



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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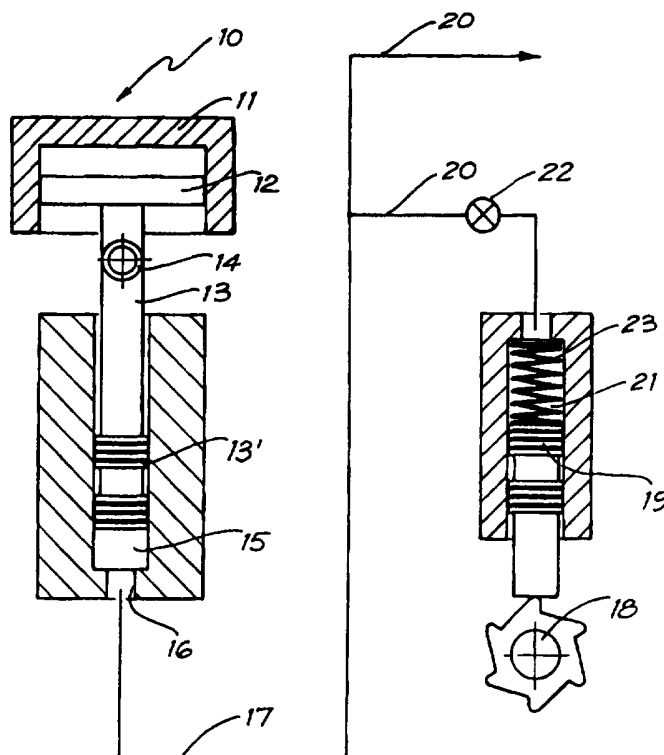
## Published

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(54) Title: FREE PISTON ENGINE

## (57) Abstract

A free piston engine (10) wherein a combustion piston (12) directly drives a pumping piston (13') to pump hydraulic fluid to and fro to a linear to rotary motion pump/motor converter which is in the form of a "split cycle" machine.



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## FREE PISTON ENGINE

### Technical Field

The present invention relates to varying the control of piston motion and in particular to methods and means for varying the stroke of a free  
5 piston in a cylinder during a cycle of operation of piston-in-cylinder motion.

### Background Art

A free piston engine essentially combines the principles of combustion and hydraulics into one engine. Combustion expands, pushing a 'combustion' piston which is rigidly attached to a "pumping piston" which  
10 together constitute the 'free' piston. The pumping piston pumps the hydraulic fluid through the power lines to a number of pump/motors which can be used in many applications.

### Disclosure of the Invention

The present invention has application to free piston-in-cylinder  
15 motion of an internal combustion engine which by means of the present invention is essentially facilitated by providing an hydraulic coupling between a chamber swept by a piston rod of a free piston internal combustion engine, the piston rod undergoing linear motion in that chamber and one or a plurality of working chambers of a rotary machine of the  
20 general form shown in our US Patents 5146880 and 5279209 but not limited to the specifics of the embodiments as shown in those specifications and which is hereinafter referred to as a "split-cycle" machine. The contents of US patent specifications 5146880 and 5279209 are incorporated herein by reference. In an arrangement of the present invention, the output of the  
25 combination is via the central rotary shaft of a rotary machine of our known type.

In one aspect the present invention provides a method for converting linear piston motion to rotary motion in a free piston engine comprising at least one free piston formed by a combustion piston and a pumping piston  
30 wherein the pumping piston pumps hydraulic fluid to at least one hydraulic pump/motor which converts the motion of said hydraulic fluid to rotary

output motion and wherein said pump/motor is a "split-cycle" machine as hereinbefore defined.

In another aspect the present invention provides a free piston engine comprising at least one free piston formed by a combustion piston and a  
5 pumping piston, wherein the pumping piston pumps hydraulic fluid via a fluid circuit to at least one hydraulic pump/motor to convert the motion of said hydraulic fluid to rotary motion and wherein the pump/motor is a "split-cycle" machine as hereinbefore defined.

To more simply explain the functioning of an arrangement of the  
10 present invention it is appropriate to assume that the bore of the pumping piston is the same as each of the bores of the working chambers of a split-cycle rotary machine to which the former is hydraulically coupled.

Assuming that the maximum piston stroke is to be, say, 36 mm and that the hydraulic coupling is to six working chambers of the split-cycle machine,  
15 then 36 mm of travel of the pumping and combustion pistons will reflect 6 mm of travel of each piston in each of six working chambers of the split-cycle machine.

To then control the stroke of the free pumping piston and hence its associated combustion piston, the hydraulic fluid flow between the pumping  
20 piston chamber and any one of the hydraulically coupled six split-cycle machine working chambers may be effected. Control of the free piston motion can be provided as follows by way of example. If movement of the free piston from top dead centre to bottom dead centre corresponds to movement of the six associated hydraulic pistons in the split-cycle machine  
25 from their respective top to bottom dead centre positions and vice versa then by the interposition of hydraulic fluid control valves in the hydraulic circuitry the stroke of the free pumping piston and hence the swept volume of its coupled combustion piston can be varied by opening or closing the fluid access to one, some or all of the hydraulically coupled working  
30 chambers of the split-cycle machine.

