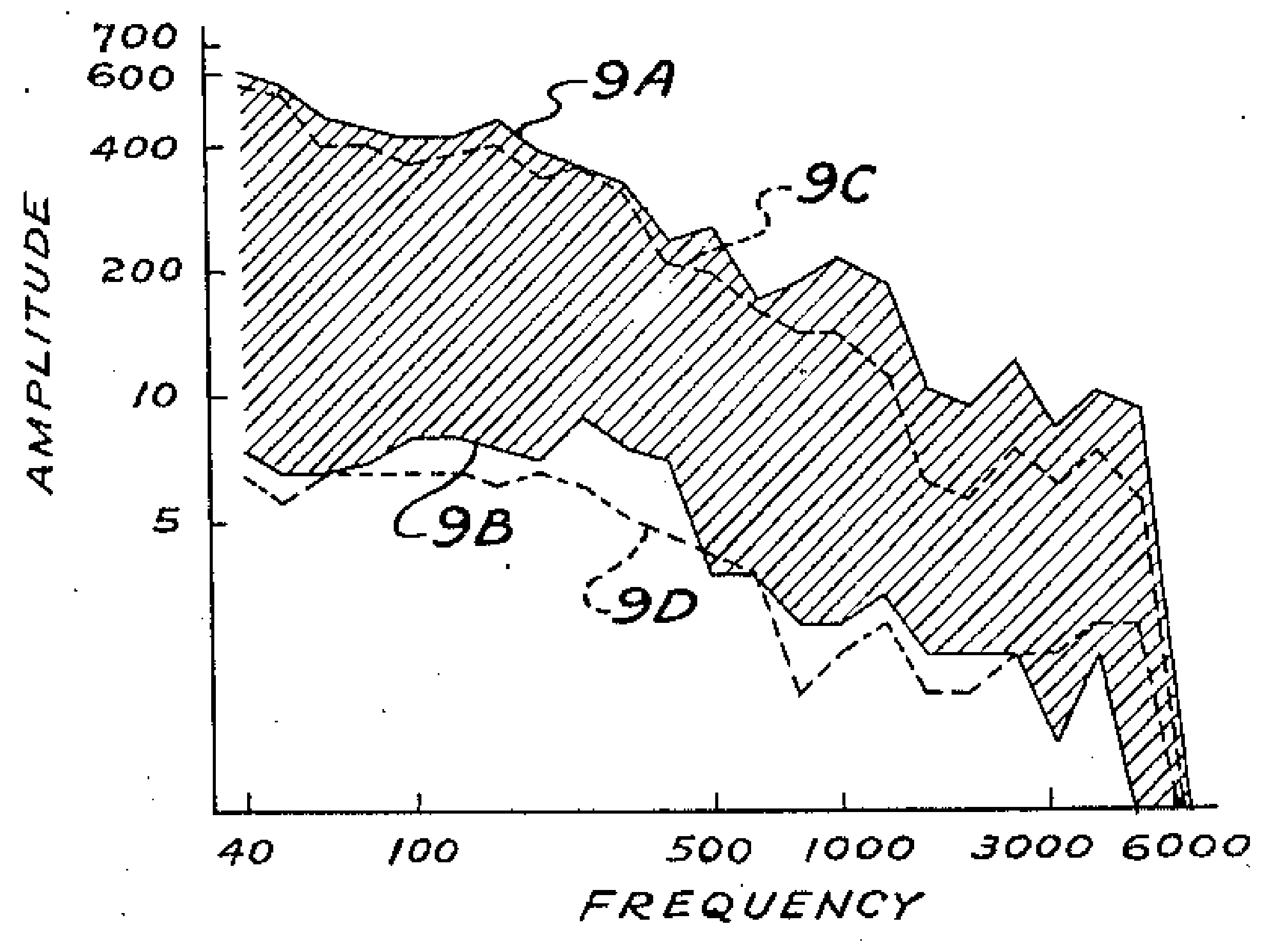

Fig. 9

Inventor
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle
Attys.

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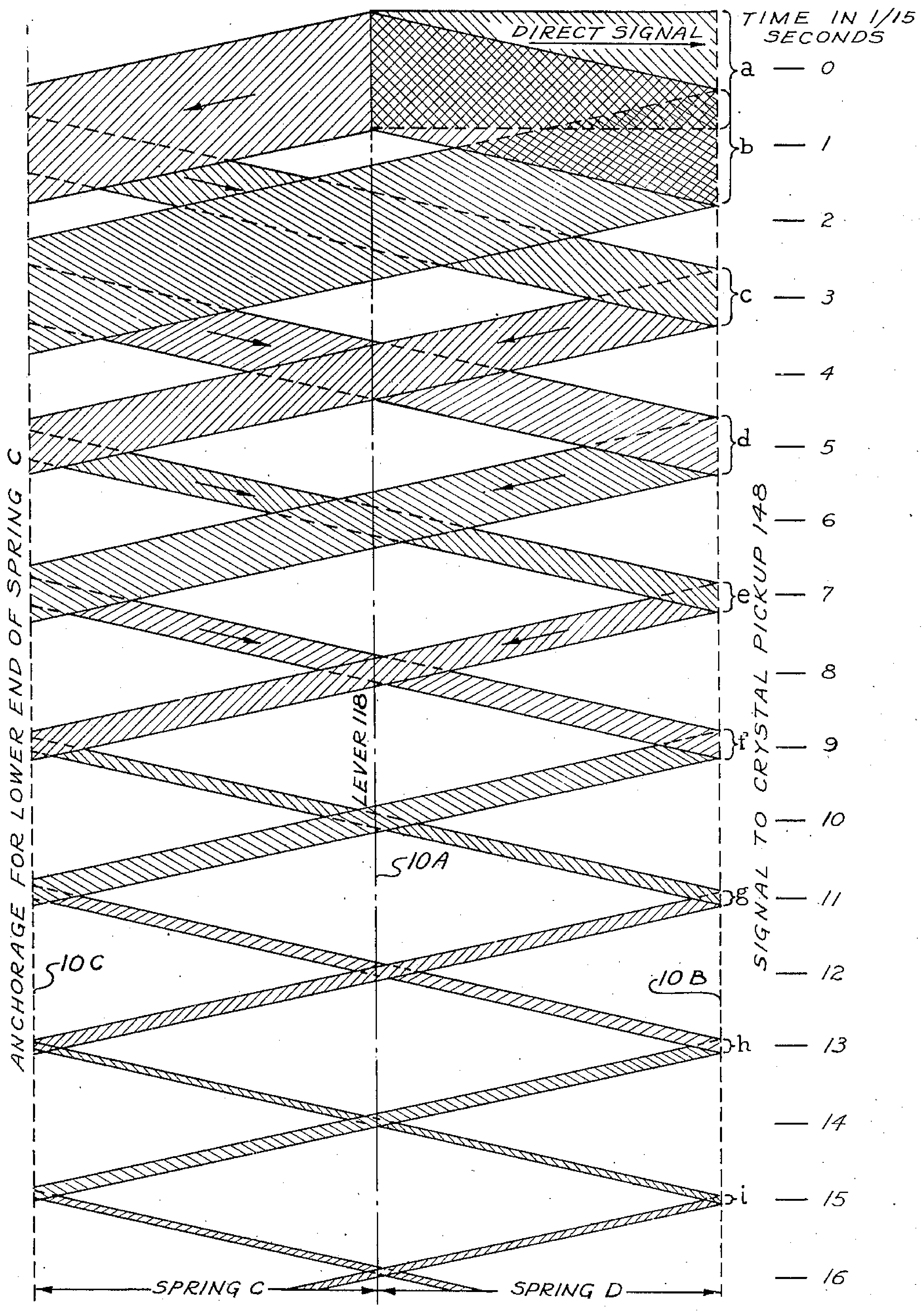

