

May 17, 1949.

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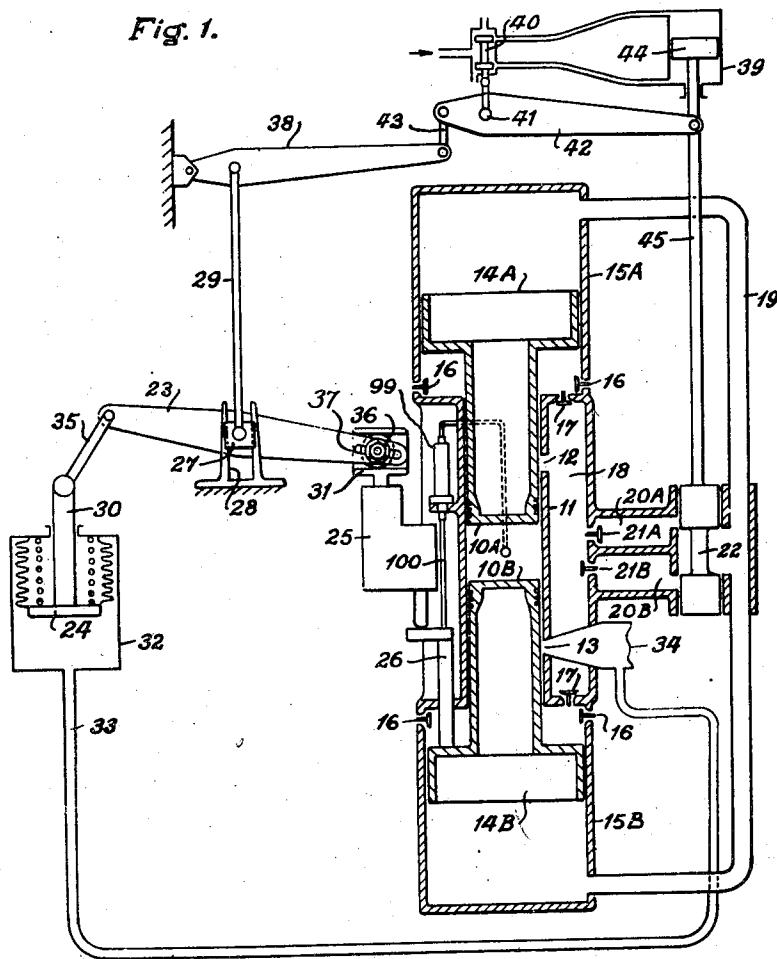
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INTERNAL-COMBUSTION OPERATED FREE-PISTON MACHINE

Filed June 30, 1943

5 Sheets-Sheet 1

Fig. 1.



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5 Sheets-Sheet 2

Fig. 2.

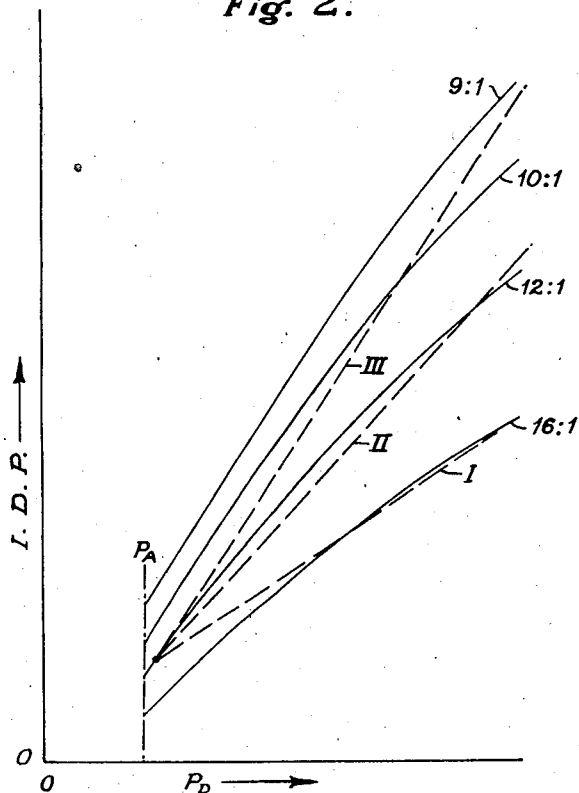


Fig. 4.

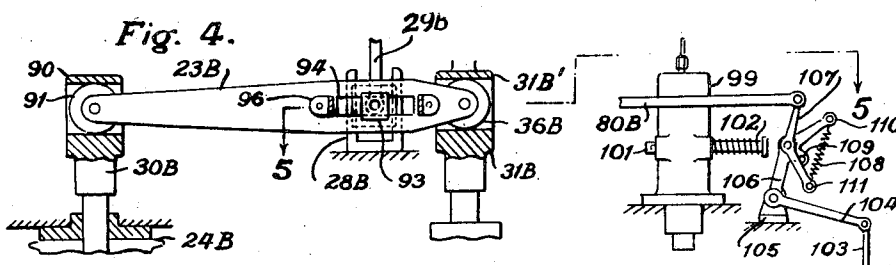
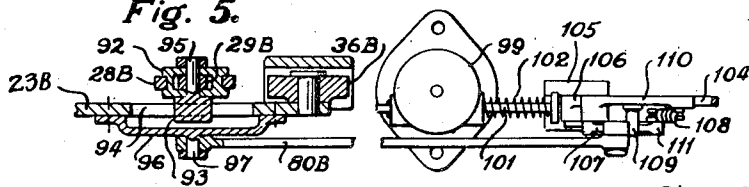


Fig. 5.



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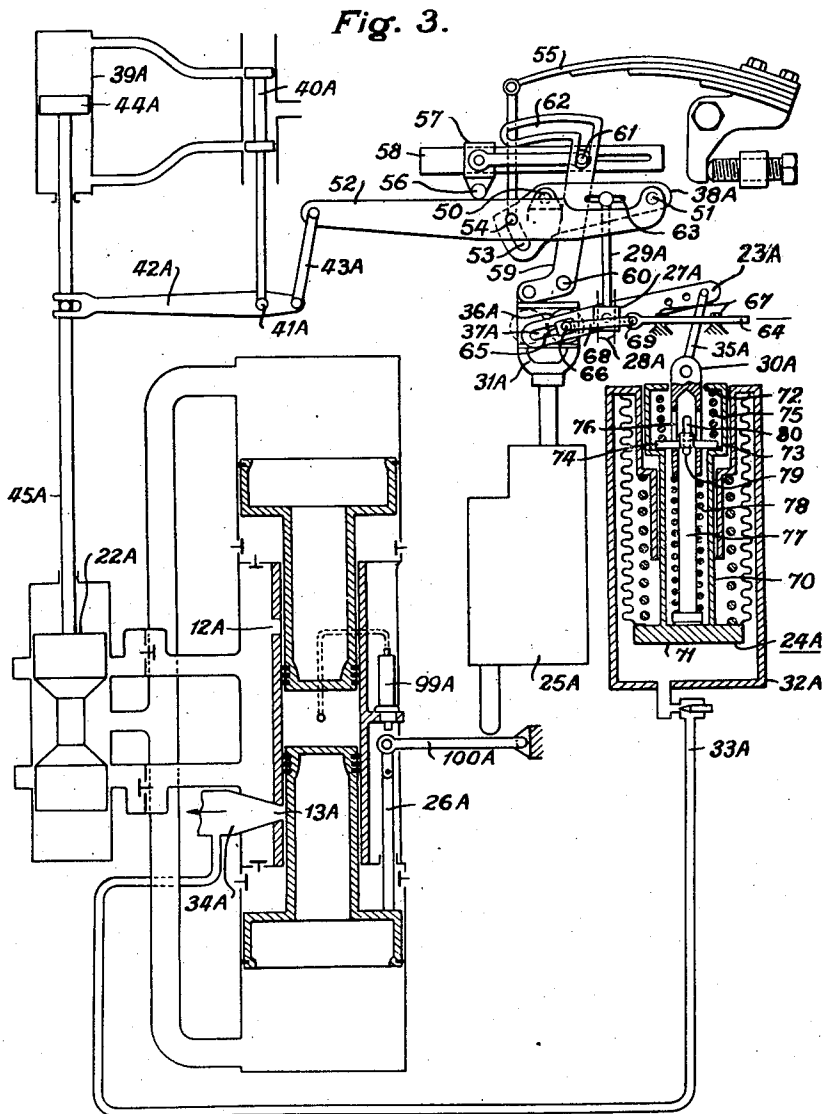
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INTERNAL-COMBUSTION OPERATED FREE-PISTON MACHINE

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5 Sheets-Sheet 3



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INTERNAL-COMBUSTION OPERATED FREE-PISTON MACHINE

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5 Sheets-Sheet 4

Fig. 6.

