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A. E. SHAW ET AL

2,640,170

DEVICE FOR CONVERTING MOTION INTO ELECTRICAL ENERGY

Filed Aug. 16, 1946

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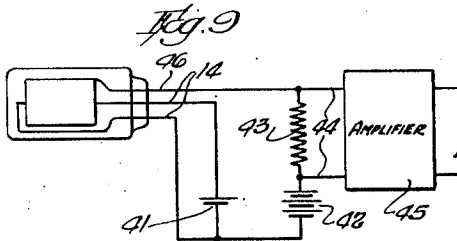
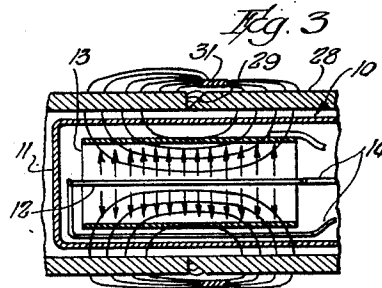
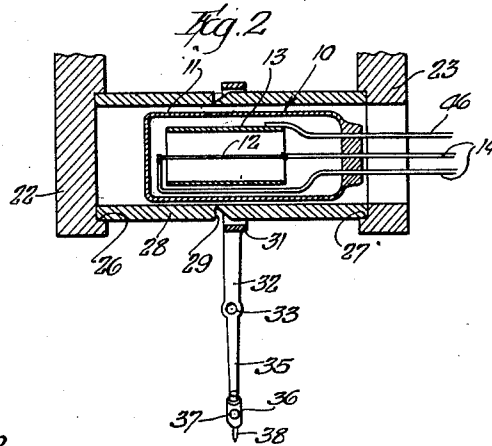
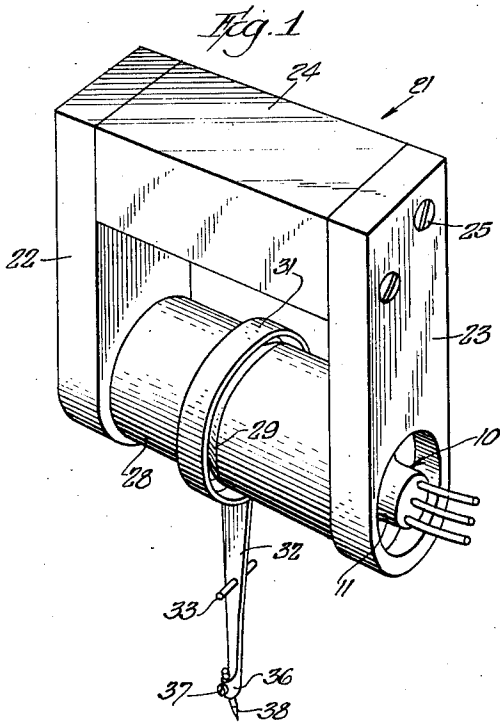
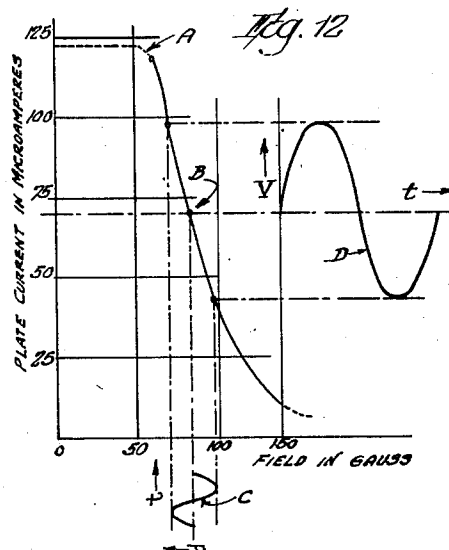
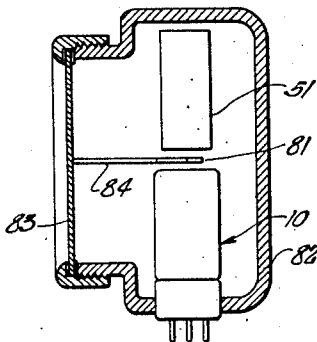


