United States Patent

[11] **3,623,566**

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a part interest

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[54] **UNDULATING BODY PROPULSION SYSTEM**
15 Claims, 9 Drawing Figs.

[52] **U.S. Cl.** **180/7,** 115/1, 46/152
[51] **Int. Cl.** **B62d 57/00**
[50] **Field of Search** 180/7, 8; 280/408; 46/152; 115/1

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Attorneys—Clarence A. O'Brien and Harvey B. Jacobson

ABSTRACT: An elongated flexible body undergoes undulations to propel a vehicle frame. A rotating control assembly regulates longitudinal expansion and contraction of cells into which the body is internally partitioned to produce a sinusoidal configuration changing in phase at a controlled rate relative to the axis of the sinusoidal curvature extending through the center of mass of the body.

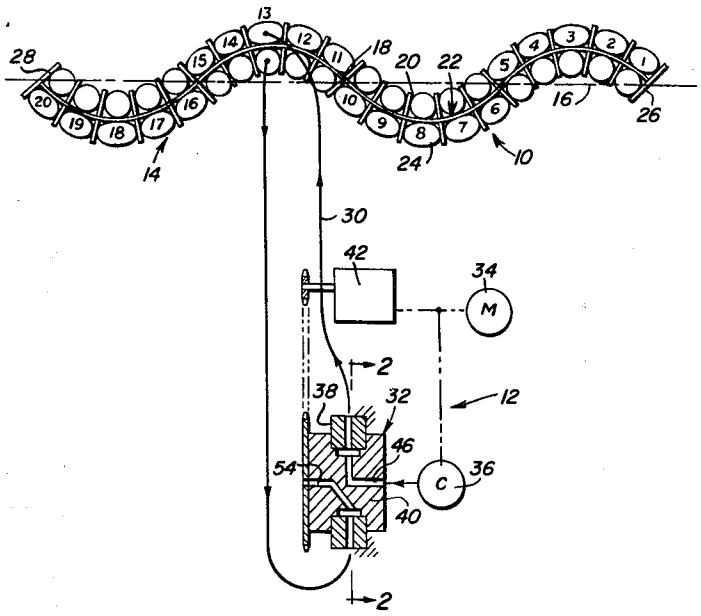

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Fig. 1

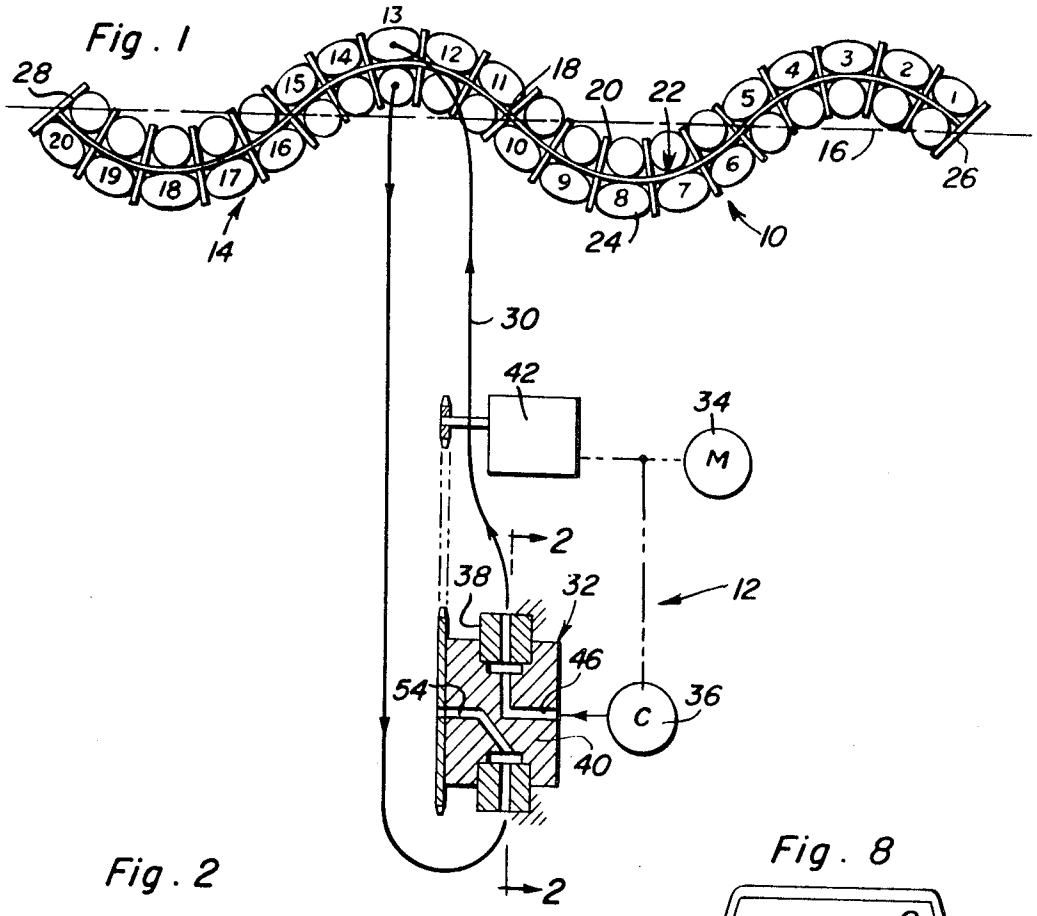

Fig. 2

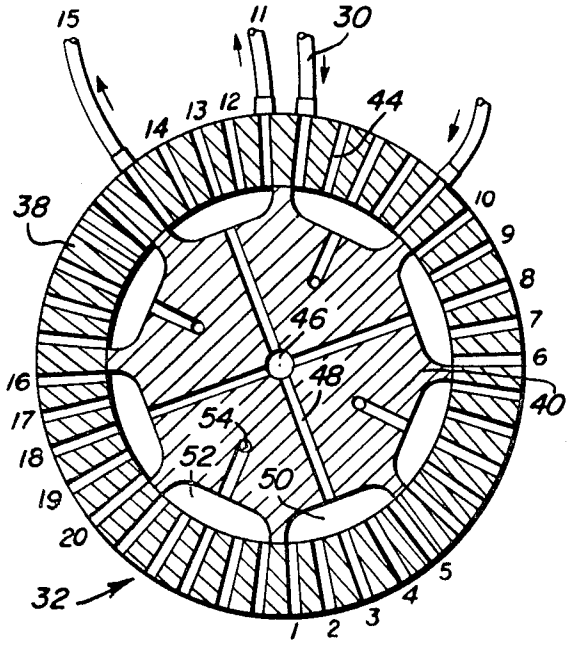

Fig. 8

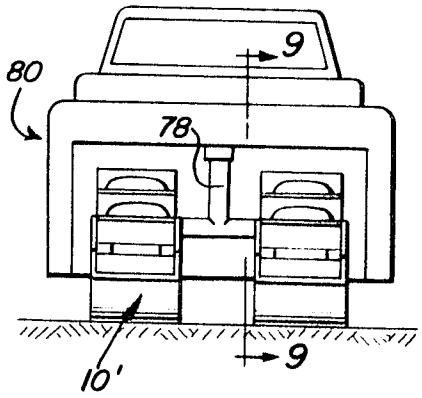

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Fig. 3

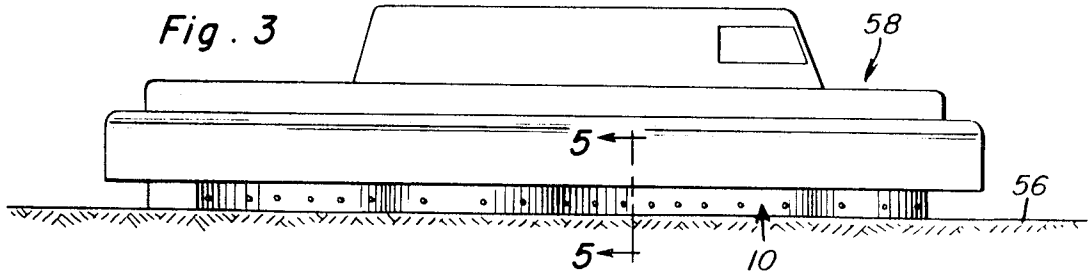


Fig. 4

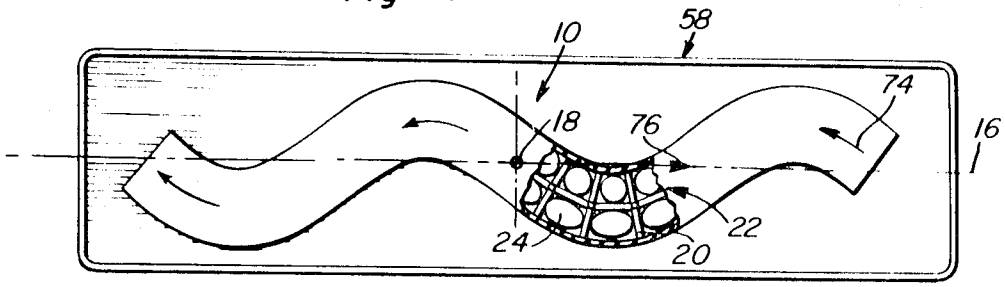


Fig. 5

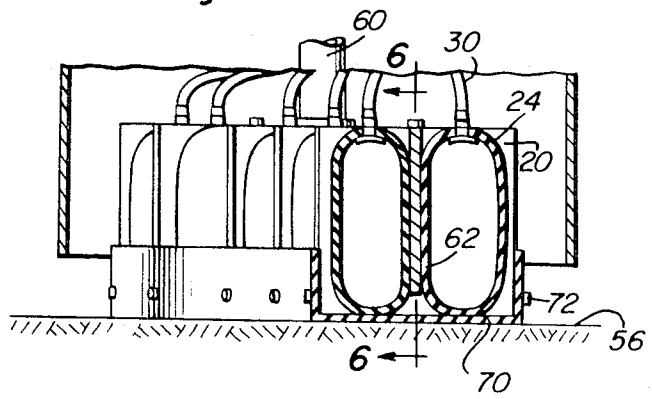


Fig. 6

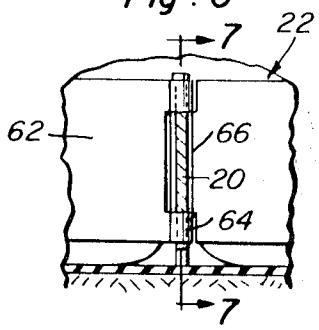


Fig. 7

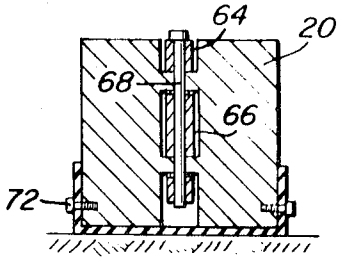
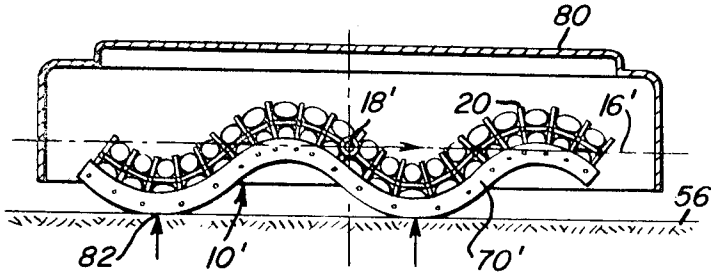


Fig. 9



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UNDULATING BODY PROPULSION SYSTEM

This invention relates generally to vehicle propulsion systems and more particularly to propulsion of a vehicle frame over a supporting surface by means of elongated flexible bodies which undergo controlled undulation.

The present invention pertains to a unique propulsion method particularly suited for land vehicles. Propelling forces in accordance with the present invention are generated from within an elongated undulating body acting directly on a supporting surface or the ground, the body being sheathed within a flexible skin in contact with the supporting surface. While the elongated propelling body somewhat resembles or simulates the body of a serpent in motion, it is not limited by variable surface resistance nor irregular in its undulations.

