

[72] Inventor **Parker C. Smiley**
Oakland, Calif.
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[73] Assignee **Physics International Company**
San Leandro, Calif.

[54] **LEVER MOTION MULTIPLIER DRIVEN BY ELECTROEXPANSIVE MATERIAL**
6 Claims, 10 Drawing Figs.

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310/8.3, 310/8.7, 310/9.1, 310/26
[51] Int. Cl. **H01v 7/00,**
H01v 9/00
[50] Field of Search **310/8.2,**
8.3, 8.1, 8.5-8.7, 26, 12, 15; 101/212, DIG. 5;
251/129, 303

[56] **References Cited**
UNITED STATES PATENTS

3,395,295	7/1968	Crane	310/8.2 X
3,462,939	8/1969	Tanaka et al.	310/8.2 UX
3,501,099	3/1970	Benson	310/8.7 X
3,504,206	3/1970	Fritsch	310/8.3 X
3,524,196	8/1970	Church et al.	310/8
2,275,256	3/1942	Fried	310/8.7
2,587,482	2/1952	Keller	310/8.7 X

3,055,631	9/1962	Kippenhan	251/129
3,242,855	3/1966	Noll et al.	101/109
3,297,889	1/1967	Breskend	310/8.6 X
3,409,787	11/1968	Agalides et al.	310/8.7 X
3,434,074	3/1969	Libby	310/8.1 X
3,443,130	5/1969	Shoh	310/8.1
3,447,051	5/1969	Attwood et al.	310/8.1 X
3,473,466	10/1969	Thayer	310/8.1 X
3,509,714	5/1970	Walton	310/8.2 X

OTHER REFERENCES

IBM Technical Disclosure Bulletin-Punch Checking by L. A. Stanton and F. W. Schaaf, Vol. 3 No. 3, Aug. 1960

Primary Examiner—D. F. Duggan
Assistant Examiner—Mark O. Budd
Attorney—Lindenberg and Freilich

ABSTRACT: Electroexpansive material such as a stack of piezoelectric discs is employed as a driver for an undamped spring-mass system, such as a lever for motion multiplication. A displacement, step or other motion, is obtained without residual motion by controlling the voltage excitation time, such as the period of a square wave voltage pulse to the natural period of the system or the period of the ramp of a step voltage to the natural period of the system. A high-speed printer exemplifies application of such controlled excitation and the advantage of controlling the pulse period. Various forms are disclosed for the lever.

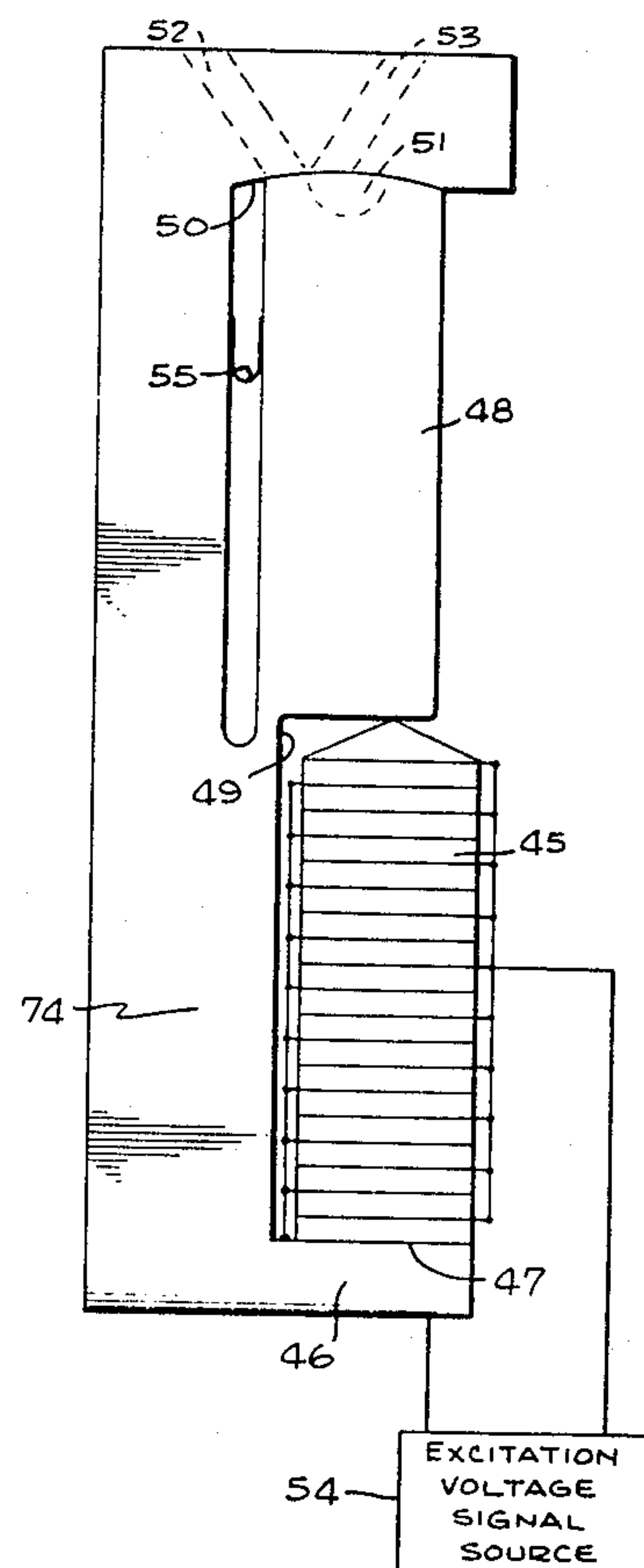
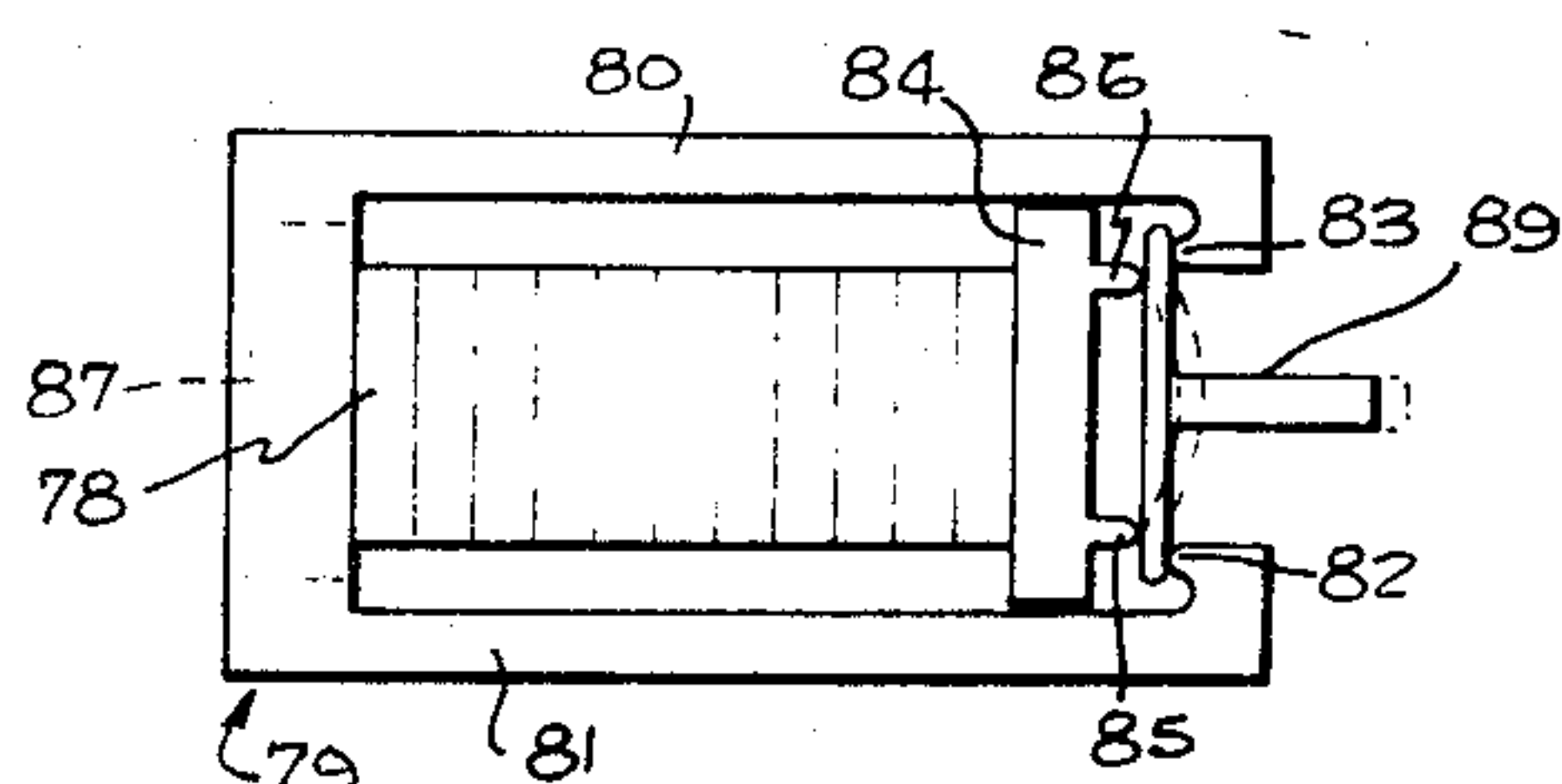
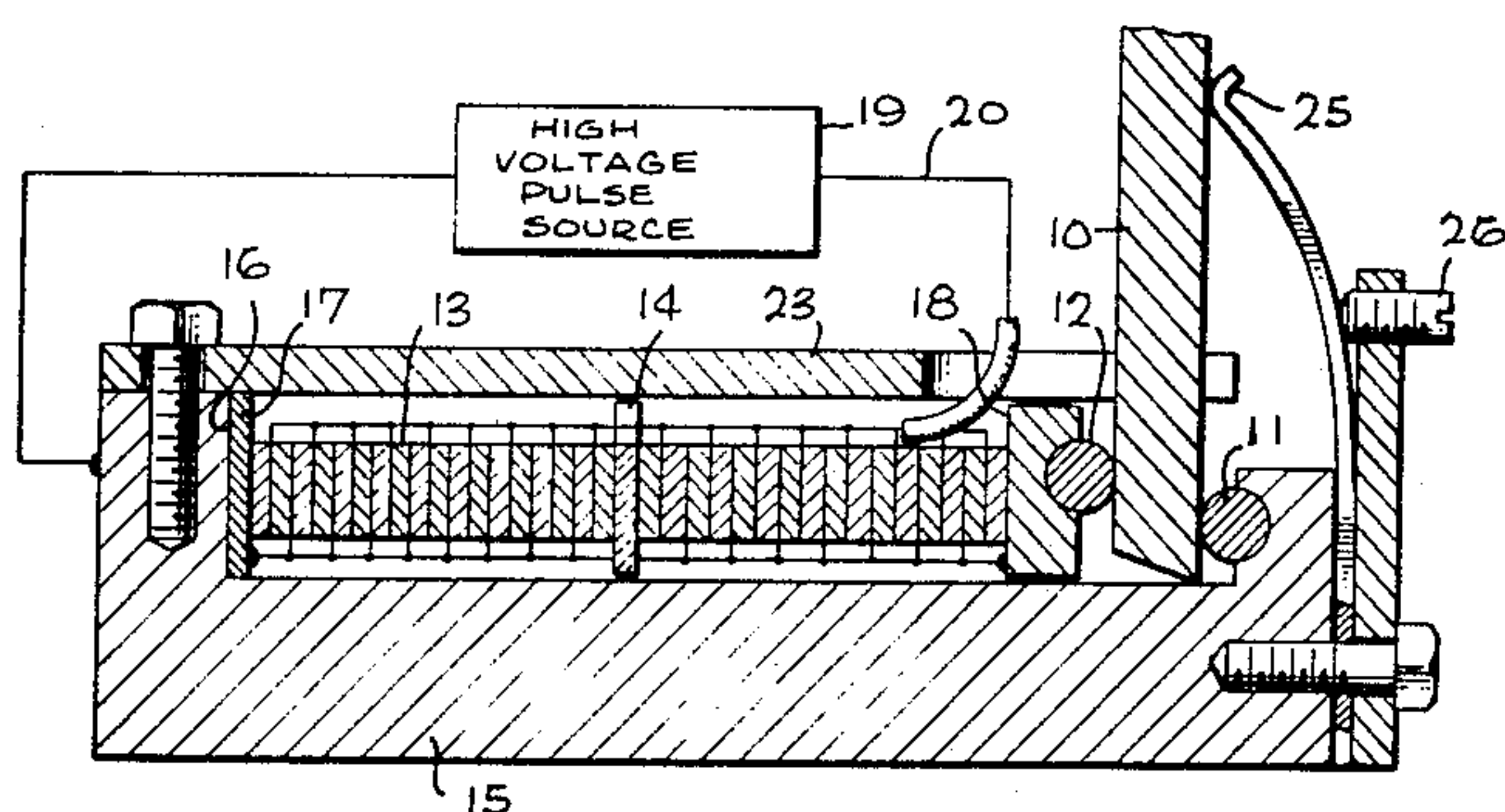