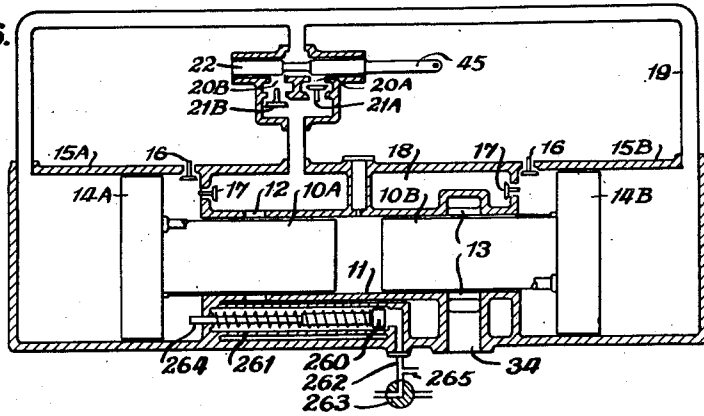


Fig. 7.

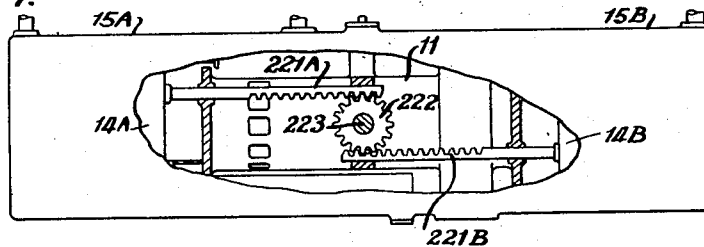
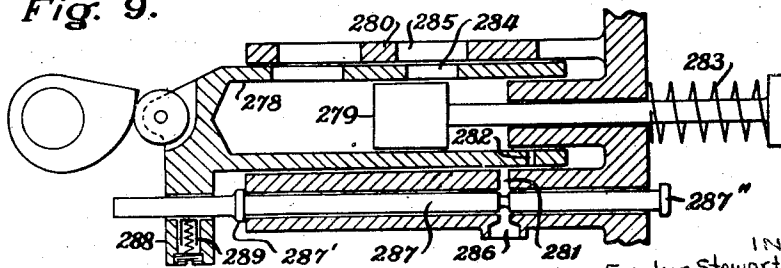


Fig. 9.



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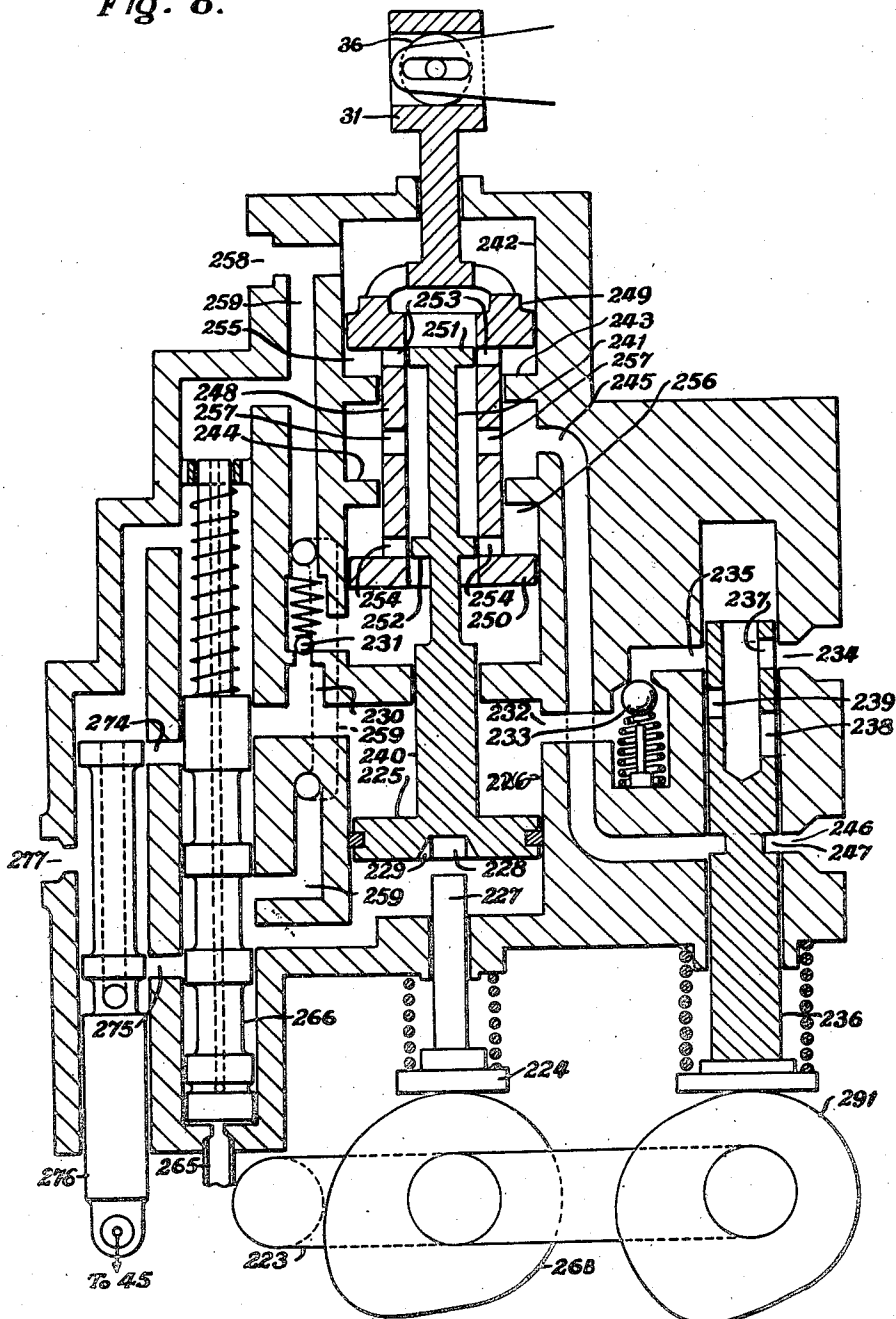
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INTERNAL-COMBUSTION OPERATED FREE-PISTON MACHINE

Filed June 30, 1943

5 Sheets-Sheet 5

Fig. 8.



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UNITED STATES PATENT OFFICE

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INTERNAL-COMBUSTION OPERATED
FREE-PISTON MACHINE

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Application June 30, 1943, Serial No. 492,865
In Great Britain June 25, 1942

30 Claims. (Cl. 123—46)

1

This invention relates to control means of pumps, compressors, and motive-gas generators of the kind in which the motion of the pumping or compressing piston or pistons is unconstrained by any continuously rotating crank or equivalent mechanism, with the consequence that the stroke, and therefore at least one of the dead points, of the piston or pistons can vary in accordance with changes in the operating conditions. It is more especially, but not exclusively, concerned with motive-gas generators of the kind in which a piston operating in an internal-combustion cylinder (hereinafter termed the power cylinder) on the two-stroke cycle is directly connected to or is integral with the piston operating in an air-compressor cylinder arranged to charge the power cylinder, the mixture of combustion products and excess scavenge air which is exhausted from the power cylinder under super-atmospheric pressure constituting the motive gas generated. The invention, in some of its aspects, is furthermore concerned with gas-generators of this kind which are provided with a pneumatic energy accumulator (hereinafter termed a cushion) arranged to receive energy from the free pistons during the expansion stroke in the power cylinder and to return energy to the free pistons during the compression stroke in the power cylinder.

