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**Tatum, III et al.**

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- (54) **THERMAL POWERED  
RECIPROCATING-FORCE MOTOR**
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**F03G 7/00** (2006.01)  
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**F02G 1/04** (2006.01)

(52) **U.S. Cl.**  
USPC ..... **60/641.8**; 60/641.13; 60/527; 60/641.15

(58) **Field of Classification Search**  
USPC ..... 60/527, 641.13, 529, 325, 531, 641.8;  
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See application file for complete search history.

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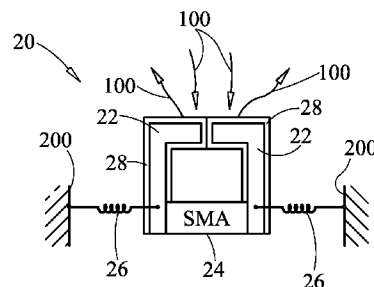
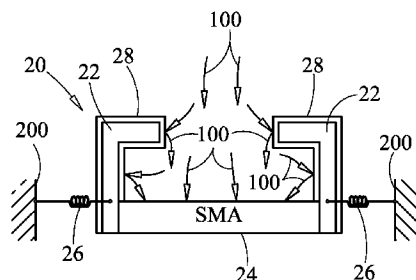
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(57) **ABSTRACT**

A thermal-powered reciprocating-force motor includes a shutter switchable between a first position that passes solar energy and a second position that blocks solar energy. A shape memory alloy (SMA) actuator is coupled to the shutter to control switching thereof between the shutter's first and second position. The actuator is positioned with respect to the shutter such that (i) solar energy impinges on the SMA when the shutter is in its first position so that the SMA experiences contraction in length until the shutter is switched to its second position, and (ii) solar energy is impeded from impingement on the SMA when the shutter is in its second position so that the SMA experiences extension in length. Elastic members coupled to the actuator apply a force to the SMA that aids in its extension in length until the shutter is switched to its first position.

**8 Claims, 3 Drawing Sheets**



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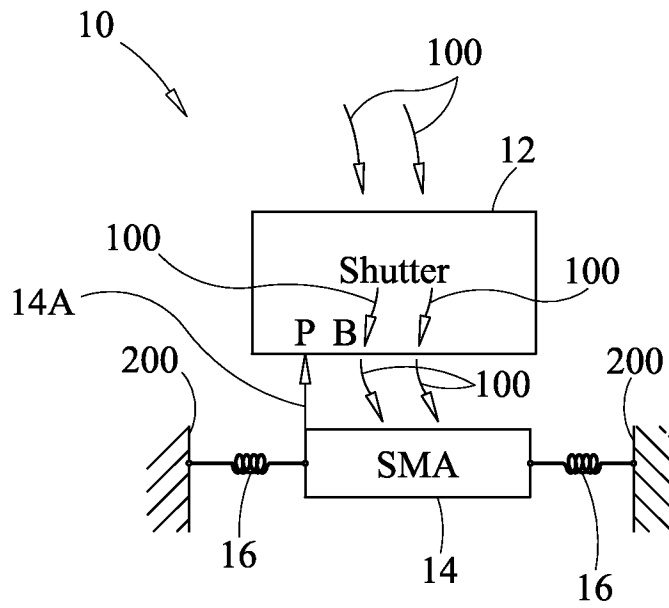