Fig. 1

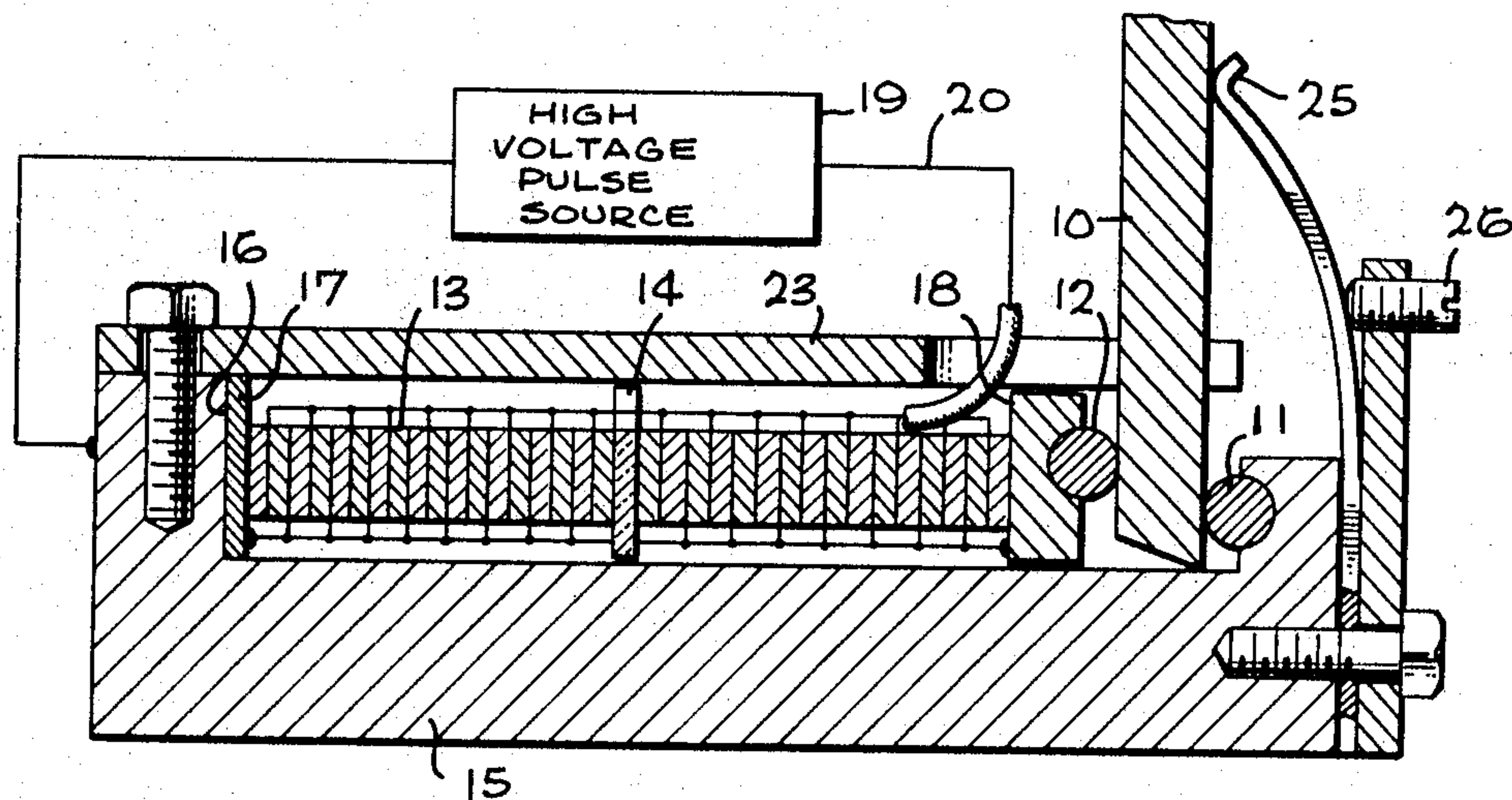


Fig. 2

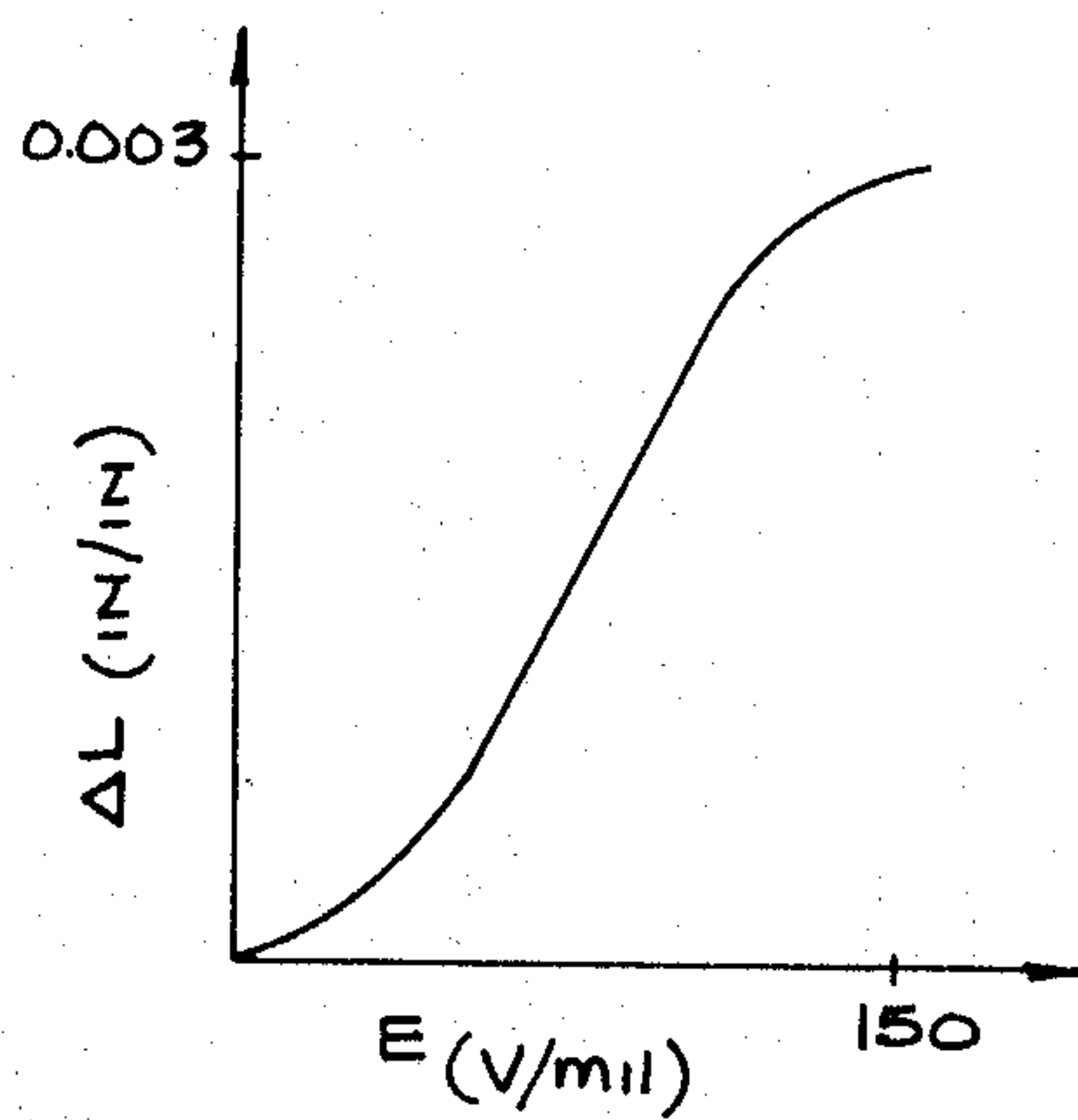
