Aug. 5, 1969 A. NYMAN 3,459,976

ROTARY ELECTRODYNAMIC DRIVER

Filed July 5, 1966 4 Sheets-Sheet 1

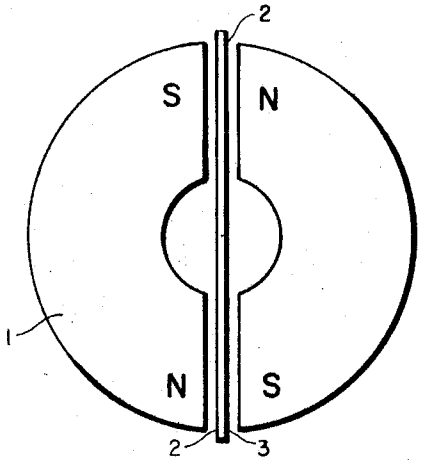


FIG_1a

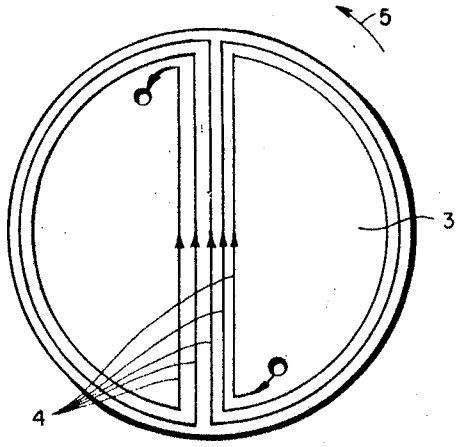


FIG_1b

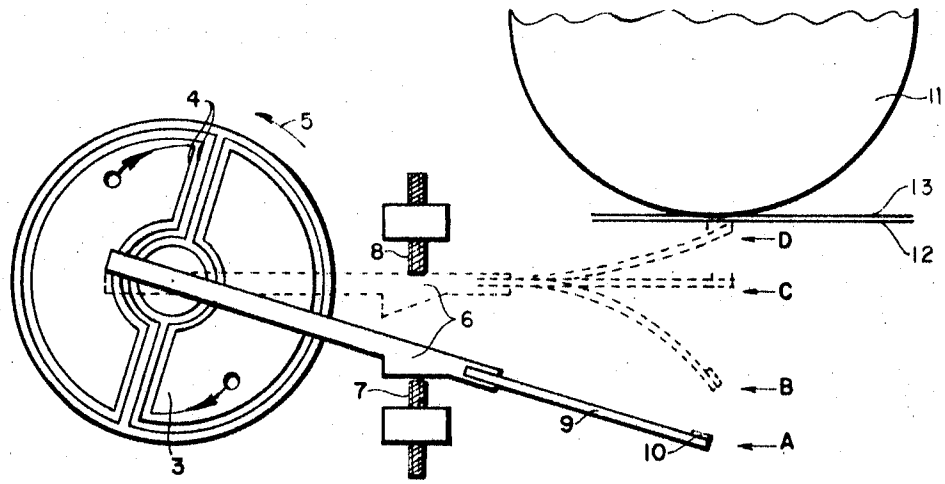


FIG_1c

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ROTARY ELECTRODYNAMIC DRIVER