Fig. 11



INVENTORS
Albert E. Shaw
 BY *Robert J. Moon*

34 Thiss Olson of Throckmberger
Attys.

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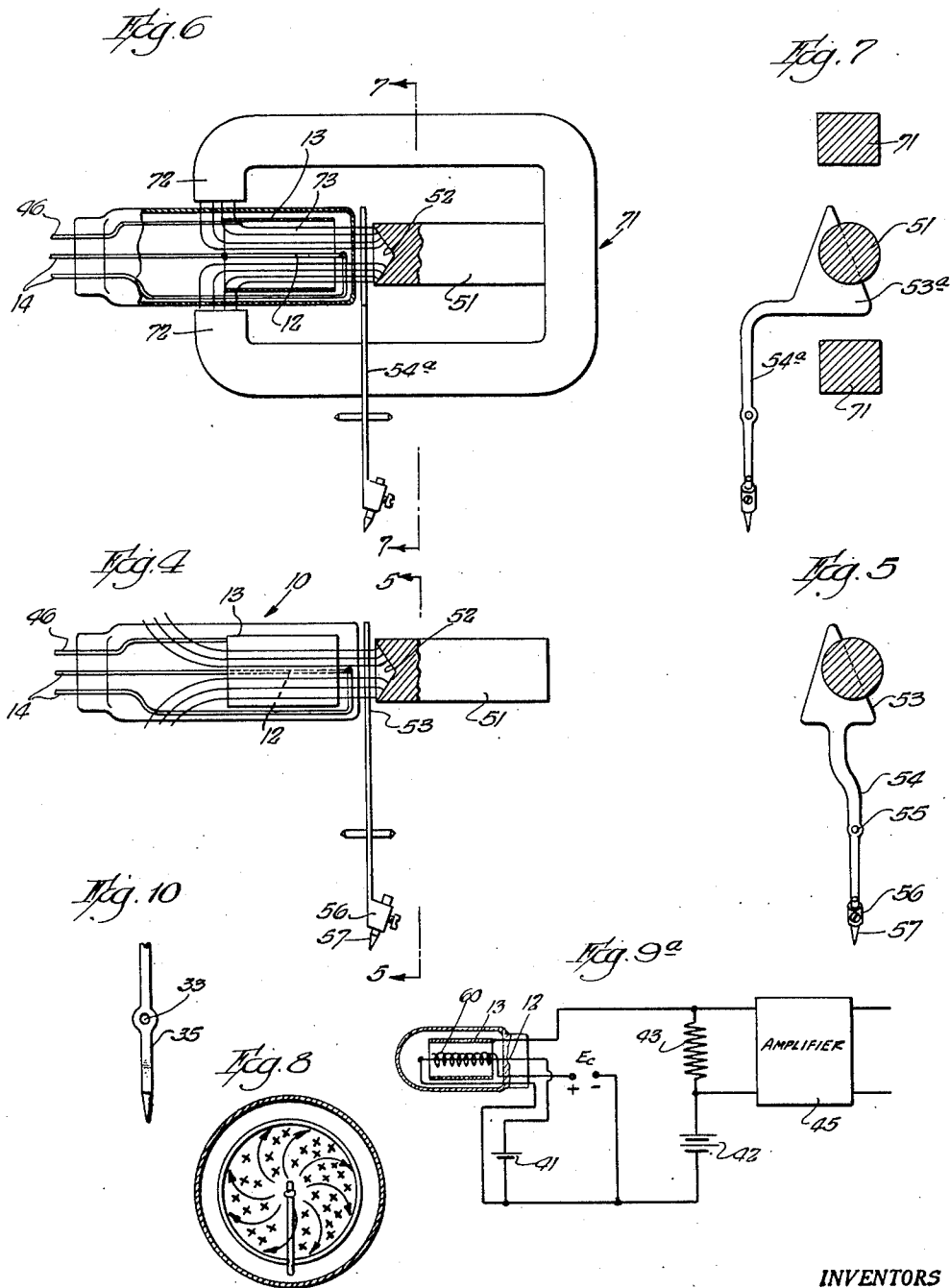
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DEVICE FOR CONVERTING MOTION INTO ELECTRICAL ENERGY

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2 Sheets-Sheet 2



INVENTORS
 Albert E. Shaw
 & Robert J. Moon
 BY

34 Thiess Olson & Mecklenburger
 Attys.

UNITED STATES PATENT OFFICE

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DEVICE FOR CONVERTING MOTION INTO ELECTRICAL ENERGY

Albert E. Shaw and Robert J. Moon, Chicago, Ill.,
assignors, by mesne assignments, to Louis
Bernat, doing business as Physics Research
Associates

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14 Claims. (Cl. 313-157)

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This invention relates to a device for converting mechanical motion into electrical energy.

