Aug. 8, 1967 W. E. MOWER ETAL 3,335,385

RECTILINEAR ACTUATOR AND POTENTIOMETER

Filed July 29, 1964

4 Sheets-Sheet 1

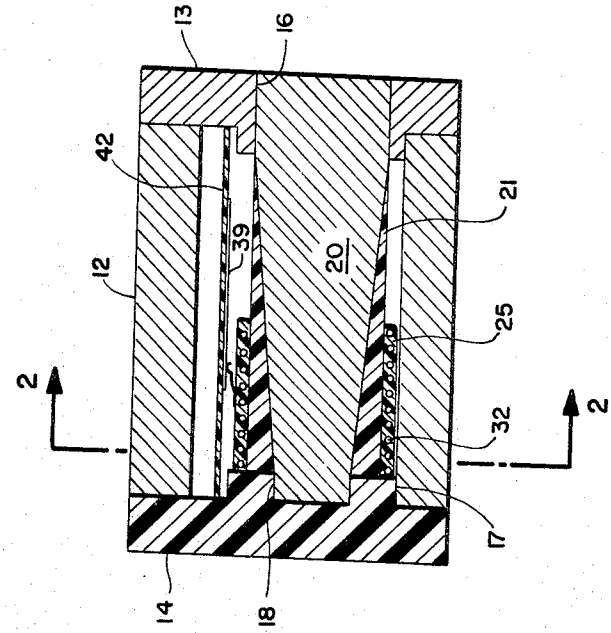


FIG. 1

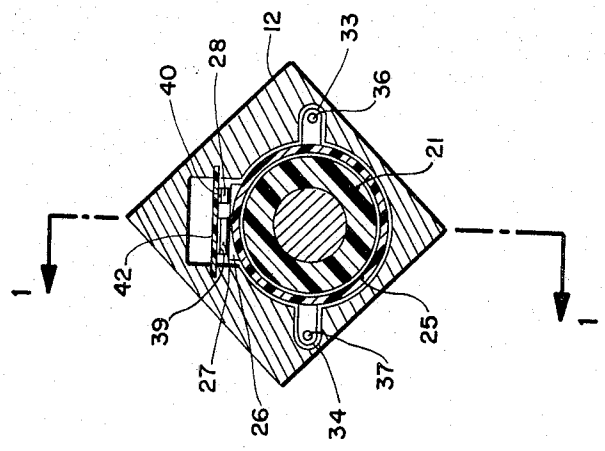


FIG. 2

INVENTORS
WILFORD E. MOWER
JAMES H. PEPPER
DOUGLAS H. SMITH
BY Paul R. Harder
ATTORNEY

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4 Sheets-Sheet 2

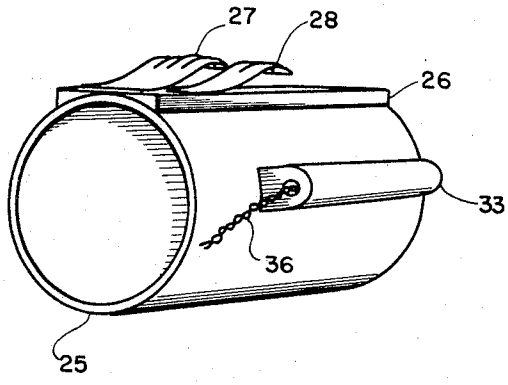


FIG. 3

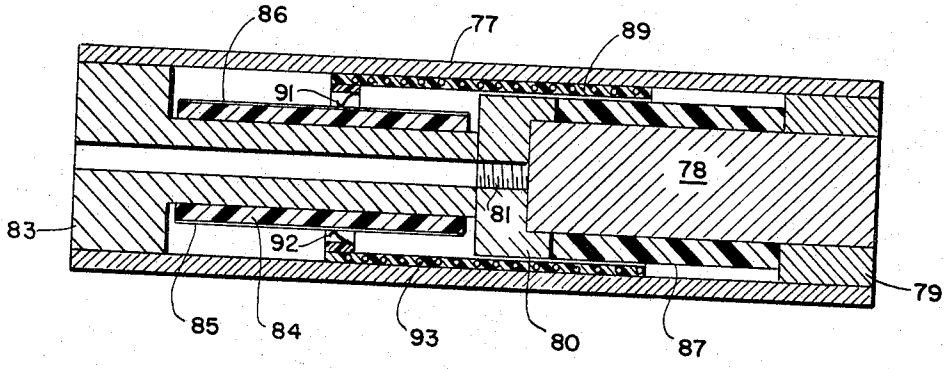


FIG. 7

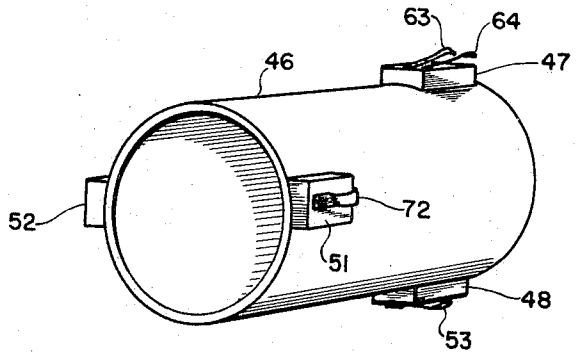


FIG. 6

INVENTORS
WILFORD E. MOWER
JAMES H. PEPPER
DOUGLAS H. SMITH
BY Paul R. Harder
ATTORNEY

Aug. 8, 1967 W. E. MOWER ETAL 3,335,385

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4 Sheets-Sheet 3

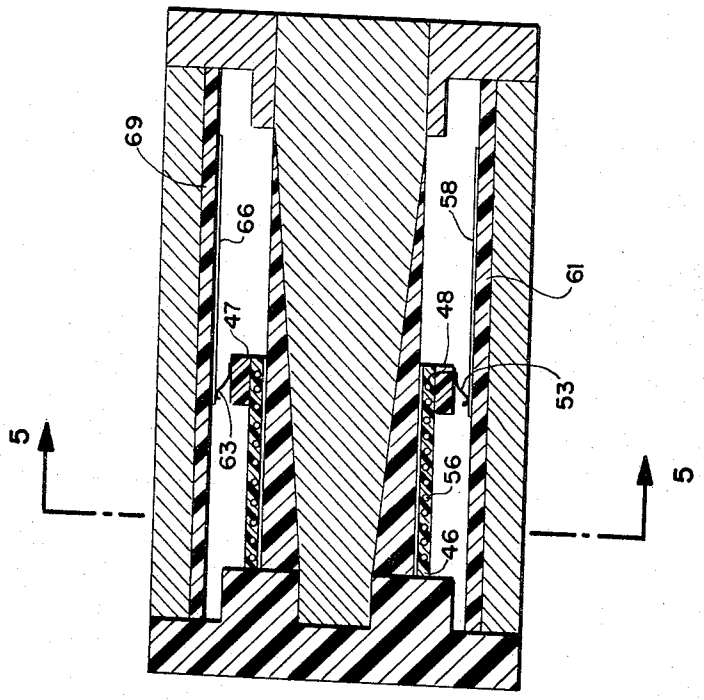