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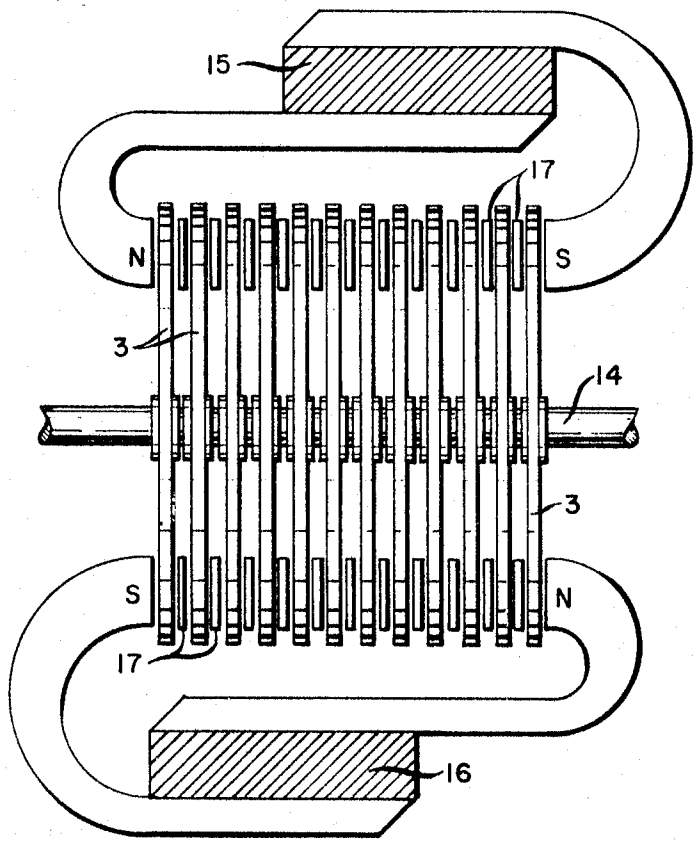
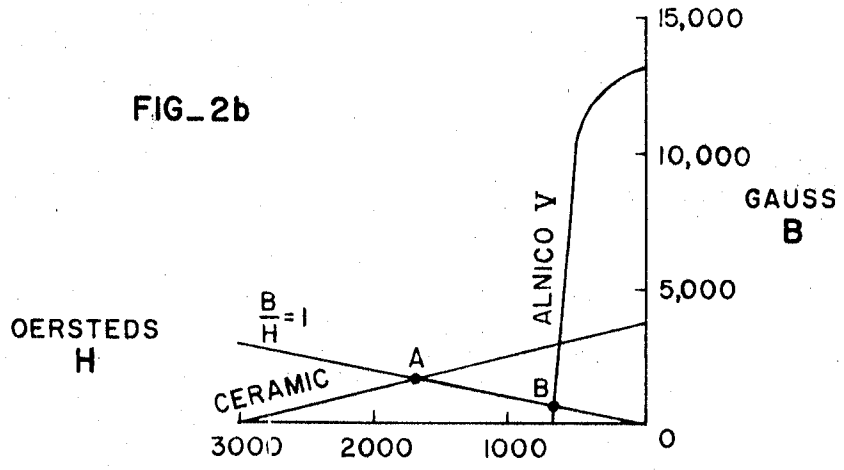


FIG_2a

FIG_2b



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ROTARY ELECTRODYNAMIC DRIVER

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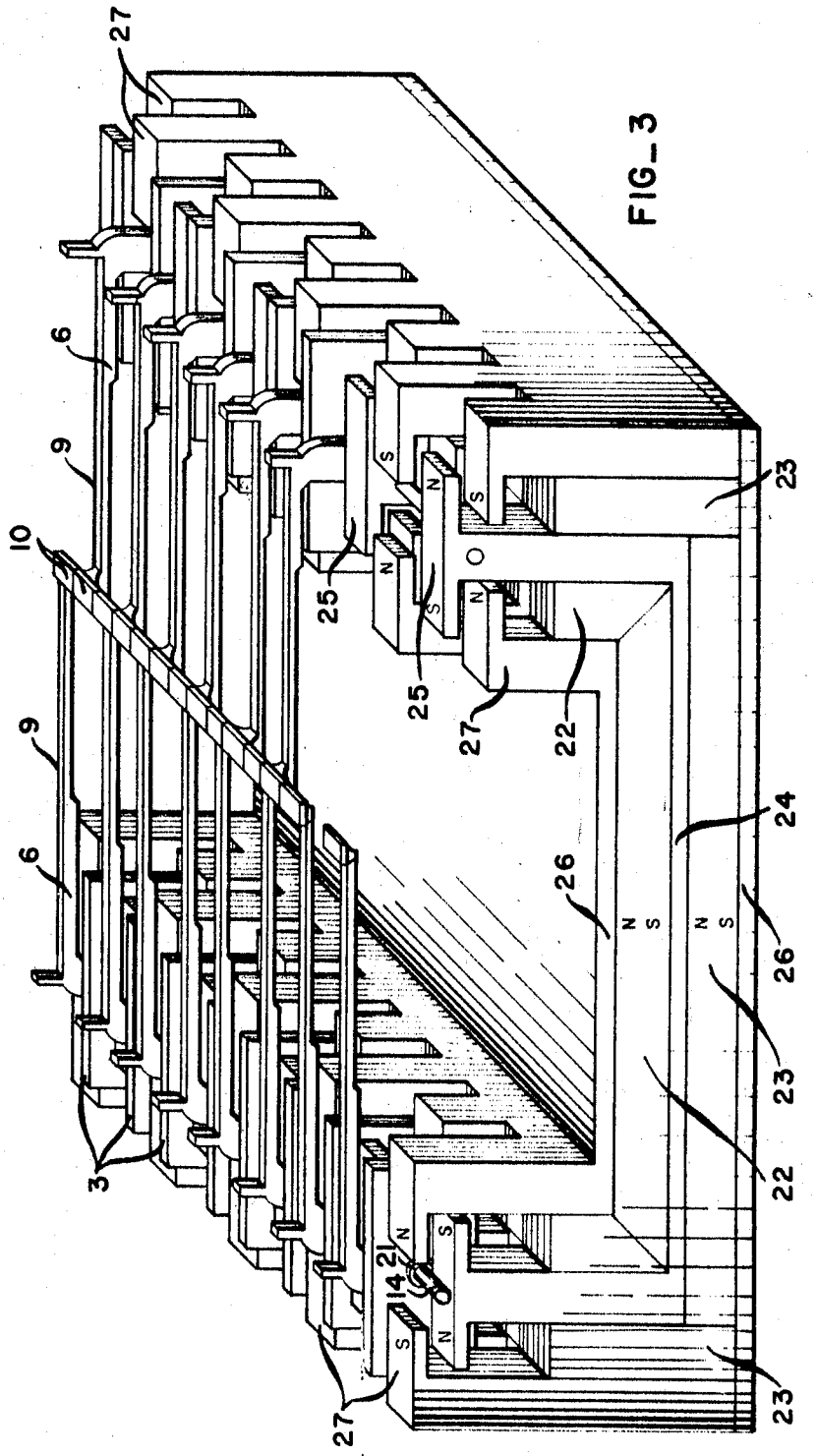