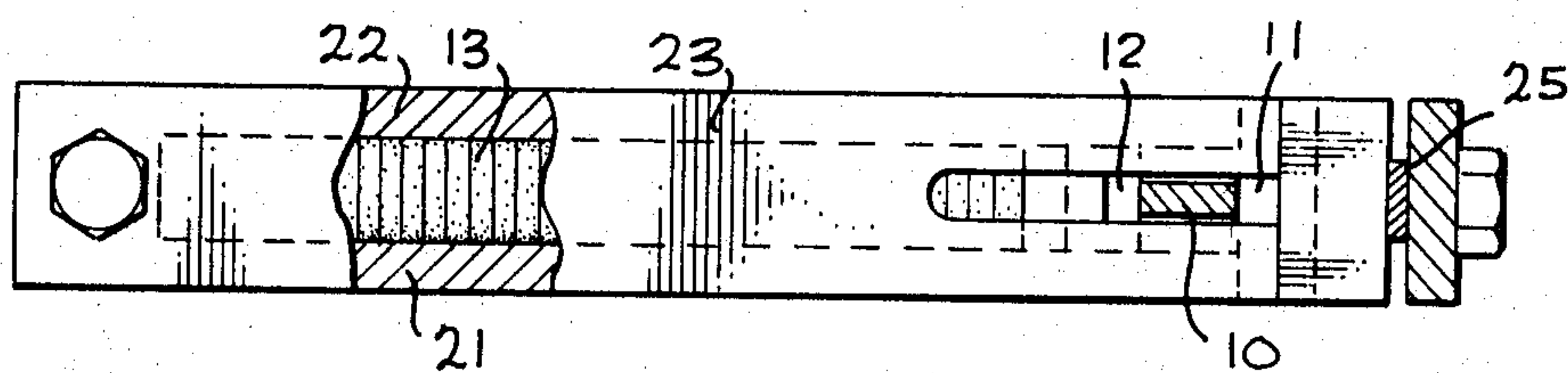
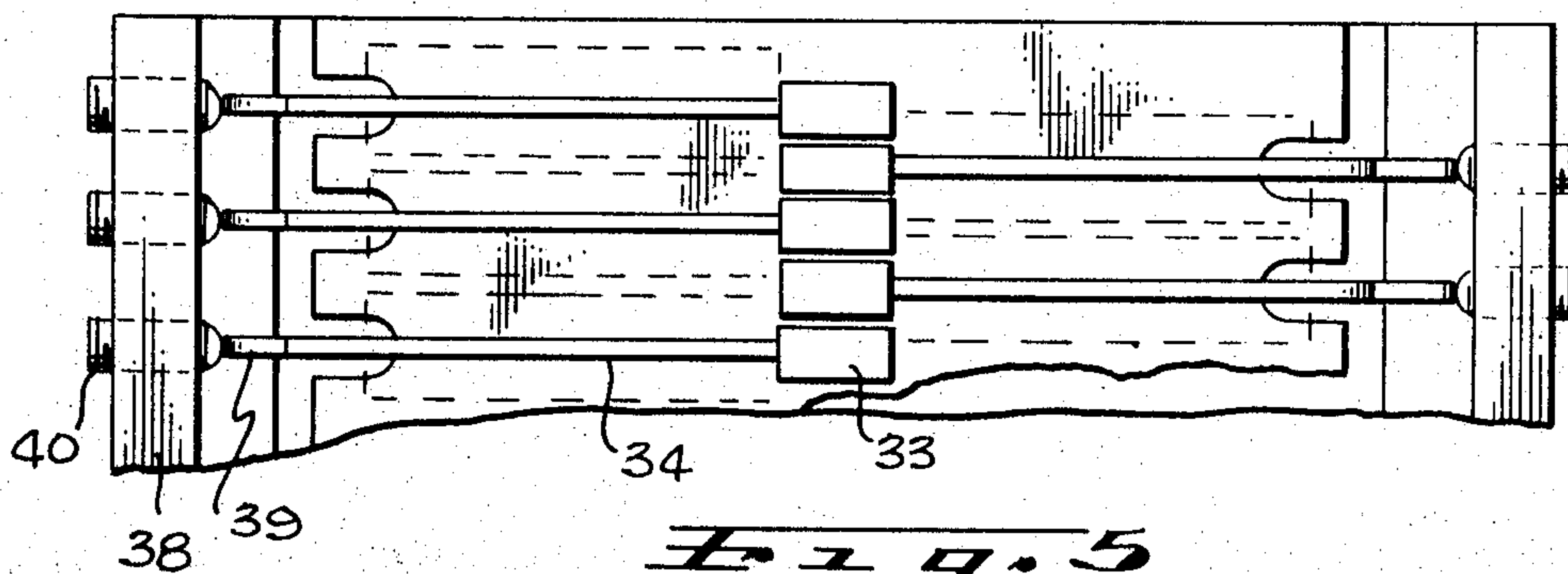
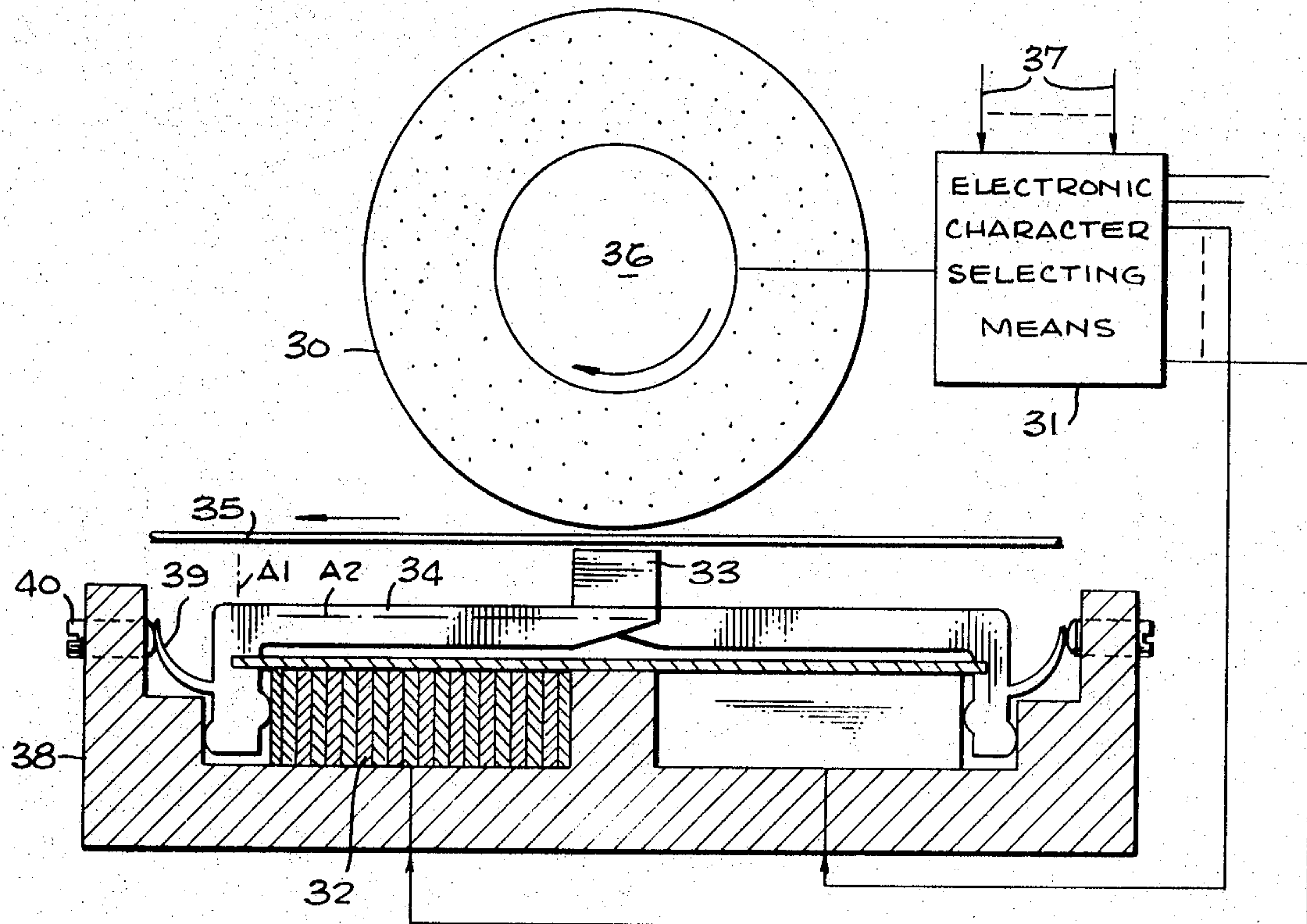