The principles governing the influence of a magnetic field upon the path of an electron have been known for some time. For example, it has been shown that an electron traveling in a uniform magnetic field directed perpendicularly to the direction of motion of the electron will be caused to travel in a circular path, and the electron will be forced to return to the initial point. Such behavior occurs in the magnetron, for example, which is a vacuum tube in which the flow of electrons from the cathode to the plate is affected by a magnetic field. That is to say, for specific values of potential differences between the cathode and plate, a cutoff value of the magnetic flux density for the current through the tube may be established and all electrons leaving the cathode may be prevented from reaching the plate. In a magnetron the plate current may be varied or cut off by changing either the electrostatic field between the plate and cathode or the magnetic field in a region about cutoff in accordance with the approximate formula:

$$r = \frac{KE_c^{1/2}}{B_c}$$

where

r —the radius of the cylindrical plate

K —a constant for a given geometry of cathode and anode

E_c —potential of the plate with respect to the cathode

B_c —magnetic flux density

Between zero value of the applied magnetic field and cutoff value thereof, the plate current may be varied from maximum to zero by variation of the magnetic flux density.

A principal object of our invention is to utilize the above principles of interaction between a moving electron and a magnetic field in order to provide a simple and effective device for controlling the current in an electric circuit in response to variations in movement of a mechanically operated member. One example of the use to which a device so constructed may be put, is as a pickup for translating the undulations of a recorded disc of music or speech into electrical impulses, as in a phonograph which utilizes vacuum tube amplification.

Another object of our invention is to provide a device as aforesaid which employs a diode, namely, an evacuated envelope enclosing a heated cathode and an anode adjacent thereto, together with a permanent magnet and associated magnetic circuit, which magnet is disposed in predetermined relation with the diode and a member of magnetic material associated with the diode and magnetic circuit, the member being

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mechanically connected to the medium initiating the mechanical impulses.

Still a further object is to provide a device as aforesaid in which the movable member is of high magnetic permeability in order to influence the field of the magnet within the interelectrode space to the highest possible degree.

Another object is to provide a device as aforesaid in which the undesirable factor of inertia of the moving parts is reduced to a negligible amount and thus renders the device responsive to a wide range of frequencies.

A still further object is to provide a device as aforesaid which is compact and of small dimensions, thereby suiting the device to applications wherein light weight and compactness are of substantial importance, for example in connection with a phonograph pickup.

Another object is to provide a device as aforesaid which is simple and rugged in construction.

In carrying out our invention in one form, we provide a diode comprising an evacuated glass envelope and enclosing a central elongated cathode and a cylindrical or annular anode arranged thereabout, the said electrodes being carried on the usual combined supports and leads sealed in the wall of the envelope. For establishing a magnetic field in the interelectrode space, there is provided a permanent magnetic circuit of U-form having hollow cylindrical pole pieces constituted by connecting the legs of the yoke by means of a hollow cylinder and peripherally grooving the cylinder to yield an air gap. The diode is disposed within the interior of the cylinder and coaxially thereof and with the longitudinal mid-point of the anode substantially in alignment with the gap whereby flux across the gap is distributed through the interelectrode space. Part of the flux passes across the gap and through an annulus positioned adjacent to the gap. The annulus is supported for oscillating movement on a suitable pivot and is mechanically connected to the source of mechanical movement. A suitable circuit for heating the cathode and for causing electron flow between the cathode and anode or any suitable source of electron flow therebetween is provided, together with a circuit for impressing variations in plate current of the diode on an external circuit which may be an amplifier.