By the method of the present invention a four stroke free piston engine may be coupled to a split-cycle rotary machine such that a plurality of hydraulic pistons may be removed from the fluid coupling during cycles of operation of the engine as required such that it becomes possible to have, say, in the example discussed above 36 mm power and exhaust strokes with 24 mm induction and compression strokes. By such an arrangement there would be provided an 8:1 compression stroke and a 12:1 power stroke. The advantages of providing a four stroke engine which can function in that manner will be readily apparent to persons who are skilled in the art. It will also be possible by the shaping of the lobes on the lobed shafts of the hydraulically coupled split-cycle machine to advantageously control the dwell of the engine piston(s) at top dead centre. This ability to control the dwell is in marked contrast with a conventionally cranked engine.

In the present invention the motive force of the engine is transmitted to the rotary shaft of the split cycle machine via an hydraulic fluid coupling to the free piston(s). This hydraulic coupling avoids problems associated with a conventional rotary cranked engine while the free pumping and combustion pistons of the engine are constrained to follow linear motion instead of a cranked motion.

In a particularly preferred embodiment four internal combustion engine free pistons have their rods hydraulically coupled to four separate sets of six working chambers of a 24 cylinder split-cycle rotary machine which is able to integrate the firings of the four pistons and provide a smooth rotary output.

A further aspect of the present invention provides that each combustion chamber is formed with two opposed free pistons with the mode of combustion being via a two-stroke cycle. Each of the opposed pistons is hydraulically coupled to at least one of the working chambers of a split cycle rotary machine.

By providing opposed free pistons in a common combustion chamber in an arrangement in accord with the present invention, the prospect of

providing an infinitely variable control to the motion of those pistons arises. By such means, the compression ratio of the combustion chamber can be varied to accommodate a range of combustible fuels, while infinite adjustability of the exhaust port opening can provide ready control over the performance of an engine.

In this aspect of the present invention, two opposed free pistons are fitted in a common cylinder forming a combustion chamber therebetween, said pistons being mounted to respective piston rods and which rods are adapted to move linearly within respective hydraulic fluid chambers. Each free piston of each opposed pair being hydraulically coupled to at least separate ones of fluid working chambers of a split cycle machine, such that the stroke of each piston of each pair of pistons is controllable by, at least in part, the stroke of each piston of the fluid working chamber(s) of the split cycle machine to which that piston of the pair is hydraulically coupled.

#### Brief Description of the Drawings

The present invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 is a schematic arrangement view to demonstrate the method of hydraulic control of the present invention as applied to a single free piston:

Fig. 2 is a schematic view of a four cylinder free piston engine having cylinders essentially as per Fig. 1 coupled to a 24 cylinder split-cycle rotary machine;

Fig. 3 is a schematic arrangement view showing an hydraulic circuit diagram of another embodiment of the present invention which demonstrates one method of hydraulic control applied to four opposed piston pairs;

Fig. 4 is a cross-sectional view of one of the opposed piston pairs of Fig. 3 in a first configuration; and

Fig. 5 is a view similar to Fig. 4 with the opposed pistons in a second configuration permitting exhausting of a combustion chamber.

### Best Modes

The schematic arrangement of Fig. 1 shows a single cylinder free piston engine 10 having cylinder head 11 containing piston 12. Piston 12 being mounted to a piston rod 13 formed in two parts with a knuckle joint 14 therebetween.

Piston rod 13 itself forms hydraulic pumping piston 13' within hydraulic cylinder 15. Outlet 16 of hydraulic cylinder 15 is coupled via hydraulic line 17 to six working cylinders of a split-cycle rotary machine all operating at the same phase of rotation of lobed shafts 18 which are in contact with respective pistons 19 of the rotary machine. Each fluid coupling via hydraulic line 17 to the split-cycle machine hydraulic cylinder 15 is via respective parallel fluid lines 20 which branch off line 17.

Hydraulic fluid coupling between each of the cylinders or chambers 21 and line 17 is controlled via the operation of respective variably openable valves 22. Valves 22 may be solenoid valves or their equivalents. The single cylinder depicted in Fig. 1 will now be described on the basis that it is a four stroke internal combustion engine controlled to have 36 mm power and exhaust strokes while having 24 mm induction and compression strokes and where the cross-sectional area of the bore of piston 13' is the same as that of each of the bores of the six hydraulic pistons 19.