FIG_3

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ROTARY ELECTRODYNAMIC DRIVER

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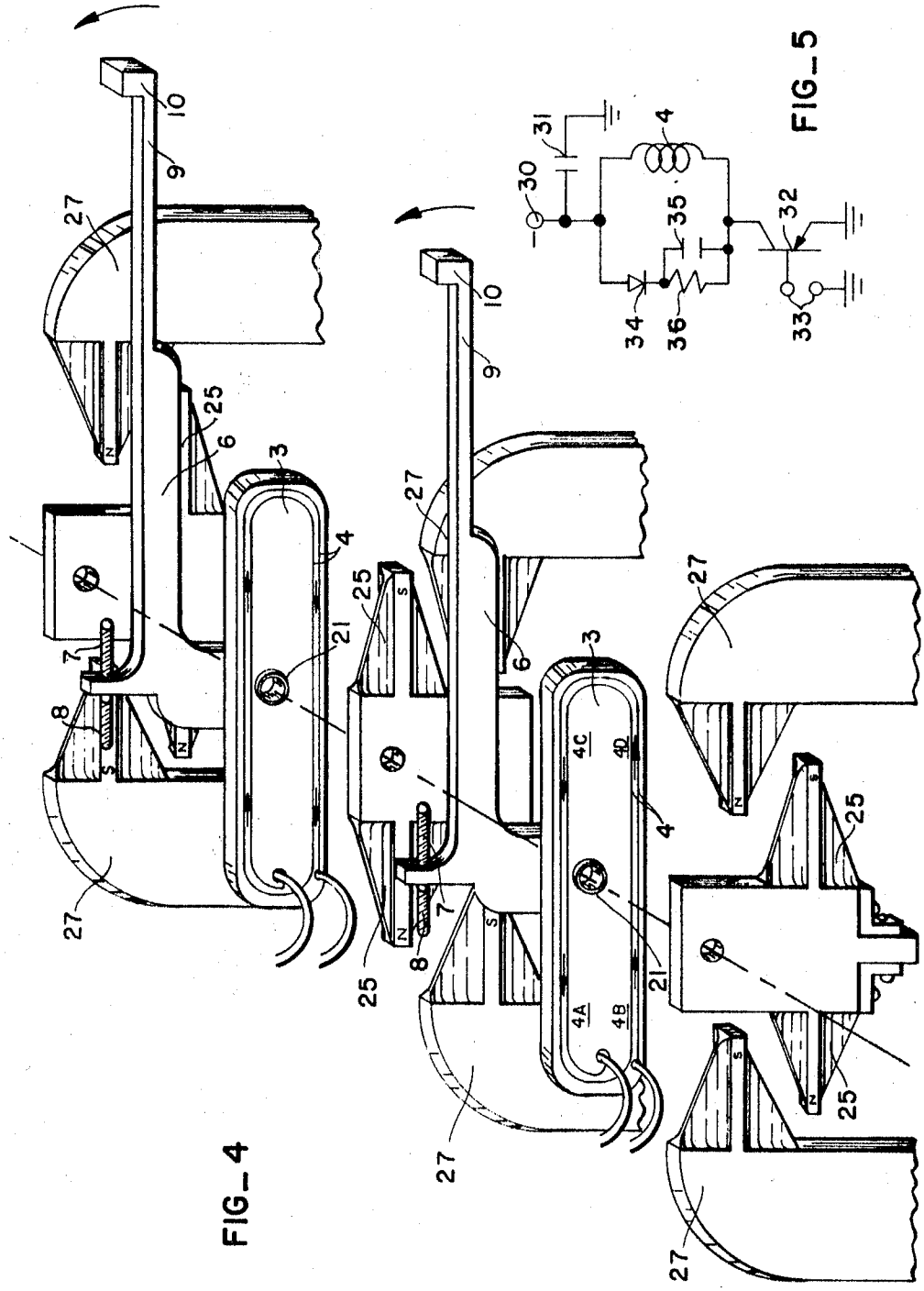