FIG. 4

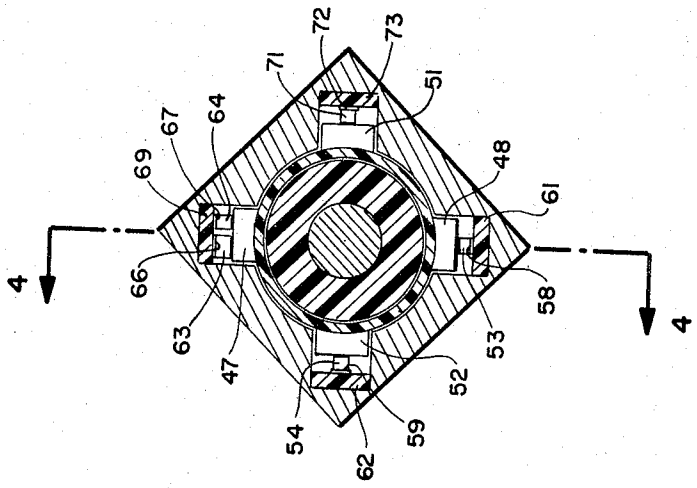


FIG. 5

INVENTORS
WILFORD E. MOWER
JAMES H. PEPPER
DOUGLAS H. SMITH
BY Paul R. Harder
ATTORNEY

Aug. 8, 1967 W. E. MOWER ETAL 3,335,385

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4 Sheets-Sheet 4

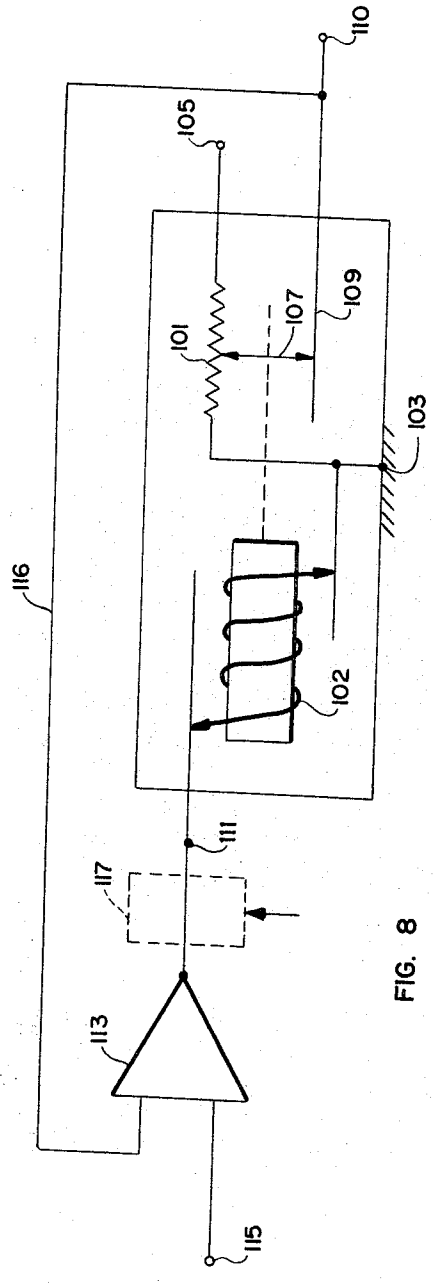


FIG. 8

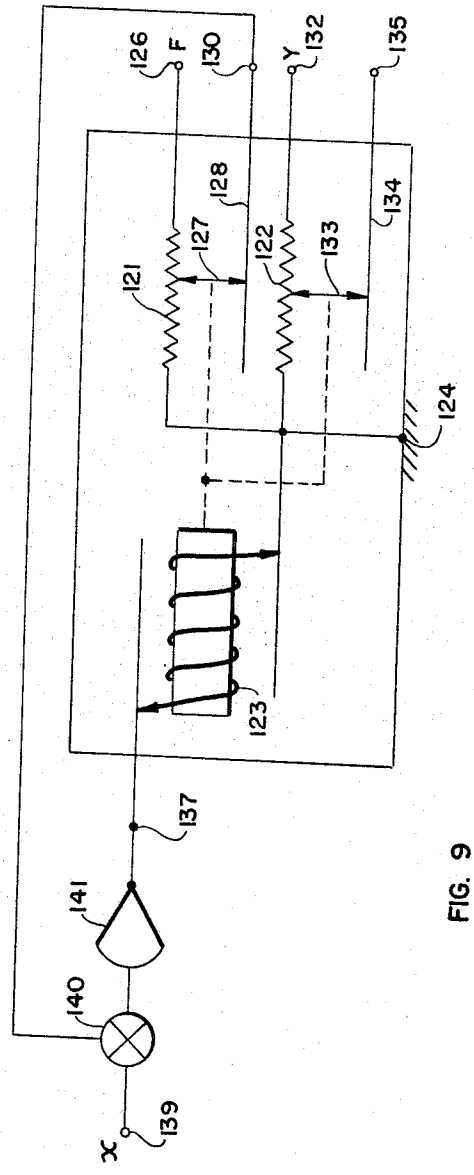


FIG. 9

INVENTORS
WILFORD E. MOWER
JAMES H. PEPPER
DOUGLAS H. SMITH
BY Paul R. Harder
ATTORNEY

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3,335,385

RECTILINEAR ACTUATOR AND POTENTIOMETER

Wilford E. Mower, Concord, James H. Pepper, Orinda, and Douglas H. Smith, Albany, Calif., assignors to Beckman Instruments, Inc., a corporation of California

Filed July 29, 1964, Ser. No. 385,839
7 Claims. (Cl. 338—116)

This invention generally relates to rectilinear potentiometers and more particularly to a unitary rectilinear actuator and rectilinear potentiometer.

In the field of analog computer applications it has been a general practice to utilize servo-set coefficient potentiometers for numerous applications. These generally comprise copper mandrel potentiometers or potentiometers of other types driven by a small servo motor. Such devices have an average volume of approximately 50 in.^{3} and an average end-to-end setting time of approximately 2 seconds. Since in many analog computers large numbers of such devices are utilized the size of the components become extremely important as does their speed of operation in the over-all size and speed of operation of the computer.