An object of this invention is to provide apparatus which is capable of operating continuously with a high degree of accuracy, and which is adapted to follow changes in a position where the direction of movement reverses (which will hereinafter for convenience be termed "dead point") of the free or semi-free piston of machines of the kind specified capable of oscillating with a varying amplitude, the apparatus having an indicating member or an output member the displacement of which is represented by the appropriate envelope of the time/displacement curve of the oscillating element. Such apparatus will be termed hereinafter a "dead-point follower."

Another object is to reduce or prevent oscillation of the indicating or output member of the dead-point follower at the frequency of the oscillating element.

A further object of this invention is to provide such a free-piston or semi-free-piston machine having control mechanism embodying the improved apparatus for following changes in a dead point of a piston thereof.

The final compression pressure in the power cylinder of a gas-generator of the kind herein-

2

before specified depends on the stroke of the free-piston assembly, as measured from the point where the exhaust ports are closed to the inner dead point (hereinafter termed "I. D. P."), and also on the pressure at which the charging air is supplied by the compressor cylinder, which is substantially equal to the delivery pressure against which the motive gas is exhausted from the power cylinder.

It is necessary to prevent a variation of the overall compression ratio wide enough to involve the risk of either over-stressing the machine or failure to secure compression ignition of the working charge in the power cylinder.

Accordingly, a further object of this invention is to provide means which will automatically correct the overall compression ratio in a predetermined manner when the operating conditions of the gas-generator vary.

Another object is to render such improved control means capable of responding with minimum delay to changes in operating conditions and yet not liable to instability.

Another object is to provide additional control mechanism which will permit the overall compression ratio to be varied independently of said automatic means.

A further object is to provide means which will ensure that the compression ratio is substantially constant at minimum delivery pressure, irrespective of the setting of said additional control mechanism.

Yet another object is to provide means for setting the dead-point follower in a predetermined position preparatory to starting the free-piston machine.

These and other objects of the invention will be explained with reference to embodiments of the invention described by way of example and shown in the accompanying diagrammatic drawings in which—

Fig. 1 is a section of a gas-generator having an elementary form of the improved cushion control mechanism, intended to maintain a constant compression ratio,

Fig. 2 is a graph illustrating the operation of a gas-generator.

Fig. 3 is a section corresponding in general to Fig. 1, but showing a preferred arrangement of control mechanism,

Fig. 4 shows a further modification of certain parts of the control mechanism,

Fig. 5 is a sectional plan, to a larger scale, taken on the line 5—5 in Fig. 4.

Fig. 6 is a sectional side elevation of the gas-

3

generator employed in the arrangements shown in Figs. 1 and 3, but less diagrammatic and showing pneumatic maneuvering gear which does not appear in Fig. 1.

Fig. 7 is a side elevation of the same gas-generator, with part of the case broken away to show a synchronising linkage.

Fig. 8 is a section of the dead-point follower, and

Fig. 9 is a section of an alternative form of dead-point follower.

Referring to Fig. 1, the gas-generator has two opposed power pistons 10A and 10B operating in a common power cylinder 11 and controlling respectively scavenge ports 12 and exhaust ports 13. Each of the pistons 10A and 10B is rigid with a compressor piston 14A and 14B operating in a compressor and cushion cylinder 15A and 15B. The annular inner faces of the compressor pistons, i. e. those faces nearer the power cylinder, serve to induce air through valves 16, compress it and deliver it through valves 17 to a receiver 18 communicating with the scavenge ports 12, while the outer faces of the compressor pistons 14A and 14B act upon air which is contained in the outter ends of the compressor cylinders 15A and 15B and which forms the cushion air. The two piston assemblies are connected together by a known kind of linkage (Fig. 7) which constrains them to operate in synchronism, but their displacement is otherwise influenced only by the gas pressures acting on their faces and by friction. The relative effective piston areas are such that, during operation, the maximum air pressure occurring during any one cycle respectively exceeds and is less than the scavenge air pressure in the receiver (which exceeds the delivery pressure of the gas-generator only by the pressure drop caused by scavenging the power cylinder). The two cushions are connected by a balance pipe 19, which communicates with the receiver 18 through two parallel ducts 20A and 20B containing non-return valves 21A and 21B respectively, so arranged that air can flow through duct 20A from the receiver to the cushions during that part of the cycle when the cushion pressure is lower than the scavenge pressure, and that air can flow through the duct 20B from the cushions to the receiver during the part of the cycle when the cushion pressure exceeds the scavenge air pressure. A transfer valve 22 normally closes both of these ducts, and is displaceable on the two sides of its neutral position to open the ducts alternatively.

The synchronising linkage, shown in Fig. 7, includes two racks 221A and 221B which are respectively connected to the two free-piston assemblies 10A, 14A and 10B, 14B and are in mesh on opposite sides of a pinion 222 rigid with a transverse shaft 223 journaled in the engine case; the angular displacement of the shaft 223 is therefore proportional to the linear displacement of the free pistons.

The gas-generator is provided with a differential device including a floating lever 23 of which one end is connected to a pressure-responsive device 24 and the other end to an I. D. P. follower 25, the actuating member 26 of which is shown diagrammatically as being directly connected to the piston 14B. In practice the actuating member is a cam 26B as shown in Fig. 8, on the shaft 223 of the synchronising linkage shown in Fig. 7. The floating lever 23 is pivotally connected, at a point intermediate its ends, to a slide block

4

27 which is guided in fixed vertical horns 28. The said point on the lever 23 is pivotally connected to a cushion control link 29. The connecting elements 30 and 31 of the pressure-responsive device 24 and the I. D. P. follower 25 respectively are constrained to move in vertical paths, i. e. parallel to the path of said intermediate point on the lever 23. The connecting element 31 of the I. D. P. follower will be assumed to move in the upward direction when the positions of the two free-piston assemblies at I. D. P. come nearer together. This will be termed "increasing I. D. P." Displacement of the position of these assemblies farther apart at I. D. P. will be termed "decreasing I. D. P." The connecting element 30 of the pressure-responsive device 24, which is a spring-loaded corrugated tubular bellows mounted in a chamber 32 maintained at the gas delivery pressure, is arranged to move upwards when the delivery pressure increases. A pipe 33 connects the chamber 32 to the gas-delivery main 34.

The connecting member 30 of the bellows is coupled to the appropriate end of the floating lever 23 by an oblique pivoted link 35, while the connecting member 31 of the I. D. P. follower has a cross-head co-operating with a roller 36 capable of adjustment longitudinally of the floating lever 23 for the purpose of varying the ratio of the lever arms and thereby varying the overall compression ratio at which the gas-generator will operate.

The adjusting means are indicated diagrammatically in Fig. 1 as a slot 37 in the lever 23 in which the bearing pin of the roller 36 is adjustably fixed. Preferred forms of adjusting means capable of varying the overall compression ratio while the gas-generator is running will be hereinafter described. The obliquity and length of the connecting link 35 and the range of inclination of the floating lever to the horizontal can be so selected that the differential mechanism will give a very close approximation to the motion required to compensate for the non-linear relation between discharge pressure and I. D. P. for any selected overall compression ratio.

The cushion control link 29 is connected, through a multiplying lever 38, to a hydraulic servo repeater which includes a double-acting cylinder 39 controlled by a slide valve 40 linked to an intermediate point 41 on a restorer lever 42, of which one end is connected by a link 43 to the multiplying lever 38 and the other end receives a return motion from a piston 44 operating in the servo cylinder 39. This piston is connected by a rod 45 to the transfer valve 22. This transfer valve is disposed on the cushion side of the non-return valves, so as to avoid pumping loss in the unavoidable clearance volume between the valves.