FIG_4

FIG_5

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ROTARY ELECTRODYNAMIC DRIVER

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U.S. Cl. 310—36 6 Claims

ABSTRACT OF THE DISCLOSURE

A flexible-shaft print hammer is arranged to pivot about a single axis and is actuated for printing by a coil connected to the hammer and wound to enclose the axis. The coil is suspended in two pairs of magnetic fields, each field running parallel to the axis and cutting a portion of the coil. Each pair of fields coacts with a pair of diametrically opposite coil portions so that a current pulse transmitted through the coil interacts with the fields to apply rotational forces at four points on the coil, actuating the hammer.

This invention refers to printers and particularly to hammers used on high speed printers of the type that are suitable for use in presenting data from computers and data processing equipment.

In the art of high speed printing it is usual to present an array or font of type characters to each position to be printed at high speed, while timing the operation of print hammers to effect printing when the desired characters pass the line to be printed. A separate hammer is usually employed for each print position so that a full line is printed as the array of type passes all hammers.

It is therefore essential to have the hammers and their drive elements arranged with a minimum of dimensional separation along the line to be printed. For example, with ten columns per inch, the separation of hammers is 0.1". Even when the hammers are alternately arranged in two parallel opposing rows, the drive mechanisms for each adjacent hammer in a row is only 0.2". This dimensional requirement imposes a limitation on the structure of the hammer drivers, requiring compact design while at the same time retaining reliability, high-speed operation, and accurate timing of print operation. The total operating time of a hammer from the instant of initiating the action to the print impression is often in the order of 1 to 1.5 milliseconds so that only 5% variations in print time (i.e. 50 to 75 microseconds) are tolerable with a character presentation rate of 160 in./sec. characters per second in order to register the characters within .012 inch.

In my invention these severe conditions are met by hammer drivers employing electrodynamic force, i.e. the force which is exerted by a magnetic field on an electric conductor at right angles to this conductor. A number of attempts have been made to use electrodynamic principles for hammer operation. The known hammers of this nature depend upon linear drive in the direction of hammer operation resulting in considerable dimensional and practical limitations. I have conceived the use of a rotational electrodynamic element: a coil mounted on a frame or a printed card so that operating portions of the coil wire are subjected to strong magnetic fields. The coils and fields are arranged so that additive rotational forces are developed in the operating portions of the coil to develop a strong rotational force about an axis. The axis is preferably parallel to the magnetic field with the operating portions of the coil arranged in essentially directions to generate tangential rotational forces on the coil.

Moreover, I have utilized a type of permanent magnet which permits the establishment of very strong magnetic

fields at the operating portions of the coil. The magnetic field of a permanent magnet is determined by the coercive magnetomotive force and the reluctance of magnetic path. I have found that certain configurations of ferromagnetic (magnetically conducting) structures permit the full utilization of the available magnetomotive forces with a minimum of wasted magnetic field (leakage). I have also combined in a single magnetic structure a multiplicity of magnetic pole areas disposed in the areas of adjacent hammer driver coils.

