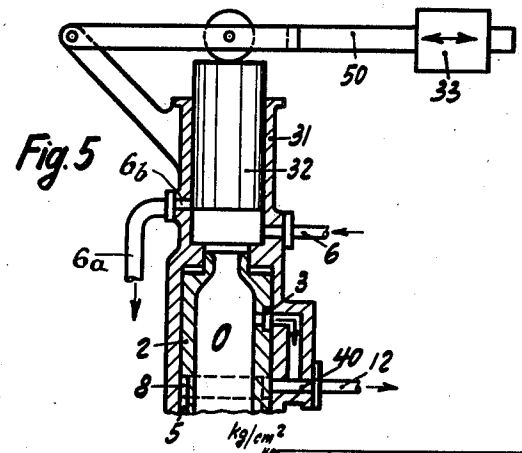
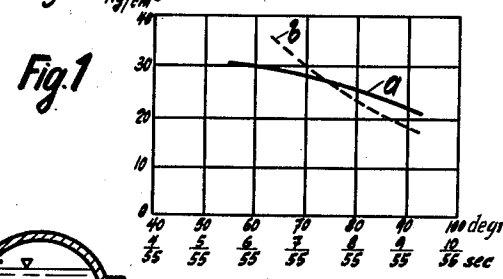
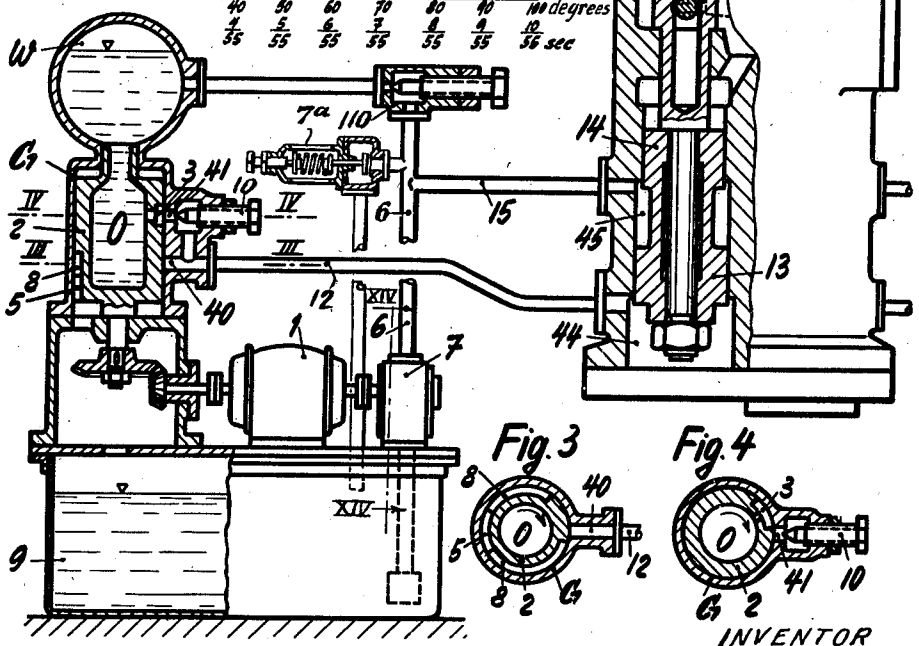
Sept. 13, 1938. H. HOLZWARTH 2,129,691

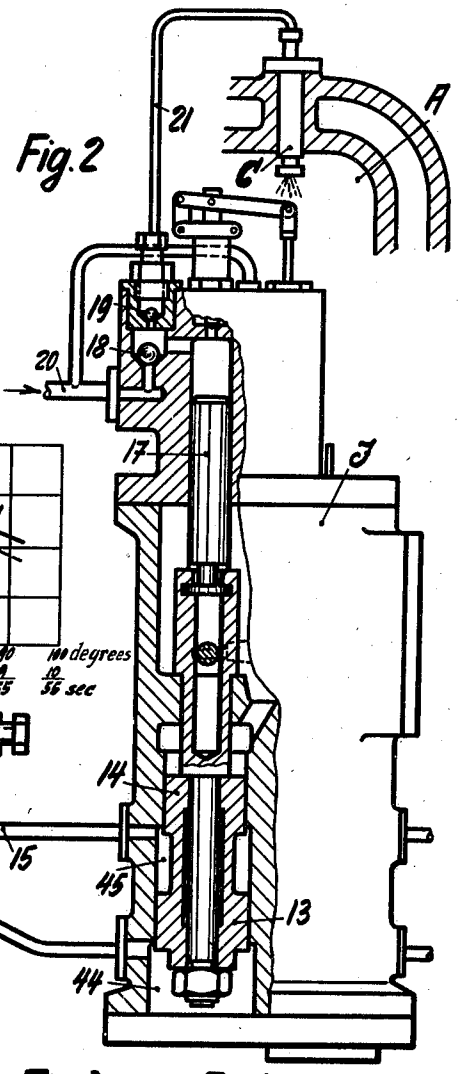
APPARATUS FOR REGULATING THE DURATION OF THE FUEL INJECTION IN EXPLOSION CHAMBERS