Fig. 10

Inventor
Laurens Hammond
By Williams, Bradbury, McCaleb & Hinkle,
Attys.

Patented Feb. 4, 1941 **2,230,836**

UNITED STATES PATENT OFFICE

2,230,836

ELECTRICAL MUSICAL INSTRUMENT

Laurens Hammond, Chicago, Ill.

Application July 15, 1939, Serial No. 284,761

40 Claims. (Cl. 179—1)

My invention relates generally to electrical musical instruments in which music is electrically originated and translated into sound, and more particularly to reverberation producing apparatus for instruments of this character.

When music is played on a mechanical musical instrument, such as a pipe organ, in a large auditorium having a long reverberation time, the sound reaching the ears of a listener who is not very close to the source of sound, is of a very complex nature compared to the sound produced by the instrument. The component frequencies are partially reinforced or cancelled, depending upon the position of the listener's ears, the amplitude modulation being caused by the repeated reflection of the sound waves from the walls, ceiling and floor of the auditorium. This reflected sound continues to reach the ears of the listener for a considerable length of time after the source has ceased to emit sound. The sound decays generally in a logarithmic manner, but individual frequencies may depart considerably from the general decay curve, such that some frequencies may be increasing in amplitude as the over-all sound intensity is decreasing. While ordinarily the listener is not able to distinguish the variations in the intensities of the individual frequencies, the composite effect is readily perceptible as a certain richness and fullness of tone, adding appreciably to the grandeur of the music.

This desirable reverberation effect is not obtained when musical instruments are played in small acoustically "dead" rooms, especially if the instrument does not produce tones having gradual decay intensity envelopes. Electric organs of the type disclosed in my prior Letters Patent No. 1,956,350 are designed to produce tones having substantially instantaneous decay, and thus, unless played in a highly reverberative auditorium, lack the ability to cause the tones to reverberate and decay gradually.

It is thus an object of the invention to provide an electrical musical instrument capable of producing tones having reverberative decay independently of the acoustical characteristics of the place where the tone is produced.

It is another object of the invention to provide means whereby the music of an electrical musical instrument, may, at will, be modified so as to have a long reverberation or decay time and thus give the impression that the music is being heard in a large reverberative auditorium even though the instrument is being heard in a small non-reverberative room, or out-of-doors.

A further object of the invention is to provide an improved electrical musical instrument having means for introducing a reverberation effect of selected degree in the music irrespective of the acoustic properties of the place where the instrument is being played.

A further object is to provide an electrical musical instrument in which the reverberation time is increased and the signal originally produced is repeated a number of times during the reverberation period, so as accurately to duplicate the sound produced when the instrument is played in a large reverberative enclosure.

A further object is to provide a sound reverberation apparatus capable of design and construction in such manner as to modify musical signals so that the reverberation characteristics of any desired auditorium may be substantially duplicated in music produced in the open air or in a room having acoustical characteristics which are unfavorable to the proper rendition of music.

A further object is to provide a mechanical reverberation system for the rendition of music, in which compensation may be made for adverse frequency response characteristics of the electro-mechanical and mechanico-electric transducers used in the system.

A further object to to provide an improved mechanical reverberation system for musical signals, in which the reverberation characteristics may be predetermined and controlled.

A further object is to provide a mechanical reverberation system for electrical musical instruments which occupies a relatively small space and may readily be incorporated in the speaker cabinets provided for such instruments.

A further object is to provide a mechanical reverberation system which is relatively simple in construction and which may be economically manufactured.

Other objects will appear from the following description, reference being had to the accompanying drawings, in which:

Figure 1 is a block diagram of the complete instrument;

Figure 2 is a side elevation of the mechanical reverberation system;

Figure 3 is a fragmentary vertical sectional view showing the parts to an enlarged scale, taken generally on the line 3—3 of Fig. 8;

Figure 4 is a perspective view of the stirrup and lever assembly;

Figure 5 is a fragmentary sectional view of the upper lever;

Figures 6, 7 and 8 are transverse sectional views taken on the line **6—6**, **7—7** and **8—8** respectively, of Figure 2;

Figure 9 is a chart showing the frequency response of the apparatus; and

Figure 10 is an illustrative diagram indicative of the manner in which a signal is transmitted through the mechanical reverberation system.

