United States Patent

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[54] **UNSYMMETRICAL, DOUBLE-ACTING FREE PISTON ENGINE**
26 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** ..... **123/46,** 123/46 A, 123/46 SC, 417/364, 417/380
[51] **Int. Cl.** **F02b 71/00,** F02d 39/10, F16h 21/44
[50] **Field of Search** ..... 123/46, 46 B, 46 SA, 46 A, 46 H, 46 E, 46 SC, 192 R, 192 B; 417/364, 380

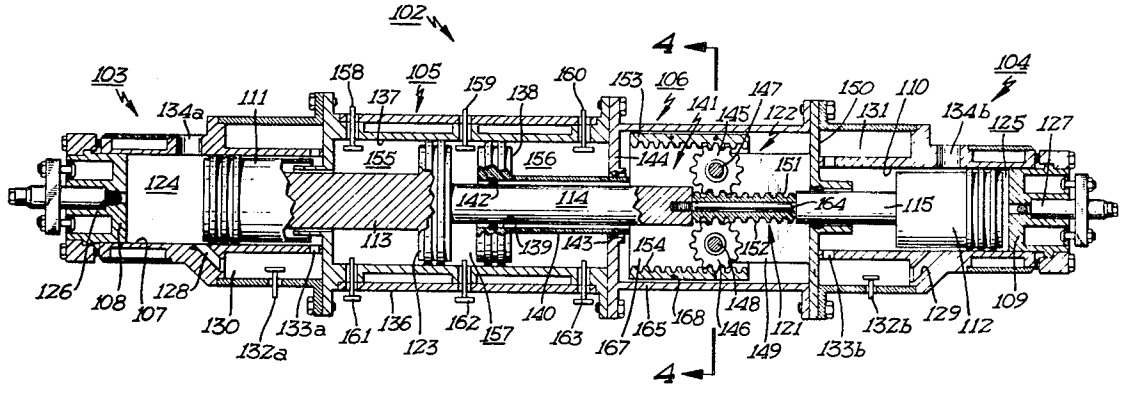
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ABSTRACT: An unsymmetrical, synchronized, balanced, free piston engine is disclosed which includes two oppositely directed, interconnected, alternately acting, coaxial power piston portions positioned for translational reciprocatory movement as a unit along their common axis, as part of a power assembly. The engine also includes a synchronizer-balancer assembly having a movable first portion attached to move as part of the power assembly and having a movable counterbalancing second portion arranged for translational reciprocating movement in an opposite direction during each movement of the power assembly. In the engine embodiment shown, a first movable member of an energy absorbing device, e.g., a first compressor piston, is attached to move with the power assembly, and a second movable member of the same or a different energy-absorbing device, e.g., a second compressor piston, is attached to move with the movable counterbalancing second portion of the synchronizer-balancer assembly in opposite directions to the power assembly. The movable counterbalancing second portion of the synchronizer is designed to be of such a weight that the absolute value of the product of all the weight associated to move with the second portion of the synchronizer in one direction (i.e., the sum of the weight of the counterbalancing movable second portion itself plus the weights of any additional elements or members moving as a unit with it, including the second movable member of an energy-absorbing device) times the length of its stroke, is equal to the absolute value of the product of all the weight associated to move with the power assembly (i.e., the sum of the weights of the power piston portions and the movable first portion of the synchronizer-balancer assembly plus the weights of any additional elements or members moving as a unit with the power assembly, including the first movable member of an energy-absorbing device) times the corresponding length of stroke of the power assembly. Also shown are alternate embodiments of the alternately acting interconnected power piston portions, in one of which the power piston portions are interconnected as parts of one double-acting piston in a single double-acting cylinder or power section. In another embodiment, the power piston portions are spaced from each other in two separate single-acting cylinders or power sections at opposite ends of the engine.