Original Filed May 8, 1933 4 Sheets-Sheet 1









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APPARATUS FOR REGULATING THE DURATION OF THE FUEL INJECTION IN EXPLOSION CHAMBERS

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Fig. 7

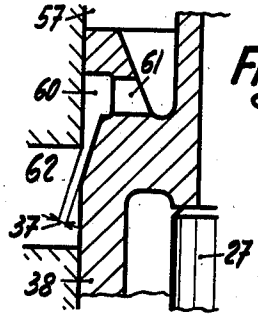


Fig. 8

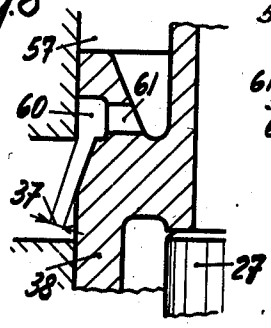


Fig. 9

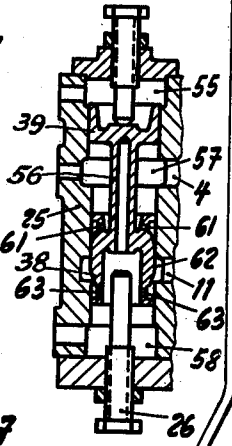


Fig. 10

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APPARATUS FOR REGULATING THE DURATION OF THE FUEL INJECTION IN EXPLOSION CHAMBERS

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Fig. 11.

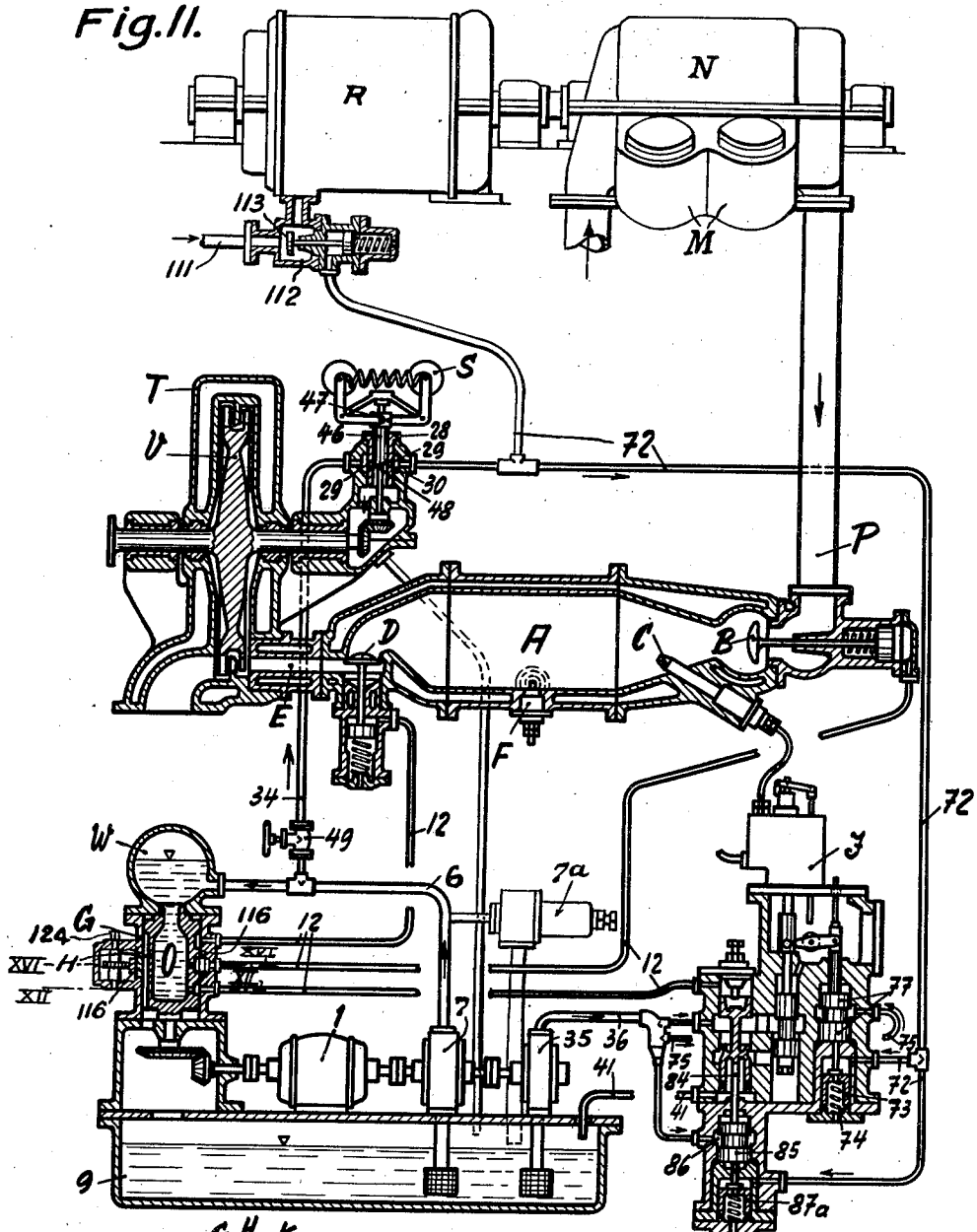


Fig. 12

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APPARATUS FOR REGULATING THE DURATION OF THE FUEL INJECTION IN EXPLOSION CHAMBERS