Fig. 3

PARKER C. SMILEY
INVENTOR.

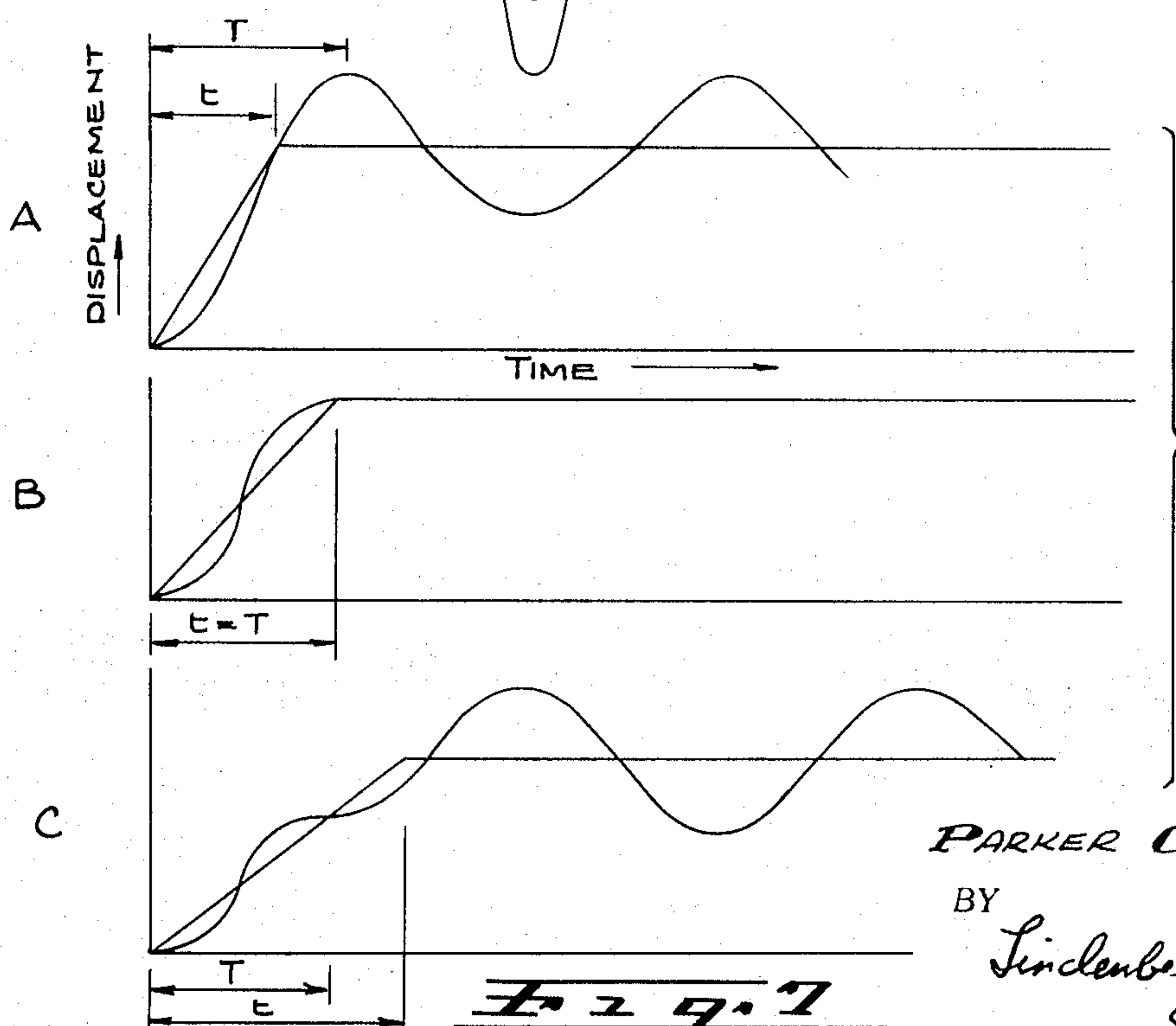
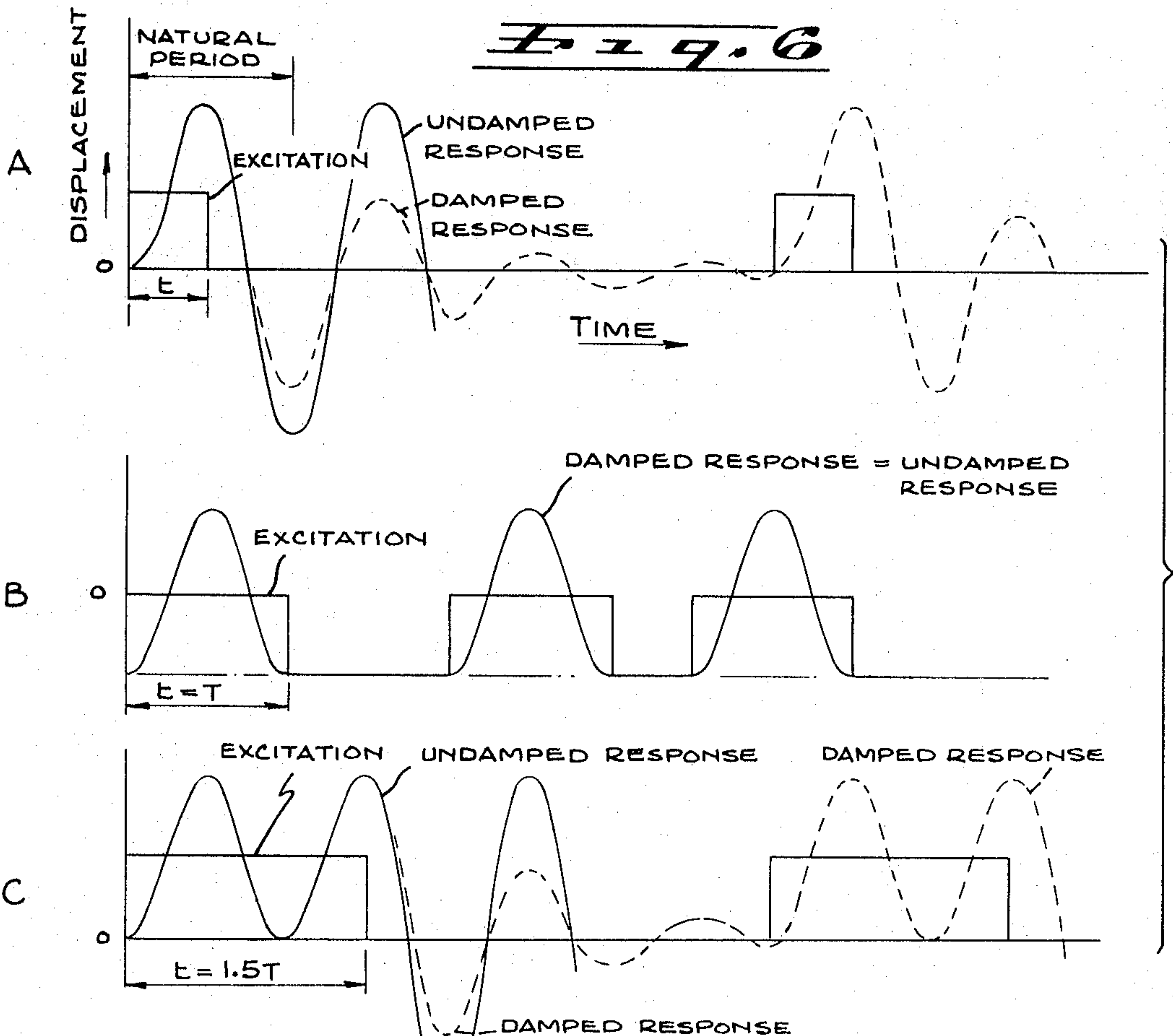
BY
Lindenberg & Fraibich
ATTORNEYS