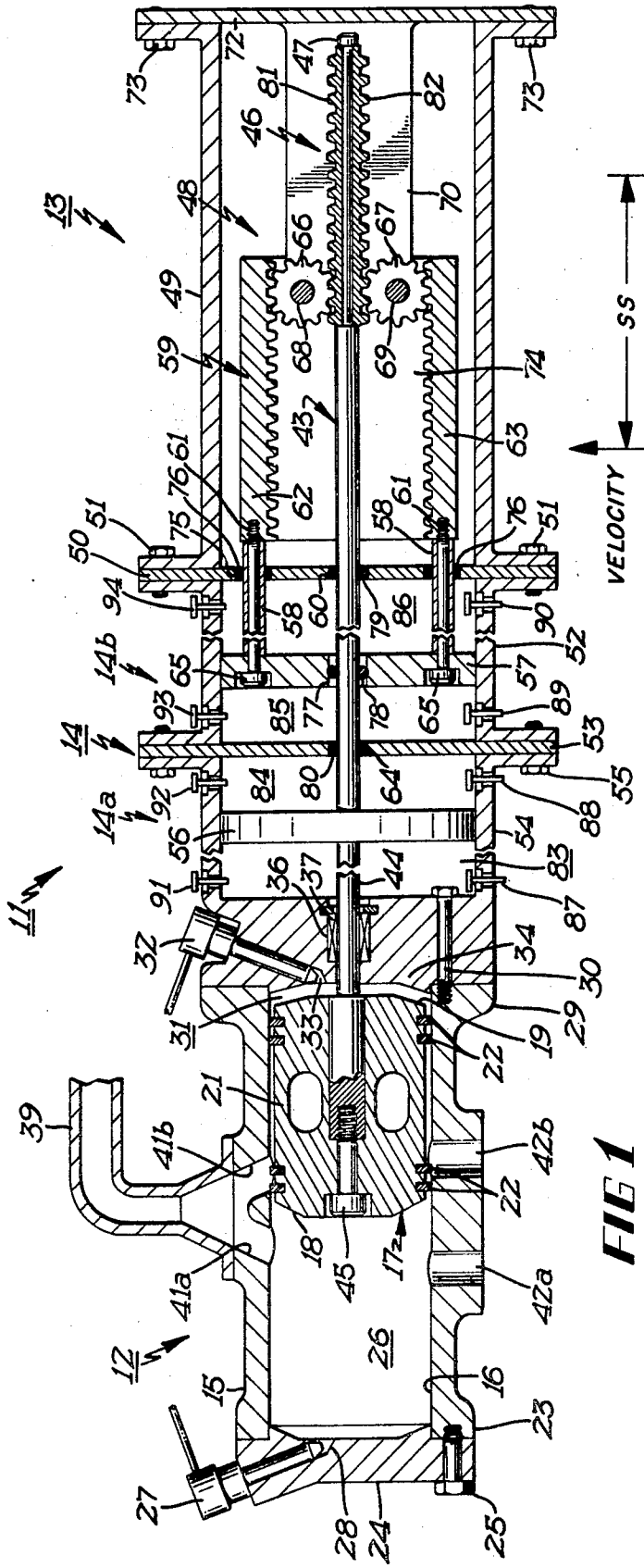


FIG 1

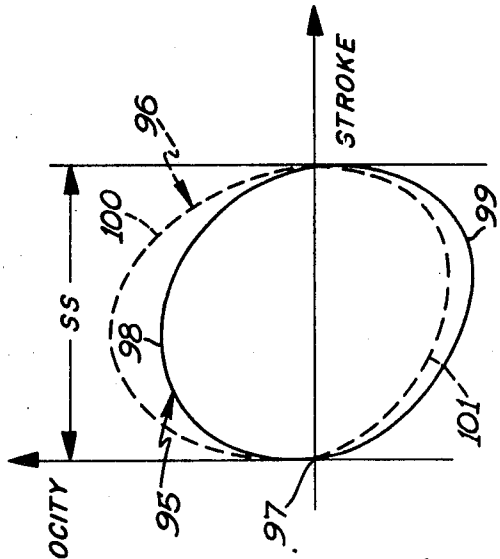


FIG 2

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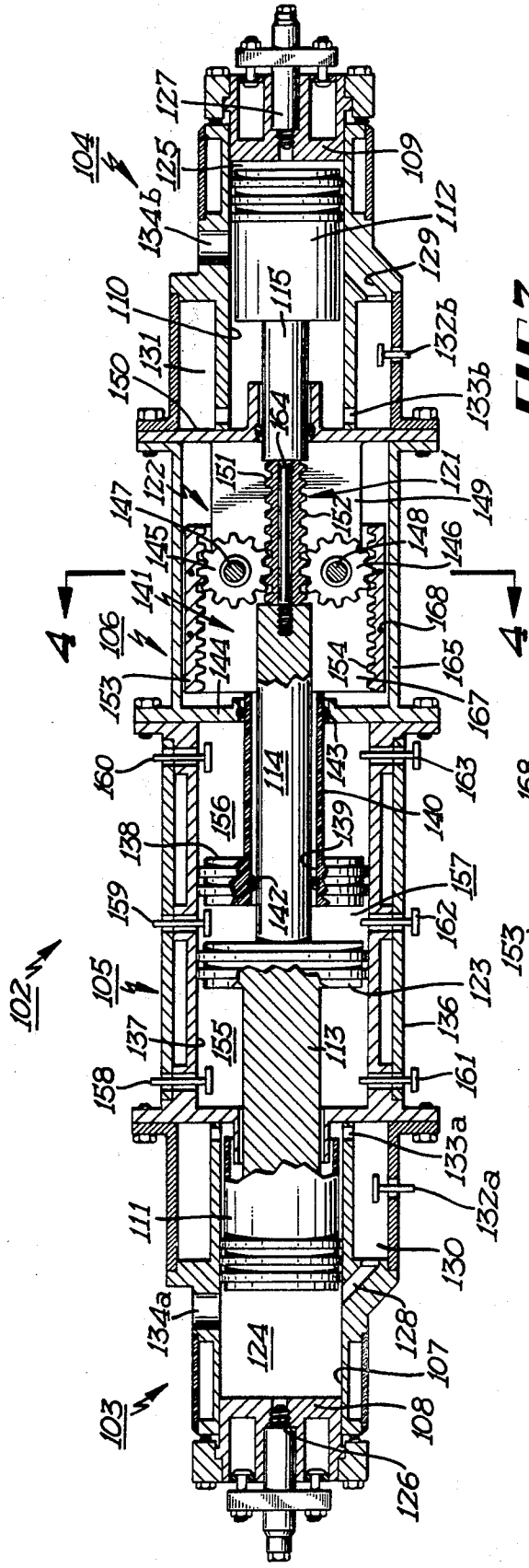


FIG 3

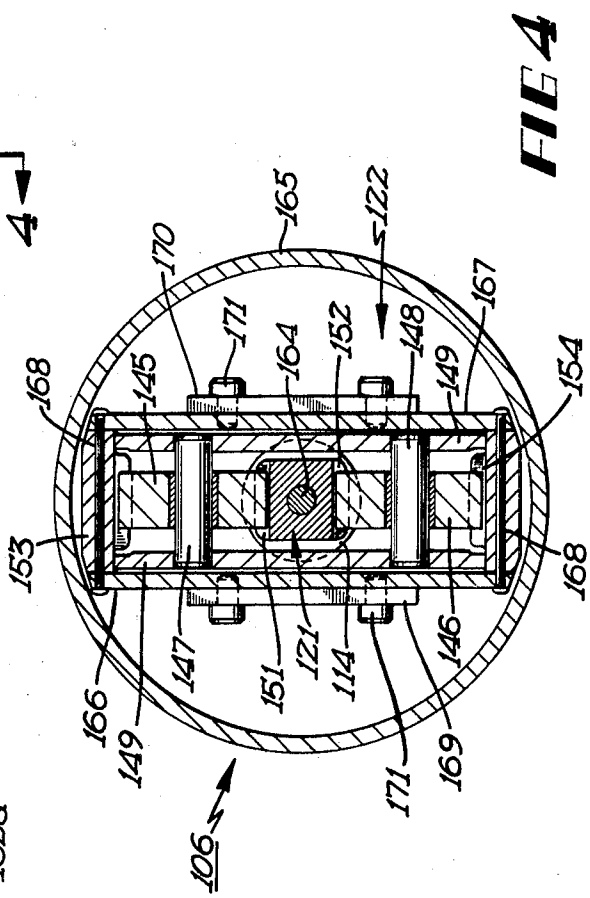


FIG 4

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UNSYMMETRICAL, DOUBLE-ACTING FREE PISTON ENGINE

CROSS REFERENCES

The free piston engines of the present inventions are improvements upon the free piston engines described in pending application Ser. No. 805,063 filed Dec. 17, 1968, by Anton Braun, and in earlier Braun parent applications (now abandoned) referred to therein.