The I. D. P. follower may be of any desired kind, but it is preferred to use that shown in Fig. 8, which is so arranged that before the gas-generator is started by maneuvering the free pistons to the outer dead point and admitting a predetermined charge of compressed gas into the cushions, the I. D. P. follower sets itself in a position such that there will be no change in the quantity of air in the cushions during the first few running cycles.

The dead-point follower (Fig. 8) has an actuating member, a master follower and a slave follower, co-operating in such a manner that the slave follower is locked except when its position is required to be corrected to conform to a new

position taken up by the master follower, while the master follower is locked during the time it is correcting the position of the slave follower. The actuating member is in the form of a spring-loaded striker 224 co-operating directly with the master follower 225, the drive between the master and the slave followers and the locking of these elements being effected hydraulically. The drive for the dead-point follower is taken from the synchronising pinion shaft 223, which oscillates through less than 360 deg. and which is rigid with a spiral striker-actuating cam 26B (shown in Fig. 1 diagrammatically as a simple push rod 26) and a pump-actuating cam 291. The master follower 225 consists of a hydraulic piston slidable in a master cylinder 226 disposed vertically, the striker 224 including a rod 227 which passes in a fluid-tight manner through the lower end wall of the cylinder 226. The striker is moved upwards by its cam as the free pistons move towards the dead centre. Towards the end of its upward stroke the striker reaches the master and pushes it up to the limit of its stroke. A hydraulic buffer is arranged to come into action between the striker and the master in order to accelerate the latter before the parts come into contact. This buffer includes a cylindrical recess 228 in the lower face of the master and positioned to be entered by the end of the striker rod 227 acting as a plunger, ports 229 for the escape of oil trapped in the recess 228 being so disposed that, as the plunger rod 227 moves towards the inner end of the buffer recess 228, the effective area of the ports 229 is progressively decreased. As the lower end of the follower cylinder is kept flooded with oil in a manner which will hereinafter be explained, the buffer recess is automatically refilled with oil when the striker parts from the master.

The upper end of the master cylinder is provided with an outlet port 230 controlled by a spring-loaded braking valve 231, and with an inlet port 232, fed through a non-return valve 233 by an oil pump driven by the pump-actuating cam 291. This pump is so timed that during each cycle it delivers a predetermined volume of oil into the upper end of the master cylinder 226 shortly before the striker 224 pushes the master 225 to the dead point. The pump is provided with a suction port 234 and a delivery port 235 in its body, both controlled by the plunger 236, and with a suction port 237, a spill port 238 and a delivery port 239 in its plunger 236, the arrangement being such that the delivery ports are opened just before the suction ports close and are reclosed just after the spill port opens. Thus the delivery port 235 is sealed except during the delivery period of the pump (and of course a corresponding period on the return stroke). This port arrangement minimises changes in quantity of oil delivered per stroke, due to variations in viscosity.

After the master piston 225 has been given a downward velocity by the positive delivery of the pump, it is brought to rest again quickly enough because the delivery port 235 has been closed and a vacuum can be created above the master piston. Soon after having been pushed downwards, the master, as already explained, is met by the striker and given an upward velocity equal to that of the striker as soon as the buffering action is finished. Thereafter as the striker is rapidly retarded towards the dead point the master must also be retarded so as to keep contact with the striker and avoid overshooting at the dead

point. This retardation is effected by the resistance to the discharge of oil through the braking valve 231.

Having reached the dead point determined by the striker, the master piston is locked in position by the oil above it. Since the master piston area is much larger than that of the buffer recess 228, the vacuum created in the latter when the striker descends, under the influence of its return spring, will not move the master.

A piston rod 240 on the master piston passes in a fluid-tight manner through the upper cover of the master cylinder 226 and is rigid with a pilot piston valve 241 of an oil relay which incorporates the slave follower. This relay consists of a casing having a cylindrical bore 242 provided with two inwardly projecting flanges 243 and 244 between which an oil inlet port 245 opens. Oil, from a separate supply admitted at 246 under pressure, is delivered to the port 245 under the control of a slave timing valve constituted by an additional port 247 in the pump plunger 236 which is arranged to act also as a piston valve. This slave timing valve is arranged to open when the pump plunger is at the bottom of its stroke. Within the bore of the relay casing is a slidable tube 248 serving as the slave follower. This tube is a working fit in the relay casing flanges 243 and 244 and at its ends it has outwardly projecting flanges 249 and 250 which are a working fit in the casing bore 242. The pilot piston valve 241 works in the bore of the slave 248 and has two annular lands 251 and 252 which normally register with ports 253 and 254 which pass through the cylindrical wall of the slave and which open respectively into the two annular chambers 255 and 256 that are formed between the flanges 243 and 249 and between the flanges 244 and 250 respectively. Admission ports 257 pass through the middle of the cylindrical wall of the slave, between the two inwardly directed flanges 243 and 244, and the open ends of the slave form discharge ports in communication with a sump connection 258, and with the lower end of the master cylinder 226 by a duct 259.

When oil is supplied to the relay under pressure through the timing valve 247, the slave 248 moves until its ports 253 and 254 are exactly in register with the lands 251 and 252 of the pilot valve 241. As soon as the timing valve is closed, the slave is thereby locked in position by the oil trapped in the relay and is thus prevented from moving while the master is moved down by the pump and up again by the striker.

If, while the gas-generator is running at a constant delivery pressure, the I. D. P. becomes too large (it will be recalled that an increase in the distance between the pistons at I. D. P. has been, for brevity, hereinbefore referred to as an increase in I. D. P.), for example owing to a reduction in the quantity of fuel injected into the power cylinder, the compression ratio will be too low and should be increased by increasing the quantity of air in the cushion. The connecting member 31 of the I. D. P. follower moves downwards as the I. D. P. increases, and since the discharge pressure is constant, the connecting member 30 of the bellows remains stationary. Consequently the differential lever is displaced in such a way as to move the cushion control link 29 downwards. The servo repeater is accordingly energized and moves the transfer valve 22 upwards so that air will be transferred gradually to the cushions. As the air content of the cushions rises to the correct value, the I. D. P. de-

creases, and the I. D. P. follower restores the differential lever 23 to its original position, the transfer valve at the same time being returned by the servo repeater to its neutral position. A corresponding sequence of operations takes place when the I. D. P. becomes too small, the control mechanism operating in this case to reduce the quantity of air in the cushions.

If, alternatively, the delivery pressure increases while the gas-generator is running, the quantity of fuel injected per cycle remaining constant, the bellows will contract and the end of the differential lever 23 connected thereto will be raised. At the same time the higher pressure existing in the power cylinder when the exhaust port closes and the higher delivery pressure of the compressor cylinders will have the effect of increasing the I. D. P., so that the end of the differential lever connected to the I. D. P. follower will be lowered. This increase in I. D. P. is larger than is required to maintain a constant overall compression ratio with the change in delivery pressure, and the net result of the displacements of the ends of the differential lever is that the intermediate point on this lever, to which the cushion control link 29 is connected, is lowered and the servo repeater therefore operates to cause air to be transferred to the cushions until the correct quantity has been added. A corresponding sequence of operations follows a decrease in working pressure, the control mechanism operating to cause air to be discharged from the cushions.

Although the elementary control system shown in Fig. 1 is designed to maintain a constant compression ratio, in a more practical design it is preferred to arrange for the compression ratio to be varied automatically, with two objects in view.

Firstly, as the working pressure falls towards the idling condition, if the compression ratio were kept constant at a high value, the combustion space would become very thin owing to the low value of the I. D. P. If, however, the compression ratio is reduced somewhat over a lower part of the range of delivery pressure, the smaller reduction in the thickness of the combustion space gives better combustion.

Fig. 2 illustrates by full lines the non-linear relationship between I. D. P. and working pressure, in the type of gas-generator shown in Fig. 1, for constant compression ratios of 9:1, 10:1, 12:1 and 16:1, and it will be apparent how small the I. D. P. becomes at high compression ratios as the delivery pressure approaches atmospheric pressure P_a . A satisfactory characteristic is represented by the straight broken line I, which conforms substantially to the 16:1 curve over the higher part of the range of delivery pressure, but which approaches the 12:1 curve over the lower part of the range.

