

Dec. 1, 1959

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2,914,955

SYNCHRONIZING MECHANISM FOR FREE PISTON ENGINES

Filed Nov. 12, 1957

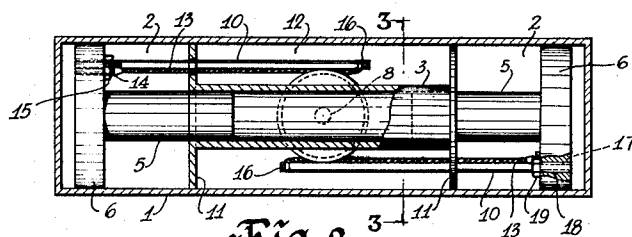


Fig. 2

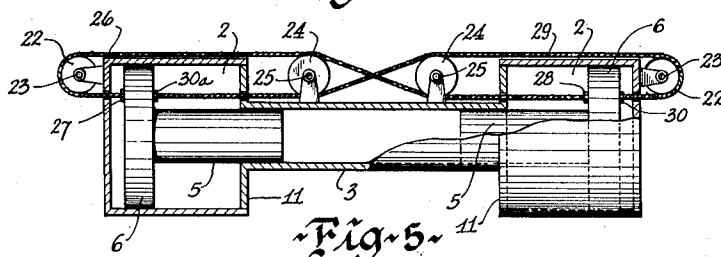


Fig. 5

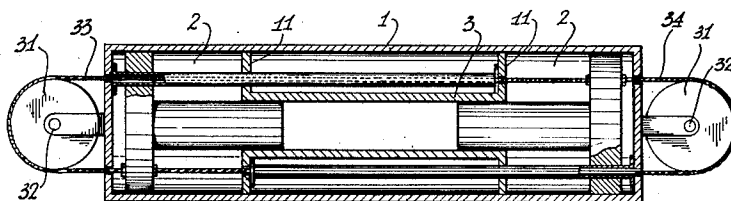


Fig. 6

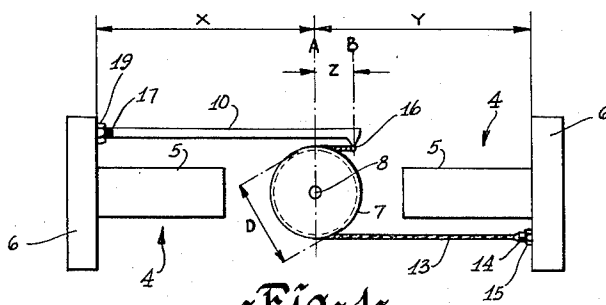


Fig. 1

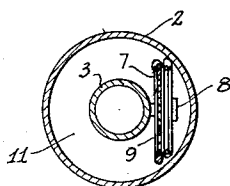


Fig. 3

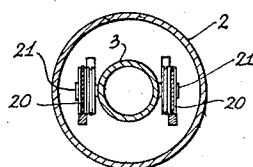


Fig. 4

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## SYNCHRONIZING MECHANISM FOR FREE PISTON ENGINES

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Application November 12, 1957, Serial No. 695,813

4 Claims. (Cl. 74-110)

This invention relates to a synchronizing mechanism for free piston engines.

In free piston engines, a pair of axially aligned pistons or piston assemblies are mounted for reciprocating motion in their respective cylinders. Due to small differences in friction and/or pressure, the two piston assemblies would not always operate in exact relative motion with respect to each other unless means were provided to synchronize their movements. It is thus conventional practice to provide a synchronizing device such as a rack and pinion, parallelogram linkage, or the like, to constrain the relative motion of the piston assemblies with respect to each other and also with respect to the rest of the engine.

The conventional synchronizer system must be manufactured with great care and accuracy and consequently this portion of the engine, although it is basically not essential for the operation of the engine, is relatively costly, sensitive and difficult to maintain. Furthermore, such a synchronizer is quite heavy and thus considerably decreases the speed of the engine. Since, moreover, in the operation of these devices, the forces reverse once in every cycle, knocking occurs between the fitted parts.