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Fig. 13

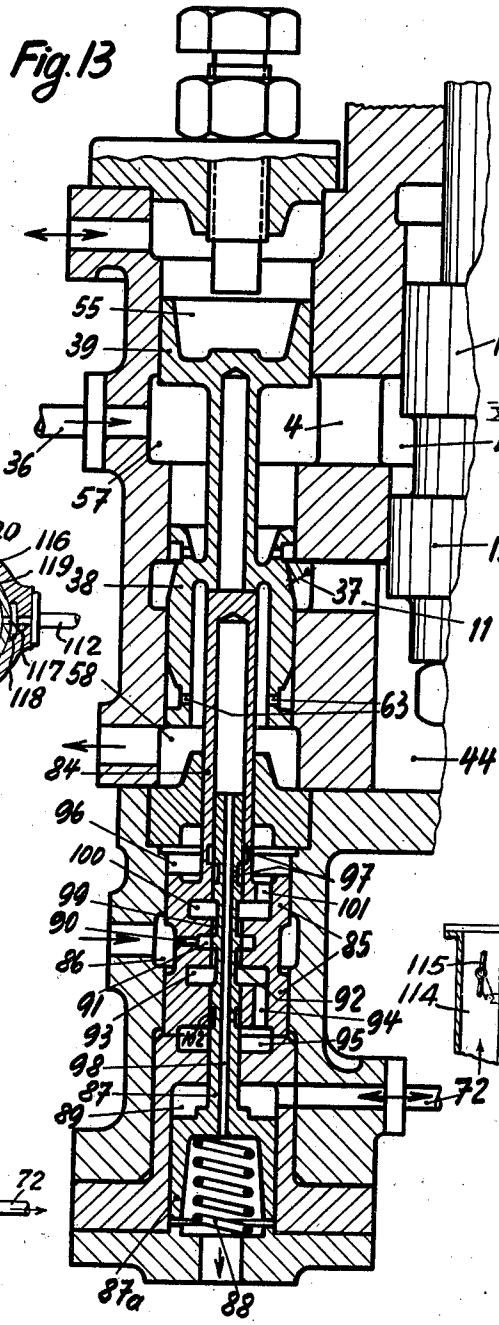


Fig. 14.

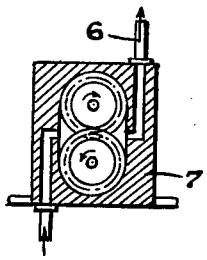


Fig. 16.

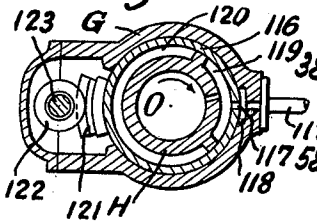


Fig. 17.

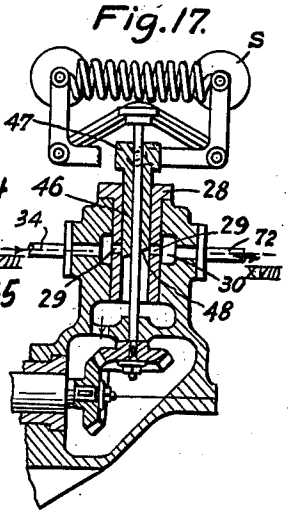


Fig. 18.

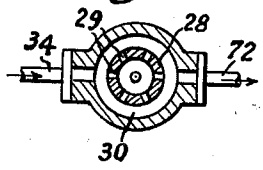
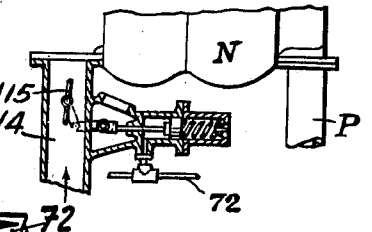


Fig. 15.



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UNITED STATES PATENT OFFICE

2,129,691

APPARATUS FOR REGULATING THE DURATION OF THE FUEL INJECTION IN EXPLOSION CHAMBERS

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Application May 8, 1933, Serial No. 669,963. Renewed November 24, 1937. In Germany May 9, 1932

11 Claims. (Cl. 60—41)

The present invention relates to an apparatus for controlling the time or duration of the injection of fuel in explosion chambers, and particularly in constant volume explosion chambers of the type employed in explosion turbines. Such regulation of the time of fuel injection is of the greatest importance when the liquid fuel to be charged into the explosion chamber is to be atomized by the charging air which is likewise to be introduced into the chamber. To obtain as uniform a mixture as possible, the injection of the fuel should be distributed as much as possible over the whole period, or at least the major portion of the period during which the charging air is admitted into the chamber. Only in such event will all the air particles be enriched with fuel immediately upon entry into the explosion chamber, so that a uniform distribution of the fuel is automatically obtained and proper combustion insured. It is the general object of the invention to provide a means for so adjusting the time interval allowed for the injection of fuel during each explosion cycle that such interval coincides more or less with the period of introduction of the charging air irrespective of changes in the amount of fuel injected in each cycle.