In this example a 36 mm stroke of piston 12 corresponds to 6 mm strokes for each of six pistons 19. When there has been combustion in engine 10, piston 12 moves with 36 mm over the power stroke of that piston which directly corresponds to the 6 mm movement of the six pistons 19. At the end of the power stroke of piston 12 with that piston at bottom dead centre and similarly with pistons 19 at their bottom dead centres, the exhaust stroke commences and each of valves 22 are maintained open to hydraulically link chamber 21 with piston 13' via lines 20 and 17. At the end of the exhaust stroke and on commencement of the induction stroke two valves 22 are closed so that only four pistons 19 are hydraulically coupled to

piston 13' which then allows piston 12 to only travel through a 24 mm induction stroke. For the two pistons 19 which are not hydraulically coupled to piston 13' during the induction stroke, a fluid addition will be required to their working chambers 21 to avoid suction effects in their  
5 respective working chambers. In the schematic of Fig. 1 a spring 23 is shown to provide assistance in returning piston 19 to its bottom dead centre.

At the end of the 24 mm induction stroke the compression stroke commences with the two out of circuit pistons 19 remaining that way so that the compression stroke of piston 12 is also limited to 24 mm with the top  
10 dead centre position of piston 12 remaining constant for all strokes of the engine 10 while the bottom dead centre position varying in dependence on the nature of the stroke of the engine.

In Fig. 2, the 24 cylinder split-cycle rotary machine 30 is arranged for hydraulic coupling to four engines 10 as exemplified by Fig. 1 with each  
15 engine 10 of the arrangement being associated with 6 working chambers of the machine 30. The output of the system is via the central rotary shaft at the axis of machine 30. By this method the hydraulic drive provided by outputs of a four cylinder engine may be harnessed in a way which permits variable control of the various strokes of the pistons of the engine during  
20 their cycles of operation.

The piston speeds of the engine cylinders can be limited to give suitable control to the hydraulic transmission of power to and from those cylinders. It is envisaged that the piston speeds of the engine cylinders will be at approximately one quarter of the speed limit of piston motion.

25 In instances where it may not be necessary to have all four cylinders of the described embodiment operating at the one time, it may be appropriate to shut the operation of one or more cylinders down as a fuel conservation measure. The flexibility of operation by means of a method and apparatus of the present invention provides enhancements not  
30 previously available.



In a further embodiment, by constantly varying the height of one hydraulic piston of the split-cycle machine with respect to the lobes on an instantaneously associated lobed shaft via an actuator it is possible to have an infinitely variable compression ratio and therefore be able to employ  
5 computer control to select any desired ratio for any fuel or to compensate for the variable stroke.

In a still further embodiment, by cutting out particular hydraulic cylinders with respect to demand on the engine eg. starting off with 6 mm stroke at idle and gradually increasing the stroke up to 36 mm for maximum  
10 power then an improved efficiency can be achieved. this is done by continuing to allow the power stroke to be 36 mm and thereby achieving a large expansion ratio especially when combined with variable compression as described above.

The present invention can be effected by driving one hydraulic  
15 piston of the split-cycle machine by one free piston.

Even though the first embodiment has been described in relation to a four stroke engine arrangement the method and apparatus of this invention are equally suited to two stroke cycle single or multi-cylinder free piston engines.

20 Fig. 3 is a view similar to that of Fig. 2 and like components are similarly numbered to those in Fig. 2. In the embodiment of Fig. 3 the opposed pistons 41 and 42 of each piston pair and cylinder combination 40 are coupled to respective hydraulic pistons 43 and 44. Piston 41 controls the opening of exhaust port 45 while the movement of piston 42 provides the  
25 major component of the stroke of the engine.

Piston rods 43 and 44 are mounted to respective hydraulic pistons 46 within each hydraulic driving cylinder assembly 47. The side in each hydraulic cylinder assembly 47 opposite respective piston rods 43 is hydraulically coupled to the working chambers and pistons 19 of the split  
30 cycle machine 30 via hydraulic circuit lines as depicted. One hydraulic line acted upon by each "exhaust" piston 41 has a high speed solenoid valve 22

interposed in its circuit while the other line is directly coupled to a piston 19.

Each "power" piston 42 in this embodiment is hydraulically coupled to four working chambers 19 with three of those couplings having high speed solenoid valves 22 in parallel with one working chamber 19 being  
5 without a high speed solenoid valve.

As shown in Figs. 4 and 5 "exhaust" piston 41 is provided with a 12mm stroke controlled from two pistons 19 of the machine 30. Each such piston 19 having a 6mm stroke with the output of one piston 19 being  
10 variable by reason of its associated solenoid valve 22 (which correspond to valves 22).

Each body of the hydraulic cylinder assembly 47 is shown mounted to a proportional controller for moving the body 48 of each cylinder assembly 47 toward or away from the combustion chamber 50. By  
15 controllably varying the displacement between one body 48 and its associated piston 41 it is possible to provide an infinitely variable opening to exhaust port 45.