In the figures, which show certain forms in which the invention may be embodied,

Fig. 1 is a perspective view of one embodiment of the invention;

Fig. 2 is a cross-sectional view of a part of the device of Fig. 1;

Fig. 3 is a partial cross-sectional view comprising a part of Fig. 2, but on a larger scale;

Fig. 4 is a side elevational view of an alternative form of the invention;

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Fig. 5 is a cross-sectional view taken on the line 5—5 of Fig. 4;

Fig. 6 is a side elevational view of another alternative form of our invention;

Fig. 7 is a cross-sectional view taken on the line 7—7 of Fig. 6;

Fig. 8 is a somewhat diagrammatic transverse cross section through the diode to indicate the magnetic field and flow of electrons;

Fig. 9 shows a schematic circuit for use with the device;

Fig. 9a shows another form of schematic circuit for use with the device;

Fig. 10 is a detailed view showing one manner of connecting a phonograph needle to the device;

Fig. 11 is a cross-sectional view showing our invention embodied in a microphone; and

Fig. 12 is a representation of a characteristic curve of one device constructed in accordance with our invention, together with a graphical showing of a "time-displacement" input signal and a "time-voltage" output signal.

Adverting first to Figs. 1 and 2, one preferred form of the device comprises a diode 10 formed by enclosing in a glass envelope 11 a cathode 12 and anode 13. Although the cathode 12 there shown is of the directly heated type, it will be understood that an indirectly heated cathode may be substituted. The cathode 12 is supported at its ends in a position substantially coaxial with the anode 13 by support wires 14 which serve to supply current to the cathode. Prong terminals of any common type carried by a base cemented to the envelope may be provided. If desired, a spring may be interposed between the cathode proper and one of its supports in order to accommodate changes in length thereof during heating and cooling.

Preferably the cathode comprises substantially non-magnetic material, of which an alloy of chromium and nickel (Nichrome V) is a suitable type. Moreover, the cathode spring, leads, and supports are preferably non-magnetic, e. g., stainless steel, tantalum-tungsten alloy, tungsten, molybdenum, or tantalum. The cathode is preferably of the coated type to improve electron-emitting efficiency, e. g., such coating may comprise 60 per cent barium oxide (BaO) and 40 per cent strontium oxide (SrO).

Anode 13 is disposed adjacent to cathode 12 and is preferably cylindrical in form. The spacing between the cathode and anode will depend upon the characteristics which the device is intended to possess. For example, the diode may have an envelope of internal diameter 0.31", and anode of mean diameter 0.25", and a cathode of diameter 0.0006".

To provide the magnetic circuit, there is a yoke 21 which includes the arms 22 and 23 of magnetic material of high permeability joined by a bridge 24 of permanent magnetic material such as Alnico V, the three members being secured together by screws 25. Attached, as by tight insertion in circular recesses 26 and 27 in the arms 22 and 23, respectively, is the hollow cylindrical pole member 28 having a peripheral groove 29 substantially centrally thereof. While the cross-sectional shape of the groove 29 may take various outlines, one preferred form is triangular, as shown, the depth of the groove being nearly equal to the thickness of the wall of the member 28.

Adjacent to the groove 29, and in close proximity to the exterior of the member 28, is the annular element 31 of magnetic material, preferably of thin, flat cross section and supported for

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oscillation along the axis of the member 28 on a rocker arm 32 pivoted at 33. Although the pivot 33 is indicated more or less schematically, as are certain other components of the device, it will be comprehended that any suitable support which will permit damped oscillations of the annular element 31 may be employed. Inasmuch as the intended range of frequency of operation of the element 31 is from zero to approximately 10,000 cycles per second, it is preferred to mount the arm 32 on a rubber or similarly resilient cushion, the elasticity of such material permitting rapid oscillations and damping thereof.

At its lower extremity 35 the arm is provided with means for transmitting mechanical impulses to the element 31. For example, in using our device as a pickup in connection with the translation of the undulations of a recorded disc into audible sound, the lower portion 35 may carry a chuck 36 and setscrew 37 for holding a needle 38 adapted to rest in the groove of the disc, as is well known. To reduce the mass, and hence the undesirable inertia effects of the rapidly oscillating element 31 and arm 32, the needle 38 may be a permanent part of the portion 35, attached as by welding or soldering (Fig. 10), thereby eliminating the mass of the chuck 36 and screw 37.