One basic form of the invention involves a lateral undulatory motion causing forward movement of the body along a longitudinal axis through the center of mass with respect to which the body is laterally deformed in opposite directions while in continuous contact with the ground on one side thereof. In another basic form of the invention, the elongated body undergoes rectilinear undulatory motion relative to the longitudinal axis in a vertical plane contacting the ground at two or more locations which shift relative to the center of mass of the body. For both types of propelling systems, the elongated body is internally partitioned into pressure cells on opposite sides of a central, flexible spine. The pressure cells are longitudinally expanded and contracted at a controlled rate and in accordance with a predetermined pattern producing an instantaneous sinusoidal configuration for the body. The sinusoidal curvature of the body undergoes a continuous change in phase at a controlled rate and in a preselected direction in order to cause migration of the body in the direction of its longitudinal axis to thereby impart movement to a vehicle frame attached for example to the body at its center of mass.

Practical applications of the propelling methods aforementioned require elongated bodies having instantaneous sinusoidal configurations with a minimum of four phase loops. A larger but even number of phase loops is of course desirable limited however by practical considerations.

These together with other objects and advantages which will become subsequently apparent reside in the details of construction and operation as more fully hereinafter described and claimed, reference being had to the accompanying drawings forming a part thereof, wherein like numerals refer to like parts throughout, and in which:

FIG. **1** is a somewhat schematic illustration of the propelling system of the present invention.

FIG. **2** is an enlarged transverse sectional view through a control valve assembly illustrated in FIG. **1** associated with the propelling system of the present invention.

FIG. **3** is a simplified side elevational view of a lateral undulatory type of vehicle propulsion system constructed in accordance with the present invention.

FIG. **4** is a bottom view of the vehicle propulsion installation illustrated in FIG. **3** with parts broken away and shown in section.

FIG. **5** is an enlarged partial sectional view taken substantially through a plane indicated by section line **5—5** in FIG. **3**.

FIG. **6** is a partial sectional view taken substantially through a plane indicated by section line **6—6** in FIG. **5**.

FIG. **7** is a partial transverse sectional view taken substantially through a plane indicated by section line **7—7** in FIG. **6**.

FIG. **8** is a front elevational view of a simplified vehicle installation employing a rectilinear undulatory type of propelling system in accordance with the present invention.

FIG. **9** is a side sectional view taken substantially through a plane indicated by section line **9—9** in FIG. **8**.

Referring now to the drawings in detail, FIG. **1** illustrates the basic components of a propelling system constructed in accordance with the present invention which includes an elongated flexible body generally referred to by reference numeral **10** and a controlled force generating component generally referred to by reference numeral **12**. In its simplest form as illustrated in FIG. **1**, the elongated body **10** when assuming a passive undulated configuration, approximates a sinusoidal curvature having a minimum of four phase loops **14** deviating on opposite sides of a longitudinal axis **16** constituting the direction along which the elongated body **10** travels as it undergoes undulation. The axis **16** intersects the center of mass **18** of the body which is shifted relative to some reference surface by forces internally generated within the body causing it to undulate.

The sinusoidal configuration assumed by the body **10** and the continuous change in the phase of the sinusoidal curvature is made possible by internally partitioning the body by means of a plurality of rib elements **20** hinged to or pivotally connected to a substantially flexible, central spine element **22**. The spine element **22** must accordingly assume the sinusoidal curvature of the elongated body while the rib elements **20** extend substantially perpendicular to the curvature in order to maintain a substantially constant body cross section. The spacing between the rib elements **20** on opposite sides of the spine **22** is controlled by a plurality of pressure chamber devices or pressure cells **24**. In the illustrated embodiment, there are **20** pressure cells on each side of the spine element **20** or a total of **40** pressure cells. By controlling the pressurization and inflation of alternate groups of cells **24** while the other cells are deflated, the body is made to assume a sinusoidal configuration as illustrated in FIG. **1**. The pressurized cells are accordingly numbered from **1** through **20** starting from the head end **26** of the body to the tail end **28** by way of example. Thus, the first group of five pressurized cells form a sinusoidal loop on one side of the axis **16** opposite the side of the next phase loop produced by pressurization of the next group of five cells **24** on the other side of the spine element. It will therefore be apparent that control over the pressurization and deflation of the cells **24** by the force generating component **12** will cause a phase shift in the sinusoidal configuration of the body.