Furthermore, it is important in certain methods of operation which have already been proposed by me for explosion chambers, particularly for explosion turbines, that the whole quantity of fuel be introduced before the initially introduced fuel particles reach the place of ignition. The adjustment then is effected by displacing the moment at which the admission of fuel begins with reference to the moment at which the charging of the charging air begins. In this way the time interval can be adjusted which elapses before the particles of fuel first introduced reach the place of ignition. If this time interval is properly adjusted in correspondence with the control intervals of the explosion chamber, then the whole period of injection must be so measured that the admission of fuel is ended before the ignition begins. On the other hand, the admission of fuel should not cease too early, as otherwise the quality of the mixture will suffer. Within these limitations, therefore, the present invention contemplates a mode of control of the fuel injection whereby, regardless of the quantity of fuel injected, the fuel injection period is caused to extend over substantially the same portion of the air charging period.

The change in the duration of the injection period for the fuel is of importance also when the fuel is atomized by other means than by the charging air, and also when the mixture is self-ignited. In such cases too the whole quantity of fuel must be introduced before the ignition begins. It thus becomes necessary to adjust the time of injection to secure proper and efficient operation.

If the ignition is effected by controlled spark-plugs, then it is possible to adjust the instant of ignition in respect of time, so that such instant can be suited within certain limits to the duration of the fuel injection. The instant of ignition cannot, however, be displaced to a very considerable extent, since a certain definite time interval must intervene between the instant of ignition and the moment at which the nozzle valve is opened to insure complete combustion, since the combustion is not instantaneous, especially with liquid and solid fuels, and this interval cannot be reduced without disadvantageous results. It is accordingly necessary, even when the ignition takes place by means of externally controlled igniting elements, to provide a means for varying the time of fuel injection as the air charging period varies, and for keeping the duration of the fuel charging sufficiently long even when the amount of fuel charged is reduced, in order that a favorable composition and complete homogeneity of the combustible mixture may be obtained.

In a further development of the invention, the duration of the fuel injection is automatically varied in dependence upon the other regulating processes upon change in the output of the explosion chamber. If, for example, the time for introduction of the charging air is varied in the course of a regulating process, the duration of the fuel injection is automatically fitted to this new period for air charging in order to maintain a uniform distribution of the fuel. In particular, the duration of the fuel injection must be specially controlled in the course of a regulation of the output, even when the time for introduction of the charging air remains the same, as the fuel charging period changes with the change in the quantity of fuel injected in correspondence with the output demanded if special precautions are not taken. The duration of the fuel charging is controlled particularly by the size of the effective feed stroke of the fuel pump, which is reduced or increased upon adjustment of the quantity of fuel to be injected. In order, nevertheless, to set the duration of the fuel injection to a correct value, it is proposed, in accordance with the invention, to vary automatically the oil pressure acting directly or indirectly upon the piston or plunger of the fuel pump in dependence upon

other control processes and in particular upon the quantity of fuel to be introduced.

While the requirement for variation in the duration of the injection of the fuel could be fulfilled with the aid of mechanically operated fuel pumps, such pumps are expensive to manufacture and subject to rapid wear. Moreover the high mechanical pressures require a strong and heavy construction.

The problem of varying the time of injection can be solved in a much simpler manner in accordance with the invention with hydraulically operated fuel pumps. If, for example, the fuel pump plunger is driven by a stepped piston, one of whose surfaces (for example, the smaller one) effects the suction stroke while subjected to a constant oil pressure, while the other surface (for example, the larger one) is subjected to an oil pressure which is periodically controlled in correspondence with the working cycle, the difference between the total pressures on the two piston surfaces effecting the pressure stroke of the fuel pump plunger necessary for injecting the fuel, then by change of the pressure acting upon the one piston surface which provides the pressure stroke of the fuel pump plunger, the time interval of injection can be altered and can be correctly fitted to any prevailing operating conditions.

The invention will be further explained with the aid of the accompanying drawings which illustrate by way of example several embodiments of the invention, the same illustrating different ways of controlling the pressure of the actuating oil or equivalent fluid medium, corresponding parts of the different arrangements being indicated with the same reference characters.

Fig. 1 is a graph indicating the relation between the moment of fuel injection expressed in crank degrees or seconds, and the oil pressure;

Fig. 2 shows schematically the connection of a pressure oil controller with the fuel pump for an explosion chamber operating preferably according to the constant volume explosion process;

Figs. 3 and 4 are two different cross sections through the pressure oil accumulator or distributor of the pressure oil control mechanism and are taken respectively along the lines III—III and IV—IV of Fig. 2;

Fig. 5 is a longitudinal section through the upper part of a different form of pressure oil accumulator;

Fig. 6 shows a still further form of pressure oil control for the fuel pump, employing a separate auxiliary piston likewise controlled by oil under pressure;

Figs. 7 and 8 illustrate on an enlarged scale and in longitudinal section the auxiliary piston of Fig. 6 in two different positions;

Fig. 9 shows the auxiliary piston of Fig. 6 in the upper end position;

Fig. 10 is a cross section through the pressure oil accumulator of the control apparatus of Fig. 6 and is taken along the line X—X of Fig. 6;