The second object of varying the compression ratio is to enable the gas-generator to give a low minimum output. This is done by arranging that, after the quantity of fuel injected per cycle has been reduced as far as possible while the compression ratio is maintained at the highest practical value so as to maintain a high thermal efficiency, the power output is further reduced by lowering the compression ratio. It is advantageous to arrange that the compression ratio shall be more or less constant, i. e. independent of the setting of compression ratio control means, when the delivery pressure is at its minimum value, since the idling compression ratio can be

so selected as to give invariably the optimum working conditions for the generator when it is idling and when it might be liable to stop accidentally under unfavourable conditions. The straight broken lines II and III of Fig. 2 show, for two ratios of the differential lever different from that corresponding to line I, how the compression ratio can vary at settings of the ratio-adjusting means yielding lower compression ratios at the higher delivery pressures and the selected optimum compression ratio, in this case 12:1, at the minimum delivery pressure (point A).

The elementary gear shown in Fig. 1 may tend to become unstable at high working pressures and at low compression ratios owing to the increased rate at which air can enter the cushions through a given port area in the transfer valve 22. This is due to the fact that the cushions are fed from the scavenge air receiver 18 and to the relation between the cushion pressure and the scavenge air pressure with the type of gas-generator described by way of example. This increased rate of transfer is equivalent to an increased sensitivity of the system under these conditions, and the system could be made, stable by a general reduction in the sensitivity. However this is undesirable, as it would reduce the rate at which the running conditions of the gas-generator could be changed with safety. The difficulty may be overcome, according to a further feature of this invention, by providing stabilising means serving automatically to reduce the sensitivity of the control system under conditions tending to cause instability. Where, as in the embodiment shown in Fig. 1, the connection between the cushion control means and the differential device is mechanical, the stabilising means may serve automatically to vary the effective mechanical advantage of this connection so as to reduce the sensitivity of the system only when the cushion control means are set to cause air to flow into the cushion and when the delivery pressure is high and the compression ratio is low. This condition imposes a large value of I. D. P. and in consequence the I. D. P. follower is a convenient element for controlling the stabilising means. Thus the stabilising means may serve automatically to vary the effective mechanical advantage of a motion transmitting system connected between the floating lever and the cushion control means, and an element actuated by the I. D. P. follower may serve to control the amount of variation of effective mechanical advantage of the motion transmitting system in dependence on the I. D. P.

In the system shown in Fig. 3, parts identical with or corresponding in function to parts shown in Fig. 1 are denoted by the same reference numeral, with the addition of the letter A. The motion of the intermediate point on the differential lever 23A is transmitted through a connecting link 29A to the multiplying lever 38A which swings about a fixed pivot 50. At its right-hand end the multiplying lever is pivoted at 51 to a stabiliser lever 52, and a tail on the multiplying lever is provided with a slot 53 in which a pin 54, fixed to the stabiliser lever, can move. The end of a leaf spring 55 is linked to this pin, pulling it up to the top of the slot so that normally the two levers 38A and 52 are locked together and can be considered as a single rigid lever swinging about the fixed fulcrum 50 in the multiplying lever. In this case a stabiliser roller 56, which is journalled on a slipper 57 on a horizontal fixed guide 58, is in a position directly above the fixed

fulcrum and so has no effect on the motion of the stabiliser lever. The stabiliser is brought into operation by moving the roller to the left along the guide. The top edge of the stabiliser lever is straight and just touches the roller when the control gear is in the central position. For an upward movement of the differential centre the stabiliser lever 52 moves away from the roller 56 and remains locked to the multiplying lever as before, but for a downward movement the stabiliser lever bears against the roller and rocks about the point of contact, causing the two levers to separate and the pin 54 to move relatively downwards in the slot in the multiplying lever. The movement of the left-hand end of the stabiliser lever is therefore reduced by a proportion which depends on the position of the stabiliser roller, thus giving the required reduction in sensitivity.

The I. D. P. control is most sensitive and there is the greatest difference between rising and falling cushion pressure when the working pressure is a maximum and the compression ratio a minimum, this case corresponding to the maximum working I. D. P. The stabiliser is thus required to be brought progressively into action as the I. D. P. increases beyond a certain value, and the I. D. P. follower provides a convenient method of adjusting the position of the stabiliser roller. The adjusting lever is a bell-crank 59, which is carried on a fixed pivot 60, one end of which is driven by the crosshead 31A on the I. D. P. follower and the other end of which drives a pin 61 linked to the slipper 57. Over the lower range of I. D. P. this pin slides in an arcuate slot 62 in the adjusting lever 59, and the stabiliser roller remains in its inactive position above the fulcrum in the multiplying lever. When the I. D. P. exceeds a predetermined limit, the pin 61 reaches the end of the slot and is driven forward, carrying the roller with it. Provision may be made for adjusting the normal sensitivity (without the stabiliser working) by changing the multiplying lever ratio. This is done by moving the pin of the connecting link 29A along the multiplying lever in a slot 63 provided for the purpose. An outward movement of the pin from the fixed pivot decreases the sensitivity, thus making the control gear more stable.

A horizontal control rod for adjusting the overall compression ratio is denoted by 64, and this is arranged to displace the roller 36A, the bearing pin 66 of which is rigid with a slide block 65 operating in a slot 37A in the floating lever 23A. The control rod 64 is slidable in guides 67 and is pivotally connected by a pin 69 and a link 68 to the roller bearing pin 66, the arrangement being such that the pin 69 and the differential centre of the lever 23A are co-axial when the roller 36A is in the middle of its range of adjustment. In this way the action of the control rod 64 is rendered substantially independent of the attitude of the floating lever 23A. In order to increase the overall compression ratio, the rod 64 is moved to the left, as seen in Fig. 3, so as to bring the roller 36A farther from the differential centre.

The connecting member 30A of the pressure responsive bellows 24A includes a double-acting preloaded spring link adapted to accommodate excessive displacements in either direction. The moving element of the bellows consists of a tube 70 rigid with a base disk 71. The top end portion of the tube is enlarged, forming two annular abutments 72 and 73. A cross pin 74, passing

through vertical slots 76 in the wall of the tubular stem of the connecting member 30A, is normally held down onto the abutment 73 by a helical compression spring 75 reacting on the abutment 72. A bolt 77, slidable within the stem of the member 30A, is urged downwards onto the base disk 71 by a helical spring 78 compressed between the head of this bolt and the lower end of the stem, and a transverse pin 79, fixed in the bolt, passes directly beneath the pin 70 with its ends engaged in vertical slots 80 in the walls of the stem. The pin 74 passes through a transverse slot in the end of the bolt 77. On compression of the link, the bolt and the transverse pins do not move relatively to the tube 70, and the spring 78 is further compressed. On extension of the link, the tubular stem, the transverse pins and the bolt move as a unit relatively to the tube, the spring 75 being compressed.

In operation, if the delivery pressure of the gas-generator falls, the quantity of fuel injected per cycle remaining constant, the connecting member 30A will descend, but at the same time the lower pressure in the power cylinder when the exhaust ports close will have the effect of decreasing the I. D. P., the net result of the consequent displacement of the floating lever 23A being that the cushion control link 29A raises the right-hand end of multiplying lever 38A so that this lever moves as one with the stabiliser lever 52. If, however, the delivery pressure rises while the quantity of fuel injected per cycle remains constant, the link 29A will descend, pulling down the multiplying lever 38A; the stabiliser lever 52 now engages the roller 56 and deflects relatively to the multiplying lever, the displacement transmitted to the restorer lever 42A being reduced in a ratio dependent on the ratio of the distances of the roller 56 from the hinge pin 51 and the pin of the restorer link 43A. If the working pressure had been lower, I. D. P. would have been smaller and the roller 56 accordingly farther to the right.

In the further alternative construction of the differential lever shown in Figs. 4 and 5, parts identical with or corresponding in function to parts in Fig. 1 or 3 are denoted by the same reference numeral, with the addition of the letter B.