Each of the pressure cells **24** is connected by a fluid pressure line **30** to a control valve assembly **32** associated with the force generating component **12**. The force generating component may include, for example, a prime mover such as motor **34** drivingly connected to a fluid pressure generator **36** from which fluid under pressure is supplied to the control valve assembly **32** connected by the fluid pressure lines **30** to the 40 pressure cells associated with the elongated body **10**. The control valve assembly **32** will thereby be operative to pressurize 20 of the pressure cells at any instant while the other 20 of the pressure cells are vented. The valve assembly includes an annular valve body **38** with respect to which a rotatable value member **40** is rotated at a controlled speed. Thus, the prime mover **34** may be drivingly connected to the rotatable valve member **34** for rotation thereof through a change speed transmission **42** of any suitable type.

As shown in FIG. **2**, the annular valve body **38** includes a plurality of radial valve passages **44** each of which is connected by one of the fluid pressure lines **30** to a corresponding pressure cell **24** associated with the elongated body **10**. Accordingly, there are 40 valve passages **44**, in the illustrated embodiment. Further, since groups of five pressure cells are pressurized, alternating on opposite sides of the spine **22** of the body **10**, groups of five passages **44** as numbered in FIG. **2**, are in fluid communication with the fluid pressure inlet port **46** through a plurality of radial passages **48** and manifold cavities **50** in the rotatable valve member **40**. Exhaust cavities **52** in the rotatable valve member span the other groups of passages **44** between the pressurized cavities **50** in order to vent the other valve passages **44** through a vent passage **54** in the rotatable valve member. It will therefore be apparent that as the rotatable valve member **40** is rotated, the elongated body **10** will undulate at a rate determined by the rotational speed of the valve body.

FIGS. **3** and **4** illustrate one installation of the present invention in which an elongated body **10** is positioned on a ground supporting surface **56**. The supporting surface may either be

solid, or semisolid such as mud. The body **10** is connected at its mass center **18** to a vehicle frame **58** by any suitable means such as the post **60** as shown in FIG. **5** so that the vehicle may be propelled by a lateral undulatory motion of the body. In the illustrated embodiment, the body has a rectangular cross-sectional shape as determined by the partitioning rib elements **20** which are in the form of rectangular plates pivotally connected to the flexible spine **22**. The flexible spine may accordingly be formed by plate sections **62** having interfitting hinge portions **64** and **66**, for example, at opposite ends as shown in FIG. **6** interconnected by a hinge pin **68** secured to the rib **20**. The ribs **20** of the body as well as the interconnecting spine **22** are at least partially enclosed by an outer flexible skin **70** made of a rubber or rubberlike material which may be anchored to the ribs **20** by pins **72**. The skin **70** therefore forms an outer surface of the body in contact with the supporting surface **56** generally in a plane parallel to the axis **16** of the body.

The body assumes a sinusoidal configuration which continuously shifts in phase in a direction indicated by the arrows **74** in FIG. **4** causing migration or travel of the center of mass **18** of the body in the direction indicated by the arrow **76** in FIG. **4** along the axis **16**. A force generating component including a rotating valve assembly as described in connection with FIGS. **1** and **2** may be utilized for this purpose. By reversing the direction of rotation of the valve assembly, and the direction in which the body undulates, the direction of movement of the vehicle may be reversed. Further, the speed of movement of the body may be controlled. This type of installation for the undulating body **10** will be particularly suited for low silhouette vehicles and for propulsion on smooth surfaces because of the substantial contact area between the supporting surface and one complete side of the body.

FIGS. **8** and **9** illustrate another installation for the propulsion system of the present invention in which two undulating bodies **10'** are interconnected at their mass centers **18'** by any suitable connecting structure **78** on which the vehicle frame **80** is supported. The structure of the body **10'** is the same as hereinbefore described in connection with FIGS. **3–7** except that the body is turned 90° about its longitudinal axis **16'**. The outer flexible skin **70'** associated with the body **10'** therefore encloses the ribs **20** on the underside of the body relative to the supporting surface **56** so as to engage the supporting surface at at least two spaced locations **82** at which the entire vehicle is supported on the ground. The ground engaging locations will of course shift relative to the mass center of the bodies **10'** as the bodies undergo undulation to produce movement of the vehicle. In this type of propulsion system, utilizing two undulating bodies **10'**, two force generating components may be employed interrelated with each other so as to produce simultaneous inphase movement of the undulating bodies for forward or reverse travel of the vehicle. Turning movement may be produced by operating the undulating bodies at a difference in phase and/or speed.