FIG. 1A

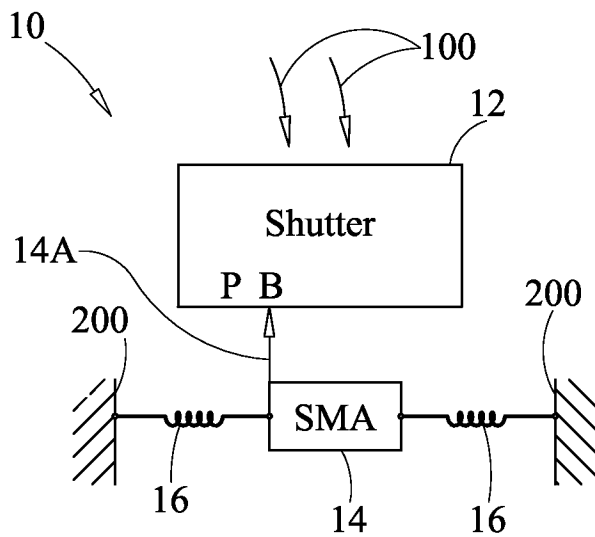


FIG. 1B

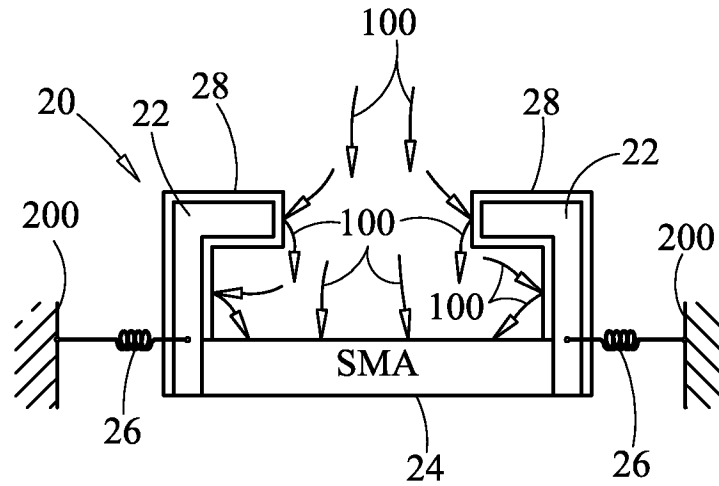


FIG. 2A

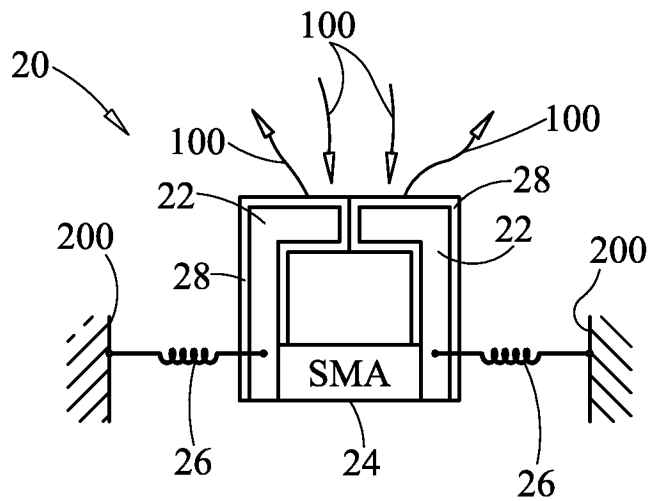


FIG. 2B

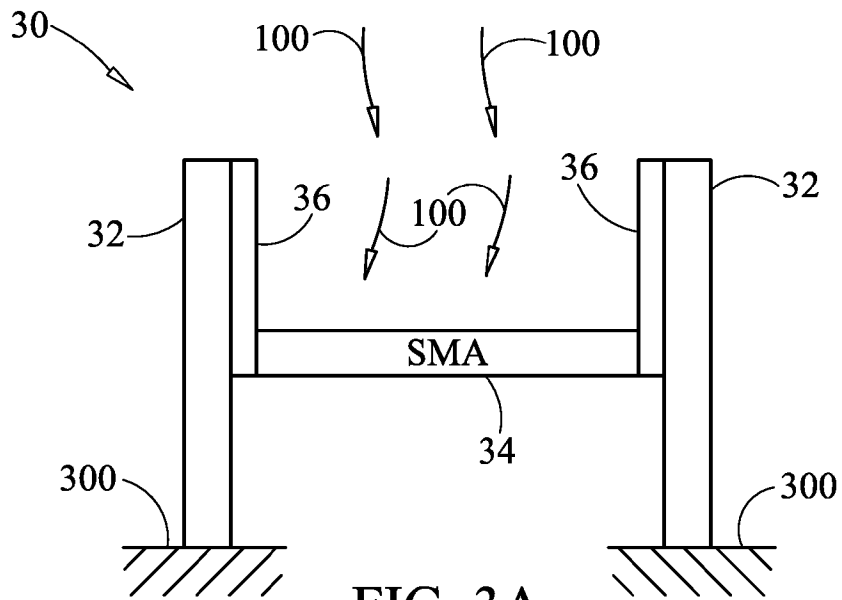


FIG. 3A

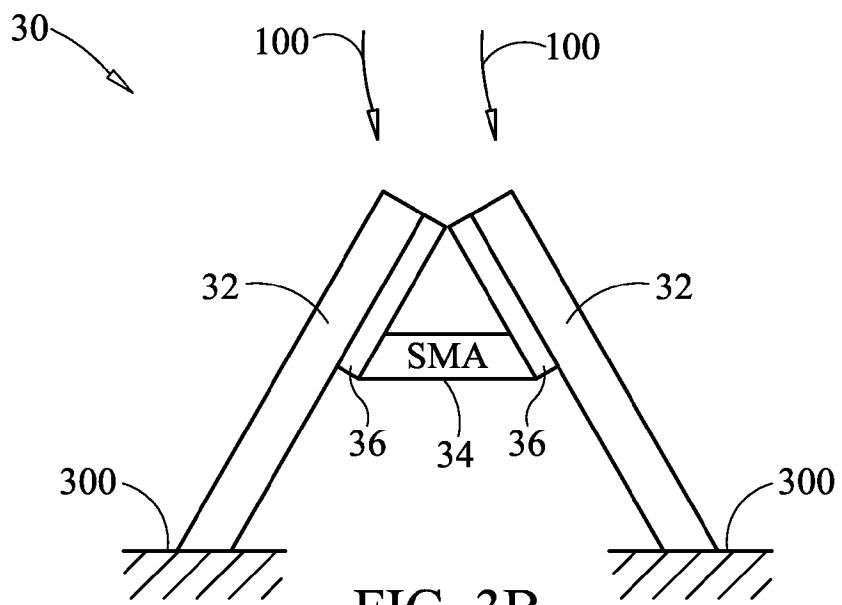


FIG. 3B

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## THERMAL POWERED RECIPROCATING-FORCE MOTOR

### ORIGIN OF THE INVENTION

The invention was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties.

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

This invention relates to non-electric powered motors. More specifically, the invention is thermal-powered, reciprocating-force motor using a shape memory alloy actuator.

#### 2. Description of the Related Art

Dirty environments have always presented challenges for designers of moving-part mechanisms that must operate in such environments. The lunar environment with its abrasive dust presents a particularly challenging environment for moving-part mechanisms. For example, typical motors are electrically-powered devices that transfer energy through bearings, shafts, and gears. Unfortunately, even with the best of seals and covers, lunar dust can quickly infiltrate a motor's various moving/bearing surfaces thereby causing a motor to fail. Furthermore, since electrical power is generally at a premium in a lunar environment, electric motors must have an adequate power supply which increases the cost, size and weight of the system utilizing the motor.

### SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a motor design that can withstand the rigors of a dirty environment.

Another object of the present invention is to provide a non-electric motor design.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

In accordance with the present invention, a thermal-powered reciprocating-force motor includes a shutter switchable between a first position that allows passage of solar energy and a second position that blocks passage of solar energy. An actuator, to include a shape memory alloy (SMA) that changes in length as a function of temperature, is coupled to the shutter for controlling switching thereof between the shutter's first and second position based on length of the SMA. The actuator is positioned with respect to the shutter such that (i) solar energy impinges on the SMA when the shutter is in its first position so that the SMA experiences contraction in length until the shutter is switched to its second position, and (ii) solar energy is impeded from impingement on the SMA when the shutter is in its second position so that the SMA experiences extension in length. One or more restoring force devices/mechanisms are coupled to at least one of the actuator and shutter for applying a force to the SMA that aids in its extension in length until the shutter is switched to its first position.