It is, therefore, an object of the present invention to provide a rectilinear actuator and rectilinear potentiometer combination which may be utilized as a servo-set coefficient potentiometer in analog applications, that is greatly reduced in size and which has an extremely fast end-to-end setting time when compared with the present day servo-set coefficient potentiometers.

It is another principal object of the present invention to provide a rectilinear actuator and rectilinear potentiometer combination which may be readily adapted to a multiplicity of functions without modification, which is simple of construction, small in size, rapid in response, low in cost and is highly accurate.

Still another object is to provide a rectilinear actuator and rectilinear potentiometer combination which may readily be utilized as a servo-set coefficient potentiometer, a track and store device, a servo multiplier or a servo function generator without significant modification or adaptation.

A further object is the provision of a rectilinear actuator and rectilinear potentiometer in which an armature carrying a slider may be accurately and rapidly positioned at any point along a resistance element.

Another object is to provide a rectilinear actuator and rectilinear potentiometer combination which may be utilized in a variety of applications without modification utilizing an armature carrying a wiper along a resistance element which may be rapidly positioned with high accuracy and in which there is no restoring force thus allowing the device to be utilized as a storage element.

Still another object is to provide a rectilinear actuator and rectilinear potentiometer combination utilizing an armature-wiper assembly having a low mass such that the wiper may be rapidly and accurately positioned along a resistance element and in which the frictional forces may readily be made to exceed gravitational forces such that the device may be made essentially independent of spacial orientation.

Other objects and many attendant advantages of this invention and many novel arrangements and combinations of parts will become more readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with

the accompanying drawings in which like reference numerals indicate like parts throughout the several views thereof and wherein:

FIG. 1 is a sectional view of one preferred embodiment taken along line 1—1 of FIG. 2;

FIG. 2 is a sectional view of the embodiment taken along line 2—2 of FIG. 1;

FIG. 3 is an isometric view of the free running armature of the embodiment of FIGS. 1 and 2;

FIG. 4 is a sectional view of a second preferred embodiment taken along line 4—4 of FIG. 5;

FIG. 5 is a sectional view of the embodiment taken along line 5—5 of FIG. 4;

FIG. 6 is an isometric view of the free running armature of embodiment of FIGS. 4 and 5;

FIG. 7 is a sectional view of a third preferred embodiment;

FIG. 8 is an electrical schematic diagram of a coefficient potentiometer constructed after the teachings of this invention; and

FIG. 9 is an electrical schematic diagram of a single quadrant multiplier constructed after the teaching of this invention.

Referring now to FIGS. 1, 2 and 3 there is illustrated one preferred embodiment of a rectilinear actuator and rectilinear potentiometer combination constructed after the teachings of this invention. The unit comprises a housing having a main body portion **12** and first and second end members **13** and **14**. End member **13** has an aperture **16** therein and end member **14** has a boss **17** formed on the internal surface, the boss having a blind aperture **18** in axial alignment with aperture **16** of end member **13**. Supported within apertures **16** and **18** is a permanent magnet **20** which may readily comprise an Alnico slug in the shape of a truncated cone having its end portions cylindrically cut for receipt in apertures **16** and **18**.

A plastic guide member **21** is formed about the slug **20** in such a manner as to form a cylindrical guide. The main body portion **12** and end member **13** may conveniently be made of soft iron to form a highly permeable flux path for the flux of permanent magnet **20**. End member **14** may be conveniently constructed of phenol. It is apparent that an air gap is formed between the guide member **21** and the soft iron housing in the flux path between the permanent magnet and the housing.

Supported by guide member **21** is a free running armature assembly generally comprising a cylindrical insulating sleeve **25** having a protrusion **26** for carrying one or more electrically conductive, resilient fingers which may form the sliders or wipers. In the particular embodiment illustrated two sliders **27** and **28** are illustrated. Sliders **27** and **28** may be affixed to the protrusion **26** in any suitable manner and are electrically connected. Embedded within sleeve **25** is an armature coil **32** having its ends thereof respectively brought out through protrusions **33** and **34** and terminating in flexible braids **36** and **37** thus forming a suitable means of energizing coil **32**.

A resistance element **39** and an electrically conductive strip **40** are supported in space relation by insulating member **42**, resistance element **39** and conductive strip **40** being in contact respectively with resilient sliders **27** and **28**.