The differential floating lever 23B is arranged to yield a constant leverage ratio throughout its range of rocking movement for any given setting of the compression-ratio adjusting means. The connecting element 30B of the pressure responsive device is provided with a crosshead 90 co-operating with a roller 91 journaled on a pin fixed to the lever 23B. The roller 36B that co-operates with the crosshead 31B' of the I. D. P. follower is likewise journaled on a pin fixed to the lever 23B. In order to vary the overall compression ratio, the lever 23B is moved bodily with respect to its point of connection with the cushion control link 29B. A hollow block 92 is vertically slidable in the fixed horns 28B, and a slide block 93 is fitted in a longitudinal slot 94 in the floating lever 23B and provided with a pivot pin 95 journaled in the hollow slide block 92. The lower eye of the link 29B engages the pin 95 within the block 92. A bracket 96 carries a pin 97 which is co-axial with the pin 95 when the floating lever is at the mid point of its range of sliding adjustment. A control link 80B is engaged with the pin 97. The range of longitudinal movement permitted to the lever 23B by the slot 94 is so limited that the rollers 36B and 91 cannot move out of engagement with the associated crosshead 31B' or 90.

In order to enable the gas-generator to give a low minimum output, it may, as hereinbefore mentioned, be desirable to control it in such a manner that, after power has been reduced by reducing the quantity of fuel injected per cycle as far as possible while the compression ratio has been kept as high as is practicable in the interests of high thermal efficiency, finally the overall compression ratio is lowered. Elementary control means giving this effect are shown in Figs. 4 and 5. The fuel injection pump 99 (which is shown in Fig. 1 as operated by an extension 100 of the actuating member 26 of the I. D. P. follower and in Fig. 3 as operated by a rocker 100A that actuates the I. D. P. follower) is provided with a control rack 101 urged by a spring 102 towards the position giving minimum fuel delivery. A control link 103 is connected to an arm 104 of a bell-crank lever pivoted on a fixed bearing 105, and the other arm 106 of the bell-crank lever is adapted to engage an end of the rack 101 and move it in the direction required to increase the fuel delivery as the link 103 is raised. A lever 107 is pivotally connected to the arm 106 of the bell-crank lever, and a tension spring 108, connected between arms 110 and 111 on the levers 106 and 107 respectively normally retains the arm 111 against a stop 109 on the lever 106, so that the lever 107 forms in effect an extension of the lever 106. The link 80B connected to the floating lever 23B is pivoted to the free end of the lever 107. During the first part of the upward movement of the control link 103 the levers 106 and 107 move as one, and the lever 107 acting through the link 80B causes the floating lever 23B to be displaced to the left, i. e. in such a direction as to increase the overall compression ratio. When the right-hand end of the slot 94 abuts against the slide block 93, the bell-crank lever arm 106 engages the fuel-pump rack 101. On continued upward movement of the control link 103, the fuel-pump rack 101 is moved in the direction yielding an increase in the fuel delivery, while the lever 107 deflects relatively to the bell-crank lever against the force of the spring 108.

In order to ensure that the compression ratio shall be substantially constant, i. e. independent of the position of the compression-ratio adjusting means, when the working pressure is at its minimum value, the floating lever 23B is arranged to be substantially perpendicular to the path of the connecting member 31B of the I. D. P. follower at minimum working pressure. Consequently, under these particular working conditions, the overall compression ratio is not changed when the compression ratio setting is changed by moving the floating lever 23B longitudinally.

It is desirable to provide means for setting the I. D. P. follower in a predetermined position while the machine is stopped. In the embodiments shown in Fig. 1 and 3, the control gear is required to be so set that, when the machine is started, the transfer valve 22 or 22A of the control gear shall be in the central position, that is with both the inlet and the outlet ports shut. This follows from the fact that the engine is started by manoeuvring the free pistons to their outer dead points and introducing from starting vessels into the cushions a quantity of compressed air such as to give the right compression on the starting stroke and also during the first few running cycles. Accordingly no change in the cushion air content must be permitted during these strokes.

The requirement that no change shall occur in

the cushion air content during the first few cycles after starting may be met by providing an auxiliary valve, which will be termed the starting position valve, operated by air pressure applied to the free-piston manoeuvring gear just before the engine is started. Such manoeuvring gear is shown in Fig. 6 and consists of a spring-loaded pneumatic plunger 260 adapted to be displaced in a cylinder 261 by air under pressure admitted to a pipe 262 under control of a two-way valve 263. A tall rod 264 on the plunger 260 is arranged to engage the piston 14A when the manoeuvring gear is energised and so displace the free pistons to their starting positions. A branch pipe 265 leads to the spring-loaded starting position valve, which is denoted by 266 in Fig. 8. This valve, when displaced upwards by air admitted below it, closes the connection between the bottom of the master cylinder 226 and the duct 259 leading to the oil sump, and at the same time puts ports 274 and 275 of a double-acting pilot valve 276 into communication respectively with the top and bottom of the master cylinder 226. The pilot valve is operatively connected to the rod 45 or 45A of the transfer valve 22 or 22A (Fig. 1 or 3). The pilot valve 276 is supplied at a port 277 with oil under pressure, with the result that, if the transfer valve is not in the desired substantially central position when the manoeuvring gear is set in action, the pilot valve supplies oil under pressure to the appropriate side of the master piston so as to move it in the direction required for centralising the transfer valve through the control gear. The slave 248 follows the master because the timing valve 247 is open when the free pistons are in the starting position. When the air pressure on the manoeuvring gear is released, the starting position valve 266 returns to its normal position, leaving the passages to the master piston as they were before the manoeuvring gear operated and with the master piston in the correct position.

If the oil under pressure admitted at the inlet 246 to the slave timing valve is liable to be mixed with entrained gas, there is a risk that the slave follower 248 will move downwards with the master follower owing to expansion of the gas in the oil locked in the slave follower. In order to ensure that the slave will remain locked as long as is necessary, even when the oil supply is not free from gas, the slave follower may be provided with a brake constituted by a friction member adapted to engage the slave follower and actuated by a piston operating in a fixed cylinder which is supplied with the oil under pressure through a brake timing valve actuated by the synchronising pinion shaft 223 in such a manner that the oil pressure is applied to the brake cylinder at all times except when the slave timing valve is open.

Another form of the improved dead-point follower has a follower element resiliently biased, e. g. by a spring, in the direction approaching the dead point and co-operates with a fixed element to form a liquid displacement chamber, the actuating element co-operating with the follower element to form an outlet valve for this chamber. The actuating element may also co-operate with the fixed element to form a valve controlling the periodic supply of liquid under pressure to the chamber.

Thus in the example shown in Fig. 9 the actuating element is a cylinder 278 arranged to reciprocate longitudinally the master follower including a piston 279 slidable in this cylinder. The slave

follower is not shown and may be arranged similarly to that shown in Fig. 8. A fixed casing 280 in which the cylinder 278 is a working fit is provided with a port 281 connected through a piston valve 287 with an inlet 286 for oil under pressure. The port 281 is arranged to register with a metering port 282 in the cylinder when the latter is at an intermediate point in its range of movement. The stem of the piston valve 287 is slidably fitted in a lug 288 on the cylinder 278 and is engaged by a spring-loaded friction plunger 289 fitted in this lug. As the cylinder 278 moves towards the inner dead point, the valve 287 is kept by the friction plunger 289 in the position shown, a collar 287' ensuring that it remains in the open position. As the metering port 282 passes the port 281 oil is admitted within the cylinder 278 and displaces the master 279 a short distance outwards, against the force exerted by biasing means 283. As the cylinder 278 approaches the inner dead point required to be followed, an exhaust port 284 in the cylinder registering with an exhaust channel 285 in the casing is uncovered by the master 279 and allows the latter to follow the cylinder 278, under the influence of the biasing means, up to the inner dead point, where it remains locked, by the oil trapped in it, until the metering port again admits a charge of oil. During the outward movement of the cylinder, the piston valve 287 is displaced by the friction plunger 279 to a closed position, in which a collar 287'' abuts the end of the casing, so that no oil is admitted to the cylinder as the port 282 passes the port 281, and consequently the master remains locked for a large part of the time cycle.