By actuating appropriate solenoid valves 22 to cut out particular hydraulic controlling pistons 19 based on the demand of the engine it is  
20 possible to provide not only an infinitely variable control to the opening of exhaust port 45 but it is also possible to readily vary the stroke of each "power" piston 42.

As shown in Figs. 4 and 5 when taken in conjunction with Fig. 3 it is possible, by cutting out particular ones of pistons 19 via respective solenoid  
25 valves 22 based upon the demand placed on the output of machine 30, to start with power piston 42 having a stroke of say 6mm at engine idle speed and to gradually increase the stroke of piston 42 to, say, 24mm for maximum power. With the stroke of piston 42 being controlled by four separate pistons 19 each having a 6mm stroke it becomes feasible to infinitely vary  
30 the compression ratio by means of varying the separation between the cylinder body 48 and piston 42. Such a facility enables a computer used

control system (not shown) to be added to set the compression ratio of each two stroke cylinder comprising opposed pistons 41 and 42. Such control of compression facilitates the use of a range of different fuels in the one engine or may add further variation to the operating cycle of that piston.

5           In another embodiment (not shown) each of pistons 41 and 42 are connected by associated hydraulic lines to respective separate pistons 19 of machine 30 instead of the depicted form in which each exhaust piston 41 is coupled to two pistons 19 and each compression piston 42 is hydraulically coupled to four pistons 19.

10           Proportionally controlled actuators 51 whether they be associated with respective cylinder bodies 48 of hydraulic cylinder assemblies 47 as shown in Fig. 3 or be incorporated in the circuitry in some other location such as acting to vary the height of followers on one or more of the pistons 19, are able to provide complex control arrangements to control the opening  
15 of exhaust ports 45 and/or the compression ratio depending upon the characteristics of the fuel being used and the setting of the spark timing of spark plug 52 via a computerised control system in a manner understood in the art.

20           It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

**CLAIMS:**

1. A method of converting linear piston motion to rotary output motion in a free piston engine comprising:  
at least one free piston formed by a combustion piston and a  
5 pumping piston wherein the pumping piston pumps hydraulic fluid to at least one hydraulic pump/motor which converts the motion of said hydraulic fluid to rotary output motion and wherein said pump/motor is a "split-cycle" machine as hereinbefore defined.
2. A method as claimed in claim 1 wherein the free piston engine is  
10 formed by at least one pair of opposed free pistons within a common bore such that combustion of fuel occurs in the bore between the pair of pistons.
3. A method as claimed in claim 1 or 2 wherein the stroke of each free piston is variable by controlling the quantity of hydraulic fluid flow between each piston and the "split-cycle" machine.
- 15 4. A method as claimed in any one of the preceding claims wherein the motion of each free combustion piston is varied in dependence upon the output required from the free piston engine and having regard to the fuel to be combusted by the engine.
5. A free piston engine comprising at least one free piston formed by a  
20 combustion piston and a pumping piston, wherein the pumping piston pumps hydraulic fluid via a fluid circuit to at least one hydraulic pump/motor to convert the motion of said hydraulic fluid to rotary motion and wherein the pump/motor is a "split-cycle" machine as hereinbefore defined.
6. A free piston engine as claimed in claim 5 wherein the engine is  
25 formed by at least one pair of opposed free pistons within a common bore and the portion of the bore between the pistons comprises a combustion chamber.
7. A free piston engine as claimed in claim 5 or 6 comprising means for  
30 varying the quantity of hydraulic fluid in the fluid circuit between the free piston and an hydraulic fluid working chamber of the "split-cycle" machine.

8. A free piston engine as claimed in claim 5, 6 or 7 wherein the hydraulic cylinder of at least one pumping piston is moveable relative to the bore of its respective combustion piston to effect changes in the compression ratio of the combustion chamber of that combustion piston.
- 5 9. A free piston engine as claimed in claim 7 wherein the means for varying comprises at least one computer controlled solenoid valve in the fluid circuit.
10. A free piston engine as claimed in claim 8 wherein means for moving the hydraulic cylinder relative to the bore of its respective
- 10 combustion piston comprises proportionally controlled actuator means.
11. A free piston engine as claimed in claim 10 wherein the means for varying comprises at least one computer controlled solenoid valve in the fluid circuit.