Conductive strip **40** may be brought to an external terminal, not shown, and provides a convenient means of external connection to slider **27**.

The sliders and protrusions **33** and **34** serve the multi-

ple functions of providing electrical contacts to the resistance and conductive elements and a means of support for the lead wires of coil **32** and as axial guides for the free running armature assembly.

The magnetic structure establishes a strong radial magnetic field in the air gap between the permanent magnet and the soft iron housing. Current flow through the armature coil creates a magnetic field which reacts with the radial field established by the permanent magnet thereby creating a force for moving the armature assembly axially along the guide **21** in a direction which depends upon the direction of current flow in the armature coil. It is apparent that by reversing the direction of current flow through the armature coil the direction of movement of the armature asesmbly may be reversed. If the force developed by the reacting magnetic fields is sufficient to overcome the frictional forces of the system, the armature assembly will move along the surface of the guide thereby moving wipers **27** and **28** along their respective elements. By forming the armature assembly of a suitable insulating material, such as the material sold under the trademark Fiberglas, the mass of the armature may be made low and the frictional forces can be made to exceed the forces due to gravity thereby making the device essentially independent of spacial orientation. Since there is no restoring force the device may also be utilized as a storage element. When the resistance element is connected in a feedback circuit the armature assembly can be rapidly positioned with a precision which is a function of the characteristics of the resistance element and the servo loop gain.

Referring now to FIGS. 4, 5 and 6, there is illustrated a second embodiment constructed after the teachings of this invention which incorporates a plurality of resistance elements which may be utilized in various configurations. The embodiment differs mainly in the free running armature assembly, best illustrated in FIG. 6, which again may comprise a low mass sleeve **46** made of an insulating material. The armature assembly has a first pair of diametrically opposite protrusions **47** and **48** located at one end of the sleeve and a second pair of diametrically opposite protrusions **51** and **52** located at the other end thereof and rotated 90° with respect to the first pair.

The resilient, electrically conductive contacts or sliders **53** and **54** respectively secured to protrusions **48** and **52** may serve as the terminals of armature coil **56** embedded in armature assembly **46**. Supported adjacent and in electrical contact with sliders **53** and **54** are electrically conductive strips **58** and **59** respectively supported within the main body portion of the housing by any suitable means such as, for example, insulating members **61** and **62** respectively. It is to be understood that the electrically conductive strips **58** and **59** are brought to the exterior of the housing by any suitable means, not shown, for connection to external circuitry. Protrusion **47** of the armature assembly may, if desired, carry a pair of electrically connected sliders **63** and **64** and respectively engaging resistance element **66** and conductive strip **67** spacially supported upon an insulating member **69** secured within the main body portion of the housing. Protrusion **51** carries a slider **71** engaging resistance element **72** supported upon an insulator **73**. Protrusion **51** may, if desired, include a second slider and a conductive strip to provide for the external connection of slider **71**. On the other hand, slider **71** may be brought to the external surface through an insulated, flexible braid similar to the coil leads in FIG. 3.

It is apparent that by bringing the coil leads to a slider and a conductive slide wire the necessity of the flexible braids of the embodiment of FIGS. 1, 2 and 3 is avoided.

Referring now to FIG. 7 there is illustrated a third embodiment of a rectilinear actuator and rectilinear potentiometer combination constructed after the teachings of this invention and generally comprises a main body housing **77** preferably constructed of soft iron and having an aperture extending through the longitudinal axis thereof. A permanent magnet slug **78** in the form of a solid cylinder and preferably of Alnico is supported within the housing by an end plug **79** preferably of soft iron and an intermediate plug member **80** having a blind aperture therein for receiving the slug **78**. Intermediate plug **80** is supported symmetrically about the axis of the device by a screw engaging threads **81** therein and extending through the end plug **83** which may preferably be constructed of a non-permeable material such as brass. A cylindrical insulating member **84** is supported by end plug **83** and is utilized in mounting the resistance and pick off elements about the axis of the device, only two of which are illustrated at **85** and **86**.

A non-ferrous guide member **87** is supported about the permanent magnet slug **78** between end plug **79** and intermediate plug **80** and is utilized as a guide for elongated sleeve member **89**. As in the other embodiments, the sleeve member **89** forms a free running armature assembly composed of a non-ferrous insulating member carrying on its internal surface a plurality of wipers, two of which are shown at **91** and **92**. Embedded in the surface of sleeve member **89** is an armature coil **93**. It is to be understood that the embodiment of FIG. 7 may utilize any number of resistance elements and pick offs in the same manner as the embodiments of FIGS. 1–6.