### BRIEF DESCRIPTION OF THE DRAWING(S)

Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the draw-

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ings, wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

FIG. 1A is a schematic view of a thermal-powered reciprocating-motion motor at the start of its contraction motion in accordance with an embodiment of the present invention;

FIG. 1B is a schematic view of the motor in FIG. 1A at the start of its extension motion;

FIG. 2A is a schematic view of a thermal-powered reciprocating-motion motor at the start of its contraction motion in accordance with another embodiment of the present invention;

FIG. 2B is a schematic view of the motor in FIG. 2A at the start of its extension motion;

FIG. 3A is a schematic view of a thermal-power reciprocating-motion motor at the start of its contraction motion in accordance with another embodiment of the present invention; and

FIG. 3B is a schematic view of the motor in FIG. 3A at the start of its extension motion.

### DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

The motor of the present invention uses thermal energy available in an environment (e.g., solar energy) to help generate a reciprocating motion/force that can be used as a motive force for a variety of applications. The present invention will be particularly useful in space applications where the presence of solar energy provides the energy for one half of a reciprocating motion cycle, while the extremely cold temperatures resulting during the absence of solar energy provides the energy for the other half of a reciprocating motion cycle. However, it is to be understood that the present invention is not limited to use in space applications.

The motor of the present invention can be realized by a variety of embodiments. Several non-limiting examples will be described herein to illustrate the motor's novelty. In each example, it will be assumed that the thermal energy accessed by the motor originates from the sun, i.e., solar energy.

Referring now to the drawings and more particularly to FIGS. 1A and 1B, a first embodiment of a motor in accordance with the present invention is shown and is referenced generally by numeral **10**. Motor **10** is shown at the two extremes of its reciprocating motion cycle. During motor operation, motor **10** continuously cycles between these two extremes whereby the resulting reciprocating motion becomes the motor's motive force for an application that is not part of or a limitation of the present invention. The thermal energy utilized by motor **10** is solar energy referenced by wavy arrows **100**.

Motor **10** includes a shutter **12**, an actuator **14** that includes (in-part or wholly) a shape memory alloy (SMA) and one or more elastic force-providing devices/members **16**. Shutter **12** must define two operating positions. The first position must provide for the passage of solar energy **100** (FIG. 1A) while the second position must block passage of solar energy **100** (FIG. 1B). It is to be understood that a variety of mechanisms can be used to perform the passage/blockage function of shutter **12**. For example, in harsh lunar environments shutter **12** could be a simple one-piece shade pulled, pushed, rotated, etc., between the two extreme positions thereof.

Actuator **14** includes (or is) an SMA that is known to change dimensionally as a function of temperature. In general, the SMA experiences linearly opposing dimensional changes at known hot/cold temperatures. More specifically, the SMA is configured to experience a linear contraction in a

length dimension thereof when heated, and then an opposing linear extension in the length dimension when the SMA is subsequently cooled. The particular choice of SMA is not a limitation of the present invention. However, some of the most common and readily-available SMAs include nickel-titanium alloys (e.g., Nitinol), copper-aluminum-nickel alloys, copper-zinc-aluminum alloys, and iron-manganese-silicon alloys.