It is a general object of the present invention to provide a synchronizer for free piston engines which is simple and inexpensive to manufacture, which is light in weight and which is subject to some elasticity in operation, whereby the disadvantages set forth above are in large part avoided.

Other objects, details, and advantages of the invention will become apparent from the following description, with particular reference to the accompanying drawing, in which, for clarity of illustration, only those parts of the engine necessary for a clear description of the invention have been shown, and in which

Figure 1 is a diagrammatic elevation of a portion of a free piston engine showing one half of a synchronizer device in accordance with the invention,

Figure 2 is a side elevation, partly in section, showing diagrammatically a free piston engine with a synchronizer in accordance with the invention incorporated therein,

Figure 3 is a sectional elevation on line 3-3 of Figure 2,

Figure 4 is a corresponding sectional elevation of a somewhat modified arrangement,

Figure 5 is a side elevation, partly in section, showing diagrammatically a free piston engine with a somewhat modified form of synchronizer in accordance with the invention incorporated therein, and

Figure 6 is a side elevation, partly in section, showing diagrammatically a free piston engine with a still further modified form of synchronizer in accordance with the invention.

Referring to Figures 1, 2 and 3, 1 is an engine housing having therein a pair of axially aligned compressor cylinder sections 2 and a central power cylinder section 3. A pair of piston assemblies 4 are reciprocally mounted in the cylinders, each piston assembly having a power

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piston portion 5 in cylinder 3 and a compressor piston portion 6 in one cylinder 2.

A synchronizer mechanism in accordance with the invention comprising a sheave 7 is mounted on a shaft 8 supported by the engine housing on one side of the axis thereof. The axis of sheave 7 in the modification shown, is at right angles to the axis of the piston assemblies 4 (and their cylinders) and substantially midway between the outer ends of cylinders 2. Sheave 7 has a pair of peripheral grooves 9. A column 10 is mounted on each compressor piston 6 and extends perpendicularly from the inner face thereof through the inner end wall 11 of cylinder 2 and into the space 12 between such inner end walls 11. Each column 10 is in approximate alignment with a respective one of the peripheral grooves 9 of sheave 7 and closely adjacent the periphery of the sheave. As shown, each column 10 extends past a plane, indicated at A in Figure 1, perpendicular to the column and passing through the axis of the sheave, to or somewhat beyond a point lying on a plane, indicated at B in Figure 1, perpendicular to the column and tangential to the sheave.

A flexible line 13, which may comprise a rope, cable, chain, wire, tape, strip or the like, connects each piston 6 with the end of the column 10 carried by the other piston 6. As shown, each line 13 has one end anchored in piston 6 as by means of a screw-threaded connector 14 which is axially adjustable in the piston as by means of a nut 15 in order to make fine adjustments in the length of the line 13. Each line 13 extends about sheave 7, being received in a respective groove 9 therein, and its other end is anchored, as indicated at 16 in the end of the column 10 carried by the other piston 6. It will be apparent that the portions of each line 13 extending from the sheave 7 are generally parallel to the axis of the pistons 6 in the modification shown.

Each column 10 is preferably adjustable as to length in a minor degree. The means for adjustment may be conveniently associated with its mounting on piston 6. As shown, a screw-threaded end portion 17 has threaded engagement with a socket 18 in the piston, and a lock-nut 19 may be employed to lock the column in any desired position.

The functioning of the device will now be explained with initial reference to Figure 1, wherein  $x$  is the distance from the inner face of one piston 6 and plane A,  $y$  is the distance from the inner face of the other piston 6 to plane A, and  $z$  is the distance between planes A and B. Dimension  $x+z$  is the effective length of column 10 and is fixed. If  $y$  is chosen so that  $y=x$ , then the total distance of the pistons 6 from one another is  $x+y$ . At a certain instant, the distance of the left hand piston 6 from the center of the engine, as represented by the plane A, must be the same as the distance of the right hand piston 6 from the center. Any motion of left hand piston 6 towards the center will necessitate a simultaneous motion of right hand piston 6 towards the center. So long as the length of line 13 is fixed, the position of each piston 6 with respect to the other as well as to the center of the engine, for any point of displacement of the pistons, is positively determined for the inward motion of left hand piston 6 and the outward motion of right hand piston 6.

