

[54] **SOLENOID WITH MULTI-RATE
RETURN SPRING**

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[58] Field of Search 335/255, 258, 274

[56] **References Cited**

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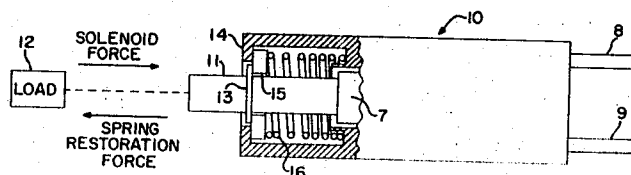
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[57] **ABSTRACT**

A multi-rate return spring optimizes solenoid operational efficiency by providing a spring restoring force versus deflection characteristic more nearly matching the inverse-square solenoid stroke versus force characteristic. The spring may be fashioned from two or more contiguous sections having progressively greater winding pitches such that the resulting multiple restoring force rates compositely more nearly match the solenoid force characteristic over a predetermined stroke.

7 Claims, 3 Drawing Figures



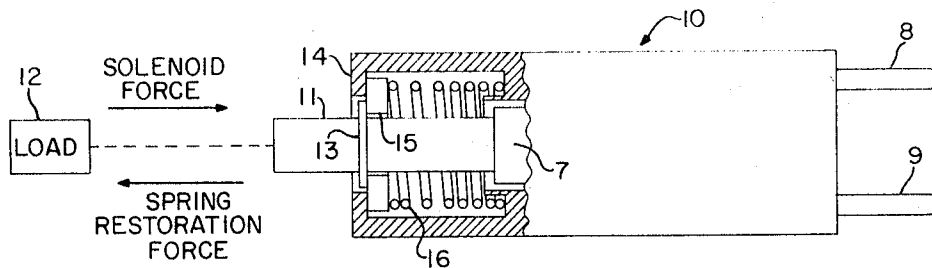


FIG. 1

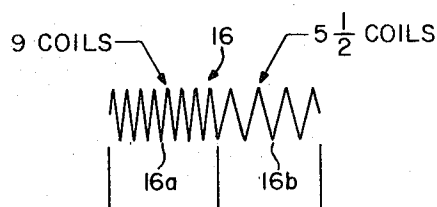


FIG. 2

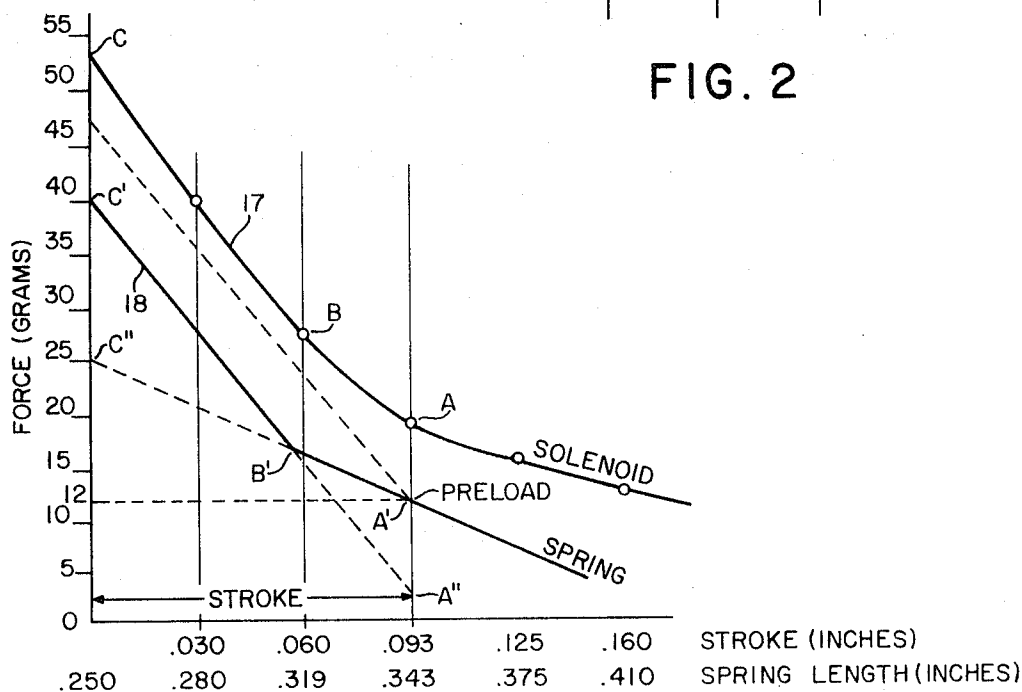


FIG. 3

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SOLENOID WITH MULTI-RATE RETURN SPRING

This invention relates generally to electrical solenoids and more particularly to an improved solenoid construction including a multi-rate return spring by means of which a large increase in usable work may be obtained from a solenoid without any increase in wattage.