General Description

Referring to Figure 1, the instrument comprises a console **20** of an electric organ or other musical instrument, which may be of the type disclosed in the aforesaid Patent No. 1,956,350, and which includes the signal generators and the various manuals and controls by which the signals from the generators are combined to produce a composite electrical signal representing the music being rendered. This composite signal, if necessary, is amplified by a preamplifier **22**. Part of the signal from this amplifier is supplied through resistances **24** to a voltage amplifier **26** and a power amplifier **28** to an electroacoustic translating means shown as a loud speaker **30**, but which may comprise a radio broadcasting system, a phonographic recording apparatus, or other apparatus or system for translating the signal into sound, or for making a record for later use in producing sound. The resistances **24**, illustrated as being adjustable, may be fixed resistors, since ordinarily the adjustable attenuator **32** will provide sufficient adjustability for the system.

The other part of the signal from the preamplifier **32** is supplied to an adjustable attenuator **32**, from which the signal is transmitted to an electro-mechanical transducer **34** which consists of a loud speaker unit, preferably of the permanent magnet type, with its sound radiating diaphragm removed. The mechanical signal vibrations produced by this transducer are conveyed through a mechanical reverberation system **36** by means of which the signal is modified to include a plurality of reverberative modified repetitions thereof, similar, in character and effect, to the results obtained when sound is produced in a large auditorium having an optimum reverberation or decay time for the rendition of music.

The modified signal from the mechanical reverberation system is picked up by a mechanico-electric transducer **38** which is preferably in the form of a crystal or a capacity pickup, from which the modified electrical signal is transmitted to a preamplifier **40**. The amplified and modified signal from the preamplifier **40** is combined with that supplied directly from the preamplifier **22** and thus is transmitted through the amplifiers **26** and **28** to the speaker **30**.

The mechanical reverberation system

The mechanical reverberation system is mounted in a strong, rigid frame consisting of four angle iron supports **42** to which eight flanged transverse plates **44** to **51** are rigidly secured by rivets or screws. The frame may be suitably mounted in a speaker cabinet, being supported by vibration insulating cushions **52**, **53** and **54**, made of sponge rubber or similar material. The electro-mechanical transducer **34** is secured to the plate **45** (Fig. 3), and comprises a permanent magnet shell **55** to which the flexible voice coil supporting spider **56** and flexible voice coil guiding and supporting element **58** are secured. The voice coil **60** oscillates in the annular gap formed between central pole **62** of the permanent magnet and the shell **54**. The coil **60** is connected to the output of the attenuator **32** by the usual flexible lead wires (not shown).

A wire **64** is secured to the center of the spider **56** and extends upwardly through a hole **66** drilled in the magnet pole **62**. The upper end of the wire **64** is rigidly secured to a thin flexible metal strap **68** (Fig. 5), which in turn is secured to a lever **70** which is channel-shaped.

The lever **70** is made as light in weight as is compatible with its necessary strength and rigidity. A suitable material for the lever **70** is a high strength aluminum alloy. The side walls **72** of the lever are conformed to provide maximum rigidity to the lever with a minimum mass of material.

The lever **70** is supported by a bracket **73** which is secured to the top of the shell **54**. This bracket **73** is generally in the shape of a J and has apertures **75** and **76** through which the lever **70** projects, there being sufficient clearance to permit the lever to move freely, the edges of the aperture **75** preventing excessive swinging of the lever **70**. A fulcrum strip **74** of thin flexible sheet metal is similarly apertured to permit the free pivotal movement of the lever **70** therethrough, the strip being clamped to the longer leg of the bracket **73** by plates **77**. The lower end of the fulcrum strip **74** is secured to the horizontal web portion of the lever **70** by a pair of angle clips **78**, which are riveted to the lower end of the strip **74** and secured to the lever **70** by rivets **79**. The rivets **79** also secure the strap **68** to the lever **70**. The ends of the web portion of the lever are curled to provide guides **80** for the strap **68**, while the ends of the strap **68** are provided with holes to receive the hooked ends of the wire **64** and a wire **86** respectively.

Although the forces acting upon the lever **70** and its connecting parts are relatively small, in the order of a few hundred grams, the lever **70** should be strong and very rigid, while at the same time, it is desirable to keep its mass and the masses of its associated parts at a minimum. The design of the parts therefore involves stressing the materials to near their maximum allowable stresses, with the necessary allowance of a reasonable factor of safety.

The flexure of the fulcrum strip **74**, for the most part, takes place just above the angle clips **78**. The lever is thus in effect pivoted at a point but slightly above a line joining the points at which the ends of the strap **68** contact with the curled guides **80**, thus rendering the lever stable.

The wire **86** has a helical spring A secured to its lower end, and spring A has its lower end anchored to an eye **90** formed in a plug **32**. The plug **92** seals the lower end of a tube **94** which surrounds the spring A and which is substantially filled with a light oil or similar liquid. The tube **94** is supported by an extension **96** of the plug **92**, the extension being frictionally clamped in vertically adjusted position by a set screw **98** threaded in a collar **99** surrounding a split bushing **100** peened to the plate **51**.

Oil filled tubes **102** and **104** which are similar to the tubes **94** and are similarly supported by the plate **50**, extend upwardly through the plates **47**, **48** and **49**, and have springs B1 and B2 therein. The springs B1 and B2 have their upper ends secured to a stirrup **106** which is of hollow triangular shape (Fig. 4), and is provided with a reinforcing flange **108**. The stirrup **106** is provided with an aperture **110** for receiving the hooked end of a short wire **112**, which is secured to the spider 56 and which may, if desired, be made integral with the wire 64.

A thin flexible metal strip 114 is clamped to the stirrup 106 by a plate 116 riveted to the stirrup. The strip 114 has an opening 115 formed therein, and its lower end is riveted to a pair of angle clips 117 which are riveted to the horizontal web portion of an equal arm lever or rocker arm 118 in a manner similar to that employed for securing the lever 70 to its flexible supporting strip 74.

The lever 118 has a metal strap 120 riveted thereto, the ends 121 and 122 of this strap being provided with holes for receiving the ends of springs C and D respectively. The spring C extends downwardly into a relatively short tube 124, partially filled with oil, and has its lower end anchored therein, the tube construction and its mounting being similar to that of the tube 94. The tube 124 is of lesser diameter than tube 94, since the spring C is of lesser diameter than the spring A. The lower end of spring D is attached to one of the plates of a crystal pickup device 148, by a metal strip 149 connected to a hooked wire 150. The crystal pickup device is secured to a rod 152 which is mounted for adjustment in a vertical direction in a bushing 154 secured to plate 49.