Although the undulating body structure associated with the propelling systems hereinbefore described are shown to have four phase loops, six phase loops may be more desirable in order to increase the number of support locations and ground contact area. The outer flexible skin may also enclose the entire body if desired. Further, any suitable fluid may be utilized to control the pressurization of the pressure cells **24**. Although an open circuit type of fluid pressure system was described, it should be appreciated that a closed circuit type of system may also be utilized and that in lieu of the mechanically controlled pneumatic force generating component shown, an electrically controlled system could be utilized whether pneumatic or hydraulic.

The foregoing is considered as illustrative only of the principles of the invention. Further, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation shown and described, and accordingly all suitable modifications and equivalents may be resorted to, falling within the scope of the invention.

What is claimed as new is as follows:

1. In combination with a rigid vehicle frame, means for propelling the vehicle frame relative to a contacting medium comprising an elongated body having a center of mass, means connecting the frame to the body said center of mass, internal body shaping means for maintaining a substantially sinusoidal configuration of the body in all positions thereof relative to the frame, and phase control means connected to said internal body shaping means for cyclically producing forced undulating movement of the body relative to said center of mass.

2. The combination of claim **1** wherein said elongated body includes a substantially flexible spine fixed by said connecting means to the frame only at the center of mass, said spine being displaceable throughout by the internal shaping means relative to the center of mass.

3. The combination of claim **2** wherein said contacting medium is a surface engaged by the body at a plurality of spaced points in a plane substantially parallel to said parallel axes.

4. The combination of claim **2** wherein said body is maintained substantially constant in cross section perpendicular to the spine.

5. The combination of claim **2** wherein said contacting medium is a surface engaged by the body substantially in a plane perpendicular to said parallel axes.

6. In combination with a vehicle frame, means for propelling the vehicle relative to a contacting medium comprising an elongated body having a center of mass, means connecting the frame to the body, internal body shaping means for establishing a substantially sinusoidal configuration, and phase control means connected to said internal body shaping means for cyclically producing undulations in said sinusoidal configuration of the body, said body shaping means including a plurality of expansible chamber elements and a source of fluid under pressure connected to said chamber elements by the phase control means for expansion and contraction thereof.

7. The combination of claim **6** wherein said elongated body includes a substantially flexible spine connected at said center of mass to the vehicle frame, a plurality of ribs pivotally connected in longitudinally spaced relation to said spine about parallel axes and extending laterally on opposite sides thereof, and a flexible skin anchored to said ribs.

8. The combination of claim **7** wherein the phase control means includes valve means for pressurizing alternately spaced groups of the chamber elements on said opposite sides of the spine while deflating the other of the chamber elements, and means connected to the valve means for rotation thereof at a controllable rate to cyclically change the phase relationship of the pressurized chamber elements relative to the vehicle frame.

9. The combination of claim **8** wherein said body is maintained substantially constant in cross section perpendicular to the spine.

10. The combination of claim **9** wherein said contacting medium is a surface engaged by the flexible skin substantially in a plane perpendicular to said parallel axes.

11. In a vehicle adapted to be propelled along a supporting surface, means for propelling the vehicle comprising an elongated flexible body of constant cross section internally partitioned into a plurality of longitudinally expansible cells, and controllable pressurizing means connected to said expansible cells for producing sinusoidal undulation of the body relative to a longitudinal axis along which the body is propelled.

12. The combination of claim **11** wherein said body includes an outer flexible skin enclosing the expansible cells to assume a sinusoidal configuration having an even number of loops deviating from said longitudinal axis of the body.

13. The combination of claim **12** wherein said skin engages the supporting surface in a plane substantially parallel to the longitudinal axis.

14. The combination of claim **13** wherein the body engages the supporting surface at a plurality of spaced points.

15. The combination of claim **11** wherein the body engages the supporting surface at a plurality of spaced points.