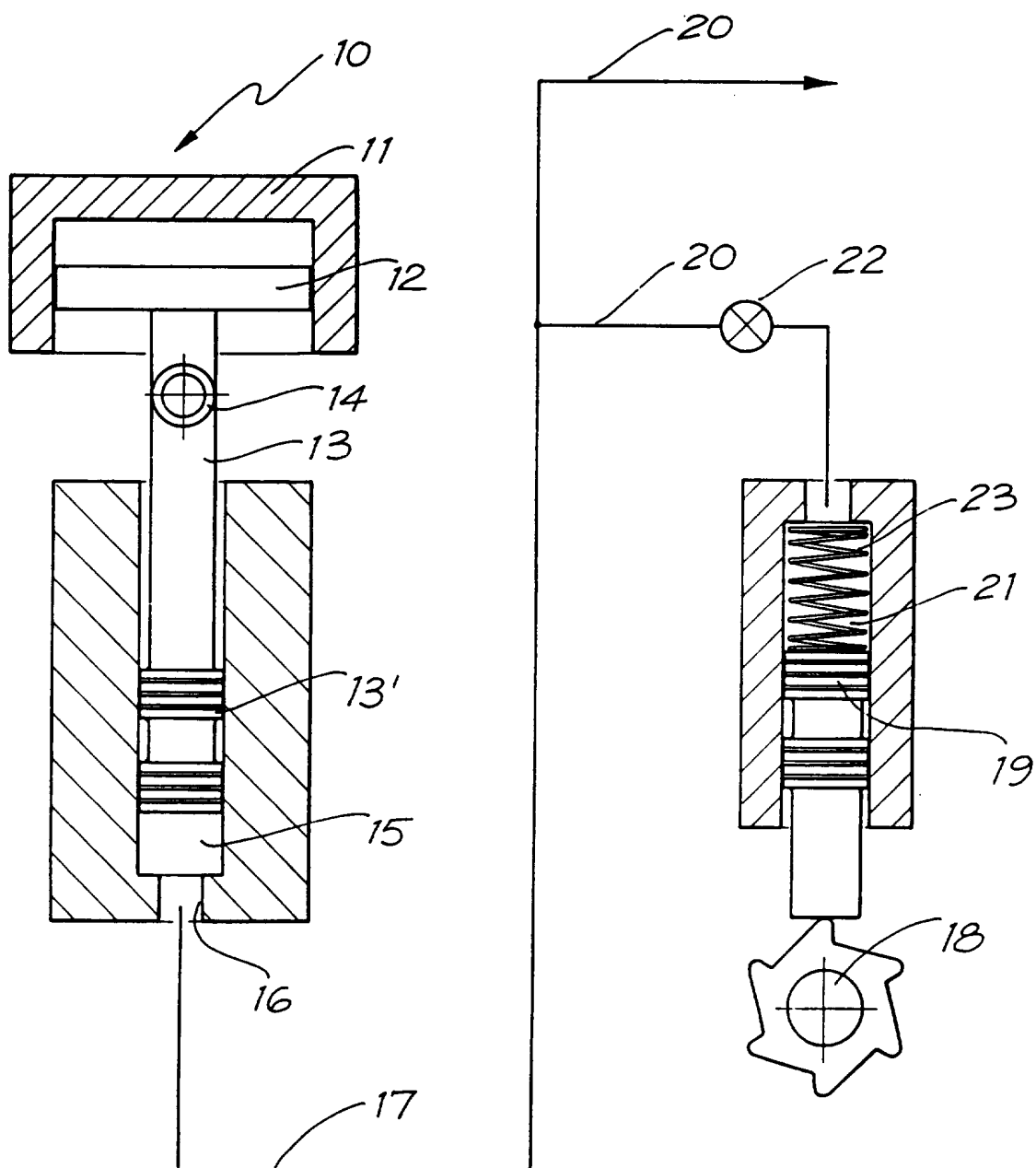


FIG. 1