In order to provide an additional point of partial reflection for the higher frequencies and thus improve the response of the system for the higher frequency partials, a mass is preferably inserted in the spring C at some point above the level of the oil in tube 124. This mass is shown as a short length of wire 160 (Fig. 3), which is inserted between adjacent coils of the spring and is thus frictionally clamped in position. As will hereinafter more fully be described, the mass of the pin 160 corresponds to an inductance in an electrical circuit, and its value is such that it will tend to reflect the higher frequencies, while transmitting the lower frequencies to the portion of the spring C which is immersed in oil, where the low frequencies are damped.

Since, as previously indicated, the supports for the springs are preferably made as light as possible, consistent with their normal function of transmitting sound vibrations, it is desirable to provide means which will prevent placing unusual strains upon their supports when the device is shipped or otherwise moved about, when it may be subjected to jars. It will be understood that the levers 70 and 118, as well as the other parts supporting the springs, are made just strong enough to carry the weight and tension of the springs and to transmit the forces applied to the springs during their normal use.

If, however, the apparatus were suddenly jarred, the inertia of the springs might subject the levers 70, 118 and their connected parts to relatively large strains which they would be unable to withstand. For this reason, means are provided to clamp the springs adjacent their relatively free ends, and thus prevent the transmission of large forces to the spring supporting parts. This means comprises a pair of plates 162 and 164 which are mounted for sliding movement directly above the transverse frame plates 46 and 49.

The plate 162 has relatively large openings through which the springs A, C, B1, B2 and D pass, these openings being formed with knife edges. The plate 162 is held closely adjacent the top surface of the frame plate 46 by a washer 166 carried by a bolt 168, which projects through a suitable elongated guiding slot 169 in the plate 162. A spring 170 is compressed between the head of the bolt 168 and washer 166 so as to apply a holding pressure to the washer 166.

An arm 172 has its end pivotally connected to the plate 162 at 173, and has a slot to receive an actuating bar 174. The arm 172 is pressed downwardly so as to hold the plate 162 closely adjacent the frame plate 46 by a compression coil spring 176 surrounding the bar 174, and held in place by a cap 178.

The plate 164 is similarly supported directly above the frame plate 49 and has a knife edged opening for the spring D, being suitably cut away to avoid contact with the tubes 94, 102, 104 and 124, the plate 164 being actuated by an arm 180, fitted over the bar 174 in a manner similar to that in which the arm 172 is secured in position.

The lower end of the actuating bar 174 is guided in a bearing 182 supported by the lower frame plate 50 and is adapted to be angularly shifted by a plunger rod 184 carrying a button handle 186 and connected to the actuating bar 174 by an arm 188. From the above description, it will be apparent that when the button handle 186 is pushed inwardly, the bar 174 will swing counter-clockwise (Figs. 6, 7 and 8) and through the arms 172 and 180 move the locking plates 162 and 164 to the right (Fig. 3), thereby causing the knife edges surrounding the spring receiving openings therein to engage between successive turns of the springs, deflect the springs laterally until they abut the edges of the openings in the frame plates 46 and 49 and rigidly clamp the springs in this position. Upon pulling the button handle 186 outwardly to the position in which it is shown in Fig. 3, the locking plates 162 and 164 will be moved back to the position in which they are shown in Fig. 3 with their spring receiving openings in alignment with corresponding openings formed in the frame plates 46 and 49, so that the springs are again free. This locking mechanism is disclosed in greater detail and is claimed in my co-pending application, Serial No. 298,366, filed Oct. 7, 1939, which has matured into Patent No. 2,211,205, issued Aug. 13, 1940.

From the above detailed description of the mechanical reverberation system, it will be seen that the mechanical vibration of the voice coil 60 is transmitted in part through the wire 64, lever 70, wire 88, to the spring A, and in part through the wire 112 to the stirrup 106. The stirrup 106 has the two damping springs B1, B2, and the partially reflecting and partially damping spring C connected thereto, as well as the spring D, which constitutes the means for transmitting the sound vibrations to the crystal pickup 148.

Exemplary dimensions of the parts of the mechanical reverberation system

While the various parts of the mechanical reverberation system may of course be made of a wide variety of sizes and of different materials, the constants of the system are determinative of the frequency response of the system as a whole, and of its efficiency in accomplishing the desired objectives. Although the factors governing the transmission of sound waves through coil springs of the character disclosed herein are known to those skilled in the art, and mathematical formulae are available for the determination of the dimensions of the springs and associated parts, the computations are somewhat complex and it is therefore believed expedient to set forth herein the important dimensional and constructional characteristics of the parts which have been found by actual experience to produce satisfactory results. It will be understood, however, that these dimensions are given merely by way of example, and that they may be varied greatly without departing from the principles underlying the invention.

The springs are preferably made of piano wire. The springs A, B1 and B2 being made of .030" wire, the coils being .30" in diameter and approximately 32" long. The tension on the spring A (measured at the top of the spring), is 160 grams, while the tension on each of the springs B1 and B2 is approximately 70 grams. The springs C and D are made of .020" piano wire, the coils being .200" in outside diameter, and the springs being of equal length, about 32" long.

The springs C and D are each stretched to have a tension at their top of approximately 70 grams. There is a tension of slightly less than 70 grams at the point of connection of the spring D with the crystal pickup 148.

The levers 70 and 118, are preferably of aluminum alloy stampings so as to be as light as possible in weight to meet the requirements of strength and rigidity, while the straps to which the springs are attached, and the flexible strips which support the levers, are made of very thin flexible steel. The oil with which the tubes 84, 102, 104 and 124 are filled may be of relatively low viscosity, and of a kind which does not change appreciably in viscosity with changes in temperature.

The springs C and D are wound with their coils at a pitch of approximately 35 turns per inch, while springs A, B1 and B2 have a pitch of approximately 22 turns per inch. After the springs have been wound they are annealed. In connecting the springs in the system they are placed under tension, as set forth above. The tension is sufficient in each instance to exceed any oppositely directed force which may be applied during the normal operation of the apparatus, so that sound vibration transmitting contact is maintained at all times.