BACKGROUND

This invention relates to free piston engines, and particularly to unsymmetrical, synchronized, balanced free piston engines. There are prior free piston engines which are unsymmetrical, synchronized and balanced and which use a single-acting power piston to provide power for movement of the piston in one direction, together with one or more bouncer compressor sections to return the power piston in the other direction to a point where repetitive combustion can occur. However, an engine using a bouncer compressor as the primary means to return the power piston towards successive firing positions does not have a naturally equal stroke-time function on both strokes in opposite directions. Moreover, the total work output is limited by the availability of a combustion power stroke in only one direction.

SUMMARY

This invention relates to unsymmetrical, synchronized, balanced, free piston engines in which two alternately acting power piston portions are connected together to move as a unit to provide power for two reciprocally and oppositely movable members of at least one energy absorbing device.

One embodiment of the unsymmetrical, synchronized, balanced, free piston engines of the present invention includes two oppositely directed, alternately acting, power piston portions interconnected as opposite ends of one double-acting power piston. This double-acting power piston is positioned in coaxial power cylinder sections which constitute opposite ends of one double-acting power cylinder. The interconnected power piston portions form a part of a power assembly all parts of which move as a unit, and which is arranged for reciprocating movement along the common central longitudinal axis of the piston portions and cylinder section. Successive combustion in alternate ends or combustion chambers of the double-acting cylinder thus drives the power assembly alternately in first one direction and then the other. The improved engine also includes a synchronizer-balancer assembly having a movable first portion attached for translational reciprocating movement as a unitary part of the power assembly. A movable counterbalancing second portion of the synchronizer-balancer assembly is also arranged for reciprocating movement along the common central longitudinal cylinder axis, but in an opposite direction to the direction of movement of the power assembly. The synchronizer-balancer assembly includes means interconnecting its movable first and second portions for synchronized opposite movement of the second portion in response to movement of the first portion as part of the power assembly. A first movable member of an energy absorbing device, e.g., a first compressor piston, is attached to move as a unit with the power assembly. A second movable member of either the same or an additional energy-absorbing device, e.g., a second compressor piston, is attached to move as a unit with the counterbalancing second portion of the synchronizer-balancer assembly in opposite directions to the power assembly. The counterbalancing portion of the synchronizer-balancer has a preselected weight such that the absolute value of the product of all the weight associated to move with the counterbalancing portion of the synchronizer (including the weight of the second movable member of an energy-absorbing device) times the length of its stroke is equal to the absolute value of the product of all the weight associated to move with the power assembly (including the weight of the first movable member of an energy-absorbing device) times the corresponding length of stroke of the power assembly.

In the preferred embodiment of the invention, the two interconnected power piston portions are positioned in coaxial power cylinder sections apaced from each other at opposite ends of the engine. Each power cylinder section, in turn, during its combustion stroke, drives its piston portion inwardly toward the opposite end of the engine. Thus, the interconnected power piston portions are positively driven axially as a unit in first one direction and then the other.

Free piston engines of the present invention are simple and compact and provide twice the work output per cycle with the same capacity synchronizer-balancer assembly and with significantly less then a factor of two increase in the overall size and weight of the engine, as compared to prior engines with single-acting power pistons which provide a combustion power stroke in only one direction. This double work output is particularly advantageous in driving two compressor pistons or two other movable members of one or more energy-absorbing devices which require a high power input. Also, the return energy requirements of engines of the present invention may be supplied primarily by the alternately acting power piston portions, rather than by the clearance volume of an output compressor or by a bouncer compressor. Thus, a separate bouncer compressor may be eliminated in many applications of such engines, particularly since a high rate of pressure rise occurs alternately in the combustion chamber of each power section as each respective power piston portion approaches its top-dead-center position. This high rate of pressure rise in the combustion chamber renders the engine relatively "stiff" at both ends of its stroke; that is, the power pistons traveling in one direction are caused to stop and "return" or to travel in the opposite direction by a force which increases at a very high rate as the power pistons approach their top-dead-center positions. This "stiff" characteristic of engines of the present invention is particularly useful when used with compressors because the "stiff" characteristic prevents any significant compressor piston travel beyond the desired nominal point, i.e., it permits a low overstroke requirement to be adopted in the compressor, which, in turn, results in the compressor being able to have a small clearance volume per given output, or a high volumetric efficiency, i.e., a high output for a given size or a small size for a given output.

Free piston engines according to the present invention may also have a naturally equal stroke-time function on both strokes of compressors driven by the engine. This naturally equal stroke-time function of the double-acting engines of this invention allows a more even output than that which is available from free piston engines of the prior single-acting type which have a combustion power stroke in only one direction.

It is thus an object of the present invention to provide improved, unsymmetrical, synchronized, balanced, free piston engines which are simple and compact, and which use oppositely directed, alternately acting, interconnected power piston portions to enhance the power output from the engine for driving at least two movable members of one or more energy absorbing devices.

It is further object of the present invention to provide improved, unsymmetrical, synchronized, balanced, free piston engines which have a naturally equal stroke-time function on both strokes, and which are particularly adapted to drive a plurality of compressor pistons or other movable members of one or more energy absorbing devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical, cross-sectional view of one embodiment of an improved free piston engine of the present invention, taken along the central longitudinal axis of the engine, with some parts of the engine being broken away and others shown in elevation and with the power and compressor piston assemblies being shown at one end of their respective strokes;

FIG. 2 is a graphical representation of velocity plotted versus stroke to illustrate a major advantage of engines according to the present invention;

FIG. 3 is a vertical, cross-sectional view, similar to the view of FIG. 1, of another preferred embodiment of the improved free piston engine of the present invention; and

FIG. 4 is a cross-sectional view of the engine of FIG. 3 taken along the section line 4—4 in FIG. 3.