With now a column 10 mounted on right hand piston 6 and a line 13 extending from such column to left hand piston 6, as in Figure 2, the two remaining motions of the pistons, that is, the inward motion of right hand piston 6 and the outward motion of left hand piston 6, are also synchronized. A simple mechanism is thus provided that positively synchronizes the two opposed reciprocating piston assemblies.

The following algebraic approach will underline some of the characteristics of the device and its stability:

From Figure 1 it will be apparent that

$$l_1 = \pi D/2 + y + z = \text{length of line 13} \quad (\text{I})$$

$$l_c = x + z = \text{length of column 10} \quad (\text{II})$$

For the proper operation of the engine it is necessary that at any position:

$$x = y \quad (\text{III})$$

From Equation II:

$$x = l_c - z$$

If this value of  $x$  is substituted in Equation I in place of  $y$  (since  $x=y$ ), the length of the line 13 that satisfies  $x=y$  will have to be:

$$l_1 = \pi D/2 + l_c - z + z = \pi D/2 + l_c \quad (\text{IV})$$

This means that, if the sheave diameter is regarded as constant, the length of the line 13 depends upon the length of the column only and only the length  $l_1$  expressed by Equation IV will satisfy  $x=y$ .

Since the outermost position of left hand piston 6 is determined by  $l_c$ , the maximum possible distance of the two pistons from one another, measured from their inner surfaces, will be  $L_{\max.} = 2 l_c$ .

An increase in the length of line 13 will allow right hand piston 6 to move a like distance away from the center if the position of left hand piston 6 remains unchanged. The same applies, in a reverse sense, to a decrease of  $l_1$  of line 13. However, any such change in length of line 13 can be balanced with a corresponding adjustment of the length of the column  $l_c$ , so that it is quite possible to adjust for any change of length during operation of the engine without necessitating a change of position of pivot 8.

Thus, the effect of a change in one set of synchronizing devices, that is, one column with its flexible line, on the other set is as follows:

If the position of, say, left hand piston 6 were fixed, an increase of  $l_1$  of line 13 would tend to move the right hand piston 6 outwardly; since column 10 is connected to the right hand piston this would result in a slackening of left hand line 13. Taking up this slack by moving the right hand piston inwardly or the left hand piston outwardly would result in transferring the same slack to right hand line 13. Therefore, the only way to take up this slack or compensate for a lengthening of one line 13 is to shorten the other line 13, thus changing the relative positions of the pistons with respect to the engine, or to bring the first line 13 back to its original length  $l_1 = \pi D/2 + l_c$ .

If this slack were not taken care of, the device would operate under unfavorable dynamic conditions resulting in jerking motion with mechanical knocking. If, on the other hand, the lines 13 were slightly stressed, any play in connections would be eliminated and knocking at the positions of change of load could readily be avoided.

In cases where it appears desirable to arrange the sheave off center, for instance, in order to operate with a shorter column, the length of the line 13 would have to be adjusted accordingly.

It will be apparent that, to achieve a proper positioning of the piston assemblies after the synchronizing mechanism is installed and to obtain the proper tension on line 13, simple adjustments only of the lengths of lines 13 and columns 10 by the means such as described are necessary.

Figure 4 illustrates a modification wherein, instead of a common sheave with two grooves for both sets of synchronizing devices, two separate sheaves 20 are provided, one for each line 13, these sheaves being symmetrically arranged on pivots 21 one on each side of the axis of the engine.

Referring to Figure 5, a further modified form of the invention is illustrated therein. A sheave or pulley 22