Referring now to FIG. 8 there is illustrated an electrical schematic diagram of the device when utilized as a coefficient potentiometer. In most applications, the low potential end of the actuator coil and the potentiometer or potentiometers may be grounded through the iron housing of the device. Therefore, in the instant embodiment only three wires need be brought to the external housing and only one of these, the coefficient potentiometer output lead, need be shielded.

As illustrated in FIG. 8 one end of potentiometer **101** and one end of armature actuating coil **102** are connected to the iron housing at **103** which may be connected to a common point of potential, usually ground. The other end of the resistance element **101** is connected to an external terminal **105** which is adapted to be connected to any source of suitable potential. Slider **107** interconnects resistance element **101** and conductive slide wire **109** which is connected to a second external terminal **110**. The non-grounded end of actuator coil **102** is brought to external terminal **111** which forms an input terminal to the actuating coil. To form a null balance servo-loop, differential amplifier **113** has one of its input terminals connected to terminal **115** adapted to receive an armature actuating signal and its other input terminal connected through lead **116** to output terminal **110** of the coefficient potentiometer. The output of the differential amplifier is connected to terminal **111** of the actuator coil **102**.

In operation, a suitable potential is applied across resistance element **101** and the output potential developed between output terminal **110** and ground is a function of the position of slider **107**. A signal having an amplitude proportional to the desired setting of the coefficient potentiometer is applied to input terminal **115**. Differential amplifier **113** compares the input signal with the feedback signal from output terminal **110** and applies to actuator coil **102** a signal which is proportional to the difference between the input signal and the feedback signal and which has a polarity dependent upon which of these signals is greater. Current flowing through coil **102** develops a magnetic field which reacts with the radial field produced in the air gap between the permanent magnet and the soft iron housing to develop a force which moves the armature assembly in one direction or the other depending upon the polarity of the input signal. The armature continues to move until the feedback signal is of such amplitude as to null the input signal. At null condition, the driving force is removed and the armature assembly remains where it is stopped since there is no restoring force. It is apparent that any of the embodiments previ-

ously set forth herein, since each contains at least one potentiometer element, may be utilized as a coefficient potentiometer in the circuit illustrated in FIG. 8.

It is apparent that with slight modification and when combined with a servo amplifier the coefficient potentiometer of FIG. 8 may be converted to a track and store device. By introducing between the output of amplifier **113** and terminal **111** a suitable switching device **117**, illustrated in phantom in FIG. 8, it is apparent that the device will track the input signal applied at **115** and will store the value of that signal which exists at the time a store command is received by switch **117** which operates to interrupt the input to coil **102** since, as hereinbefore pointed out, there is no restoring force and the free running armature will remain in the position it had when the input signal thereto was interrupted. If ± reference signals are applied across potentiometer **101**, signals of either polarity at input terminal **115** may be tracked and stored. In this type of circuit, it would be desirable to have a grounded center tap on resistance element **101**.

Referring now to FIG. 9 there is illustrated how an embodiment constructed after the teachings of this invention incorporating at least two resistance elements may be connected as a single quadrant multiplier. One end of potentiometers **121** and **122** and one end of armature actuating coil **123** are connected to the iron housing at **124**. The other end of resistance element **121** is connected to an external terminal **126** which is adapted to be connected to any source of suitable potential and slider **127** interconnects resistance element **121** and conductive slide wire **128**, slide wire **128** being connected to a second external terminal **130**. In a similar manner resistance element **122** has its non-grounded end connected to an external terminal **132** and conductive slider **133** interconnects resistance element **122** and slide wire **134** which is connected to external terminal **135**.

The non-grounded end of actuator coil **123** is brought to an external terminal **137** in any suitable manner as hereinbefore described. Input terminal **139** is adapted to receive a signal which is a function of x and is connected through a comparator **140** and operational amplifier **141** to terminal **137**. Slider **127** is connected through slide wire **128** and output terminal **130** to comparator **140**. The operation of the closed loop feedback servo system of the embodiment of FIG. 9 is similar to that of FIG. 8. If a fixed reference signal F is applied to terminal **126** and a signal which is a function of x applied to terminal **139**, the free running armature assembly will move until the feedback signal is substantially equal to the input signal. The position of slider **127**, and hence the position of slider **133**, is then proportional to Fx. If a signal that is a function of y is applied to input terminal **132**, the output signal at terminal **135** is kxy, where k is a constant.