Actuator **14** is positioned relative to shutter **12** such that solar energy **100** impinges on the SMA when the shutter **12** is passing solar energy **100** (FIG. 1A), and such that solar energy **100** is prevented from impinging on the SMA when shutter **12** is blocking solar energy **100** (FIG. 1B). In the present invention, the contraction and extension of the SMA of actuator **14** is used to switch the position of shutter **12** between its passage/blockage functions. Accordingly, actuator **14** is coupled to shutter **12** in a way that switches the function (i.e., position) of shutter **12** from passage-to-blockage or blockage-to-passage. Such coupling is indicated in FIGS. 1A and 1B by arrow **14A** (e.g., a non-SMA control arm) that “toggles” shutter **12** between its solar energy passage mode (“P”) and solar energy blocking mode (“B”) based on the length of the SMA.

In operation, the SMA of actuator **14** is illustrated in FIG. 1A at the beginning of its contraction motion when solar energy **100** impinges on the SMA of actuator **14** as governed by the “P” position of shutter **12**. As the SMA heats, it contracts in length until shutter **12** is placed in its “B” position (FIG. 1B) where solar energy **100** is no longer able to impinge on the SMA of actuator **14**. At this point, the SMA begins to cool whereby it begins to experience extension in its length. The cooling and lengthening of the SMA continues until shutter **12** is switched back to its “P” position (FIG. 1A) so that the SMA can again be heated/contracted. This cycle of heating and cooling is continually repeated such that actuator **14** undergoes reciprocating motion that can be utilized by a device/application (not shown) of choice.

Note that in a space environment, the cooling of the SMA is fairly rapid once solar energy **100** is no longer incident on the SMA. One or more elastic force-producing devices/members **16** can be coupled to actuator **14** and fixed supports **200** to aid or enhance the cooling/lengthening of the SMA. Since the SMA will already be lengthening on its own, the restoring force supplied by member(s) **16** can be fairly small such that this restoring force can be easily overcome by the force of contraction when the SMA is heated. Member(s) **16** can be simple springs, elastic material, etc., without departing from the scope of the present invention. The presence of member(s) **16** hastens the toggle action provided by the contracting/lengthening SMA.

Another embodiment of a motor in accordance with the present invention is illustrated in FIGS. 2A and 2B and is referenced generally by numeral **20**. Motor **20** employs a different structure than motor **10**, but applies the same principles described above. Motor **20** includes a shutter **22**, an actuator **24** that can be made solely of an SMA, and elastic force-producing devices/members **26** coupled to shutter **22** and fixed supports **200**. In this embodiment, shutter **22** essentially defines a housing that is open to solar energy **100** when SMA actuator **24** is at the beginning of its contraction motion (FIG. 2A), and closed to solar energy **100** when SMA actuator **24** is at the beginning of its extension motion (FIG. 2B). To enhance heating and cooling of SMA actuator **24**, shutter **22** can be coated on all sides thereof with reflective material **28**. Thus, when shutter **22** is open (FIG. 2A), solar energy **100** can be directly incident on SMA actuator **24** as well as reflect off portions of material **28** facing SMA actuator **24** to be incident

on SMA actuator **24**. When shutter **22** is closed (FIG. 2B), the portions of material **28** exposed to solar energy **100** will reflect it away from motor **20** and SMA actuator **24** to hasten the cooling of actuator **24**. Operation of motor **20** is similar to that of motor **10** with members **26** operating in an analogous fashion to members **16** described above.

Still another embodiment of the present invention is illustrated in FIGS. 3A and 3B and is referenced generally by numeral **30**. Once again, motor **30** employs a different structure as compared to motors **10** and **20**, but applies the same principles already described herein. Motor **30** includes a shutter **32** defined by two flexible walls mounted on fixed supports **300**, SMA actuator **34** that spans and is coupled to the two walls defining shutter **32**, and leaf springs **36** coupled to each wall of shutter **32** at either end of SMA actuator **34**. In this embodiment, each wall of shutter **32** is configured to flex as SMA actuator **34** contracts in length. More specifically, the walls defining shutter **32** are positioned in FIG. 3A to allow solar energy **100** to impinge on SMA actuator **34** whereby it heats/contracts. As SMA actuator **34** contracts, the walls of shutter **32** flex until they snap over SMA actuator **34** and thereby block the transmission of solar energy **100** to SMA actuator **34** as illustrated in FIG. 3B. Then, as SMA actuator cools/lengthens, leaf springs **36** act to hasten the lengthening of SMA actuator **34** and also cause shutter **32** to snap open whereby heating/contraction of SMA actuator can begin again. Reflective material (not shown) can also be applied to shutter **32** to enhance the heating/cooling of SMA actuator **34**.