Operation of mechanical reverberation system

As previously pointed out, the general purpose of the mechanical reverberation system is to alter the signal received by it in substantially the same way that the corresponding sound would be altered if it were produced in an auditorium having optimum reverberation characteristics for the music being rendered. A requirement of the system is therefore that the transmission of the signal be delayed, and that the signal must be repeated a number of times at fractional second intervals and at generally decreasing amplitude. Each repetition of the signal constitutes a separate echo. The number of echoes of this kind must be very large so that they are not heard as pronounced separate echoes, but as a steady stream of sound. A single series of echoes recurring at a regular rate is ordinarily recognized as such by the listener, and must be avoided.

These purposes are satisfactorily accomplished by the apparatus described. The electrical signals produced by the organ are divided, a regulatable part thereof being fed directly to the amplifier and speaker system, while the remaining portion is fed to the diaphragm-less speaker 34 where the electrical signal is converted into mechanical vibration. The sound is transmitted as mechanical vibrations through the coil spring system.

The signal fed to the voice coil operates the springs A and B1 and B2, which are for the purpose of providing a resistive load and thus damping the driving unit and compensating for the adverse frequency response characteristics of the latter. They form no direct part of the system for transmitting the signal from the driving unit to the crystal pickup. In describing the operation, we shall assume, as may be the fact, that springs C and D are of the same size. Likewise, we shall assume that the lever or rocker arm 118 is made of a material so stiff and having so little mass that it acts as an ideal lever.

A signal which is impressed on the rocker arm 118 constrains the pivot of this arm to move up and down. A signal is thus propagated down the spring C and down the spring D. This signal passes along the spring at the characteristic propagation velocity which depends on the ratio of the elasticity to the distributed mass of the spring. In the springs actually employed, the propagation velocity is around forty feet per second, which is roughly one twenty-fifth as fast as the sound wave would be propagated in a column of air. The motions of compression and elongation within the spring are of the same general nature as obtain in a column of air. The total length of spring D is approximately 32", and the crystal receives impulses of spring motion which reach it approximately 1/15 of a second after they leave the rocker arm 118. Disregarding, for the moment, the effect of the mass 160, the motions in the spring C become attenuated approximately 50% as they travel down through the oil in tube 124, are reflected at the lower fixed end of the spring, and return upwardly through the oil.

When the signal reaches the crystal pickup end of the spring D, the motion of the spring is arrested at this point because the crystal constitutes a point of great stiffness. The motions of the hook on the crystal resulting from the oscillatory forces in the spring are so slight that for the present purpose this motion may be neglected, and the end of the spring may be considered as a fixed point. The forces which are set up on the hook of the crystal actually do cause a small motion of the crystal, generating within the crystal voltages which are proportional to the forces applied. These voltages are amplified and are connected to the output system as described above. As a result of the fixed character of the end of the spring, total reflection of the wave motion within the spring will occur at this point, and the signal is therefore reflected and starts back along the spring in the reverse direction.

It is of course possible for different signals to pass in opposite directions within the spring in the same manner that sound may be carried in two directions through a column of air without interaction or interference.

Motions within the spring D are highly undamped. That is to say, very little friction is introduced by the action of the air around the spring, and the spring of course touches no other object along its length. Thus, sound waves may be transmitted through this type of spring for very long distances with only exceedingly small attenuation. The signal which comes back to the rocker arm 118 is therefor substantially as large as it was when it left the rocker arm going in the reverse direction.

When the signal reaches the end of the rocker arm 118 going upward, the rocker is vibrationally displaced swinging about its fulcrum and carrying the vibrations of the spring D into the spring C. This is true because the impedance to translatory motion of the fulcrum of the rocker arm is very great, as this fulcrum is attached to the system including the voice coil and the heavy springs B1 and B2. If it is assumed that the rocker arm is an ideal one and the impedance to motion of the fulcrum is sufficiently great, then all of the signal reaching the rocker going upward along the spring D will be transmitted into similar motion going downward in the spring C in the direction of the oil, where the signal will be partially damped out and partially reflected.

If, as assumed, the springs C and D are of the same size, and if the rocker arm **118** operates as an ideal transformer of the direction of the motion and of the forces involved, then the output signal would be a faithful electrical reproduction of the input signal differing from the original signal only by the elapse of time of 1/15 of a second, followed in 3/15 of a second by the half strength signal reflected from the lower end of spring C, etc.

In Figure 10, the character of the signal produced by the system is graphically illustrated. In this figure, the signal is considered as originating at the central vertical line **10A** which corresponds to the lever or rocker arm **118**. It will be noted that a portion of the signal is transmitted to the right, representing transmission through the spring D, to the dotted line **10B**, representative of the crystal pickup. A signal of equal amplitude travels to the left to the line **10C** by which the signal is partly damped and partly reflected.

The width of the cross-hatched bands is indicative of the approximate amplitude of the signal. In order to show the time relationship of the signal transmitted from the musical instrument directly to the speaker, the cross-hatched area marked "Direct signal" is indicated as supplying an output signal of amplitude indicated by the bracket *a* at the time "0." From this diagrammatic chart, it will be noted that the signal transmitted through the spring D, the amplitude of which is represented by the bracket *b*, arrives at the pickup 1/15 of a second after the direct signal. Then, at 3/15 of a second after the direct signal, a signal represented by the bracket *c* is received at the pickup, this signal being the undamped portion of the signal originally produced and transmitted up through spring C, through rocker arm **118** and through the spring D. In a similar manner, signals indicated by brackets *d* to *i* inclusive are successively impressed upon the crystal pickup **148** at intervals of approximately 2/15 of a second, the signals decreasing generally in amplitude.

It will be understood that the chart, Fig. 10, is included solely for the purpose of illustrating the general principles of operation, and is not intended as an exact graphical representation of the operation of the system, since it does not take into account the function of the mass **160** inserted in the spring C, nor does it take into account many other factors which influence the character of the final output of the instrument. However, the chart illustrates, in a possibly oversimplified fashion, the general principle of operation of the system.