The actual printing operation with a rotary drive is accomplished by attaching a hammer-supporting extension arm to the rotating driver. The dimensional and elastic features of the extension arm permit a whip action by means of which the velocity of the hammer element is greatly accentuated. The rotating coil rapidly bends the extension arm which then unwinds at its natural frequency which is quite high. This imparts a peak velocity to the hammer head at the instant of operation, when there is a complete transfer of the potential energy of the bent arm into kinetic energy of the hammer.

It is thus an object of my invention to provide an improved electrodynamic hammer driver structure.

Another object is to provide improved electrodynamic hammer drivers employing a compact arrangement as required for high speed printers.

Another object is to provide improved electrodynamic hammer drivers employing strong magnetic fields permitting the use of coils of minimized wire length and reduced operating inertia, thereby achieving rapid response to activating electric current pulses.

Another object is to provide improved electrodynamic hammer drivers employing coils with reduced inductance and resistance permitting short pulses of relatively large current to assure accurately-timed print operation without overheating the coils.

A further object is to provide an improved hammer driver employing electrodynamic driving and braking, employing a single coil.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

In the drawings:

FIGS. 1*a*, 1*b* and 1*c* are diagrams illustrating the principle of operation of a rotary electrodynamic coil with a whip-action hammer head.

FIG. 2*a* is a diagram illustrating a first embodiment of my invention, including a two element magnetic structure operating a multiplicity of hammer drivers.

FIG. 2*b* is a graph showing the magnetic characteristics of the device shown in FIG. 2*a*.

FIG. 3 is a diagram showing a second and preferred embodiment of my invention.

FIG. 4 is an exploded view of a portion of the device shown in FIG. 3.

FIG. 5 is a schematic diagram illustrating an electrical circuit that is suitable for use with both embodiments of my invention.

Referring to FIGS. 1*a*, 1*b* and 1*c*, a high speed printing hammer with a rotary electrodynamic driver is shown in its simplest generic form. In FIG. 1*a*, two arc-shaped permanent magnets **1** having north (N.) and south (S.) poles as shown providing two air gaps **2** with concentrated magnetic fields in opposite directions as shown by the arrows. A printed circuit driver **3** is mounted between the magnets. FIG. 1*b* shows a section view through the air gaps showing the surface of the printed circuit driver **3**. The driver contains parallel conductors **4** that are located so that the current in each conductor interacts with the magnetic fields to produce aggregative rotational

forces in the counterclockwise direction shown by an arrow 5.

FIG. 1*c* shows the same driver 3 with a rigidly-mounted arm 6 which is free to swing between a pair of stops 7 and 8. The arm 6 supports a flexible extension arm 9 upon which a hammer 10 is mounted. A print drum 11 containing peripherally-engraved type faces (not shown) is continuously rotated above the hammer. A document 12 to be printed and a ribbon 13 are placed between the hammer and the print drum so that actuation of the hammer forces the ribbon and document against the selected type face to effect printing. The arm 6 is biased against stop 7 by a spring (not shown) to maintain the hammer 10 in a non-printing position, designated as A. When the hammer is to be actuated, a short-duration, high-current pulse is passed through the coil 3, causing it to turn with a high rotary acceleration in the counterclockwise direction as shown by the arrow 5. The rotation is arrested by stop 8. The rapid motion causes the extension 9 to bend to a position B, thereby storing potential energy in the extension. At about the time that the arm 6 has stopped, this potential energy is released into the motion of the print hammer 10. The print hammer reaches its maximum velocity at the instant the extension 9 is completely straight (position C). The preferred position for impacting the print drum 12 is at this maximum velocity position or at a slightly higher position D, assuring a reversal of both potential and kinetic energy at the completion of printing. Thus, stop 7 essentially controls the flight time of the hammer and stop 8 essentially controls the hammer penetration (ignoring the interaction between the effects of the stops on the speed of the hammer). Stops 7 and 8 are adjustable to provide control of these parameters.

Between 20% and 65% of the initial energy is generally returned to the extension 9 and hence to arm 6 and coil 3. This returning energy can be dissipated as described below with respect to the actuation circuit shown in FIG. 5.

FIG. 2*a* shows an arrangement of several hammer drivers 3 mounted on a common pivot 14. Each of the drivers consists of a printed circuit with diametric conductors as shown in FIG. 1*b*. Arms and hammers of the type illustrated in FIG. 1*c* extend from the rear of the drivers and are not shown in FIG. 2*a*. The hammers are arranged to form a line parallel to the axis 14. Preferably, two hammer assemblies are employed, each of the type shown in FIG. 2*a* where one assembly contains odd-numbered hammers and is interleaved with an assembly containing even-numbered hammers. The axes 14 of the assemblies are then arranged parallel to each other on opposite sides of the line of hammers.