Positioned within the member 28 is the diode 10, as previously described in detail, the same being positioned with that median plane of the anode which is perpendicular to the axis of said anode substantially in the gap 29.

Pole member 23 is a sleeve of high magnetic permeability such as soft iron, whereas the yoke 24 is a high retentivity permanent magnet such as Alnico V. The distribution of the flux adjacent the groove 29 is substantially as indicated in Fig. 3. By reason of the air gap incident to the groove 29, a substantial proportion of the flux will take a path through the element 31, these flux lines being part of the entire body of flux lines linking the two portions of the member 28. On the interior of the member 28 the flux enters the interelectrode space, as indicated schematically in Fig. 3.

It is not intended that the shape of groove 29 be limited to that shown, since other cross-sectional contours may prove equally effective. Nor is it necessary that the depth of the groove be less than the thickness of the wall of the member 28. That is to say, member 28 may comprise two independent pole pieces, one chamfered and the other blunt, arranged to abut end to end to define a space therebetween functioning similarly to the groove 29, the desideratum being that an air gap be presented to the flux to constrain the flux to link with the element 31.

The several components of the device as just described are mounted on a support, which may take any of several suitable forms, the same constituting no part of our invention. However, it has been found that non-magnetic materials should be used for all parts other than the magnetic yoke 21 and element 31, in order to avoid distortion due to stray magnetic fields. One method of mounting utilizes a cartridge unit adaptable to tone-arms of record players of various types, thus providing a device readily interchangeable with other types of pickups presently available.

To connect the device in the circuit of which it forms a part, the leads 14 may be connected as shown in Fig. 9. Filament or cathode current is furnished by a suitable source of direct current, e. g., a battery 41, while plate or anode cur-

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rent supplied through lead 46 is similarly provided, e. g., from a battery 42. A resistor 43, of the order of 50,000 ohms in the plate circuit, serves as a circuit element for the generation of a potential variation which is impressed on the conductors 44 to the input of a vacuum tube amplifier 45, the output thereof being utilized as desired, e. g., to operate a loud-speaker. It will be appreciated that the device is capable of use with other types of coupling into the amplifier. That is to say, transformer or other modes of coupling are equally applicable.

Operation of the device is as follows: The magnet circuit creates a magnetic field through the diode 10, and particularly in the interelectrode space. Flux forming said field is represented schematically by small crosses in Fig. 8. Assume that the cathode is emitting electrons. These electrons will leave the cathode and travel to the plate, as indicated by the curved arrows in Fig. 8, these arrows representing typical paths of the electrons which are approximately arcs of circles of equal radii. The centers for these arcs fall upon another circle of the same radius, the center of the latter circle being coincident with the axis of the cathode. It will be understood from Fig. 8 that an ideal condition is there schematically represented. Assuming that the magnetic flux density is of a value less than cutoff, point A (Fig. 12), the space current will be a maximum.

Upon displacement of the element 31 by actuation of the needle 38 or other source of mechanical movement, the shifts of position of the element with respect to the groove 29 will distort the flux adjacent to the groove, including that portion thereof in the interelectrode space.

The oscillations of the element 31 superimpose on this steady state of the magnetic flux, which distorts the interelectrode field to cause a variation of the density of flux lines in the interelectrode space. Such condition is sufficient to provide a field at certain zones of said space which is at cutoff value or lower, thereby varying the number of electrons reaching the plate. Accordingly the plate current is made to fluctuate in unison with the oscillations of the element 31. Such fluctuations in plate current are impressed across the resistor 43 and amplified and reproduced as desired.

In Figs. 4 and 5 is shown a modified embodiment of the invention, in which there is disposed in spaced relation to the diode 10 and coaxially therewith a permanent magnet 51, preferably cylindrical in form, and having high retentiveness, e. g., Alnico, an alloy of aluminum, nickel, and cobalt. Suitable specifications of a magnet 51 for use with the diode 10 heretofore specified would include a length of about 0.75" and a diameter of about 0.25", the flux density being in the range of 600 to 700 gauss. Preferably the end of the magnet 51 adjacent the diode is provided with a conical recess 52 to focus the magnetic field into a bundle of flux lines substantially coextensive with the interior of the anode 13, i. e., the interelectrode space. The magnet 51 is spaced from the adjacent end of the diode 10 by a distance of about 0.19", and interposed between the magnet and diode is the movable vane 53 (Fig. 5) substantially triangular in contour and about 0.02" in thickness, one important consideration being that one sloping edge of the vane be normally substantially coincident with a diameter of the bundle of flux lines associated with the magnet 51. Moreover, the vane 53 is of metal