Fig. 11 shows a different form of the invention in connection with a constant volume explosion turbine plant which is illustrated more or less in detail, the control oil pressure acting upon the fuel pump, in contrast with the forms of the invention shown in the previous figures, being varied automatically, i. e. in dependence upon the speed governor and hence in dependence upon the output of the machine;

Fig. 12 is a cross section through the oil distributor of the pressure oil control apparatus of Fig. 1 and is taken along the line XII—XII of Fig. 11, at the section of the oil distributor allocated to the fuel pump;

Fig. 13 shows on an enlarged scale the auxiliary or control piston and the abutment according to Fig. 11 which is automatically actuated and determines the lower end position of the piston; and

Fig. 14 is a section through the pressure oil supplying pump along the line XIV—XIV of Fig. 2;

Fig. 15 shows a modification of the invention illustrated in Fig. 11, the suction side of the compressor which feeds air into the explosion chambers being controlled from the output governor in accordance with the quantity of fuel injected into the explosion chamber per cycle to maintain a predetermined ratio between the fuel and air;

Fig. 16 is a horizontal section along the line XVI—XVI of Fig. 11;

Fig. 17 shows on an enlarged scale a section through the oil throttle mechanism controlled by the speed governor; and

Fig. 18 is a horizontal section along the line XVIII—XVIII of Fig. 17.

Before the individual embodiments of the invention are described, there will first be explained the relationship between the duration of injection of the fuel and the oil pressure of the fuel pump, the same being illustrated in Fig. 1. In such figure the ordinates indicate pressures in kg/cm^2 of the oil which operates the fuel feeding plunger of a hydraulic fuel pump, and the abscissae indicate the time interval for injection both in angular degrees and also in seconds. The selected second scale results from measurements made during the investigation upon which the diagram is based, and during the course of which 5500 working cycles occurred per hour in the explosion chamber. The letter b indicates a curve obtained by plotting the formula

$$v=\sqrt{2gH} \text{ or } \sqrt{20gp}$$

This formula is derived as follows:

The flow area q for the fuel in the injection valve must once and for all be adjusted to a certain magnitude, for the stream thickness may not be exceeded if good atomization is to be maintained. The constant quantity of fuel m is expelled in the time t through the cross section q with the velocity v. Therefore,

$$t.v.q=m, \text{ or } t=\frac{m}{v.q}$$

As the quantity of fuel m and the cross section q are to remain constant, the time of injection is inversely proportional to the velocity v of the fuel stream in the cross section q. The velocity of a stream of liquid flowing out of an opening q under a pressure $p=\frac{H}{10}$ (where H is the column of water, expressed in meters, corresponding to the pressure p measured in atmospheres) is determined according to the formula:

$$v=\sqrt{2gH}=\sqrt{20gp}$$

g being the acceleration of gravity, measured in meters.

The time of injection is thus inversely proportional to the square root of the pressure of the fuel. However, as the pressure of the fuel is proportional to the pressure of the oil which operates the fuel pump plunger, the time of injec-

tion is inversely proportional also to the square root of the pressure of such oil.

According to the curve *b*, the time of injection, in the case of an injection pressure at 30 atmospheres above atmospheric, extends over an angle at 70°; at a lower injection pressure of, for example, 24 atmospheres above atmospheric, the injection time extends over a much greater angle, namely over 80°. The letter *a* indicates a second curve which was derived upon the basis of experiments. In this curve, under the same conditions as appear from the calculated curve *b*, an injection pressure of 30 atmospheres above atmospheric corresponds to an angle of 58° and 24 atmospheres above atmospheric to an angle of 84°. The difference in the course of the practical curve *a*, in comparison with the theoretical curve *b*, is explained by the additional factors which appear in practical operation, as, for example, resistance to flow in the conduits. The calculations for the curve *b* did not take account of these additional factors. Nevertheless, it will clearly be seen from the course of both of these curves that the time required for the injection of a predetermined quantity of fuel falls with increasing injection pressure.