is mounted on a shaft 23 on the outer end of each cylinder section 2 adjacent the periphery thereof. A pair of pulleys 24 on shafts 25 are mounted between the inner ends of cylinder sections 2. Preferably, each pulley 24 has a double-grooved periphery. Pulleys 22 and 24 are, as shown, in aligned relation and are of uniform diameter. A flexible line 26 has one end anchored in the outer face of left hand piston 6 as by means of an adjustable connector 27. Line 26 then extends through the outer end wall of adjacent cylinder 2, over pulley 22, along the outer side of such cylinder 2, over one pulley 24, under the other pulley 24, through the inner end wall of the other cylinder 2, and has its other end anchored in the inner face of the right hand piston 6 as by adjustable connector 28. Another flexible line 29 has one end anchored in the outer face of right hand piston 6 as by adjustable connector 30, and extends through the outer end wall of adjacent cylinder 2, over pulley 22, along the outer side of such cylinder 2, over right hand pulley 24, under left hand pulley 24, through the inner end wall of the left hand cylinder 2, and has its other end anchored in the inner face of left hand piston 6 as by adjustable connector 30a. It will be apparent that a turnbuckle or similar means could also be inserted in line 26 or 29 for adjustment as to the length thereof. It will also be apparent that operation of the synchronizing mechanism shown in Figure 5 will be similar to that of the mechanism previously described. It will be understood that instead of the arrangement of pulleys 24, as shown, other pulley arrangements may be employed.

Figure 6 illustrates still another modified form of the invention. As shown, a pulley 31 is mounted on shaft 32 on the outer end wall of each cylinder section 2. A flexible line 33 has one end anchored in the outer face of left hand piston 6 and extends through the outer end wall of its cylinder 2, over adjacent pulley 31, back through such outer end wall of cylinder 2, through such cylinder 2 and the piston 6 therein, through the inner end wall of left hand cylinder 2, along the outer side of cylinder section 3, through the inner end wall of right hand cylinder 2, and has its other end anchored in the inner face of right hand piston 6. Similarly, a second flexible line 34 has one end anchored in the outer face of right hand piston 6 and extends through a like path in the reverse direction with its other end anchored in the inner face of left hand piston 6. As before, the operation, in function and effect will be substantially the same as in the previously described modifications.

We claim:

1. A synchronizing mechanism for two axially aligned reciprocating pistons having inward and outward strokes which comprises a flexible line having one end fixed to a first one of said pistons and its other end fixed to the second one of said pistons, guide means including a pulley engaging an intermediate portion of said flexible line to maintain tension thereon during the inward stroke of said first piston and the outward stroke of said second piston, a second flexible line having one end fixed to said second piston and its other end fixed to said first piston, and guide means including a pulley engaging an intermediate portion of said second flexible line to maintain tension thereon during the inward stroke of said second piston and the outward stroke of said first piston.

2. A synchronizing mechanism for first and second axially aligned reciprocating pistons having inward and outward strokes which comprises a first rigid column fixed to said first piston and extending perpendicularly from the inner face thereof, a second rigid column fixed to said second piston and extending perpendicularly from the inner face thereof, a pulley fixedly mounted between said pistons and between the end portions of said columns, a tensioned flexible line having one end anchored to the end of said first column and its other end anchored to said second piston, and a second flexible line

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having one end anchored to the end of said second column and its other end anchored to said first piston, said pulley having a peripheral portion in engagement with an intermediate portion of said first flexible line and a second peripheral portion in engagement with an intermediate portion of said second flexible line.

3. A synchronizing mechanism for first and second axially aligned reciprocating pistons having inward and outward strokes which comprises a first rigid column fixed to said first piston and extending perpendicularly from the inner face thereof, a second rigid column fixed to said second piston and extending perpendicularly from the inner face thereof, a pair of pulleys fixedly mounted between said pistons, each said column having an end portion overlying one of said pulleys, a tensioned flexible line having one end anchored to the end of said first column and its other end anchored to said second piston, and a second flexible line having one end anchored to the end of said second column and its other end anchored to said first piston, an intermediate portion of each of said flexible lines engaging an adjacent one of said pulleys.

4. A synchronizing mechanism for first and second axially aligned reciprocating pistons having inward and

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outward strokes which comprises a first pulley fixedly mounted exteriorly of and adjacent the outer face of said first piston, a second pulley fixedly mounted exteriorly of and adjacent the outer face of said second piston, a tensioned flexible line having one end anchored to the outer face of said first piston, its other end anchored to the inner face of said second piston, and an intermediate portion engaging said first pulley, and a second tensioned flexible line having one end anchored to the outer face of said second piston, its other end anchored to the inner face of said first piston, and an intermediate portion engaging said second pulley.

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