Throughout the various figures of the drawings, the same reference numerals are used to designate the same parts in the various engines. Moreover, to the extent that the terms "right," "left," "right end" and "left end" are used herein, it is understood that these terms have reference to the structure shown in the drawings as it would appear to a person viewing the drawings and are merely a convenient designation to facilitate the description of the invention with respect to such drawings.

DESCRIPTION

Fig. 1 Embodiment

An improved, balanced, free piston engine **11** of the present invention is generally shown in FIG. 1. The free piston engine **11** includes a double-acting power section **12**, a synchronizer-balancer section **13**, and an energy absorbing device section, shown at **14**, between the power section and the synchronizer-balancer section. The energy absorbing device section in this case includes two devices, i.e., two double-acting reciprocal compressor sections **14***a* and **14***b*.

The power section **12** includes a cylindrical housing **15** which has a power cylinder **16** formed therein. A double-acting power piston **17** is positioned within the cylinder **16** for reciprocal movement therein substantially parallel to the longitudinal axis of the cylinder **16**. The piston includes a first outer power piston portion **18**, a second inner power piston portion **19** and a generally cylindrical portion **21** interconnecting the outer power piston portion **18** and the inner power piston portion **19** so that they reciprocate together as a unit and form a single, alternately acting double-acting power piston. Piston rings **22** are carried in grooves formed in the piston **17** for minimizing the leakage of gases between cylinder **16** and the piston member **17**.

The left end **23** of the housing **15** is closed by a cylinder head **24** which is bolted to the end **23** of the housing **15** by bolts **25**. The cylinder head **24** together with the outer portion **18** of the power piston **17** define a first combustion chamber **26** in the left or outer section of cylinder **16**. A conventional fuel injector unit **27** is positioned in an aperture **28** formed in the cylinder head **24** so that its inner end communicates with chamber **26**.

Similarly, the right end **29** of the housing **15** is closed by a cylinder head **34** which is bolted to the end **29** of the housing **15** by bolts **30**. The cylinder head **34** together with the second power piston portion **19** of the piston **17** define a second combustion chamber **31** in the right or inner section of cylinder **16**. A further conventional fuel injector unit **32** is positioned in an aperture **33** formed in the cylinder head **34** so that the inner end of fuel injector **32** communicates with the inner combustion chamber **31**.

The inner cylinder head **34** also forms a wall between the power section **12** and the first energy absorbing device section **14***a*. In order to provide a connection between the power piston and the first energy absorbing device, the cylinder head **34** has a central aperture **36** formed therein so that the central longitudinal axes of the aperture **36** and the cylinder **16** are coaxial. Conventional combustion chamber shaft seals **37** are positioned in the aperture **36**. Shaft seals **37** must withstand the temperature and pressure of the combustion chamber **31**, and seals of this kind are well known in the art.

A duct **39** is shown connected with housing **15** to provide communication between a plurality of peripherally spaced dual inlet ports or openings, of which one pair is shown at **41***a* and **41***b* , and a source (not shown) of air or fuel-air mixture. A plurality of peripherally spaced dual exhaust ports or openings, of which one set is shown at **42***a* and **42***b*, permit combustion gas in the combustion chambers **26** and **31** to be exhausted from cylinder **16**.

Piston **17** is fastened to the left end of a shaft **44**, e.g., by bolt **45**. The right end of shaft **44** is connected with the left end of a double-rack member **46** by another bolt **47**. Rack member **46** constitutes a movable first portion of a synchronizer-balancer assembly **48** included in the combination of the present invention. The shaft **44** interconnecting the power piston **17** and the double-rack member **46** extends into the first energy-absorbing device section **14***a* of the engine through the aperture **36** formed in the cylinder head **34** and is sealed by the conventional combustion chamber shaft seals **37**.

The power piston portions **18** and **19** of piston **17** are interconnected with the movable first portion **46** of the synchronizer-balancer assembly by shaft **44** as parts of a power assembly **43** which is adapted for translational reciprocating movement as a unit back and forth along the central longitudinal axis of the power cylinder sections and piston portions. Thus, in engine **11**, the power assembly **43** includes the double-acting power piston member **17**, and the shaft **44**, the double-rack member **46**, together with the bolts **45** and **47** and many other fastening means utilized to interconnect the aforementioned parts, and the piston rings **22**.

The synchronizer-balancer section **13** includes housing portion **49**, which has its left end closed by a partition wall **50**. Bolts **51** fasten the housing **49** and end wall **50** to the right end of cylindrical housing **52** of the second energy-absorbing device section **14***b*. The other end of housing **52** is closed by a partition wall **53**, and these parts are connected to the right end of cylindrical housing **54** by bolts **55**. Housings **54** and **52** serve as separate first and second compressor cylinders in which the respective first and second compressor pistons **56** and **57** are mounted for translational reciprocating movement along the central longitudinal axis of the engine. Piston **56** is secured to shaft **44** and thus moves as a unit with power assembly **43**. Piston **57** is connected to move as a unit with the movable counterbalancing second portion **59** of the synchronizer-balancer assembly **48**. For this purpose, the hollow shafts **58** are secured to piston **57** and to the left ends of upper and lower racks, **62** and **63** respectively, of the counterbalancing portion **59** by means of bolts **65** extending through the hollow shafts **58** into the threaded recesses **61**. Shafts **58** pass through openings **75** and suitable sealing members **76** in wall **50**. Piston **57** has a central opening **77** and appropriate sealing member **79** and **80** for central openings **60** and **64** in walls **50** and **53**, respectively, permit translational movement of shaft **44** without undesired leakage or fluid flow along the shaft.

The synchronizer-balancer assembly, which may be referred to for convenience as the "Braun Mechanism," is described in detail in U.S. Pat. application Ser. No. 805,063 filed Dec. 17, 1968, by Anton Braun. Briefly, it includes the movable first portion **46**, the movable counterbalancing second portion **59**, and interconnecting means for providing synchronized translational reciprocating movement of counterbalancing portion **59** in opposite directions to the corresponding translational reciprocating movements of the first portion **46**. This interconnecting means is preferably a pair of pinions **66** and **67** carried on pivots **68** and **69** supported between two parallel wall portions **70** projecting longitudinally from the right-hand wall member **72** on each side of movable portion **46** of the synchronizer-balancer assembly **49**. Bolts **73** secure wall **72** to housing **49**. The pinions engage back-to-back rack members **81** and **82** on the first movable portion **46** and are driven thereby in opposite rotary directions. This rotary movement in turn is transmitted to the opposed racks **62** and **63** carried by the movable counterbalancing portion **59** of the assembly.