In the explosion turbine plant shown in Fig. 11, A represents a constant volume explosion chamber, preferably of elongated form, the air inlet member B and fuel inlet member C being located at one end of the chamber and the outlet member D being located at the opposite end of the chamber. The latter member controls the communication between the explosion chamber and its nozzle E, for which reason it is usually designated as a nozzle valve. An igniting member F, for example an electric spark plug, is arranged in the main cylindrical portion of the chamber A. The fuel feeding member C receives the required quantity of fuel for injection into the chamber from the fuel pump J, while the air valve B receives compressed air through the conduit P from the compressor N provided with two cooling stages M. The compressor may be driven by a steam turbine R or by any other suitable driving engine. The fuel pump and the inlet and outlet members of the chamber are hydraulically controlled in known manner. This control is accomplished by a controlling apparatus in the form of a pressure oil distributor G which includes a rotating disc or cylinder H driven at uniform velocity by an electric motor 1 through suitable reduction gearing, which is illustrated only conventionally. The distributor is provided with a number of control blocks K upon its circumference (see Fig. 12), two of which lie in the same plane and thus divide the annular space between the stationary housing of the distributor G and the rotating cylinder H into two compartments, one of the compartments being permanently connected through a suitable port in the wall of the cylinder with the interior O of the latter which contains controlling oil under pressure, while the other compartment leads to a space of low pressure, such as the oil supply tank 9. Conduits 12 are connected with the distributor G on a level with the various pairs of compartments and lead to the control pistons of the inlet and outlet valves B and D and of the fuel pump J. The length of the compartments under pressure and the speed of the distributor are so determined that the separate conduits 12 are periodically placed under the pressure of the oil in the space O for a predetermined time interval and during the remaining time are relieved of pressure. Oil of a definite quantity and pressure is constantly charged into the accumulator space O by conduit 6, such conduit leading from the oil pump 7 which is continually driven by the motor 1, the pump sucking the oil from the tank 9. The pressure of the oil may be determined by an adjustable, spring-pressed overflow valve 7*a* which permits excess oil delivered by the pump 7 to return to the tank 9. This valve is of known construction and no invention is claimed therein. An air chamber W located above the level of the oil in the accumulator insures maintenance of the oil pressure at a practically constant value, because of the elasticity of the body of compressed air, in spite of variations in the amount of pressure oil discharged by the distributor.

The explosion gases generated in the chamber A following the ignition and combustion of the explosive charge are discharged at predetermined instants through the nozzle valve D in the manner known in the art, the gases flowing into the nozzle E where they may be partially or completely expanded and are then directed against the rotor V of the turbine T which is coupled in any suitable manner with a speed governor S. The rotor V is of the impulse type and is provided with two rings of blades.

As will become clearer from the following description, the construction of the fuel pump and the manner of its connection with the pressure oil controller can be accomplished in various ways. One of the many possibilities is shown in Fig. 2 in which, for the sake of clearer illustration, the control blocks for the air inlet member B and the nozzle valve D (which blocks are shown at K in Fig. 11 attached to the rotating cylinder H) have been omitted from the rotating cylinder 2 of the oil distributor G. The cylinder 2 in this constructional embodiment has two arcuate grooves or compartments 3 and 8 lying in different planes, the upper groove 3 being connected with the oil accumulator O and the lower groove 8 with the tank 9 through a longitudinal passage 5, the tank being under a low or atmospheric pressure. The grooves 3 and 8 are periodically connected with channels 41 and 40, respectively, in the wall of the distributor housing during the rotation of the cylinder 2, such channels leading to the control oil conduit 12. In the channel 41, which temporarily connects the rotating groove 3 in the cylinder with the control oil conduit 12, there is located a throttle in the form of a screw 10. The fuel pump J includes a fuel feeding plunger 17 and a two-stepped or two-sectioned piston 13, 14 connected with the plunger. The cylinder space 44 below the piston step or section 13 is constantly in communication with the control oil conduit 12 and the space 45 between the two piston steps 13 and 14 is connected through conduit 15 with the oil accumulator space O within the rotating distributor cylinder. Depending on whether the total net pressure in space 45 or 44 preponderates, the piston 13, 14 moves downwardly or upwardly, as will be described below.

The fuel pump is provided with a suction valve 18 and a pressure valve 19. The fuel flows to the pump through conduit 20 and flows off through the pressure conduit 21 connected behind the pressure valve 19 to the injection nozzle C.

The mechanism shown in Fig. 2 operates in the following manner: So long as the groove 8 in the cylinder 2 of the distributor G is connected with the channel 40 in the distributor housing, and hence with the control oil conduit 12, the two

stepped piston 13, 14 is forced downwardly into its lowest end position, because the space 44 is exhausted. As soon as the groove 8 moves out of registry with the channel 40, the control oil conduit 12 is closed against the atmosphere by the wall of the distributor housing. This position is shown in Figs. 2, 3, and 4 wherein the upper groove 3 in the cylinder 2 is about to move into registry with the channel 41 in the distributor housing, so that the hydraulic pressure prevailing in the pressure oil accumulator space O is transmitted through the control oil conduit 12 to the cylinder space 44 under the piston step 13. The pressure exerted upon the under side of this piston step now preponderates over the net downward pressure of the oil in the space 45, so that the two-stepped piston 13, 14 and together therewith the fuel pump plunger 17 is forced upwardly and the latter accomplishes its pressure stroke whereby fuel is injected into the explosion chamber A. When the control oil conduit 12, during the further rotation of the cylinder 2, again becomes connected with the groove 8 of the latter, and hence with the space of lower pressure, the pressure in space 44 beneath the piston step 13 is released and the pressure in the space 45 again preponderates. The plunger actuating piston 13, 14 is then pressed downwardly together with the plunger 17, the latter then performing its suction stroke and the new charge of fuel being sucked through the conduit 20 into the fuel space of the pump. By adjustment (rotation) of the throttling member 10, the passageway from the interior of the rotating cylinder 2 to the control oil conduit 12, and hence the control or operating oil pressure and the velocity of the fuel pump plunger during its pressure stroke, and thus also the time period of injection, can be varied at will. The more said passageway is throttled, the smaller is the oil pressure beyond the throttle, that is, the pressure upon the side leading to the control oil conduit 12. From the graph in Fig. 1 it will be seen that with decreasing oil pressure the time of injection is increased. If, therefore, the time of injection is to be short, the pressure which is transmitted to the control oil conduit 12 must be made sufficiently high by the provision of a large throttle cross-section.