It is obvious that the embodiment of FIG. 9 may also be utilized as a servo function generator if the linear resistance element **121** is replaced by a non-linear element having the desired function.

By utilizing a one inch resistance element the overall structure may be made less than 1 in.^{2} by approximately 2½ inches long for a total volume of approximately 2.5 in.^{3}. This compares with an average volume of approximately 50 in.^{3} for servo-set coefficient potentiometers presently available. This represents a reduction in size by a factor of 20. End-to-end setting times of less than 10 ms. may readily be achieved. This compares with a setting time of approximately 2 seconds for conventional servo-set coefficient potentiometers making the device of the instant invention approximately 200 times faster.

The particular type of resistance element utilized in the embodiments constructed after the teachings of this invention forms no part of the invention and will depend only upon availability and the particular application. However, the utilization of cermet resistance elements has been found advantageous.

The cermet potentiometer has an inherent band width of approximately 1 mc. which compares with approximately 6 kc. for present copper mandrel potentiometers, an increase by a factor of 160. This increased band width means that no phase compensation is required in high performance equipment with the attendant elimination of load matching problems. Because of the small size of the over-all structure, short system wire lengths make it possible to exploit this improved band width in a large system. Further, the resolution of a cermet resistance element is, for most practical purposes, infinite. The accuracy of the setting of the coefficient potentiometer is, therefore, limited only by factors such as servo loop gain, reference accuracy and stability, and closed loop system stability. No difficulty has been found in achieving accuracies of 1 part in 10,000 which is equivalent to present servo-set coefficient potentiometers. Temperature coefficients of 100 p.p.m./° C. have been achieved in cermet resistance elements. This temperature stability is further inherently enhanced in a device constructed after the teachings of the present invention since the soft iron housing in which the resistance element is mounted acts as a heat sink preventing large temperature changes due to self heating.

It should be understood that while the armature assembly has been disclosed as being of insulating material, in some applications a large amount of damping may be desired. If this be the case, it is apparent that the armature may be made of a conducting material such, for example, as aluminum and the actuating coil and the sliders must then obviously be insulated therefrom. It should also be understood that various permanent magnet configurations may be utilized in order to control the flux distribution in the air gap.

Many modifications and variations are possible in the embodiments, which are illustrated by way of example only and not by way of limitation, in light of the teachings of this invention without departing from the spirit and scope thereof which is defined by the appended claims.

What is claimed is:

1. In a rectilinear actuator and potentiometer combination

magnetic means comprising a housing including an elongated highly permeable body portion and an elongated magnet supported within said housing and forming therebetween an elongated air gap, said magnetic means establishing a first magnetic field within said air gap;

a free running armature supported within said air gap by said magnetic means and including actuating means for establishing a second magnetic field, the reacting forces of said magnetic fields driving said armature in one or the other direction in the air gap of said magnetic means depending upon the orientation of said magnetic fields;

at least one rectilinear resistance element supported within said housing and longitudinally disposed therein;

an electrically conductive slider means carried by said armature and engaging said resistance element; and

means for connecting said resistance element, said slider means and said actuating means to external circuitry whereby said slider means may be positioned along said resistance element in response to energization of said actuating means.

2. In a rectilinear actuator and potentiometer combination

magnetic means comprising a housing including an elongated highly permeable body portion and an elongated magnet supported within said housing and forming therebetween an elongated air gap, said magnetic means establishing a first magnetic field within said air gap;

a free running armature supported within said air gap by said magnetic means and movable along at least

a substantial portion of the length of said elongated body portion;

actuating means carried by said armature for establishing a second magnetic field reacting with said first magnetic field for driving said armature in one direction or the other along said elongated body portion depending upon the orientation of said magnetic field;

at least one rectilinear resistance element supported within said housing and longitudinally disposed therein;

slider means carried by said armature and engaging said resistance element; and

means for connecting said resistance element, said slider means and said actuating means to external circuitry whereby said slider means may be positioned along said resistance element in response to energization of said actuating means.