When sound vibrations pass along a spring they are reflected from any point which is held fixedly. Total reflection will also take place from the unsupported end of a spring. It is, however, possible to have a partial reflecting point at which sound vibrations will be in part transmitted, and in part reflected. If, for instance, a small mass is attached to a spring, then partial reflection will take place from this point. In that event, the reflection will be the more pronounced for any given mass, the higher the frequency. Similarly, if any point of the spring is secured to a stationary part by a resilient connection, then reflection will take place from this point and the reflection will be the greater the lower the frequency. If two springs of unequal sizes are connected together, then reflection will take place from the juncture of the two springs, and the reflection will be the greater as the springs become more and more dissimilar in size. In this event, reflection will be alike for all frequencies. Thus, reflection takes place at every point in the system where the mechanical impedances of adjacent transmitting elements are mis-matched.

Thus, in the embodiment of the invention herein disclosed, the small pin **160** constitutes a point of partial reflection. Its mass, however, is so small that it does not constitute a point of appreciable reflection for sound vibrations of the lower frequencies, although it serves as a point of considerable reflection for the higher musical frequencies. As a result, the lower portion of the spring C which is immersed in oil within the tube **124**, receives the lower frequencies in greater proportionate amplitude than the higher frequencies. The damping action of the oil is greater at the higher frequencies, and thus it is the lower frequencies, substantially to the exclusion of the higher frequencies, which are reflected from the lower end of the spring C to pass upwardly through the spring C, and which are ultimately impressed upon the crystal pickup **148**.

The depth of oil in the tube **124** is approximately 3", and thus a sufficiently long portion of the spring C is immersed to provide appreciable damping for the lower frequencies, and to provide substantially more damping for the higher frequencies. The mass of the pin **160** is preferably of such value with respect to the parameters of the spring C that it commences becoming noticeably effective as a point of partial reflection for frequencies at approximately 400 c.p.s., and of course, becomes increasingly effective as a point of reflection as the frequency increases.

Thus, in order more accurately to represent the actual operation of the system, the illustrative chart, Fig. 10, would have to differentiate between signals of different frequencies.

Furthermore, it was assumed above that the rocker arm **118** was perfectly rigid and of negligible mass, thus an ideal lever. However, since this is not the case, the points of attachment of the springs C and D to the rocker arm **118** constitute additional minor points of reflection for the signal, and thus render the final output of the system much more complex than is indicated by the illustrative chart, Fig. 10. Of course the crystal pickup **148** is not an ideal point of reflection, nor is the rocker arm **118** entirely free from mechanical resistance. Thus, the various frequencies are damped to some extent because of these non-ideal characteristics of these parts of the system, but the controlling damping effect is of course obtained in the portion of the spring C, which is immersed in the oil in the tube **124**. Because of the fact that the mass **160** reflects a large part of the higher frequency vibrations which travel downwardly along spring C, the very high frequencies are attenuated less rapidly than the intermediate frequencies.

When a spring, such as the spring C, extends for a short distance into a damping medium such as the oil in the tube 124, the damping effect for high frequencies is greater than that for low frequencies, probably due to the damping that takes place between adjacent turns of the spring.

The spring vibration transmitting system as a whole thus tends to damp the higher frequencies to a progressively greater extent than lower frequencies, but because of the use of the pin 160, this general trend is changed at very high frequencies so that the latter, as well as the very low frequencies, are damped less than the intermediate frequencies. A sound containing very low, intermediate, and very high frequencies will thus decay in a manner to compensate for the non-uniform frequency response characteristics of the human ear, that is, the intermediate frequencies, to which the ear is most sensitive, will be damped most rapidly.

By adjustment of the level of the oil in the tube 124, or rather adjustment of the length of the portion of the spring immersed therein, and by changing the size of the pin C, the relative rates at which very low, intermediate, and very high frequencies are damped, may readily be controlled.

The effect of utilizing the pin 160 as a reflecting mass in the spring C is illustrated by the frequency response curves of the system shown in Fig. 9. In this figure, the upper full line curve 9A represents the approximate maximum response at frequencies within limited incremental ranges, while the lower full line curve 9B represents the minimum response of the system within corresponding incremental ranges. Thus, the actual response of the system at any given frequency will lie at some point between the two curves 9A and 9B, i.e., within the cross-hatched area between these two curves.

The dotted line curves 9C and 9D correspond to the curves 9A and 9B respectively and represent the response of the system when the pin 160 is removed from the spring C. It will be noted that the principal effect of the pin 160 is to increase the frequency response at frequencies above approximately 400 c.p.s.

The actual response curve of the system would be a jagged line alternately touching the curves 9A and 9B at intervals of from 2 to 10 c.p.s., depending upon the particular design of the springs C and D, and the parts connected thereto.

From these curves it will be noted that the response of the system is generally at a maximum at the lowermost frequencies, and decreases generally with increased frequency and decreases rapidly as a frequency of 6000 c.p.s. is approached.

The crystal pickup will receive impulses which have come to it through a large number of paths of different lengths. Considering any particular frequency, the signal so received may not be in such phase as will cause the pressure to add up. One component of signal may tend to cancel another, and another tend to reinforce it. This is of course the condition which prevails as regards air pressure at the ear of a listener in an auditorium, where sound waves are reaching that point by paths of different lengths occasioned by the reflection of sound waves from the walls of the auditorium. If the number of different paths of different lengths is very large, then the phase arrangement may be considered as a random one, and the pressures developed must be dealt with on the theory of probabilities.

Where the springs C and D are of the same size, there are three reflecting points, located at the lower ends of the springs C and D respectively, and at the pin 160, provided that the rocker arm 118 operates as an ideal lever without mass and without any restoring force preventing it from oscillating about its fulcrum. This is not the case, however, as stability requires that the fulcrum of the lever 118 be located slightly out of line with the points of attachment of the spring straps. The fulcrum is also of a resilient nature, and the elastic support therefore introduces some reflection for low frequencies, while the mass of the rocker arm 118 introduces some reflection for high frequencies.

Likewise, small amounts of reflection take place from the hooks on the end of springs and all of these partial reflections contribute to the complexity of the signal received by the crystal pickup.

Reverberation in an auditorium is greater as the auditorium is larger, and is less as damping is greater. Damping, of course, takes place as a result of the presence of sound absorbing material and openings from the enclosures to the out-of-doors. If the reverberation time in a large auditorium is the same as that in a small one, then the damping in the large auditorium must be greater. Similarly, in this system, the reverberation time will be the greater as the total length of the springs C and D is increased, and will be less as damping is increased. In this case, the spring C is partially damped, particularly for frequencies under 400 c.p.s. which are not appreciably reflected at pin 160, so that the damping of the whole system depends upon the number of reflecting points and the amount of reflection which takes place at each point.