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of high magnetic permeability and is supported on one end of the rocker 54 pivoted at 55. Pivot 55, chuck 56, and needle 57 are of the same construction as described in connection with Figs. 1 and 2. It will be understood that a substantial portion of the flux leaving the pole of the magnet adjacent the diode is concentrated through the vane 53, due to the high permeability thereof as compared to air.

Because of the negligible mass of the vane 53 and the mechanical parts associated therewith, together with the damping pivot suspension described, the response of the device is instantaneous, and a reproduction of the mechanical vibrations imparted to the needle 57 in terms of current variations in the resistor 43 is achieved.

The use of a diode having the dimensions outlined above, a filament current of 30 milliamperes at 1.5 to 3 volts, and a plate current of 15 to 20 microamperes at 20 volts, combined with a flux density of 600 to 700 gauss, has produced good results. Another example utilized a flux density of 1500 gauss and was responsive to incremental changes in the density of as low as 50 gauss. However, such specifications and examples are indicative only and are not intended as limitative of the invention. Important factors influencing the design of the diode are the necessity for accurate spacing between cathode and anode and the avoidance of magnetic materials in the device as a whole, excepting, as mentioned, the magnetic circuit; i. e., yoke 21 or magnet 51, annulus 31, and vane 53.

In Figs. 6 and 7 is depicted an alternative form of our invention identical in most respects with the embodiment of Figs. 4 and 5 hereinabove described, but provided with a yoke 71 of solid iron or laminations thereof, substantially of U form as shown, and having the magnet 51 affixed to the right thereof. The legs of the U are bent inwardly, as indicated, to form pole pieces 72, and the dimensions of the yoke are such that the pole pieces 72 are disposed adjacent to the base end of the cathode and anode, as shown. The flux lines from the magnet 51 through the interelectrode space and to the pole pieces 72 are indicated somewhat diagrammatically at 73. By employing the yoke 71 in association with the magnet 51, a magnetic return path is provided to concentrate the flux in the interelectrode space to a greater degree. However, when the device is to be used as a pickup, extreme lightness is highly important, and a yoke as described would be a disadvantage. For those applications wherein greater weight is a relatively inconsequential matter, the form of Figs. 6 and 7 is to be preferred. It will be apparent that in the embodiment of Figs. 6 and 7, the rocker arm 54a will be offset with respect to the vane 53a in order to clear the yoke 71 (Fig. 7).

Referring to Fig. 12, there is shown a graph to indicate the relationship between plate current and flux density for a value of load resistance 43 of 50,000 ohms. The particular characteristic curve there shown is the result of a plate supply of 12 volts. Cutoff of the field begins at a point indicated at A, and complete cutoff would be near zero value of plate current. We prefer to operate our device at the point B, which is the mean value approximately midway between the beginning and end of cutoff, and in which zone the curve is substantially a straight line whereby to yield linear response. Signal variations, i. e., oscillations of amplitude d as a function of time t due to movement of the annulus 31 or vane

53, are reflected as variations of magnetic flux shown schematically at C, and the resultant changes in plate current produce a voltage variation V with time *t* across resistor 43. This is shown schematically at D. Although C and D are shown for simplicity as of sine-wave form, it will be understood that the actual curves will consist of audio frequencies.

It will be comprehended from the description herein that the device, although illustrated in a typical environment, namely, as a pick-up for translating the undulations of a recording disc into electrical energy, is not limited thereto but is capable of other uses wherein it is required to transform discontinuities of a surface into audible or visible intelligence. For example, one such application would be in the field of measuring the roughness of a finished machined surface. The device of our invention may be so arranged that a feeler of the proper contour and size could be caused to trace the surface in a predetermined path in order that undulations or discontinuities of the surface may be imparted to the oscillatory annulus or vane to affect the device in the manner described, and thus to cause audible or visible manifestations indicative of the nature of the surface being traced.