Portion **59** includes two side plates **74** extending vertically between and rigidly interconnecting the racks **62** and **63**. The

respective first and second portions of the synchronizer-balancer assembly preferably have their mass or weight distributed symmetrically about the central longitudinal axis of translational movement of the parts so that there are no unbalanced forces or movements produced during operation of the assembly.

Thus, the two movable members of the energy absorbing devices, in this case compressor pistons **56** and **57**, are respectively connected to the power assembly and to the oppositely moving counterbalancing portion of the synchronizer-balancer assembly, so that these pistons have translational reciprocating movement along the same central axis in opposite directions toward and away from each other. The various parts of the synchronizer-balancer assembly have sufficient strength to receive and transmit the forces involved in the power strokes of the power assembly and the driving of the energy-absorbing devices without substantial wear, distortion or other damage to the synchronizer-balancer parts.

To achieve dynamic balance, the product of the sum of all the weights associated to move with the movable counterbalancing portion **59** of the synchronizer-balancer assembly **48** times the corresponding distances all these weights move during a stroke of the engine must be equal to the product of the sum of all the weights associated to move with the power assembly **43** times the length of the corresponding stroke of the assembly **43** in the opposite direction. The weights associated to move with the counterbalancing movable portion of the synchronizer-balancer assembly **48** of FIG. **1** include the weights of the parts of the counterbalancing portion itself, i.e., racks **62** and **63**, side plates **74**, and the pins (not shown) connecting racks **62** and **63** to the side plates, as well as the weights of the compressor piston **57**, shafts **58**, and bolts **65**. Means for adjusting the total weight of the counterbalancing movable portion may also be provided, as discussed below in connection with the preferred embodiment of FIGS. **3** and **4**.

The weights associated to move with the power assembly **43** of FIG. **1** include the weights of the parts of the power assembly itself, i.e., the power piston **17**, piston rings **22**, shaft **44**, double-rack member **46**, and bolts **45** and **47**, as well as the weight of the compressor piston **56** and any other elements such as scavenge pistons or other control members which are actually connected to move as a unit with the power assembly.

The pistons **56** and **57** divide the respective compressor cylinders **54** and **52** into four compressor chambers **83**, **84**, **85** and **86** as shown in FIG. 1. These chambers may be provided with respective inlet valves **87**, **88**, **89** and **90**, and corresponding outlet valves **91**, **92**, **93** and **94**. The chambers **83** and **86** will be increasing in volume while power assembly **43** moves from left to right. At the same time, chambers **84** and **85** will be decreasing in volume. Conversely, when power assembly **43** moves from right to left, chambers **83** and **86** will be decreasing in volume, while chambers **84** and **85** are increasing in volume.

These compressor chambers may be used as four separate compressors or may be interconnected in various ways. For example, two or more chambers may be connected in series to provide a plurality of successive compression stages. Two oppositely acting chambers such as **83** and **84** may be connected in parallel to provide alternating portions of a single stage compressor. Two similarly acting chambers such as **84** and **85** may be connected in parallel for increased single stage output volume. If desired, one or more of the chambers may be connected directly, or through a suitable resevoir, to conduit **39** to function as scavenge compressors for the double-acting power cylinder section.

Special piston constructions, such as stepped pistons and cylinders (not shown) may be used for additional chambers or stages, if desired.

A major advantage of the engines according to the present invention is that they can provide twice the work output per cycle with the same capacity synchronizer and with substantially less than twice the overall size and weight, as compared to prior engines, with only one power stroke per cycle. I have found that the synchronizer-balancer parts, which must be strong enough to transmit and withstand the forces involved in a power combustion stroke in one direction, can also transmit and withstand the forces involved in a return power combustion stroke in the opposite direction, without the necessity of adding substantial mass or reinforcement. Thus, the doubling of the work output can be achieved by adding only the weight of a second power piston portion and power cylinder section, without adding to the weight of the other elements of the engine.

An additional advantage of the present invention, as described above, may now be graphically represented. FIG. **2** shows the velocity versus stroke relationship between the power assemblies of engines according to the present invention, as shown in solid line **95**, and single-acting prior engines having power strokes in only one direction, as shown in dashed line **96**. Both are shown with respect to the swept stroke as of the engine. Both curves start at the origin **97**, as it represents the left endpoint position of the power assembly where the power assembly is at zero velocity. Both curves return to the axis at the right endpoint or dead center position of their power assemblies, where again the velocities are zero. As can be seen from a comparison of the two representation, the velocity upon the rightward stroke of engines according to the present invention, represented by the top-half **98** of curve **95**, is substantially identical to the velocity upon the leftward stroke, represented by the bottom-half **99** of curve **95**. As can also be seen, in the case of prior engines using bouncer compressors to control the return of a power piston for successive combustion power strokes, the velocity during the rightward power stroke as represented by the top half **100** of curve **96** is not equal to the velocity during the leftward return stroke, represented by the bottom-half **101** of curve **96**.

Thus, engines according to the present invention have a naturally equal stroke-time function. This naturally equal stroke-time function may be particularly important in association with certain energy-absorbing devices. For example, with respect to the energy-absorbing device in the form of the compressor piston **56** of FIG. **1**, substantially identical pressure versus time wave forms may be produced in chambers **84** and **83**, respectively, upon the rightward and leftward strokes of the engine. This may also be important in certain other forms of energy-absorbing devices, for example hydraulic pumps or alternating current wave generators, which may be used in engine **11** in place of the compressors illustrated in FIG. **1**.

FIG. 3 Embodiment

A preferred embodiment of the free piston engine of the present invention is shown at **102** in FIG. **3**. The engine **102** includes sections which provide three different functional components, that is a combustion or power component, and energy absorbing or load component, and a synchronizer balancer component. The combustion of power component includes two oppositely arranged single-acting power sections **103** and **104** located at opposite ends of the engine **102**. Between these spaced power sections, the energy-absorbing device is shown as a compressor unit **105**, and the synchronizer-balancer section is shown at **106**.