Solenoids normally include return springs such that the solenoid plunger, upon electrical release, is forcefully and rapidly returned to home position. Known spring return solenoids include a single rate return spring by means of which a linear "rate" as concerns spring restoring force versus spring deflection is realized. Thus, a particular spring restoring force versus spring deflection rate must be chosen such that throughout the stroke of the solenoid plunger the spring restoring force characteristic as a function of spring length does not "cross over" the solenoid force-stroke characteristic. Obviously, if during any portion of the stroke the spring restoring force equals or exceeds the force developed by the solenoid winding on the plunger, the solenoid plunger cannot be positioned over its intended stroke. Single rate return springs additionally impose restrictions and/or design compromises to approach spring preload and full stroke spring return energy design specifications for a given application.

If solenoids had linear characteristics as concerns stroke versus force developed, a single rate return spring design could efficiently maximize the full stroke spring return force for any given solenoid application. Solenoids, however, exhibit an inverse-square relationship as concerns stroke versus force and this relationship is characterized by a pronounced knee. Thus, for any given single rate return spring design, a compromise must be made between maximizing the spring return force at the full stroke position of the solenoid core and avoiding a crossover in the spring and solenoid force-displacement/deflection characteristics.

In the interest of optimizing the efficiency of any given spring return solenoid and maximizing the usable work obtained, it is desirable that the spring restoring force versus deflection characteristic match the solenoid stroke versus force characteristic as closely as possible. A single rate restoring spring cannot be designed to match the inherent inverse-square characteristic of a solenoid.

Accordingly the object of the present invention is the provision of an improved spring return means for a given wattage solenoid by means of which the spring return force characteristic is caused to more nearly match the solenoid force characteristic and by means of which the operating efficiency is improved and a large increase in usable work is obtained without any increase in wattage required for a given application.

The present invention is featured in the provision of a multi-rate return spring for a solenoid wherein the spring means comprises at least two sections having progressively greater winding pitches, such that multi-spring restoring force rates are employed which compositely can be made to closely match the solenoid force characteristic over a predetermined stroke.

These and other features and objects of the present invention will become apparent upon reading the following description with reference to the accompanying drawing in which;

FIG. 1 is a diagrammatic representation of a solenoid member including a return spring;

FIG. 1 is a mechanical schematic representation of a multi-rate spring in accordance with the present invention; and

FIG. 3 is a diagrammatic representation of a solenoid force-stroke characteristic and a matching spring restoring force-deflection characteristic for an exemplified embodiment in accordance with the present invention.

In many solenoid actuated devices, the return spring is required to drive an external load as well as return the plunger to its normal unenergized position. Certain devices employing solenoids require that the load be repeatedly positioned to precisely defined positions at the respective ends of the solenoid stroke. Such an application is exemplified in my co-pending application entitled "Compact Annunciator Package" filed

Oct. 14, 1969, Ser. No. 866,307, wherein is described an annunciator comprising a rotatable prism which carries information on the surfaces thereof. Solenoids means are employed to rotate the prism to selectively present a desired one of the information bearing surfaces for display. In such an application it is imperative that an energized solenoid position a load to a first precisely defined position and upon electrical release, return the load to a second precisely defined position. It is extremely desirable in such applications to maximize the spring return force for any given wattage solenoid employed. In general, the use of conventional single rate return springs in solenoids employed for precise load positioning, fails to maximize the return force, and a compromise design employing a single rate return spring may fail to meet the positioning specifications necessary for a given application.

As above described, the force developed by a solenoid throughout the plunger stroke will in general vary inversely as the square of the air gap. The resulting inverse-square force relationship results in a pronounced knee in the solenoid force characteristic which cannot be matched by a single rate spring. It will become apparent from the following description that, while preloading techniques may improve the return spring force characteristic such means alone do not optimize the efficiency of the device. In accordance with the present invention means are employed to match the spring return force characteristic with the solenoid force characteristic such that throughout the stroke of a solenoid plunger substantially constant differential exists between the solenoid force and the spring return force in the interest of improving efficiency and maximizing spring return force at full stroke for a given wattage solenoid.