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PARKER C. SMILEY
INVENTOR.

BY
Lundberg & Freilich
ATTORNEYS



INVENTOR.
PARKER C. SMILEY

BY

Lindenberg & Freilich
ATTORNEYS

Fig. 9

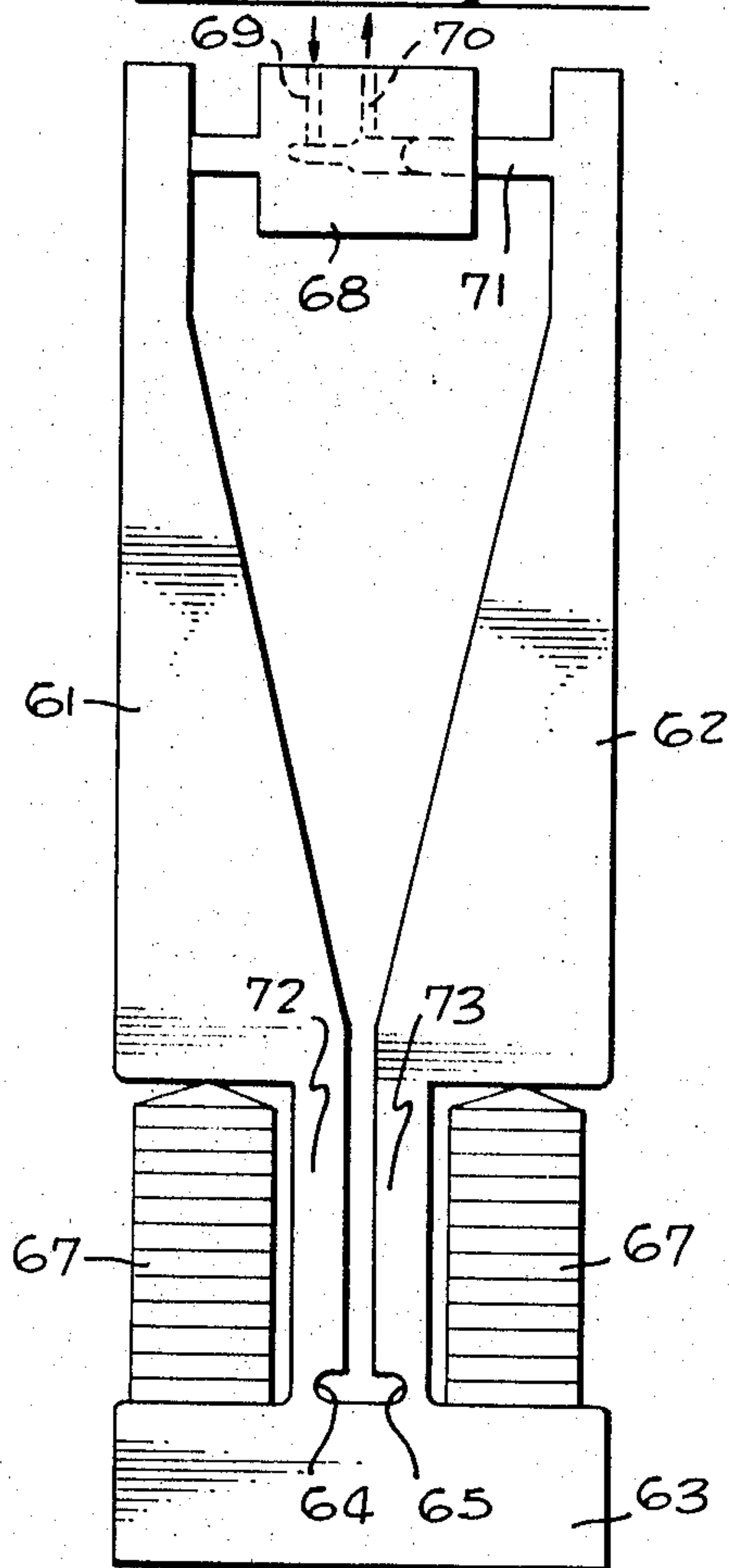


Fig. 8

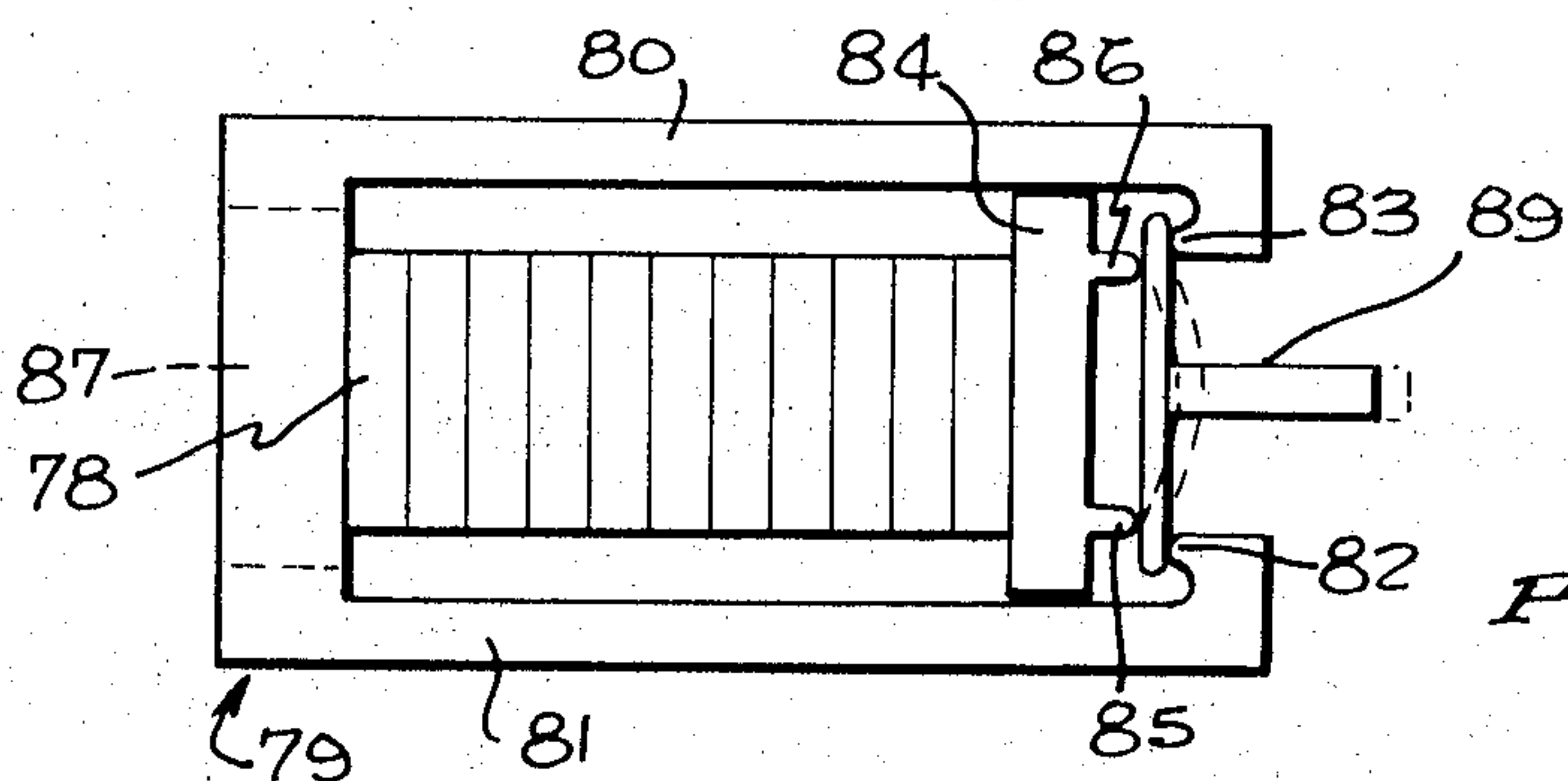
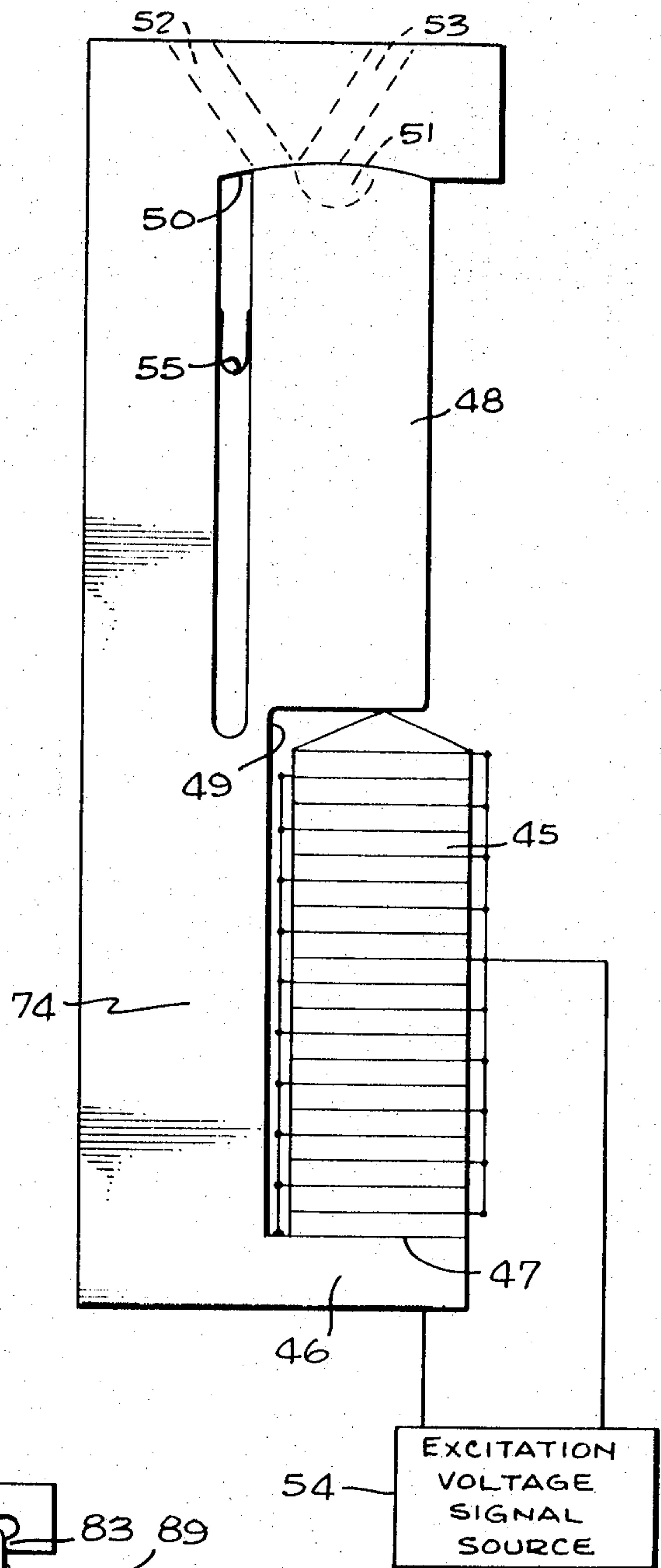


Fig. 10

PARKER C. SMILEY
INVENTOR.

BY
Lindenberg & Erickson
ATTORNEYS

LEVER MOTION MULTIPLIER DRIVEN BY ELECTROEXPANSIVE MATERIAL

FIELD OF THE INVENTION

This invention relates to electromechanic actuators, and more particularly to actuators employing the inverse piezoelectric and electrostrictive effects on crystal or ceramic elements (referred to hereinafter generically as electroexpansive materials) to produce mechanical motion in response to an electrical pulse.

In the past, actuators have been devised for high-speed printer hammers and the like using solenoids. Such electromagnetic actuators have been made to perform satisfactorily, but not without various design problems and limitations on systems in which employed due to the inherently low-energy density and low efficiency of the solenoid.

In some actuator applications, it is desirable to produce a series of displacement pulses in very rapid succession of very short duration, e.g. less than a millisecond, and cause the actuator mechanism to return to its initial position without any residual vibration. If there is any residual vibration when the next displacement pulse is produced, the residual vibration will affect that displacement pulse and repeated displacement pulses will not be identical.

Present actuators are brought to rest by mechanical or electromechanical damping. The more rapidly the actuator is brought to rest the more power is dissipated in the damper, so that more power is required to operate the device. In such a system, the time required to bring the actuator to rest (the recovery time) is determined by the characteristics of the damper. The recovery time with a damper is usually more than one period of natural vibration for the spring-mass system. It would be desirable to provide actuators virtually free of all damping forces in what are referred to hereinafter as undamped spring-mass system.

In a high-speed printer, for example, a high-level signal is applied to a solenoid to drive the hammer against a sheet of paper and ink ribbon backed by a character drum or chain. The level to which the signal rises controls the impact energy of the hammer and hence the print density. Therefore, the level is usually controlled as a function of the area of the character to be printed. While that technique provides uniform printing, it also complicates the problem of bringing the hammer to rest without residual vibration so that the solenoid may be immediately pulsed again for printing another character. This is because it is the practice to quickly remove the hammer from the paper by designing the hammer to rebound. The residual current in the solenoid is then relied upon to slow the rebound of the hammer so that it will come to rest in its initial position against a backstop with low-impact energy. Consequently, current is often purposely maintained in the solenoid after rebound by providing a slow decay time for the drive pulse, and it is difficult to provide the proper decay time for all characters if the level of the drive pulse is varied according to the area of the character being printed. The problem of damping the hammer so that it comes to rest against the backstop without residual vibration is thus made quite difficult to control.