The two power sections **103** and **104** are essentially identical, except that they are positioned so that they are arranged with cylinder heads at their opposite outer ends. Thus, the left-hand section **103** includes a cylinder **107** which is closed at the left end by a cylinder head **108** which fits within the left end of cylinder **107**. The right-hand power section **104** has a similar cylinder head **109** at its outer end to provide a closure for the outer end of the combustion chamber of cylinder **110**. Thus, the open ends of the respective cylinder sections are directed oppositely, i.e., inwardly toward each other, and these cylinder sections have their central longitudinal axes in alignment with each other so that the cylinders are coaxial.

Power piston portions **111** and **112**, which are, in this embodiment separate individual pistons, are positioned in the respective power cylinders and are interconnected with each other for translational reciprocating movement back and forth

along the common central longitudinal axis of the respective cylinders and pistons as a unit. For this purpose, shaft portions **113, 114** and **115**, together with the movable central portion **121** of the synchronizer-balancer assembly **122** provide an essentially rigid connection between the two power pistons and a first compressor piston **123**, to insure movement of all of these parts together as unitary members of a common power assembly.

The outer faces of the respective pistons and the corresponding cylinder heads define internal combustion chambers **124** and **125** within cylinders **107** and **110**, respectively. In FIG. **3**, with the power pistons at the right end of the respective combustion chambers, the engine is in position for combustion of a fuel-air mixture in the chamber **125**, which occurs after compression of the air or the fuel-air mixture between the outer face of piston **112** and the cylinder head **109**, in accordance with the principles of operation of conventional internal combustion engines. In the case of a diesel engine, conventional fuel injectors **126** and **127**, on their respective cylinder heads, communicate with the chambers **124** and **125**. Of course, combustion of the fuel-air mixture in these chambers may also be accomplished by use of a conventional spark plug and accompanying ignition system.

In the event, combustion in chamber **125** will drive its piston **112** and the associated parts, which also include piston **111**, to the left in the figure to compress a suitable mixture in the left-hand chamber **124**. Such compression will then be followed by an alternate firing stroke in that chamber to drive the piston members again to the right.

Air under pressure is introduced into the respective combustion chambers through one or more intake ports, such as those shown at **128** and **129**. The air is drawn into annular chambers **130** and **131** through one-way valves **132***a* and **132***b*. Openings **133***a* and **133***b* between these chambers and the respective inner ends of the cylinders **107** and **110** permit the inner ends of the power pistons to function as scavenge compressors to draw air into the annular chambers and then to compress it and force it into the combustion chambers at the end of each combustion or power stroke. The hot combustion gases are exhausted from the chambers **124** and **125** through exhaust ports **134***a* and **134***b* arranged in known manner.

In this embodiment of the engine, the energy-absorbing device or load section **105** is illustrated as a compressor having a central cylindrical housing **136** enclosed a cylindrical bore **137** which is also coaxial with the power cylinders. Within this compressor cylinder **137**, the first compressor piston **123** is located for translational reciprocating movement back and forth along the common central longitudinal axis. Piston **124** is rigidly interconnected to the two power pistons by shafts **113, 114, 115** and portion **121**, previously described. Thus, these three pistons move together in the engine as a unit and constitute parts of the power assembly of the engine.

A second compressor piston **138** is also located in compressor cylinder **137** for translational reciprocating movement along the same central axis. This second piston **138** has a central aperture **139** permitting relative movement of the piston along shaft **114**. Piston **138** is rigidly connected by a tubular section **140** to the movable counterbalancing second portion **141** of the synchronizer-balancer assembly **122**. Suitable sealing means **142** prevents leakage of fluid through the central aperture **139** of piston **138** along shaft **114**. Similarly, seal **143** prevents leakage between the outer surface of tubular connection **140** and the partition wall **144** which separates the compressor or energy absorbing section **105** from the synchronizer-balancer assembly section **106**.

The synchronizer-balancer assembly is again shown as a "-Braun Mechanism," described generally above. In addition to the movable first portion **121** and movable counterbalancing second portion **141**, the assembly includes interconnecting means for providing synchronized translational reciprocating movement of the counterbalancing portion **141** in opposite directions to the corresponding translational reciprocating movement of the first portion **121**. This interconnecting means, as in FIG. **1**, includes pinions **145** and **146** on pivots **147** and **148** supported between wall portions **149** projecting from the right-hand wall member **150** of the synchronizer-balancer section **106**. These pinions engage the back-to-back rack members **151** and **152** on the first movable portion **121** and the opposed racks **153** and **154** carried by portion **141**. Thus, the two movable members of the energy-absorbing device (i.e., compressor pistons **123** and **138**) are respectively connected to the power assembly and to the oppositely moving counterbalancing second portion of the synchronizer-balancer unit, so they have translational reciprocating movement along the same central axis in opposite directions to each other.

These two pistons **123** and **138**, within the single compressor cylinder **137**, provide three compressor chambers, i.e., outer chambers **155** and **156** and a central chamber **157**. Appropriate inlet valves **158, 159** and **160** permit the entrance of air into the respective compressor chambers **155** and **157** and **156** when the pistons are moving in directions to expand the volume of these chambers.

Outlet valves **161, 162** and **163** provide for exit of air from the respective chambers during that portion of each operating stroke when the particular chamber is decreasing in volume. The various compressor chambers may again be interconnected in various ways to provide a variety of different desired operating effects.

If desired, connections may be made so that the three compressor chambers **155, 156** and **157**, or any selected pair of them, may function either as parallel compressor sections working together, or as successive stages of a multiple stage compressor.