With reference to FIG. 1, a spring return pull-type solenoid is depicted as comprising a body member 10 within which (not illustrated) a solenoid winding is affixed which may be energized by application of power to terminals 8 and 9. With application of power to terminals 8 and 9, the solenoid core member 7 is withdrawn into the body of the solenoid and against the restraining force of the compression spring member 16. The solenoid plunger 11 extends from the solenoid core 7 and is functionally depicted as being attached to and driving a load member 12. Withdrawal of the plunger 7 within the body of the solenoid 10 develops a spring restoring force proportional to the deflection of the compression spring member, which deflection is exerted by lip 13 on the solenoid plunger 11 forcing spring retainer 15 against the spring member 16 in a compression mode. The illustrated solenoid in FIG. 1 is formed with a lip member 14, annular in form, which mechanically stops the spring retainer 15 such that a preloading of spring 16 may be realized by a predetermined deflection of spring member 16 in the compression mode when the solenoid plunger 11 is in the illustrated unenergized or rest position. The preloading feature is normally utilized to establish a positive "home" position of the plunger upon electrical release of the solenoid, and the amount of spring preloading is generally a design requirement for a given system which depends on the characteristics of the positionable load member 12.

A typical solenoid force versus stroke characteristic is depicted in FIG. 3 by the curve 17 through points A, B, and C which exhibits an inverse-square characteristic which defines a pronounced knee in the vicinity of the points A and B. As above described, the inverse-square characteristic is typical of solenoids since the force of a solenoid will in general vary inversely with the square of the air gap. The home or unenergized position of the solenoid is depicted at point A of curve 17, corresponding to a stroke of 0.093 inches. The full energized position of the solenoid plunger is depicted as zero stroke at point C on curve 17, at which point a solenoid force of approximately 55 grams is developed.

In accordance with the present invention a spring characteristic as depicted by curve 18 of FIG. 3 is realized, wherein a substantially constant force differential between the solenoid positioning force and the spring restoring force is maintained

throughout the stroke. In the exemplified embodiment discussed here, the spring characteristic is seen to be comprised of two discretely different rate segments, the first rate being established between points A' and B' on curve 18 and a second appreciably higher rate being established from the knee at point B' to the zero stroke point at C'. Point A' on curve 18 indicates a preload force of approximately 12 grams being exerted by the spring during unenergized position of the solenoid plunger.

The dual rate spring restoring force characteristic of FIG. 3 is realized by employment of a dual rate spring as functionally depicted in FIG. 2, wherein the spring 16 is comprised of a first section 16a having a winding pitch substantially less than that of a subsequent section 16b. Point B' on the spring characteristic of FIG. 3 corresponds to that point during the solenoid stroke when the winding of lesser pitched coil 16a of spring 16 close, with only the remaining greater pitched coil 16b being involved at a much higher rate. At the beginning of the stroke at point A', and including that portion of the characteristic from point A' to B', all the spring coils are opened and active and produce the initial rate as concerns the spring restoring force. The initial rate in the exemplified embodiment is depicted as 0.505 lb./in. between points A' and B' on the spring characteristic 18. When the closer spaced coil 16a of the spring close at a stroke of 0.060 (point B') only the higher rate wider spaced coil 16b of the spring is involved and establishes the higher spring rate of 0.853 lb./in. It is noted that the inverse-square solenoid force characteristic is very nearly approximated by the resulting spring characteristic which exhibits two distinctly different rates throughout the solenoid stroke.

The solenoid and spring characteristics of FIG. 3 depict a more efficient design than any design employing a single rate spring and additionally allow a considerable flexibility as to solenoid design for a particular work application.

For a given load, a predetermined spring preloading may be necessary to assure a well-defined and positive return position when electrical release is initiated. The use of a too steep single rate spring with preloading to maximize stored spring energy at the full stroke position may result in an intersect of the spring force-deflection characteristic with the solenoid force-stroke characteristic and prevent full stroke position from being attained. Further, the use of too great a spring rate on a single rate basis with preloading in a design with a predetermined preload may establish a desired return force from full stroke at the expense of a solenoid force-spring restoring force differential too small to facilitate desired plunger acceleration.