FIG. 2*a* shows two ceramic magnets 15 and 16 with pole pieces arranged to provide two magnetic fields in opposite directions which cross the diametric conductors on the drivers 3. Suitable ceramic magnets are barium ferrite $B_aFe_{12}O_{19}$ in a ceramic or plastic matrix. A ferromagnetic interposer 17 is arranged between each driver to confine the field strength to the operating portions of the conductors.

The ceramic magnets have the characteristic of very high magnetomotive forces without significant demagnetizing effects. FIG. 2*b* shows a typical B–H curve for a ceramic magnet and for a typical metallic magnet (Alnico V). The vertical axis represents the magnetizing field B within the magnet and the horizontal axis represents the magnetomotive force H available for driving the magnetic flux through a ferromagnetic structure with air gaps. The B–H curve for the metallic magnet has a sharp knee which limits the available magnetomotive force H. The interacting line labelled B–H represents diagrammatically the effectiveness of the magnetic structures employed with the present invention. The selection of this line is a result of tests and calculations taking account of active air gaps, the areas of the magnets, any leakage magnetic fields that are present, and the relation of the active field areas to the total cross section area of the magnet. The B–H line that is shown has a slope of 1.0 but, for the structures employed with the present invention, slopes between 0.5 and 1.5 are generally obtained. With a ceramic magnet, the available magnetomotive force H is relatively high (point A) with a strong magnetic field. With the same magnetic structure and a metallic magnet the available magnetomotive force H is much lower (point B). The structure could be redesigned to produce a steep B–H curve that would intersect the substantially horizontal portion of the metallic magnet curve, but then an even lower magnetomotive force H is obtained. However, in this case, the reaction due to simultaneous drive current in a multiplicity of drivers demagnetizes the permanent magnet, whereas with the ceramic magnet, the reaction is insignificant because of the margin of available magnetomotive force, and there is no permanent demagnetization because the ceramic magnet characteristics are linear.

FIGS. 3 and 4 show a preferred form of the invention employing a magnetic structure and a multiplicity of hammer drivers. In this embodiment, arrays of drivers 3 are supported by two pivots 14 (only one of which is shown in FIG. 3 because several elements of the right side of the apparatus have been omitted for clarity). The drivers are mounted for pivotal action by bushings 21. As shown in greater detail in FIG. 4, each driver 3 rigidly supports an arm 6 with a flexible extension arm 9 and a hammer 10. Any suitable attachment means (not shown) may be employed to connect arm 6 to driver 3. The operation of the arm drivers is similar to the operation described with respect to FIGS. 1*a*, 1*b* and 1*c*. The hammers on the drivers in the array on the left side are mounted to the rear of the drivers while the hammers in the array on the right side are mounted to the front of the drivers. This arrangement enables the opposing hammers to all drivers to be identically fabricated but reversely assembled.

As shown in FIG. 3, two ceramic magnets 22 and 23 are polarized in the same direction with a ferromagnetic center plate 24 between them. Each magnet 22 and 23 is comprised of three elements for simplicity of fabrication and assembly and to limit leakage magnetic fields. The center plate 24 carries an array of center pole pieces 25. The outer surfaces of the magnets are covered with plates 26 which carry outer pole pieces 27. The arrangement of pole pieces is shown in detail in FIG. 4, where it can be seen that alternate sets of pole pieces along the depth of the device are similarly arranged and between these sets of pole pieces are oppositely arranged pole pieces. That is, in the first (forward) and third set of pole pieces, the outer pole pieces 27 are arranged above the inner pole pieces 25, but in the second set of pole pieces the outer pole pieces are arranged below the inner pole pieces. The pole pieces are preferably shaped as shown in FIG. 4 with flat vertical sides and sufficiently large upper and lower portions to provide a maximum concentrated (horizontal) field between each adjacent pair of pole pieces in the same horizontal plane. The pole pieces are shown with simplified shapes in FIG. 3 merely to avoid complicating the drawing.