FIG. **4** shows cross-sectional details of the synchronizer-balancer assembly **122** and particularly indicates the manner in which the respective movable portions of the assembly have their weight distributed symmetrically about the central longitudinal axis which extends along the center of member **121** and its retaining bolt **164**. The mechanism is enclosed within cylindrical housing **165**. The upper and lower racks **153** and **154** are rigidly connected by side plates **166** and **167** and pins **168**, so that all these parts slide longitudinally as a unit. To facilitate the balancing of the engine in different applications, the movable counterbalancing portion **141** of the synchronizer-balancer assembly is provided with means for adjustment of its effective weight. For this purpose, the movable members **166** and **167** can be readily removed and replaced by movable wall members of different weights. Alternately, weight may easily be removed from or added to movable wall members **166** and **167** without replacing them, for example by the use of separate supplemental weight members **169** and **170** secured by bolts **171** to these wall members. In this way, standard movable members **169** and **170** may serve for a variety of different energy absorbing devices.

This "Braun Mechanism" is capable of transmitting relatively large instantaneous differential forces between the power assembly, including power pistons **111, 112** and first compressing piston **123** on the one hand and the second compressor piston **138** and counterbalancing portion **141**, on the other hand, with minimal losses due to friction. By this particular arrangement of racks and pinions, the substantial normal forces resulting from the engagement of teeth of the racks and pinions do not and cannot cause any substantial loss of energy, due to friction, since there is no sliding contact caused by these normal forces between the racks of the synchronizer and any other relatively fixed member, such as a fixed guide member. Thus, the normal forces are completely balanced within the synchronizer. Furthermore, frictional losses in the assembly are further reduced, since the movable first portion **121** and the counterbalancing movable portion **141** and its racks **153** and **154** are self-aligning and inherently seek a position relative to pinions **145** and **146** in which the forces created by the meshing of teeth of the pinions and racks are minimized.

The engine of FIGS. 3 and 4 also has the advantages described in connection with the embodiment of FIG. 1 in that it can provide twice the work output per cycle with the same capacity synchronizer and with substantially less than a doubling in overall size and weight, as compared to prior engines needing a bouncer compressor to control the return energy. The engine also has a naturally equal stroke-time function, and a velocity- stroke relationship similar to that illustrated by the solid curve 95 in FIG. 2.

CONCLUSION

From the foregoing description, it is apparent that a relatively lightweight, balanced, free piston engine of simple design can be constructed utilizing the principles of this invention to drive two or more movable energy-absorbing device members. The energy-absorbing device members may take a variety of forms in addition to the specific compressor constructions shown herein. The invention is particularly useful with energy-absorbing devices in which either a high work output or a naturally equal stroke-time function on both engine strokes is desirable or required.

The movable members of an energy-absorbing device or devices which are connected to move with the power assembly and with the counterbalancing movable second portion of the synchronizer-balancer assembly may either be actual working members (such as the compressor pistons shown herein) or may be other actuating or control members, such as cams or other elements which reciprocate as contemplated herein but are operatively connected to actuate the actual working members along some other path of movement.

Also, is should be noted that in addition to the alternately acting interconnected power piston portions and the synchronizer-balancer assembly which constitute the main or principal operating members of the free piston engines of the present invention, such engines will also normally include other elements, some of which, such as oil pump pistons, water pump pistons, fuel pump pistons, scavenge pistons, and the like, may move either with or in the opposite direction to the power pistons during operation of the engines of the present invention. For example, an auxiliary oil pump piston could be attached to and moved with the walls of the synchronizer-balancer assembly, in the opposite direction to the power pistons, or the same oil pump piston could be attached to and moved with the power assembly, in the same direction as the power pistons. Such auxiliary elements may also be driven by cams or other mechanisms in directions other than along the axis of translational movement of the power assembly and synchronizer-balancer assembly. Of course, the effective translational weight of any auxiliary piston or other movable member, i.e., that proportion of its weight which could be considered as having translational movement along said axis, must be included as a part of the weight associated with the counterbalancing portion of the synchronizer-balancer assembly or with the power assembly, as the case may be, in order to balance the engine.

It is also possible for one of the movable energy-absorbing device members to perform another function, e.g., a scavenge or bouncer compressor function. For example, outlet valves 91 and 92 in compressor chambers 83 and 84 of FIG. 1 can be connected to duct 39 as previously described, so one energy-absorbing device member (the compressor piston 56) performs a scavenge function. By eliminating valves 87, 88, 91 and 92 or by maintaining them in controlled closed positions, compressor chambers 83 and 84 could be utilized as bouncer compressors in known manner, thus performing a desired control function Similarly, by eliminating or closing valves 87, 89, 91 and 93, chambers 83 and 85 may perform a bouncer compressor function during respective movements of the power assembly in both directions. In this case each energy-absorbing device member (pistons 56 and 57) may perform an engine control function on one stroke and function as part of an energy-absorbing load device during an opposite stroke.

The foregoing description and examples suggest possible variations in the functions to be performed by an energy-absorbing device type of movable counterbalancing portion of the synchronizer balancer assembly. With reference to the specific example shown in the drawings, it will be further noted that all the power pistons of the engine are connected to move with and as part of the power assembly.

The terms "reciprocating," "reciprocal" or "reciprocatory," as used herein in connection with either such an additional engine element or a movable member of an energy-absorbing device, may include linear, swinging, rotary or other paths of movement which are not strictly or entirely along a straight line path parallel to corresponding to the longitudinal central axis of the engine cylinders. However, the weight to be attributed to such engine element or movable member in determining the total weight associated with the power assembly or with the counterbalancing portion of the synchronizer-balancer assembly is only that proportional component of the total weight of the movable member which could be considered as having effective translational movement along such a straight line path.

It should also be obvious to those skilled in the art that the engines specifically described herein could be otherwise modified without affecting the principles of the present invention. For example, other types of gears, linkages, or other mechanisms could be utilized in place of the preferred embodiment of the synchronizer-balancer assembly shown. However, such other mechanisms must be so arranged that vibrations including second and higher order vibrations are eliminated by maintaining a fixed common center of gravity of all moving elements at every instant and position.

In the foregoing specification I have accordingly described the background and nature of my invention, and some of the ways in which it may be practiced.