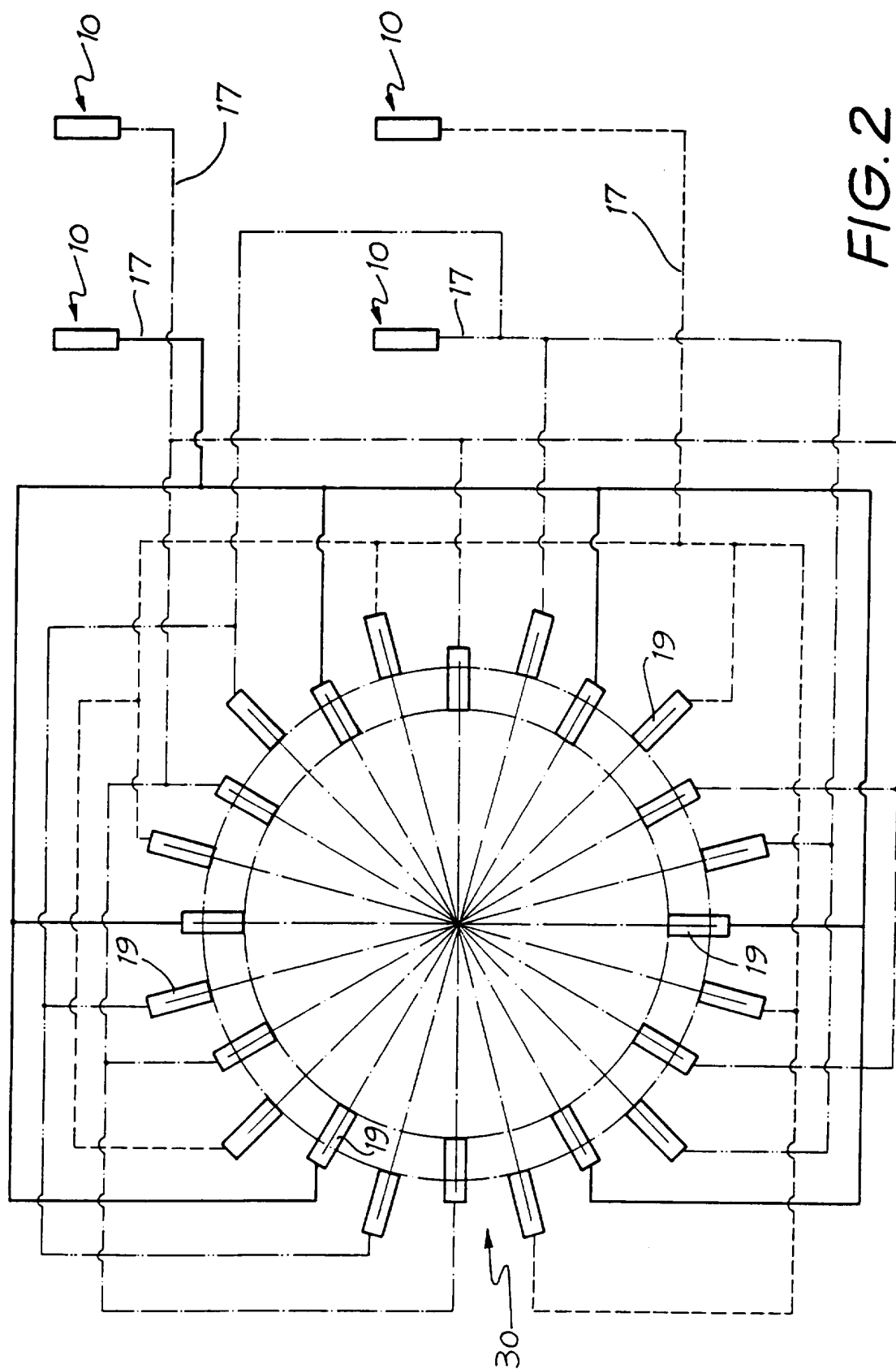
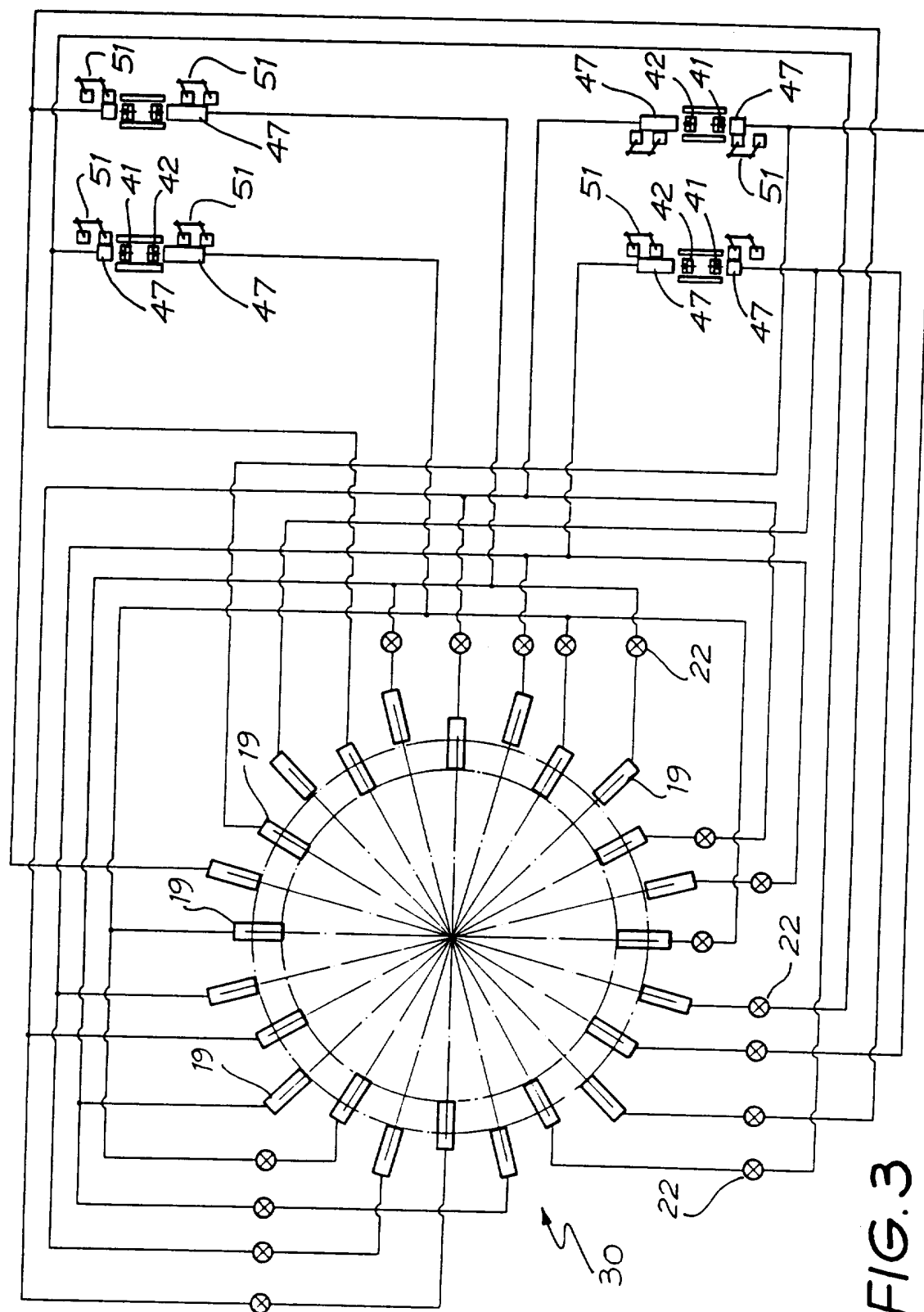