It will be apparent that an equivalent device may be arranged in which the cylinder is adapted to oscillate about its axis and the master follower includes a vane co-operating with this cylinder.

The improved dead-point follower may be applied to internal-combustion operated free-piston gas-generators for purposes other than that herein described by way of example.

I claim:

1. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, and a differential device capable of compounding the responses of said inner dead point follower and said pressure responsive means and thereby yielding a control influence for said cushion control means such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio.

2. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a

power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device capable of compounding the responses of said inner dead point follower and said pressure responsive means and thereby yielding a control influence for said cushion control means such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, and means for adjusting the ratio of said differential device.

3. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device capable of compounding the responses of said inner dead point follower and said pressure responsive means and thereby yielding a control influence for said cushion control means such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, and means for adjusting the ratio of said differential device, said differential device being so arranged that, when the delivery pressure is at its minimum working value, adjustment of its ratio produces no substantial control influence.

4. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during

15

the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device capable of compounding the responses of said inner dead point follower and said pressure responsive means and thereby yielding a control influence for said cushion control means such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, and means capable of being actuated while said differential device is in operation for adjusting the ratio of said differential device.

5. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device capable of compounding the responses of said inner dead point follower and said pressure responsive means and thereby yielding a control influence for said cushion control means such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, and means capable of being actuated while said differential device is in operation for adjusting the ratio of said differential device, said differential device being so arranged that, when the delivery pressure is at its minimum working value, adjustment of the ratio of said differential device produces no substantial control influence.

6. Apparatus as claimed in claim 1 wherein said differential device includes a floating lever capable of compounding the responses of said inner dead point follower and said pressure responsive means.

7. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower respon-

16

sive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device including a floating lever capable of compounding the responses of said inner dead point follower and said pressure responsive means and thereby yielding a control influence for said cushion control means such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, and means for adjusting the ratio of said floating lever, at least one of the connections from said inner dead point follower and from said pressure responsive device being made to said floating lever through a roller carried by said lever and co-operating with a crosshead on the other element of the connection, and said roller being adjustable longitudinally of said crosshead.

8. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device including a floating lever capable of compounding the responses of said inner dead point follower and said pressure responsive means and thereby yielding a control influence for said cushion control means such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, and means for adjusting the ratio of said floating lever, at least one of the connections from said inner dead point follower and from said pressure responsive device being made to said floating lever through a roller carried by said lever and co-operating with a crosshead on the other element of the connection, and said roller being adjustable longitudinally of said crosshead in such a manner that, when the delivery pressure is at its minimum working value, the direction of adjusting movement of said roller is perpendicular to the direction of displacement of said crosshead.

9. Apparatus as claimed in claim 7 including a control member for adjusting said roller, said control member having a pivotal connection approximately co-axial with the point on said lever that yields the required cushion control displacement, the direction of adjusting motion of said pivotal connection being approximately perpendicular to the direction of motion of said point.

10. An internal-combustion-operated free-piston gas-generator of the kind specified, including a power cylinder, a power piston therein, a scavenge air receiver for said power cylinder, an air-compressor cylinder, a compressor piston therein and connected to said power piston to

17

form a free-piston assembly, said compressor cylinder being arranged to charge said receiver, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion by admitting air from the scavenge air receiver to the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device capable of compounding the responses of said inner dead point follower and said pressure responsive means and thereby yielding a control influence for said cushion control means such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, and stabilising means serving automatically to reduce the sensitivity of the control system under conditions tending to cause instability.

11. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device capable of compounding the responses of said inner dead point follower and said pressure responsive means, a mechanical connection for transmitting to said cushion control means from said differential device a control influence such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, and stabilising means capable of varying automatically the effective ratio of said connection so as to reduce the sensitivity of the control system only when said cushion control means are set to cause air to flow into the cushion and when the delivery pressure is high and the compression ratio is low.

12. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of re-

18

ceiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device including a floating lever capable of compounding the responses of said inner dead point follower and said pressure responsive means, a mechanical motion-transmitting system connected for transmitting from said floating lever to said cushion control means a control influence such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, and stabilising means capable of varying automatically the velocity ratio of said motion-transmitting system so as to reduce the sensitivity of the control system only when said cushion control means are set to cause air to flow into the cushion and when the delivery pressure is high and the compression ratio is low, said stabilising means including an element actuated by said inner dead point follower which serves to control the amount of variation of effective ratio of said motion transmitting system in dependence on the inner dead point.

13. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device including a floating lever capable of compounding the responses of said inner dead point follower and said pressure responsive means, a mechanical motion-transmitting system connected for transmitting from said floating lever to said cushion control means a control influence such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, and stabilising means capable of varying automatically the velocity ratio of said motion-transmitting system so as to reduce the sensitivity of the control system only when said cushion control means are set to cause air to flow into the cushion and when the delivery pressure is high and the compression ratio is low, said motion transmitting system including a stop, and a lever having two parts hingedly connected together and normally resiliently retained in predetermined relationship, one of said parts being operatively connected to said floating lever, and the other of said parts being adapted to engage said stop and having a pivotal connection for said cushion control means.

14. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device including a floating lever capable of compounding the responses of said inner dead point follower and said pressure responsive means, a mechanical motion-transmitting system connected for transmitting from said floating lever to said cushion control means a control influence such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, and stabilising means capable of varying automatically the velocity ratio of said motion-transmitting system so as to reduce the sensitivity of the control system only when said cushion control means are set to cause air to flow into the cushion and when the delivery pressure is high and the compression ratio is low, said stabilising means including an element actuated by said inner dead point follower which serves to control the amount of variation of effective ratio of said motion transmitting system in dependence on the inner dead point, said motion transmitting system including a stop, and a lever having two parts hingedly connected together and normally resiliently retained in predetermined relationship, one of said parts being operatively connected to said floating lever, and the other of said parts being adapted to engage said stop and having a pivotal connection for said cushion control means.

15. Apparatus as claimed in claim 14, wherein said stop is displaceable in a path substantially parallel to the length of said two-part lever through the agency of said inner dead point follower.

16. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, fuel-control means for varying the quantity of fuel injected into the power cylinder per cycle, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower respon-

sive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device capable of compounding the responses of said inner dead point follower and said pressure responsive means and thereby yielding a control influence for said cushion control means such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, means capable of being actuated while said differential device is in operation for adjusting the ratio of said differential device, and a common control member capable of actuating said fuel-control means and said ratio-adjusting means.

17. An internal-combustion-operated free-piston gas-generator, including a power cylinder, a power piston therein, an air-compressor cylinder, a compressor piston therein and connected to said power piston to form a free-piston assembly, said compressor cylinder being arranged to scavenge said power cylinder, and the mixture of combustion products and excess scavenge air delivered under superatmospheric pressure constituting the motive gas generated, means for maintaining a pneumatic cushion capable of receiving energy from said free-piston assembly during the expansion stroke in the power cylinder and of returning energy to said assembly during the compression stroke in the power cylinder, fuel-control means for varying the quantity of fuel injected into the power cylinder per cycle, cushion-control means operable while the gas-generator is running for varying the quantity of gas in the cushion, a dead-point follower responsive to change in the inner dead point of the free-piston assembly, means responsive to change in the delivery pressure of the gas-generator, a differential device capable of compounding the responses of said inner dead point follower and said pressure responsive means and thereby yielding a control influence for said cushion control means such that the quantity of gas in said cushion is increased and reduced as necessary to reduce changes in the overall compression ratio, means capable of being actuated while said differential device is in operation for adjusting the ratio of said differential device, and a common control member capable of differentially actuating said fuel-control means and said ratio-adjusting means in such a manner as to maintain said ratio at a value yielding a high overall compression ratio in the power cylinder of the gas-generator over a higher part of the range of fuel control and to actuate said ratio-adjusting means to lower said overall compression ratio progressively when the quantity of fuel injected per cycle is small.