Now, therefore, I claim:

1. An unsymmetrical, synchronized, balanced, free piston engine arranged to drive two reciprocally and oppositely movable energy-absorbing device members comprising, in combination: means for defining a first power cylinder section, means for defining a second power cylinder section with its central longitudinal axis substantially coaxial with the corresponding axis of the first power cylinder section; a first power piston portion reciprocable along said axis in the first power cylinder section, a second power piston portion reciprocable along said axis in the second power cylinder section; said first and second power piston portions being interconnected for simultaneous translational reciprocating movement back and forth as a unit along said axis, said power cylinder sections and a piston portions defining respective combustion chambers arranged to provide a power strike for the first power piston portion in one direction, and a power stroke for the second power piston portion in the opposite direction along said axis, means for causing combustion alternately and successively in the respective combustion chambers and thereby providing the reciprocating movement of said interconnected power piston portions; a synchronizer-balancer assembly having a movable first portion connected for reciprocating movement as a unit with said power piston portions, said assembly also having a movable counterbalancing second portion, and means interconnecting said movable first and second portions for reciprocating movement of the second portion in a direction opposite to the direction of movement of the first portion, said interconnected power piston portions and said movable first synchronizer-balancer portion constituting parts of a power assembly; a first movable energy-absorbing device member mounted for reciprocating movement along said axis and connected to move as a unit with said power assembly; and a second movable energy-absorbing device member mounted for reciprocating movement along said axis and connected to move as a unit with said movable counterbalancing second portion of the synchronizer-balancer assembly, said synchronizer-balancer assembly having a construction transmitting relatively large

instantaneous differential forces between said power assembly and said counterbalancing portion (and their respective energy-absorbing device members), the movable counterbalancing second portion having a preselected weight such that the absolute value of the product of all weight associated to move with the power assembly multiplied by the length of its stroke is substantially equal to the absolute value of the product of all the weight associated to move with the counterbalancing portion multiplied by the length of its corresponding stroke.

2. The free piston engine of claim 1 in which the first and second movable members are parts of a single energy-absorbing device.

3. The free piston engine of claim 2 in which the first movable member of an energy-absorbing device is a first compressor piston, the second movable member of an energy-absorbing device is a second compressor piston, and said first and second compressor pistons are parts of a single energy-absorbing device having a compressor cylinder in which said compressor pistons move toward and away from each other.

4. The free piston engine of claim 3 in which said compressor pistons and compressor cylinder have their central longitudinal axis coaxial with that of the power cylinder sections, and said compressor cylinder is located axially between one of said power cylinder sections and said synchronizer-balancer assembly.

5. The free piston engine of claim 1 in which the first movable member is part of a first energy-absorbing device and the second movable member is part of a second energy-absorbing device.

6. The free piston engine according to claim 5 in which each of the first and second energy-absorbing devices has a separate compressor cylinder with a partition therebetween and each of said compressor cylinders has its central longitudinal axis coaxial with that of the power piston portions.

7. The free piston engine according to claim 6 in which said compressor cylinders are located axially adjacent each other between the synchronizer-balancer assembly and at least one of said power piston portions.

8. The free piston engine of claim 1 having shaft means connecting the movable first portion of the synchronizer-balancer assembly to the power piston portions and to the first movable energy-absorbing device member, the central longitudinal axes of all of the shaft means, power piston sections, movable first portion and first movable member being coaxial.

9. The free piston engine of claim 1, wherein the second power cylinder section is adjacent to, coaxial with, and interconnected with the first power cylinder section to form a double-acting power cylinder, wherein the first power piston portion and the second power piston portion are interconnected as parts of a single double-acting power piston, and wherein the combination of the double-acting power piston and the double-acting power cylinder form a double-acting power section.

10. The free piston engine of claim 1, wherein the first power piston portion and the first power cylinder section comprise a first single-acting power section, wherein the first single-acting power section is positioned at one end of the engine, and wherein the second power piston portion and the second power cylinder section comprise a second single-acting power section.

11. The free piston engine of claim 10, wherein a first combustion chamber is defined in the first power cylinder section between the outer face of the first power piston portion and the closed outer end of the first power cylinder section, and wherein a second combustion chamber is defined in the second power cylinder section between the outer face of the second power piston portion and the closed outer end of the second power cylinder section.

12. The free piston engine of claim 10, wherein the second single-acting power section is positioned on the other end of the engine opposite from the first single-acting power section.

13. The free piston engine of claim 1, wherein the first power cylinder section and first power piston portion define a first combustion chamber at one end of the engine, the second power cylinder section and second power piston portion define an oppositely acting second combustion chamber at the opposite end of the engine, and the synchronizer-balancer assembly is located between said combustion chambers.

14. The free piston engine according to claim 13 in which the first and second movable members are parts of a single energy-absorbing device located between said combustion chambers along the central longitudinal axis of the engine.

15. The free piston engine according to claim 13 in which the first movable member is part of a first energy-absorbing device, the second movable member is part of a second energy-absorbing device, and each of said energy-absorbing devices is located between said combustion chambers along the central longitudinal axis of the engine.

16. The free piston engine of claim 15 in which said synchronizer-balancer assembly is located axially adjacent one of said power cylinder sections and said energy-absorbing devices are located axially between said synchronizer-balancer assembly and the other of said power cylinder sections.

17. The free piston engine of claim 1 wherein the movable counterbalancing portion of the synchronizer-balancer assembly includes counterbalancing movable weight means symmetrically distributed with respect to the common central longitudinal axis of translational movement of the power pistons.

18. The free piston engine of claim 17 having means for adjustment of the total weight of said counterbalancing movable weight means.

19. The free piston engine of claim 18 having means for removal of at least a portion of said counterbalancing movable weight means.

20. The free piston engine of claim 17 wherein the total weight of the movable counterbalancing portion of the synchronizer-balancer assembly is greater than the weight required to counterbalance only the movable first portion of the synchronizer-balancer assembly.

21. A free piston engine according to claim 1 in which the power assembly includes all the power pistons of the engine and in which all main components of the power assembly always move together as a unit.

22. A free piston engine according to claim 1 in which one of the movable energy-absorbing device members performs an engine control function.

23. A free piston engine according to claim 1 in which the first and second movable energy-absorbing device members are compressor pistons.

24. A free piston engine according to claim 23 in which one compressor piston functions at least in part as a scavenge compressor piston.

25. A free piston engine according to claim 24 in which each compressor piston is a member of an energy-absorbing load device.

26. A free piston engine according to claim 1 in which each movable energy-absorbing device member is axially spaced from the sychronizer-balancer assembly along the central longitudinal axis of the engine.