It will be understood that for certain applications of the device it may be desirable to control the anode current by the use of a third electrode (Fig. 9a). This may be accomplished, for example, by inserting a grid 60 between the cathode and anode, as is well known, and impressing the necessary control voltage E_c on the grid. That is to say, the grid 60 may be used as a space-charge grid. Moreover, the usual screen grid and suppressor grid may be employed for achieving specified characteristics in the operation of the thermionic tube 10. Inasmuch as the various modes of interconnecting such grid or grids for specific control purposes are well known, no detailed description thereof is deemed necessary.

One manner of adapting our device to a microphone is indicated in Fig. 11, wherein the diode 10, magnet 51, and vane 81 are positioned with respect to each other similarly to the arrangement of Fig. 4, the diode and magnet being supported in any suitable manner in the shell 82, the vane being oscillatory with the diaphragm 83 through the medium of the rod 84. Thus sound waves impinging on the diaphragm 83 will oscillate the vane 81, with results as explained heretofore.

From the foregoing it will have been noted that we have provided a device capable of translating mechanical vibrations of a wide range of frequencies into a varying electric current for operation of an electro-responsive device. When used as a phonograph pickup, it has many advantages over devices presently available. For example, when compared to the so-called crystal pickup, it does not require any special protection against moisture, the crystal being highly hygroscopic and therefore requiring careful sealing against moisture. Our device does not become erratic at high temperatures—for example, over 110° F.—as does a crystal of potassium sodium tartrate (Rochelle salt). Moreover, the performance of our device is independent of the temperature of the ambient air. Because of their fragility, crystal pickups are easily damaged in shipment, while our device is rugged and stable in adjustment.

The device of our invention is characterized

by excellent fidelity, and has high output in proportion to its weight. A conventional magnetic type of pickup for high output is of relatively heavy weight and generally unadaptable for use on the tone-arm of a disc type of reproducer.

By employing a permanent magnet of high retentiveness, the flux in the interelectrode space is of high density. Thus a slight change in such flux, due to even infinitesimal movements of the flux-varying ring or vane, will produce large changes in plate current.

Of great importance is the ability of our device to respond to frequencies in the low range, a characteristic wherein presently available corresponding devices are inadequate. Moreover, in our device output is independent of the frequency.

While we have shown particular embodiments of our invention, it will be understood, of course, that we do not wish to be limited thereto since many modifications may be made, and we therefore contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of our invention.

Having thus described our invention, what we claim and desire to secure by Letters Patent is:

1. A device for converting mechanical motion into electrical energy comprising an evacuated vessel enclosing an electron-emitting cathodic electrode, an anodic electrode positioned within said vessel and adjacent said cathodic electrode, magnetic means for providing a magnetic field extending into the space between said electrodes, a magnetically permeable member supported for movement and positioned within said magnetic field, and mechanically actuated means connected to said member whereby actuation of said means is effective to move said member to vary the pattern of the field in the interelectrode space between said cathodic electrode and said anodic electrode.

2. A device for translating the sound track of a transcription disk or the like into electrical energy comprising an evacuated envelope containing a cathode and an anode, a magnet for supplying a magnetic field intercepting the electron flow between said cathode and said anode, means for varying the magnetic field pattern within said envelope by changing the magnetic circuit of said magnet, and said means including an element pivotally positioned within that portion of the magnetic field which passes through the anode and cathode to vary the reluctance of the magnetic circuit of said magnet thereby varying the electron flow between said cathode and said anode.

3. A device for translating the sound track of a transcription disc or the like into electrical energy comprising a diode, magnetic means for creating a magnetic flux through the electron stream of the diode, and means for varying the quantity of said flux including an element operable in unison with the undulations of the sound track, said element carrying a vane disposed substantially perpendicularly to the principal direction of the flux and intercepting said flux, the area of the vane being substantially equal to the cross-sectional area of the magnetic field coincident with the electron stream.

4. A device for converting motion of mechanically movable means into electrical energy comprising an evacuated vessel, an electron-emitting cathode and an anode enclosed in said vessel, said anode being positioned in electron-receiving relation with said cathode, a permanent magnet

for providing a magnetic flux threading the vessel, the magnet being disposed exteriorly to said cathode and anode and positioned so that the flux emanating from said magnet is directed intermediate to the space between said cathode and anode, means interconnected to the movable means and including a member of high magnetic permeability disposed in the aforesaid flux emanating from said magnet, whereby movement of the movable means will vary the quantity of flux that passes between the anode and cathode intersecting the electric field in the interelectrode space in accordance with the variations in movement of the movable means.