The advantages of the present invention are numerous. The reciprocating-motion motor requires no electricity and is readily adapted for harsh and/or dirty environments. The motor can also take advantage of the extreme temperatures encountered in space in order to enhance the motor's efficiency and output. The motor can be realized in a variety of ways and on a variety of size scales thereby further increasing its versatility.

Although the invention has been described relative to a specific embodiment thereof, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A thermal-powered reciprocating-force motor, comprising:

- a shutter switchable between a first position adapted to allow passage of solar energy and a second position adapted to block passage of solar energy;
- an actuator having opposing ends, said actuator including a shape memory alloy (SMA) that changes in length as a function of temperature, said actuator coupled to said shutter for controlling switching thereof between said first position and said second position based on length of said SMA, said actuator positioned with respect to said shutter such that (i) solar energy is adapted to impinge on said SMA when said shutter is in said first position wherein said SMA experiences contraction in length until said shutter is switched to said second position, and (ii) solar energy is adapted to be impeded from impingement on said SMA when said shutter is in said second position wherein said SMA experiences extension in length;

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an elastic member coupled to each of said opposing ends of said actuator for applying a force to said SMA that aids in said extension in length until said shutter is switched to said first position; and

reflective material directly in contact with said shutter for reflecting said solar energy towards said actuator when said shutter is in said first position and for reflecting said solar energy away from said actuator when said shutter is in said second position.

2. A motor as in claim 1, wherein said actuator includes a non-SMA portion coupled to said SMA and said shutter, and wherein said non-SMA portion controls switching of said shutter between said first position and said second position when said SMA experiences one of said extension in length and said contraction in length.

3. A motor as in claim 1, wherein said actuator is comprised entirely of said SMA.

4. A motor as in claim 1, wherein said SMA is selected from the group consisting of nickel-titanium alloys, copper-aluminum-nickel alloys, copper-zinc-aluminum alloys, and iron-manganese-silicon alloys.

5. A thermal-powered reciprocating-force motor, comprising:

a shutter switchable between a first position adapted to transmit thermal energy and a second position adapted to block thermal energy;

an actuator having opposing ends, said actuator including a shape memory alloy (SMA) that experiences linear contraction when heated and then linear extension when subsequently cooled, said actuator coupled to said shutter for controlling switching thereof from said first posi-

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tion to said second position during said linear contraction and for switching said shutter from said second position to said first position during said linear extension, said actuator positioned with respect to said shutter such that (i) thermal energy transmitted by said shutter in said first position reaches said SMA, and (ii) thermal energy blocked by said shutter in said second position is prevented from reaching said SMA;

an elastic member coupled to each of said opposing ends of said actuator for applying a force to said SMA that aids said linear extension until said shutter is switched to said first position; and

reflective material coating said shutter for movement therewith, said reflective material directing said thermal energy towards said actuator when said shutter is in said first position and directing said thermal energy away from said actuator when said shutter is in said second position.

6. A motor as in claim 5, wherein said actuator includes a non-SMA portion coupled to said SMA and said shutter, and wherein said non-SMA portion controls switching of said shutter between said first position and said second position when said SMA is experiencing one of said linear extension and said linear contraction.

7. A motor as in claim 5, wherein said actuator is comprised entirely of said SMA.

8. A motor as in claim 5, wherein said SMA is selected from the group consisting of nickel-titanium alloys, copper-aluminum-nickel alloys, copper-zinc-aluminum alloys, and iron-manganese-silicon alloys.

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