It is possible to produce from an undamped spring-mass system displacement without residual vibration by imposing an excitation pulse (force) of a controlled duration, such as a square pulse of a duration substantially equal to the natural period of the system. The term "spring-mass system" as used herein refers to actuators of the type to which the present invention relates having a certain mass to be displaced and a spring attached to the mass which will exert a restoring force in the mass proportional to its displacement. Electroexpansive material used for driving a mechanical actuator has a particular advantage in that regard because the duration of the excitation pulse is virtually equal to the duration of the voltage pulse applied to produce the excitation pulse. In an electromagnetic actuator, the duration of the excitation pulse is not equal to the duration of the voltage pulse due to in-

ductance. Thus, in the case of a printer, for example, where it is desired to have short displacement pulses in rapid succession this technique of controlling the excitation pulse duration of electroexpansive material by controlling the voltage pulse applied would be extremely valuable (with some adjustment to account for the rebound force).

In other applications, e.g. in valves, a sustained displacement quickly produced is desired without residual vibration. It is possible to produce such a displacement (step displacement as opposed to a pulse displacement) from an undamped spring-mass system without residual vibration if the excitation step has a rise time substantially equal to the natural period of the spring-mass system. As in the case of pulsed excitation, an actuator utilizing electroexpansive material has an advantage.

Another advantage of the electroexpansive actuator is that the electroexpansive material itself has a high spring rate so that the actuator would tend to have a high spring rate and thus a short natural period of vibration. This is required for fast-acting actuators.

SUMMARY OF THE INVENTION

In accordance with the present invention, an undamped spring-mass system is driven by electroexpansive material in response to a voltage signal, such as in the form of a pulse or step, where the excitation time (period of a square wave pulse or rise time of a step wave since excitation time of the electroexpansive material is virtually equal to the voltage time) is controlled in relation to the natural period of the mass-spring system to provide a response of the system without residual vibration. In accordance with a further aspect of the present invention, an actuator with motion multiplication is provided by a lever comprising a substantially rigid body pivoted on a fulcrum. The force for moving the body is provided in response to a voltage signal such as a pulse or step wave applied to electroexpansive material disposed between the body and a rigid base for the fulcrum. The electroexpansive material may be of either the type exhibiting a piezoelectric effect or the type exhibiting an electrostrictive effect, or both; all that is required is a change in length ΔL in the direction the force is to be applied. A restoring force is applied to the body by means comprising either an integral elastic structure or an external spring.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side sectional view of an exemplary embodiment of the present invention.