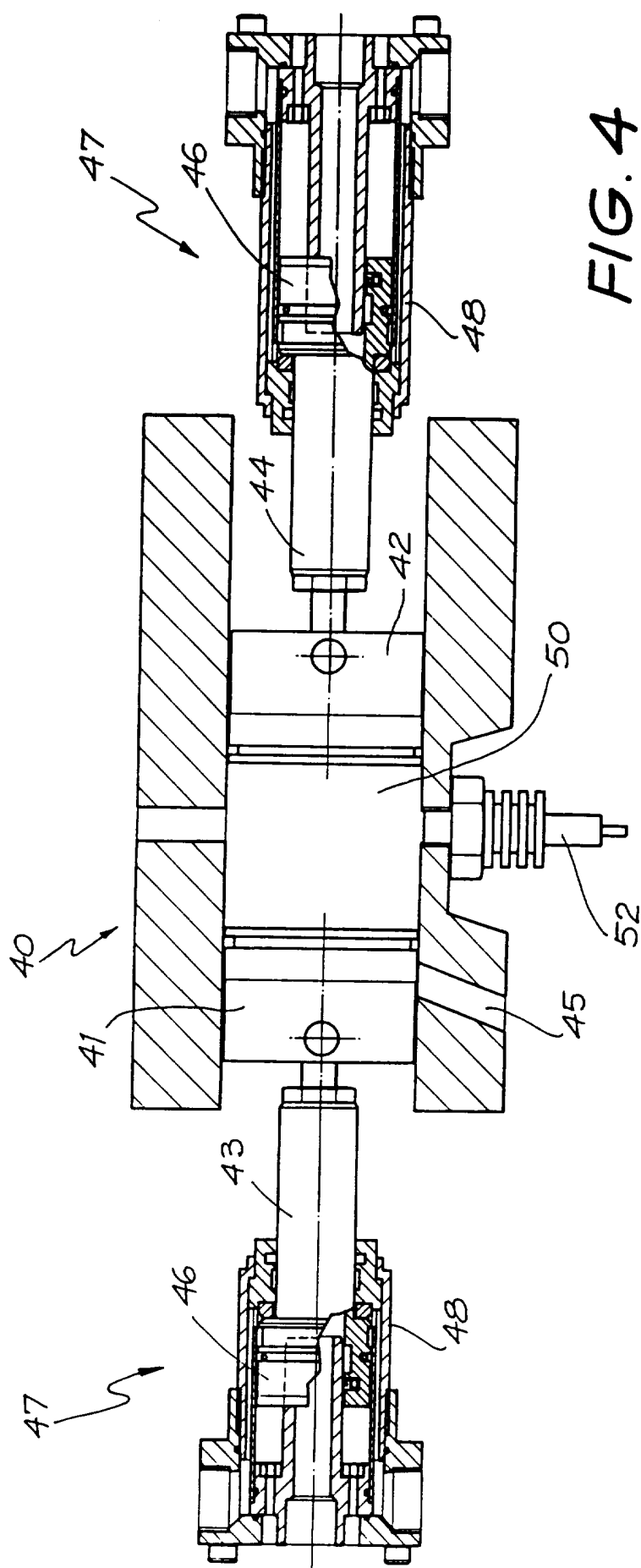