18. A free-piston machine having a free-piston element which is capable of oscillating with a varying amplitude, a dead-point follower including an actuating element arranged to be oscillated by said free-piston element in such a manner that the displacements of said two elements are related to one another at least at and near the appropriate dead point, a master follower element so co-operating with said actuating element that it can be moved in one sense, in response to the entry of said actuating element into a dead point, to a position depending on said dead point, means operating automatically to move said follower element periodically through a limited distance in the other sense when said actuating element is not at and near said dead point, a slave follower element, and means operable for periodically bringing said follower elements into

predetermined relationship, for locking said slave follower element stationary throughout that part of the cycle in the which said master follower element is displaced in said other sense, and for locking said master follower element stationary during the part of the cycle, in which it corrects, if necessary, the position of said slave follower element.

19. A free-piston machine having a free-piston element which is capable of oscillating with a varying amplitude, a dead-point follower including an actuating element arranged to be oscillated by said free-piston element in such a manner that the displacements of said two elements are related to one another at least at and near the appropriate dead point, a follower element so co-operating with said actuating element that it can be moved in one sense, in response to the entry of said actuating element into a dead point, to a position depending on said dead point, a hydraulic buffer arranged to come into action between said actuating element and said follower element in order to accelerate the latter before it is positively driven by the actuating element, and means operating automatically to move said follower element periodically through a limited distance in the other sense when said actuating element is not at and near said dead point.

20. A free-piston machine having a free-piston element which is capable of oscillating with a varying amplitude a dead-point follower including an actuating element arranged to be oscillated by said free-piston element in such a manner that the displacements of said two elements are related to one another at least at and near the appropriate dead point, a follower element so co-operating with said actuating element that it can be moved in one sense, in response to the entry of said actuating element into a dead point, to a position depending on said dead point, means operating automatically to move said follower element periodically through a limited distance in the other sense when said actuating element is not at and near said dead point, and a hydraulic damper serving to prevent said follower element from overshooting the dead point, said damper including a piston co-operating with a cylinder and a loaded exhaust valve for said cylinder.

21. A free-piston machine having a free-piston element which is capable of oscillating with a varying amplitude, a dead-point follower including an actuating element arranged to be oscillated by said free-piston element in such a manner that the displacements of said two elements are related to one another at least at and near the appropriate dead point, a follower element so co-operating with said actuating element that it can be moved in one sense, in response to the entry of said actuating element into a dead point, to a position depending on said dead point, a hydraulic motor for moving said follower element through a limited distance in the other sense, and a hydraulic pump, operable by the element capable of oscillating with a varying amplitude, and serving periodically to energise said motor and thereby to move said follower element in said other sense.

22. Apparatus as claimed in claim 21, wherein said pump has plunger-controlled suction, delivery and spill ports, so arranged that said delivery ports are opened just before said suction ports close and are reclosed just after said spill port opens.

23. A free-piston machine having a free-piston element which is capable of oscillating with a varying amplitude, a dead-point follower including an actuating element arranged to be oscillated by said free-piston element in such a manner that the displacements of said two elements are related to one another at least at and near the appropriate dead point, a master follower element so co-operating with said actuating element that it can be moved in one sense, in response to the entry of said actuating element into a dead point, to a position depending on said dead point, means operating automatically to move said follower element periodically through a limited distance in the other sense when said actuating element is not at and near said dead point, a slave follower element, a hydraulic relay for coupling said follower elements in predetermined relationship, means for locking said slave follower element stationary throughout that part of the cycle in which said master follower element is displaced in said other sense, means for periodically energising said hydraulic relay to correct, if necessary, the position of said slave follower element, and means for locking said master follower element stationary at least throughout the period during which said relay so operates.

24. A free-piston machine having a free-piston element which is capable of oscillating with a varying amplitude, a dead-point follower including an actuating element arranged to be oscillated by said free-piston element in such a manner that the displacements of said two elements are related to one another at least at and near the appropriate dead point, a follower element so co-operating with said actuating element that it can be moved in one sense, in response to the entry of said actuating element into a dead point, to a position depending on said dead point, a hydraulic motor for moving said follower element through a limited distance in the other sense, a hydraulic plunger pump, operable by the element capable of oscillating with a varying amplitude, and serving periodically to energise said motor and thereby to move said follower element in said other sense, a slave follower element, a hydraulic relay for coupling said follower elements in predetermined relationship, means for locking said slave follower element stationary throughout that part of the cycle in which said master follower element is displaced in said other sense, a valve controlled by the plunger of said pump for controlling the energising of said hydraulic relay to correct, if necessary, the position of said slave follower element, and means for locking said master follower element stationary at least throughout the period during which said relay so operates.

25. An internal-combustion-operated free-piston machine provided with a free-piston element which is capable of oscillating with a varying amplitude, a dead-point follower including an actuating element arranged to be oscillated by said free-piston element in such a manner that the displacements of said two elements are related to one another at least at and near the appropriate dead point, a follower element so co-operating with said actuating element that it can be moved in one sense, in response to the entry of said actuating element into a dead point, to a position depending on said dead point, means operating automatically to move said follower element periodically through a limited distance in the other sense when said actuating element is

23

not at and near said dead point, a control member required to be operated preparatory to starting the machine, and means which serve to set said follower element to a predetermined position in response to operation of said control member.

26. An internal-combustion-operated free-piston machine provided with a free-piston element which is capable of oscillating with a varying amplitude, a dead-point follower including an actuating element arranged to be oscillated by said free-piston element in such a manner that the displacements of said two elements are related to one another at least at and near the appropriate dead point, a follower element including a hydraulic piston slidable in a cylinder, said follower element so co-operating with said actuating element that it can be moved in one sense, in response to the entry of said actuating element into a dead point, to a position depending on said dead point, means operating automatically to move said follower element periodically through a limited distance in the other sense when said actuating element is not at and near said dead point, a control member required to be operated preparatory to starting the machine, an automatic controller for the machine, a pilot valve operatively connected with said automatic controller and capable of controlling the supply of liquid under pressure alternatively to the one or the other side of said piston, and means, responsive to operation of said control member of the machine preparatory to starting, serving to put said pilot valve into operative condition and responsive to the reverse operation of said control member to disable said pilot valve.

27. An internal-combustion-operated free-piston machine provided with a free-piston element which is capable of oscillating with a varying amplitude, a dead-point follower including an actuating element arranged to be oscillated by said free-piston element in such a manner that the displacements of said two elements are related to one another at least at and near the appropriate dead point, a follower element including a hydraulic piston slidable in a cylinder, said follower element so co-operating with said actuating element that it can be moved in one sense, in response to the entry of said actuating element into a dead point, to a position depending on said dead point, means operating automatically to move said follower element periodically through a limited distance in the other sense when said actuating element is not at and near said dead point, a fluid-pressure gear for maneuvering said free-piston element into the starting position, an automatic controller for the machine, a pilot valve operatively connected with said automatic controller and capable of controlling the supply of liquid under pressure alternatively to the one or the other side of said piston, and an auxiliary valve, capable of being actuated by fluid pressure applied to said maneuvering gear for putting said pilot valve into operative condition.

24

28. A free-piston machine having a free-piston element which is capable of oscillating with a varying amplitude, a dead-point follower including an actuating element arranged to be oscillated by said free-piston element in such a manner that the displacements of said two elements are related to one another at least at and near the appropriate dead point, a follower element so co-operating with said actuating element that it can be moved in one sense, in response to the entry of said actuating element into a dead point, to a position depending on said dead point, said follower element being resiliently biased in the direction approaching the dead point and co-operating with a fixed element to form a liquid displacement chamber, and means operating automatically to admit a charge of liquid periodically under pressure to said chamber when said actuating element is not at and near said dead point and thereby to move said follower element through a limited distance in the other sense, said actuating element co-operating with said follower element to form an outlet valve for said chamber.

29. Apparatus as claimed in claim 28 wherein said actuating element co-operates with said fixed element to form a valve controlling the periodic supply of liquid under pressure to said chamber.

30. Apparatus as claimed in claim 28 wherein valve means serve automatically to admit a charge of liquid to said chamber only during movement of said actuating element in the direction approaching the dead point but before said actuating element is in the neighbourhood of the dead point.

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