FIG. 2 is a top view partly in section of the embodiment of FIG. 1.

FIG. 3 is a voltage-displacement diagram of a typical piezoelectric material commercially available.

FIG. 4 illustrates schematically an adaptation of the embodiment of FIG. 1 to a high-speed printer application.

FIG. 5 is a top view of a portion of the system of FIG. 4.

FIG. 6 illustrates in diagrams A, B and C the displacement response of a mass-spring system to pulse of different duration relative to the natural period of the system.

FIG. 7 illustrates in diagrams A, B and C the response of a mass-spring system to step voltages with rise times of different duration relative to the natural period of the system.

FIG. 8 illustrates schematically an adaptation of the present invention to a valve.

FIG. 9 illustrates schematically another adaptation of the present invention to a valve.

FIG. 10 illustrates still another adaptation of the present invention to a motion amplifier for actuation of devices at high speeds.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIGS. 1 and 2, an exemplary embodiment of the present invention is illustrated as a motion multiplier for use in applications which require high speed, accuracy and virtually no vibration, such as in high-speed printers, surgical

instruments, scientific instruments, and the like, It comprises a lever having a rigid bar 10 which pivots about an orthogonal fulcrum pin 11 in response to a force applied through a load pin 12 having its axis parallel to the axis of the pin 11. The lever rolls through a very small angle without slipping on the pins. The driving force is produced by electroexpansive material such as a piezoelectric (PZ) driver 13 which is divided into two sections by a supporting member 14 made of dielectric material.

The lever and PZ driver are nested in a supporting block 15 having a load bearing surface 16. The PZ driver 13 comprises a stack of thin ceramic discs with a conductive coating on both sides of each disc. The stack of discs is placed between end blocks 17 and 18 of conductive material and the conductive coatings on alternate opposing sides are connected to the end blocks as shown to provide a ground connection to one side of every disc through the supporting block. The remaining sides of the discs are connected to a high-voltage pulse source 19 through an insulated lead 20.

The PZ drive assembly comprising the stacked and electrically connected discs, end blocks and the midstack supporting member 14 and lever 10 are held in place by side plates 21 and 22 shown in FIG. 2, and a top plate 23 shown in both FIGS. 1 and 2. All of these plates are lined with suitable insulating material. When a voltage pulse is applied between the lead 20 and the supporting block 15, the thickness of each disc will increase in the direction of the applied electric field in proportion to the amplitude of the pulse as shown in FIG. 3, which shows the characteristic strain curve (for commercially available material of one type) from 0 to 150 volts. Other types of material are available for which similar characteristic curves may be easily established.

The PZ stack 13 tends to expand in response to an applied voltage. If the stack has no forces on it the expansion will be equal to the "free strain" times the length of the stack. However, if the stack is restricted the force exerted by the stack is proportional to the difference between the free expansion and the actual expansion. If the voltage is applied instantaneously and the stack is restricted by a mass (such as the equivalent mass of the lever 10) the initial actual expansion will be zero and the initial force will be determined by the full free expansion (several thousand pounds per square inch of stack area). AS THE MASS accelerates, the stack expands and the force decreases, reaching zero when the stack expands to its free dimension. In this case the work done is given by:

$$Wk = \frac{1}{2} Y \epsilon_0^2 AL.$$

Where Y is Young's modulus of elasticity, A is the cross-sectional area of the stack, ϵ_0 is the free strain of the PZ material and L is the length of the stack. This general analysis of work done by the PZ stack relates the work to the load associated with accelerating a mass in a fast-acting actuator. A more detailed analysis would include the restoring spring force, and other forces that may be present.

Theoretically the material of the type which the characteristic strain curve is given in FIG. 3 is capable of producing 3.5 joules per cubic inch per stroke or 28 joules per kilogram per stroke

It should be noted that the PZ driver 13 employs thin discs in order to achieve high electric fields with low voltages, but the movement from a single disc is very small. Accordingly, to increase the movement to a useful amount (in the order of a few thousandths of an inch), it has been standard practice to stack many thin discs and connect them electrically in parallel. The total actual movement achieved is not sufficient to accomplish many useful functions, such as high-speed printing in a data-processing system. However, the force that can be generated is several thousand pounds. The present invention utilizes such a large force to drive a motion amplifier in the form of a lever for functions requiring much larger movement and a proportionately smaller force.

The length and shape of the bar 10 (shown broken away just beyond the spring 25) is selected for the particular application. The compression force on the PZ stack 13 is also

selected, through a setscrew 26, to satisfy the operating requirements of the particular application.

FIGS. 4 and 5 illustrate application of the present invention to a high-speed printer of the type having a character drum 30 rotated at a substantially constant speed to print one line of characters during one drum revolution. As a given character to be printed in a particular position in a line is rotated into position, electronic character-selecting means 31 pulses the appropriate one of the PZ drivers, i.e., pulses the PZ driver associated with the print hammer of the particular position, such as the PZ driver 32 of a print hammer 33 on the free end of a bar 34. The hammer 33 impacts a sheet of paper 35 which is tangent to the character drum along the line to be printed. The characters on the drum are here assumed to be inked (by means not shown) so that as the hammer 33 impacts the paper 35 against the character to be printed, ink is transferred to the paper, leaving an image of the character. However, in practice a ribbon carrying ink may be positioned between the paper and the character drum to provide the ink.

The selecting means 31 functions on the basis of input codes provided by a character code-timing wheel 36 in a conventional manner to not only select the proper timing for the energizing pulse but also the slope of the pulse to control the impact energy of the hammer, and hence the print density, as a function of the area of the character to be printed. For example, all characters may be grouped into two or three classes according to their area. The selecting means 31 determines which character class is involved in response to input data at terminals 37 and selects the appropriate slope for the pulse applied.

The bar 34 is L-shaped to facilitate positioning the PZ driver 32 in a supporting block 38 close to the drum. Thus, as a rigid body for a lever, the bar 34 has a principal axis A_1 , an elongated axis A_2 at a right angle to the principal axis. Motion of the hammer 33 is thereby in a direction offset from an axis along which the PZ stack exerts its force. The drive mechanisms (PZ drivers and levers) for the hammers numbered in succession are disposed on one side for the even-numbered hammers and on the other side for odd-numbered hammers, as may be more clearly seen from FIG. 5 showing a bank of hammers and drive mechanisms, with part of the bank broken away.

Referring again to FIG. 4, which shows the side of the bank of hammers broken away in FIG. 5, it should be noted that the fulcrum and drive pins of the embodiment of FIGS. 1 and 2 have been provided as integral parts of the bar 34. A recess is provided in the supporting block 38 to aid in holding the bar 34 in position. Return springs, such as an integral leaf spring 39, further assist in keeping the bar 34 in position by maintaining the PZ driver under compression when deenergized. A setscrew 40 is provided for individual adjustment of the compression on the PZ driver when deenergized.

The laws of motion governing a mass connected to a supporting block through a spring apply to a PZ driven motion multiplier such as the lever-actuated hammer of FIGS. 4 and 5 for a high-speed printer. Accordingly, the motion multiplier will have a natural period of vibration. If the motion multiplier is to be actuated and then returned to its rest position without vibration, in order that a second square-wave pulse may be applied in rapid succession for the desired motion without interference from residual vibration from the previous square-wave pulse, the duration of the pulse must be equal to the natural period of vibration of the mass-spring system. If the excitation pulse period is less or greater than that period, it is necessary to wait until the vibration is damped out before the next pulse can be applied. Otherwise, the residual vibration will interfere with the motion desired from the next pulse.

Square wave pulses are referred to since they will provide the maximum work for a given movement ΔL , and therefore are to be preferred in most applications. However, pulses of other shapes may also be employed to the same advantage by calculating the period of the pulse which must be used in order for the damped response to be the same as the undamped

response. Because a particular mass-spring system is often difficult to analyze, it is sometimes necessary to experimentally determine the period of a pulse required to produce an undamped response without residual vibration. For example, in a high-speed printer it may be desirable to apply a pulse of a shape which differs from a square wave when printing characters of lesser area. That may be done by selectively shaping the leading edge of a square wave pulse normally used for large area characters to the PZ driver to reduce the kinetic energy of the hammer as it is caused to move the same distance as for large area characters, and delaying the trailing edge just enough to produce the desired undamped response.