5. A device for converting mechanical motion into electrical energy comprising an evacuated envelope containing a cathode and an anode, means for establishing a magnetic field within said envelope, means for causing electron flow between said cathode and said anode, a member connected to the source of motion and positioned within the magnetic field, said member being pivotally supported for oscillation with respect to said magnetic field to thus vary the effect of the magnetic field on said electron flow.

6. A device for converting mechanical motion into electrical energy comprising an evacuated envelope containing a cathode and an anode, means for establishing a magnetic field between said cathode and said anode, said means for establishing a magnetic field being external to said evacuated envelope, means for causing an electron flow between said cathode and said anode, a member connected to the source of motion and movably positioned in the magnetic field, said member being pivotally supported for oscillation with respect to said magnetic field to thus vary the effect of the magnetic field on said electron flow, and said member comprising a metal of high magnetic permeability.

7. A device for converting mechanical motion into electrical energy comprising in combination a diode including an elongated cathode and a correspondingly elongated anode in spaced relation thereto, a permanent magnet disposed exteriorly of the diode and positioned with one pole thereof adjacent the diode and with the flux emanating from said pole threading the interelectrode space, and a movable metallic element of relatively high magnetic permeability intermediate said pole and diode, said element being connected to the source of motion and responsive to variations in said motion whereby to influence the quantity of flux in the interelectrode space.

8. The invention set forth in claim 7 characterized in that said permanent magnet comprises a substantially U-shaped yoke having an intermediate pole positioned centrally of the U and extending axially of the U, and said pole terminating within the legs of the U.

9. A device for translating mechanical motion into variations of electrical energy comprising an evacuated envelope containing a cathode and an anode, a magnet for supplying magnetic flux to the space between said anode and said cathode, a mechanically actuated member movably positioned in that portion of the magnetic flux which passes through the anode and cathode, and said mechanically actuated member capable of bearing the reluctance of the flux path of said magnet thereby varying the flux density within said space.

10. A device for translating mechanical motion into variations of electrical energy comprising an evacuated envelope containing a cathode

and an anode, a magnet for supplying a magnetic flux field to the space between said anode and said cathode in a direction normal to the electron flow between said cathode and said anode, and a movable metal member positioned within said magnetic flux field to vary the reluctance of the flux path of said magnet thereby to vary the electron flow between said cathode and said anode.

11. A device for translating mechanical motion into variations of electrical energy comprising an evacuated envelope containing a cathode and an anode, a magnet for supplying a magnetic flux field between said anode and said cathode, a magnetic permeable metal member movably positioned to influence said magnetic flux field that passes between said cathode and anode by varying the reluctance of the magnetic circuit of said magnet thereby to vary the electron flow between said cathode and said anode.

12. A device for translating mechanical motion into variations of electrical energy comprising an evacuated envelope containing a cathode and an anode, a magnet for supplying a magnetic flux field between said anode and said cathode, a magnetic permeable metal member disposed normally between said magnet and said envelope and movably positioned to influence said magnetic flux field by varying the reluctance of the external flux path of said magnet thereby to vary the electron flow between said cathode and said anode, said permeable metal member having an area normal to the flux which is substantially equal to the cross-sectional area of the flux path between said cathode and said anode.

13. A device for translating mechanical motion into variations of electrical energy comprising an evacuated envelope containing a cathode and an anode, a magnet for supplying a magnetic flux field intercepting the electrical flow between said anode and said cathode, a movable permeable member positioned within said magnetic flux field to vary the reluctance of the magnetic circuit of said magnet thereby to change the magnetic field pattern thus varying the electron flow between said cathode and said anode.

14. A device for translating the sound track of a transcription disk or the like into electrical energy comprising an evacuated envelope containing a cathode and an anode, magnetic means for supplying a magnetic field between said cathode and said anode, and means positioned within said field for varying the magnetic field pattern.

ALBERT E. SHAW.
ROBERT J. MOON.

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