FIG. 2







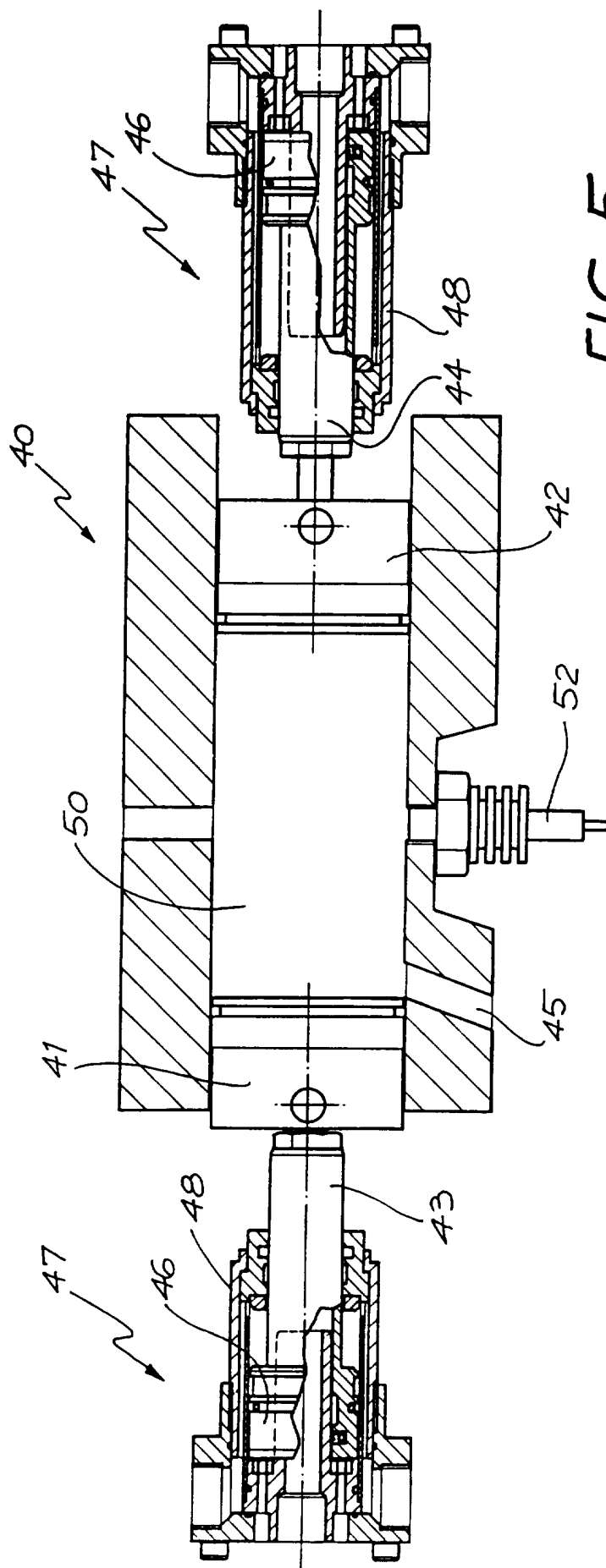


FIG. 5

## INTERNATIONAL SEARCH REPORT

 International Application No.  
**PCT/AU 96/00222**
**A. CLASSIFICATION OF SUBJECT MATTER**Int Cl<sup>6</sup>: F02B 71/00; F01B 11/08

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC: F02B 71/00; F01B 11/08, 11/00

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Derwent**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5279209 A (MAYNE) 18 January 1994	
A	US 5146880 A (MAYNE) 15 September 1992	
A	DE 4024591 A (BRANDL) 6 February 1992	
A	Derwent Abstract Accession No.91-079382/11, Class Q52, SU 1576702 A, (PASSENGER VEHICLE) 7 July 1990	
A	EP 183258 A (DAIKICHIRO) 4 June 1986	
A	US 4530317 A (SCHUTTEN) 23 July 1985	



Further documents are listed in the continuation of Box C



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International Application No.

**PCT/AU 96/00222**

C (Continuation)		DOCUMENTS CONSIDERED TO BE RELEVANT
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 57300 A (HARBIDGE) 18 August 1982	
A	US 4084710 A (SAVARIMUTHU) 25 April 1978	
A	US 4016719 A (YAVNAI) 12 April 1977	
A	US 3119230 A (KOSOFF) 28 January 1964	

**INTERNATIONAL SEARCH REPORT****Information on patent family members**

International Application No.

**PCT/AU 96/00222**

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Patent Document Cited in Search Report				Patent Family Member			
US	5279209	AU	79655/91	CA	2083517	EP	530289
		FI	025242	HU	62370	NO	924469
		WO	9118188	BR	9106497		
US	5146880	AU	39626/89	EP	422082	WO	9000218
EP	183258	JP	61129401				
US	4016719	DE	2613596	FR	2306384	GB	1511423
		IL	46964	IT	1062574	JP	51123468
DE	4024591	WO	9202730				
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