It will be observed that whereas there is effective only one spring joining the input and the output, the number of paths of different lengths traversed by the signal between the input and the output can be made as large as desired by simply increasing the number of reflecting points along the transmission line.

The voice coil in the driving unit has a characteristic resonant frequency which should be damped if a comparatively smooth response curve is to be obtained. The voice coil damping in this unit consists of the two springs B1 and B2, attached directly to the voice coil, and the spring A attached to the voice coil through lever 70. The tension wires 84 and 86 are of such size that compliance of the wires causes the damping of spring A to become ineffective at approximately 800 c.p.s.

The resonance point of the undamped voice coil is approximately 120 cycles. By having the spring A effective only below 800 cycles, the response above this frequency tends to be increased, due to reduced damping, and since the response tends to drop for high frequencies due to compliances in the system and other reasons, the uniformity of output is thereby improved.

Other points of resonance in the response of the voice coil, the spider which supports it and other elements of the system are flattened out by the springs B1 and B2. The damping produced by the springs B1 and B2 is effective at substantially all frequencies because the connection to the voice coil is substantially rigid.

The effect of the system, as previously noted, is comparable to that obtained when sound is emitted in an enclosure and the sound waves are reflected back and forth by the walls of the enclosure so that the sound may be heard after the source is no longer emitting sound waves. The system may have a reverberation time of approximately two seconds, which has been found to be pleasing for organ music, but which of course would not be suitable for the transmission of speech. In the particular system described, the transmission time for a sound wave from the voice coil to the pick-up is approximately $\frac{1}{15}$ of a second. Thus, the sound signal transmitted to the speaker precedes, by this time interval, the first signal which is derived from the pickup 148 as previously noted in connection with the description of Fig. 10. By proper proportioning of the relative amplitudes of directly and indirectly transmitted portions of the output signal, very pleasing musical effects may be obtained.

While I have shown and described a particular embodiment of my invention, and have herein specified exemplary dimensions and characteristics of the parts, it will be understood by those skilled in the art that such dimensions and characteristics are intended as illustrative of a practical form of embodiment of the invention rather than as limiting the invention to such details. I therefore desire to include within the scope of my invention defined by the following claims, all such similar modified constructions whereby substantially the results of my invention may be obtained by substantially the same or equivalent means.

I claim:

1. In an electrical musical instrument having means for producing and controlling electrical signals corresponding to sound, and having an output system for utilizing the signals produced by said means; a signal transmitting apparatus for conveying the signal from said producing means to said utilizing means comprising, an electro-mechanical transducer connected to receive signals from said signal producing means, a mechanico-electric transducer connected to transmit signals to said output system, and a mechanical sound vibration transmitting apparatus operatively associated with said electro-mechanical transducer and with said mechanico-electric transducer, said apparatus comprising interconnected solid elements providing a plurality of points effective to reflect sound vibrations, some of said elements having distributed mass and compliance.

2. The combination set forth in claim 1 in which said apparatus comprises a plurality of helical coil springs and a pivoted lever interconnecting said springs, and in which at least one of said springs forms a vibration transmitting connection between said electro-mechanical transducer and said mechanico-electric transducer.

3. The combination set forth in claim 1 in which said apparatus includes a plurality of helical coil springs connected to said electro-mechanical transducer, in which one of said springs serves to transmit sound vibrations to said mechanico-electric transducer, and in which a coil spring element partially immersed in a viscous liquid is connected to said electro-mechanical transducer.

4. The combination set forth in claim 1 in which said apparatus includes a mechanical element connected to the moving part of said electro-mechanical transducer for damping low frequency vibrations of the latter more effectively than high frequency vibrations thereof.

5. The combination set forth in claim 1 in which said apparatus includes a plurality of helical coil springs, at least one of which differs in size from the others, and a plurality of levers of relatively small mass interconnecting said springs.

6. In a mechanical sound transmission system, the combination of a source of mechanical vibrations corresponding to sound, said source having a moving part, a helical coil spring immersed in a liquid for damping vibration thereof, and means for connecting said moving part to said spring including an element having substantial compliance at the higher frequencies of the sound vibrations produced by the moving part of said source.

7. The combination set forth in claim 6 in which said element having substantial compliance comprises a relatively thin wire of appreciable length.

8. An output system for an electrical musical instrument which is capable of producing electrical signals corresponding to music comprising, an amplifying system, electroacoustic translating means connected to the output of said amplifying system, means for transmitting signals from said instrument directly to said amplifier, and a mechanical reverberation system including a plurality of solid elements connected to receive energy from said instrument and to transmit to said amplifying system a signal corresponding to that produced by said instrument as modified by appreciable delay and repeated reflection of said signal by and through said solid elements.

9. A sound transmitting system comprising a rigid frame, an electro-mechanical transducer secured to said frame, a mechanico-electric transducer secured to said frame, a plurality of springs, one of said springs having one end thereof connected to said mechanico-electric transducer and another of said springs having one end anchored to a pivotally mounted low mass lever interconnecting the other ends of said springs, and means connecting said electro-mechanical transducer to said lever.

10. A sound transmission and modifying apparatus comprising a rigid frame, a diaphragmless speaker unit secured to said frame, said unit having a voice coil supporting spider, a lever pivotally mounted with respect to said frame, a tension element connected between one end of said lever and said spider, a damping coil spring, a tension element connecting the other end of said lever and said coil spring, a liquid-containing vessel surrounding said coil spring to immerse the latter in the liquid thereof, a plurality of vibration transmitting coil springs, a second lever having its ends connected to said vibration transmitting coil springs, a pivotal support for said second lever, a connection between said support and said spider, and additional damping coil springs immersed in a viscous medium and connected to said support.

11. In a sound transmitting system for electrical musical instruments, the combination of a source of sound vibrations, a plurality of coil springs immersed in a liquid and each having one end connected to said source for vibration thereby, each of said springs being of sufficient length and size to provide a damping effect corresponding to a substantially pure resistance.