3. In a rectilinear actuator and potentiometer combination

magnetic means comprising a housing including an elongated highly permeable body portion and an elongated magnet supported within said housing and forming therebetween an elongated air gap, said magnetic means establishing a first magnetic field within said air gap;

a free running armature supported within said air gap by said magnetic means and movable along at least a substantial portion of the length of said body portion;

coil means supported by said armature for establishing a second magnetic field within said air gap upon energization of said coil means, the reacting forces of said magnetic fields driving said armature in one direction or the other depending upon the direction of current flow within said coil;

at least one rectilinear resistance element supported within said housing and longitudinally disposed therein;

electrically conductive slider means carried by said armature and engaging said resistance element; and

means for connecting said resistance element, said slider means and said coil means to external circuitry whereby said slider means may be positioned along said resistance element in response to energization of said coil.

4. A rectilinear actuator and potentiometer combination comprising:

a housing including an elongated highly permeable body portion;

elongated magnetic means supported within said housing and establishing a transverse magnetic field between said mangetic means and said body portion;

guide means longitudinally disposed on said magnetic means and forming with said body portion an air gap;

a free running armature supported by said guide means, for longitudinal motion within said air gap;

actuating coil means supported by said armature for moving said armature in either direction dependent upon the direction of current flow within said coil means;

at least one rectilinear resistance element supported within said housing adjacent said armature;

electrically conductive slider means carried by said armature and engaging said resistance element; and

means for connecting said resistance element, said slider means and said coil to external circuitry whereby said slider means may be positioned along said resistance element in response to energization of said actuating coil means.

5. A rectilinear actuator and potentiometer combination comprising:

a housing including an elongated highly permeable body portion;

elongated magnetic means supported within said housing and establishing a transverse magnetic field between said magnetic means and said body portion;

guide means longitudinally disposed on said magnetic means and forming with said body portion an air gap;

a free running armature supported by said guide means for longitudinal motion within said air gap;

actuating coil means supported by said armature for moving said armature in either direction dependent upon the direction of current flow within said coil means;

at least one rectilinear resistance element supported within said housing adjacent said armature;

electrically conductive slider means carried by said armature and engaging said resistance element;

a pair of electrically conductive strip means supported by said housing adjacent said armature;

a pair of slider means carried by said armature and respectively connected to opposite ends of said coil, respective ones of said pair of slider means engaging said first and second electrically conductive strip means; and

means for connecting said resistance element, said electrically conductive slider means and said electrically conductive strips to external circuitry whereby said electrically conductive slider means may be positioned along said resistance element in response to energization of said actuating coil.

6. A rectilinear actuator and potentiometer combination comprising:

a housing including an elongated highly permeable body portion;

an elongated magnet supported within said housing and establishing a radial magnetic field therebetween;

guide means supported by said elongated magnet and forming with said body portion an air gap;

a free running armature supported by said guide means within said air gap;

actuating coil means connected to said armature for moving said armature in either direction dependent upon the direction of current flow within said coil means;

a pair of electrically conductive strip means supported within said housing adjacent said armature;

a pair of sliders carried by said armature and respectively connected to opposite ends of said coil, respective ones of said pair of sliders engaging respective ones of said pair of electrically conductive strips;

a plurality of rectilinear resistance elements supported within said housing adjacent said armature;

a like plurality of electrically conductive slider means carried by said armature, respective ones of said plurality of electrically conductive slider means engaging respective resistance elements; and

means for connecting said resistance elements, said plurality of electrically conductive strip means and said plurality of electrically conductive slider means to external circuitry whereby said plurality of slider means may be positioned along their respective resistance elements in response to energization of said actuating coil.

7. A rectilinear actuator and potentiometer combination comprising:

a housing including an elongated highly permeable body portion;

elongated magnetic means supported within said housing and establishing a transverse magnetic field between said magnetic means and said body portion;

guide means longitudinally disposed on said magnetic means and forming with said body portion an air gap;

a free running armature supported by said guide means for longitudinal motion within said air gap;

actuating coil means connected to said armature for moving said armature in either direction dependent upon the direction of current flow within said coil means;

means for connecting said coil means to external circuitry;

at least one elongated, rectilinear resistance element supported within said housing adjacent said armature;

at least one electrically conductive strip means supported within said housing adjacent said armature;

electrically conductive slider means carried by said armature and engaging said resistance element and said electrically conductive strip means; and

means for connecting said resistance element and said electrically conductive slider means to external circuitry whereby said slider means may be positioned

along said resistance element in response to energization of said actuating coil.

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RICHARD M. WOOD, *Primary Examiner.*

W. D. BROOKS, *Assistant Examiner.*