FIG. 6 illustrates in three different waveform diagrams the advantage of controlling the period OF the excitation pulse using the simple case of square pulses; the results are similar for pulse shapes other than square. In diagram A, the excitation pulse period t is half of the natural period T of a spring-mass system. The undamped displacement resulting from the square-wave pulse is shown by a solid-line sinusoidal waveform and a damped displacement by a dotted line sinusoidal waveform where the amount of damping has been arbitrarily selected. From that it may be seen that about three natural periods are required for damping after the first natural period. In diagram B the period of the excitation pulse is equal to the natural period ($t=T$), and the damped response is the same as the undamped response. Since there is no residual vibration in the system, a new excitation pulse could be applied almost immediately. IN diagram C, the excitation pulse period is half again as long as the natural period and the results after the first natural period are the same as for an excitation pulse of half the natural period. Therefore a new excitation pulse should be delayed another half natural period for if applied at the same time as the second pulse in diagram A, there will be some residual vibration that will interfere with the desired excitation displacement.

Although the observations just made with respect to the diagrams OF FIG. 6 may be true of any spring-mass system, i.e., any mass having attached to it a spring which will exert a restoring force on the mass proportional to its displacement, regardless of the nature of the displacement driver, it should be note that use of electroexpansive material permits precise control of the excitation displacement while other drivers, such as a solenoid, will not. In addition, response of electroexpansive materials is up to five times faster than a solenoid, and such materials have higher energy density than a solenoid, and are more efficient than a solenoid.

A step displacement of an actuator using electroexpansive material may be produced in an undamped mass-spring system without residual vibration if the rise time of the excitation step is controlled. In diagram A of FIG. 7, the rise time t of the step excitation is less than the natural period T of the system, and oscillations occur in the undamped response of the system as shown. In diagram B, the rise time t is made equal to the natural period T , and displacement occurs without residual vibration of the undamped system. If the rise time t is extended to a period greater than the natural period T , residual oscillations will again be found to exist. Therefore, by controlling the excitation rise time in the case of a step excitation, an actuator using electroexpansive material has an advantage as in the case of a controlled pulse excitation. It should be noted that a reverse (negative) step excitation will behave just as the forward (positive) step excitation illustrated.

While pulse and step excitations are special cases, both will find greater utility than other forms of excitation, such as versed sine, cycloidal or exponential. However, regardless of the form of excitation, the duration of the excitation can be controlled to produce motion virtually free of residual vibration by controlling the applied voltage signal. In each case the duration period can be determined experimentally.

Referring now to another embodiment illustrated in FIG. 8, a PZ driver 45 is nested in a supporting block 46 having a load-bearing surface 47. A rigid member 48 is disposed above the PZ driver 45 as a lever body having one end attached to

the supporting block 46 by a bending and tensioning section 49 which functions as a fulcrum. The upper end of the member 48 is contoured to slide against an arcuate surface 50 of the block 46 opposing the load-bearing surface 47. The member 48 can thus be regarded as an L-shaped member having its "principal axis" parallel to the load-bearing surface 47 while the PZ driver is not being activated by a voltage signal and a "second axis" at right angle to the principal axis to produce motion at the upper end when the PZ driver is actuated.

The upper end of the member 48 is cut out in the center in order to provide a passage between ports 52 and 53 when an applied voltage from a source 54 is applied to the driver 45. Once the applied voltage is removed, the bending and tensioning section will restore the member 48 to the position shown to close the ports 52 and 53. For a greater restoring force, a spring 55 may be provided between the block 46 and the member 48. For a sustained displacement quickly produced without residual vibration from the undamped mass-spring system of the device, the step of the applied voltage is controlled as described with reference to FIG. 7.

FIG. 9 illustrates schematically still another embodiment comprising a valve actuator having two rigid members 61 and 62 attached to a supporting block 63 by bending and tensioning section 64 and 65. Like the rigid member 48 of FIG. 8, the rigid members 61 and 62 can be regarded as being L-shaped. PZ drivers 66 and 67 are nested between the block 63 and the members 61 and 62 which function as lever bodies pivoting on the sections 64 and 65. When an excitation pulse is applied to both drivers 66 and 67 simultaneously, the members 61 and 62 are driven toward each other with greatly amplified motion at their ends. The end of the member 61 carries a valve block 68 having an inlet port 69 and an outlet port 70. A valve plunger 71 is carried by the end of the member 62. The normal position is with the port 69 connected to the port 70 by an internal passage of the block 68. Pressure at the inlet port 69 assures that the valve remain in the normally open position until the drivers are energized, at which time the plunger 71 closes the port 70.

The levers of FIG. 9 are unique in that the flexible sections 64 and 65 which form the fulcrums are near the supporting block 63. The rigid members 61 and 62 are then connected to the block 63 by rigid support bars 72 and 73. In the embodiment of FIG. 7, the flexible section 49 which forms the fulcrum for the lever is at the upper end of a support bar 74 extending upwardly beside the PZ stack 45 from the support block 46.

Still other adaptations of the present invention will occur to those skilled in the art, including adaptations based on levers of the type where the force and the weight are on opposite sides of the fulcrum. Altering the ratio of the lengths of the rigid body on each side of the fulcrum yields variable amplification factors, in the usual manner. The advantage is again faster operation with higher energy density and greater efficiency than with a solenoid. There is also the further advantage of better control of the excitation pulse or step to achieve a response without residual vibrations in the manner described hereinbefore with reference to FIGS. 6 and 7.

FIG. 10 illustrates still another form of adaptation the present invention may take. It comprises a PZ driver 78 nested in a supporting block 79. The upper ends of fulcrum support bars 80 and 81 are turned down to provide fulcrums 82 and 83 against which a flexing beam is held by the PZ driver through a load block 84 having points 85 and 86 protruding upwardly. A disc 87 may be threaded into the base of the supporting block 81 to adjust the position of the load points 85 and 86 against the flexing beam, i.e., to adjust the compression of the PZ stack. When the PZ driver 80 is energized, the two load points 85 and 86 (which are inside the two fulcrums 82 and 83) cause the flexing beam on both sides of its center to be move upwardly with the greatest (amplified) motion at the center. A rod 89 is attached to the center of the flexing beam to facilitate connecting a device thereto such as a valve.

If the block 81 is cylindrical, the flexing beam may be a circular plate and the fulcrums would be in the form of a continuous annular ridge. The load points would similarly form part of a continuous annular ridge.

It should be appreciated that the invention is in no sense dependent upon any particular fabrication technology, and that embodiments illustrate are by way of example and not by way of limitation since other actuators and lever-type motion multipliers may be adapted to be driven by electroexpansive material to equal advantage. Moreover, while such material is shown in the form of stacked discs, other forms may be used, such as a hollow cylinder coated on the outside and inside with a film of conductive material so that an electric field can be applied radially. The hollow cylinder will then expand radially, but contract axially. Such a form would then actuate a mass-spring system in the absence of a voltage signal if oriented to drive axially. It should also be appreciated that hydraulic coupling or amplification of force or motion may be introduced between the electroexpansive material and the driven element of the actuator in any mass-spring system without departing from the spirit and scope of the invention as defined by the appended claims.

I claim:

1. A motion multiplier comprising:

a supporting block having a load-bearing surface;

a lever having a substantially rigid body pivoted on a fulcrum secured to said supporting block;

electroexpansive material disposed between said surface and said rigid body;

means for applying an electric field to said material for expansion of said material along an axis normal to said load bearing surface, thereby pivoting said rigid body on said fulcrum and wherein said means comprises a dynamic voltage signal for producing a desired excitation of said system of a predetermined period to provide an undamped response of said system without residual vibration; and

a restoring spring between said lever and said block to form a mass-spring system having a natural period of vibration.

2. The combination as defined in claim 1 said voltage signal comprises a voltage pulse having a duration equal to said natu-

ral period of vibration to provide an undamped response of said spring-mass system without residual vibration.

3. The combination as defined in claim 2 wherein said voltage pulse is substantially rectangular.

4. The combination as defined in claim 1 wherein said voltage signal comprises a voltage step having a transition period from one static level to another equal said natural period of vibration to produce an undamped step displacement of said lever which is sustained without residual vibration about its new position.

5. The combination as defined in claim 4 wherein said signal change from one static level to another is of a substantially constant slope.

6. A motion multiplier suitable for actuating a device in response to an electric signal comprising:

a supporting block having a load-bearing surface;

electroexpansive material disposed on said surface for expansion along a first axis normal to said surface in response to said signal;

a pair of rigid fulcrum support bars extending from said supporting block beside said electroexpansive material on opposite sides thereof said bars being turned in toward each other at the free ends thereof and further turned back toward said supporting block to form a pair of fulcrums, one on each side of said axis;

a flexing member disposed between said electroexpansive material and said pair of fulcrums with one end of said member against one fulcrum, and the other end against the remaining fulcrum of said pair;

a load block having a pair of load points protruding therefrom in a direction away from said electroexpansive material and toward said flexible member, said load block being disposed between said flexing member and said electroexpansive material with said load points on opposite sides of said first axis and each against said flexing member at a position between said first axis and a fulcrum; and

means for connecting said device to the center of said flexing member on a side thereof opposite said electroexpansive material.

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