On the other hand, the employment of a single rate spring of comparatively steep characteristic, as in the steeper characteristic portion of the spring characteristic of FIG. 3, to avoid intersect with the solenoid force displacement characteristic while maximizing spring energy at full stroke may establish too small a preload capability as depicted by point A'' in FIG. 3. Thus, while maximum spring energy may be stored at full stroke the use of this greater rate may impose a preload limit insufficient to positively and repeatedly define a stable return plunger position for a given application.

The use of a single rate spring as defined by portion A'-B' of curve 18 of FIG. 3 would effect a full stroke restoring force of approximately 25 grams in the exemplified embodiment, far from the optimum maximum stored spring energy at electrical release that can be realized by the multi-rate spring embodiment of the present invention.

In the exemplified embodiment therefor it is seen that the most efficient operation for a given wattage solenoid is attained by closely approximating the inverse-square characteristic of the solenoid force curve 17, and this may be closely approached for any given solenoid by the employment of a multi-rate spring.

Obviously in accordance with the present invention the spring member 16 might be comprised of more than two sections in which case the solenoid force characteristic might be more nearly and exactly approximated by the spring charac-

teristic. It is to be understood that when employing springs having more than two sections, successive ones of the sections would have progressively greater winding pitches or be otherwise designed as to introduce predetermined spring rate segments in the spring loading characteristics the composite of which effect a match of the solenoid force characteristic as necessary for a given solenoid.

The present invention is thus seen to provide a flexible design capability as concerns use of a given wattage solenoid in a work application. The solenoid efficiency for a given wattage rating is optimized, and the spring return force maximized so as to enable precisely defined solenoid plunger positions for a given load application.

Although the present invention has been described with respect to a particular embodiment thereof, it is not to be so limited as changes might be made therein which fall within the scope of the invention as defined in the appended claims.

I claim:

1. In a solenoid of the type comprising a spring loaded plunger member the loading imposed on which defines a predetermined spring return force upon electrical release on said solenoid plunger member, means for structuring said return spring to exhibit at least two progressively greater loading rates over the stroke of said solenoid plunger to realize a spring length-force characteristic over the stroke of said solenoid plunger the slope of which approximates that of the inherent inverse-square solenoid force-stroke characteristic, thereby maintaining a substantially constant differential between solenoid force and spring retaining force over the stroke of said solenoid plunger while maximizing the retaining force of said return spring at the energized terminus of the solenoid stroke.

2. A solenoid with multi-rate return spring as defined in claim 1 wherein said spring is comprised of multiple contiguous helical sections having progressively greater winding pitches.

3. A solenoid with multi-rate spring return means as defined in claim 2 wherein said multi-rate return spring comprises first and second contiguous sections having progressively greater winding pitches.

4. A solenoid with multi-rate return spring as defined in claim 2 wherein the resilient characteristics of said spring member sections and the respective comparative pitches thereof effect a closing of coils in the lesser pitched sections of said spring at selected points within the stroke of said solenoid plunger so as to define successive greater rate spring force-deflection characteristics from the unenergized position of said solenoid plunger stroke to the fully energized terminus of said solenoid plunger stroke, said successive different spring force-deflection rates forming a composite spring rate characteristic over the stroke of said solenoid substantially approximating the slope of the inverse-square solenoid force-stroke characteristic.

5. Means as defined in claim 4 wherein said spring return means is compressibly confined to exert a predetermined preload force in the unenergized position of said solenoid against which said solenoid plunger stroke is initially restrained upon energization of said solenoid.

6. Means for optimizing the efficiency of a spring return solenoid having a predetermined stroke versus force characteristic comprising means for fashioning said return spring so as to exhibit successively different return rates over predetermined segments of said solenoid stroke to effect a spring return force characteristic as a function of said solenoid stroke substantially approximating the slope of said solenoid force-stroke characteristic.

7. Means for optimizing as defined in claim 6 wherein said return spring is preloaded to exert a predetermined restraining force on said solenoid plunger with said solenoid unenergized to establish a predetermined differential over the stroke of said solenoid plunger between solenoid force imparted on said plunger and the restraining force exerted on said plunger by said return spring, said solenoid force being in excess of the

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restraining means imparted by said spring member over the stroke of said solenoid.

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