It will be understood that in the above described mechanism, and likewise in those described hereinbelow, the operating oil control is so determined that the feed of pressure oil lasts at least as long as and preferably somewhat longer, than the time necessary for completing the desired effective pump stroke even at the lowest oil pressure, i. e., when the fuel feed is slowest.

Instead of adjusting the control oil pressure beyond the accumulator O to the desired value with the throttling member 10, it is, of course, also possible to arrange a pressure reducing mechanism in advance of the pressure oil accumulator, for example, a throttling device 110 in the pump conduit 6, as shown in Fig. 2. With such mechanism the oil pressure in the oil accumulator is itself adjusted to the required value conditioned by the desired period of injection. This pressure regulation is effected by the throttling device 110 by virtue of the fact that beyond such device a practically constant withdrawal of oil occurs from the distributor O, while in advance of such device the pressure is maintained practically constant by the overflow valve 7a. The smaller the throttle opening is adjusted, the larger must be the pressure differential for forcing the quantity of oil, which is withdrawn from the distributor at an approximately constant rate, through such throttle opening. If the oil pressure in advance of the throttling device is constant then under these conditions the pressure must be lower beyond such device.

Fig. 5 shows another embodiment of mechanism for varying the predetermined pressure of the control oil and hence the time for injection. This mechainsm differs from that above described mainly in the fact that in place of the throttling member (e. g., the screw 10) there is employed a loaded pressure piston 32 which exerts a predetermined pressure upon liquid located in the interior of the rotating cylinder 2 of the pressure oil controller corresponding to its load. The piston 32 moves in a cylinder 31. The load on the piston is in the form of a weight 33 located upon the pivoted lever 50 and movable thereupon according to the required loading of the piston. If, for example, the weight 33 is shifted upon the lever 50 toward the right, as viewed in the drawings, the load on the piston 32 is increased and hence also the pressure both in the pressure oil accumulator O and in the control oil conduit 12 as long as the latter, as shown in Fig. 5, is connected with the space O and is closed against the atmosphere or the exhaust space of lower pressure. Upon increase of the oil pressure, the lifting velocity of the fuel pump plunger 17 is simultaneously increased, just as in the arrangement shown in Fig. 2, such increase in velocity resulting in a reduction in the time of injection. The pressure oil is fed to the distributor O by the conduit 6, as in Fig. 2, excess pressure above that determined by the loading of piston 32 being relieved by the discharge of excess oil into conduit 6a through port 6b in cylinder 31. In the construction shown in Fig. 5, not only the throttling members (screws 10 and 110) in the control and oil passageways, but also the air chamber W are dispensed with.

Fig. 6 shows a third construction for varying the control oil pressure and the stroke velocity of the fuel pump plunger, an air chamber W being provided in such construction as in that shown in Fig. 2. In Fig. 6 the pressure oil control differs from both of the preceding constructions mainly in the fact that a separate auxiliary piston acting as control piston is arranged between the control oil conduit 12 and the stepped oil pressure piston 13, 14 which actuates the plunger 17. The auxiliary piston is equipped with a throttling device with whose aid the oil pressure acting upon the stepped piston 13, 14 is regulated.

The numeral 51 indicates the rotating cylinder in the pressure oil distributor G driven by the motor 1, the distributor having an interior space O serving as a pressure oil accumulator, which space is in constant communication with the air chamber W into which the pressure oil conduit 6, leading from the pump 7, debouches. The revolving cylinder 51 is provided with blocks K upon its circumference, which together with the housing of the pressure oil distributor G define a pressure compartment 52 which is constantly in connection with the accumulator O, and a compartment 53 which communicates with an exhaust space of lower pressure, both compartments, in contrast to the construction of Fig. 2, lying in the same plane. The compartment 53, which is at the middle of the cylinder, is connected with spaces provided at both ends of the cylinder through longitudinal grooves 54 cut in the circumference of the revolving cylinder from both