12. In an electrical musical instrument having an output circuit and means for generating and controlling the transmission of electrical impulses of a plurality of frequencies to said output circuit, the combination of an electro-mechanical transducer connected to said output circuit, a mechanico-electric transducer, an amplifier and

electroacoustic translating means connected to said mechanico-electric transducer, and a mechanical sound vibration transmission system connected between said transducers, said system having a plurality of sound vibration reflecting points whereby the signal impulses supplied from the output circuit of said instrument will be reflected a plurality of times in the course of their transmission to said electroacoustic translating means and thus produce a reverberation effect in the sound produced by the latter.

13. A sound transmission system comprising an electro-mechanical transducer and a mechanico-electric transducer, and a mechanical sound transmission and attenuation means between said transducers, said means comprising a plurality of coil springs connected to said electro-mechanical transducer, at least one of said coil springs being connected to said mechanico-electric transducer, and means associated with said coil springs providing a point for sound wave reflection.

14. A damper for sound waves transmitted through a solid medium comprising a vertical tube containing a liquid and a helical coil spring having a portion thereof immersed in said liquid.

15. The combination set forth in claim 14 in which said coil spring has one end anchored to the bottom of said tube.

16. A system for the transmission of sound waves comprising a plurality of coil springs interconnected by levers and in which at least one of said springs is partly immersed in a liquid.

17. An apparatus for transmitting sound comprising an electro-mechanical transducer having a part moving in a vertical direction, a mechanico-electric transducer, a plurality of springs at least one of which is connected between said vertically moving part and said mechanico-electric transducer, said springs having their axes extending substantially vertically, and a freely pivoted lever connected between at least two of said springs.

18. The combination set forth in claim 17 in which said springs are under slight tension, and in which the tension of said springs upon said moving part of said transducer is counterbalanced by spring tension applied in an opposite direction to said part through a lever.

19. The combination set forth in claim 17 in which additional springs immersed in a liquid are connected to the moving part of said transducer.

20. The combination set forth in claim 17 in which means are provided for adjusting the tension on said springs.

21. The combination set forth in claim 17 in which said lever is supported by a thin flexible metal strip.

22. The combination set forth in claim 17 in which the springs are attached to said levers by thin flexible metallic ribbons.

23. The combination set forth in claim 17 in which at least one of said springs is connected to form a sound vibration transmitting path between said moving part and said mechanico-electric transducer, and in which additional springs immersed in a liquid are connected to said moving part.

24. In an electrical musical instrument capable of producing an electrical signal, and electroacoustic translating means, means for transmitting a portion of said signal from said instrument to said translating means, means including a mechanical reverberation system composed of solid elements providing a plurality of points of reflection for transmitting a second portion of the signal from said instrument to said translating means, and means for varying the relative amplitudes of said portions of said signal.

25. The combination set forth in claim 24 in which said mechanical reverberation system includes an element which transmits low frequencies more effectively than high frequencies.

26. The combination set forth in claim 24 in which said mechanical reverberation system comprises a plurality of coil springs interconnected by levers.

27. The combination set forth in claim 24 in which said mechanical reverberation system includes a network of interconnected springs and levers, and in which means are provided for damping oscillations in some of said springs.

28. The combination set forth in claim 24 in which said mechanical reverberation system includes a mechanico-electrical transducer comprising an element having substantially infinite mechanical impedance relative to the other parts of the system.

29. An apparatus for transmitting sound vibrations, a source of sound vibrations comprising an electro-mechanical transducer having a moving part, frequency responsive means for damping vibration of said part, a pair of coil springs each having one end connected to said moving part, a mechanico-electric transducer connected to the other end of one of said springs, and an anchorage for the other end of the other spring.

30. The combination set forth in claim 29, in which said anchorage includes a damping liquid immersing the adjacent end portion of said spring anchored thereby.

31. The combination set forth in claim 29, in which means are provided to damp vibrations in a portion of said spring adjacent said anchorage.

32. In an apparatus for transmitting sound vibrations, a source of sound vibrations comprising an electro-mechanical transducer having a moving part, a lever having its fulcrum secured to said part, a mechanico-electric transducer, a coil spring having one end connected to an end of said lever and its other end connected to said mechanico-electric transducer, a second coil spring having one end secured to the other end of said lever, fixed means secured to the other end of said second spring, and a mass secured to said second spring intermediate the ends of the latter.

33. The combination set forth in claim 32, in which the fixed end portion of said second spring is immersed in a damping liquid.

34. The combination set forth in claim 32, in which said second spring extends in a vertical direction, and has its lower end secured to said fixed means, in which said lower fixed end portion of said second spring is immersed in a liquid, and in which said mass is secured to said spring at a point above the level of said liquid.

35. In a sound vibration transmitting system, a source of sound vibrations having a moving part, a lever secured to said moving part, a pair of coil springs secured respectively to the ends of the lever and depending therefrom, a sound vibration receiving element connected to the lower end of one of said springs, and a fixed anchorage for the lower end of the other of said springs.

36. The combination set forth in claim 35 wherein a portion of the lower end of said anchored spring is immersed in a liquid.

37. The combination set forth in claim 35, in which said spring which has its lower end secured to a fixed anchorage is provided with a vibration reflecting mass intermediate its ends, which is capable of reflecting vibrations of high audio frequencies and transmitting vibrations of low audio frequencies.

38. The combination of a sound vibration transmitting system having elements of distributed mass and compliance and a plurality of points at which reflection may take place, and frequency selective means for controlling the rate of damping of vibrations in said system, whereby intermediate frequencies will be damped more rapidly than high and low frequencies.

39. In a reverberation system for mechanically transmitting sound vibrations, the combination of an element having distributed mass and compliance forming a path for the sound vibrations and having at least two points of total or partial reflection of the vibrations, and adjustable means for changing the rate of damping of vibrations of different frequencies.

40. In an apparatus for transmitting sound vibrations, the combination of a part forming a source of sound vibrations, a pair of springs each having one end thereof connected to said part, a mechanico-electric transducer of very high mechanical impedance connected to the other end of the first of said springs, an anchorage fixedly securing the other end of the second of said pair of springs, a tube surrounding the end of said second spring adjacent said anchorage, and a damping liquid in said tube and immersing a portion of said spring of length approximating one-fourth of the wave length of the lowest frequency produced by said source.

LAURENS HAMMOND.