The drivers 3 are sandwiched between the layers of pole pieces and their conductors 4 are arranged so that the application of current through the conductors causes four aggregative forces to impart counterclockwise motion to the drivers. As shown in FIG. 4, a region 4A of the conductor 4 on the first driver element is sandwiched between an S. pole piece 27 and an N. pole piece 25, so that current through the conductor in the direction shown causes a downward force on the left side of the driver 3. A similar downward force is developed in a region 4B of the conductor (the magnetic field is opposite to the field in region 4A, but current flow is also in the opposite direction). Similarly, upward forces are applied in regions

4C and 4D of the conductor with the magnetic fields and current direction shown in FIG. 4. The second (rear) driver 3 is sandwiched between pole pieces which are opposite in polarity to those for the forward driver, but this is compensated for by reversing the current in the conductor 4 as shown.

Adjustable stops 7 and 8 for each hammer driver (FIG. 4) are accessibly mounted on two parallel channels (not shown). The stops 7 control the initial positions of the hammers 10 and, hence, the flight time for the hammers. Hammer arms 6 are held against stops 7 either by a linear or torsion spring (not shown), as is well known in the art. This initial position determines the length of travel of the drive coil and hence the duration of the hammer stroke and its eventual velocity, permitting accurate adjustment of print timing. Stops 8 determine the position of the hammer arms 6 at which they stop and after which the whip action of extensions 9 take place (hammer penetration). Stop 8 also controls the timing and velocity of the hammer head.

FIG. 5 illustrates a circuit arrangement by means of which suitable pulses are applied to conductors 4 of the drivers 3. A negative voltage source is supplied between a terminal 30 and ground. A capacitor 31 is used to augment the current pulse capacity of the applied source. A transistor 32 is connected in series with the driver conductor 4 between the negative source and ground. Actuating pulses are applied to the base of the transistor (by way of terminals 33) to cause current to flow through the conductor 4 to actuate the hammer. The conductor 4 is bypassed by a circuit containing a diode 34 in series with a parallel-connected capacitor 35 and resistor 36. The diode does not conduct while the circuit is pulsed. However, the inductance of the conductor 4 develops a counter-EMF immediately after the pulse is terminated. At this time, the diode conducts, preventing oscillation in the circuit and reducing the speed of the returning hammer during its rebound. (Since the current passed by the diode passes through the conductor 4 in the same direction as the current during the actuating pulse, braking is accomplished because the rebounding hammer is, in effect, partially actuated with the result that the rebound speed is reduced.) The capacitor protects the transistor from excessive voltage and the resistor protects the diode from excessive current. Additional braking can be achieved by applying a brake pulse to terminals 33, if desired. This brake pulse is obviously of sufficiently short duration to decelerate the hammer without causing it again to be actuated. Thus, the present invention provides for precise hammer actuation with a simple, compact, and economical structure that is suitable for use in high-speed printing application.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A print hammer assembly comprising, in combination:

a print hammer mounted to pivot about a single axis;

a current conducting coil connected to said hammer and wound so as to enclose said axis;

permanent magnet means positioned adjacent said coil and constructed and arranged to generate at least a pair of magnetic fields having lines of flux parallel to said axis, and in the same relative direction, each said field cutting a portion of said coil, said portions being located on opposite sides of said axis and running in directions having radial components relative to said axis whereby current transmitted through said coil reacts with said fields to rotate said coil about said axis, pivoting said hammer into print position.

2. The hammer assembly set forth in claim 1 wherein said permanent magnet means is constructed and arranged to generate two pairs of magnetic fields located to cut across two pairs of diametrically opposite portions of said coil.

3. The hammer assembly set forth in claim 2 wherein said ceramic magnet is located remote from said coil and arranged to generate said two pairs of fields in mutually opposite directions.

4. The hammer assembly set forth in claim 3 wherein the flux-producing element in said permanent magnet means comprises a ceramic permanent magnet.

5. The hammer assembly set forth in claim 4 wherein said ceramic magnet is located remote from said coil and wherein said magnet means further comprises four pairs of magnetically conductive pole pieces cooperating with said ceramic magnet to conduct the flux therefrom to locations adjacent said diametrically opposite portions of said coil.

6. The hammer assembly set forth in claim 1 wherein said print hammer comprises:

a hub mounted to pivot about said axis and connected to said coil;

a hammer head; and

a resilient shaft connecting said head to said hub whereby the pivot motion imparted to said hub by said coil induces a whipping action in said shaft, increasing the velocity of said head above that attributable to said hub alone.

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U.S. Cl. X.R.

101—93; 310—268; 318—132