its ends, and opening into the compartment 53, the space at the lower end being connected with the oil supply tank 9 and thus draining any oil which may accumulate at the top of the cylinder. The blocks K control the oil conduit 12 in the usual manner, the conduit coming into communication alternatingly with the pressure space 52 and with the exhaust space 53 of lower pressure as the cylinder continually revolves. In the illustrated position of the cylinder 51, the control oil conduit 12 is connected with the pressure space 52, so that pressure oil flows out of the accumulator O into the conduit which conveys the oil into the cylinder space 55 of the housing 25 in which is arranged, parallel to the stepped piston 13, 14, a control or auxiliary piston consisting of two sections 38 and 39 of different diameters. The two steps 38 and 39 are connected with each other by a stem 56, an annular space 57 being formed between the two steps. The pressure conduit 36 of a second pressure oil pump 35 opens into this space, the pump 35 being coupled with the control oil pump 7 which supplies the accumulator space O in the revolving cylinder with control oil. The cylinder space 58 below the piston portion 38 is connected by a conduit 41 with the supply tank 9. The annular space 57, which is under constant oil pressure, is permanently connected with the annular space 45 through a transverse bore 4 in the common cylinder wall of the two juxtaposed stepped pistons, the space 45 lying between the two steps 13, 14 of the stepped piston which serves for driving the fuel pump plunger 17. As can best be seen from the enlarged sectional views of Figs. 7 and 8, there is provided an annular groove 60 in the lower stepped portion 38 of the auxiliary control piston near its upper end, such groove 60 being connected with the space 57 through a radial bore 61. The stepped portion 38 is cut at an inclination for a short distance along its circumference from the lower edge of the annular groove 60, so that a short bevel which diminishes in diameter toward the upper end is formed in the piston step. An annular groove 62 is provided in the guiding surface of the cylinder for this piston step, such groove being in communication with the cylinder space 44 under the stepped piston 13, 14 through the transverse bore 11. In the lower position of the control or auxiliary piston the outer surface of the bevel portion of the step 38 together with the upper edge of the annular groove 62 forms a throttling area 37. By means of an adjustable stop 26, the lower end position of the auxiliary piston in which its downward movement is checked can be adjusted at will. Depending upon the selected lower end position, a larger or smaller throttling cross-section 37 is obtained, as indicated in Figs. 7 and 8 which show different limiting downward positions of such piston.

The mechanism just described operates in the following manner:

In the illustrated position of the revolving cylinder 51, the accumulator space O is placed in communication with the conduit 12 through the compartment 52. Pressure oil then flows into the cylinder space 55 and acts upon the upper surface of larger diameter of the step 39 of the control or auxiliary piston. This control oil pressure preponderates over the pressure of the oil delivered by the pump 35 and exerted in the intermediate space 57 upon the differential surface of the two piston sections 38, 39. The control piston moves downwardly until it strikes the adjustable stop 26. Thereupon, depending upon the adjustment of the stop 26, a correspondingly dimensioned throttling cross-section 37 is established through which the oil under pressure flows from the space 57 by way of the bore 61, and then enters the annular space 62 and thence passes through the transverse bore 11 into the cylinder space 44, where the pressure oil acts upon the lower and larger surface of the stepped main piston 13, 14. The pressure created by the inflow of pressure oil into this cylinder space drives the main piston and with it the fuel pump plunger 17 upwardly while overcoming the differential pressure acting in the intermediate space 45, the plunger 17 thereby accomplishing its pressure or feed stroke. As soon as the rear control block K, considered in the direction of rotation of the cylinder 51, passes the connection of the oil conduit 12, the latter comes into communication with the exhaust space 53. The greater pressure in the control oil conduit and in the cylinder space 55 of the auxiliary piston ceases immediately, so that the differential pressure acting upon the piston in the intermediate space 57 preponderates and the auxiliary piston is again moved upwardly. The upper end position of such piston is shown in Fig. 9. The cylinder space 44 of the main piston is then connected with the lower cylinder space 58 through the transverse port 11, annular space 62, and openings 63 in the lower section 38 of the auxiliary piston, the pressure oil flowing from the space 58 to the supply tank 9. While the auxiliary piston is moved upwardly, the main piston moves downwardly under the influence of the differential pressure acting in the intermediate piston space 45, and the fuel pump plunger 17 then sucks in a new charge of fuel.

The velocity of the pressure stroke of the plunger 17 consequently is greater the lower the stop 26 is adjusted, that is, the greater the throttling cross-section 37 is.

The quantity of fuel which is fed during every pressure stroke of the plunger 17 remains uninfluenced by the above described regulation of the duration of the fuel injection. The quantity of fuel per charge depends rather upon the limitation of the effective stroke of the plunger 17, and such limitation may be accomplished by controlling the instant at which the fuel advanced during the latter portion of the stroke of the plunger is caused to return to the suction side of the fuel pump instead of being fed to the injection device C. To this end, the fuel pump is provided in known manner with a by-pass or overflow valve 47 which is actuated by a linkage 16. This linkage is driven by the lever 22 which is articulated with the piston plunger 17, such lever oscillating in a vertical plane about the pivot 23 whose vertical position is adjustable. The lever 22 carries a roller 24 which, depending upon the adjustment of the fulcrum 23, contacts and actuates the linkage 16 either earlier or later with reference to the feed stroke of the plunger 17, so that the spring-pressed by-pass valve 47 opens and from that instant on the fuel in the further course of the feed stroke is not fed into the fuel pump conduit 21, but is conveyed back to the suction conduit 20 by a conduit 27.

The adjustment of the quantity of fuel per charge, which in the construction illustrated is determined by the position of the fulcrum 23 of the lever 22, occurs as usual in dependence upon the output of the machine through the governor S (see Figs. 11, 17 and 18). For this purpose the latter is provided with a sleeve 28 having ports

29 which communicate with a pressure oil space 30 to which control oil is conducted by the pump 7 through a conduit 34 branching from the conduit 6. Upon the shaft of the governor is positioned a piston-like member 46 which fits closely within the sleeve 28 and is connected with the controller collar 47 to move positively therewith. The member 46 is tapered at the end lying within the sleeve 28 so that a regulating edge 48 is formed. Upon axial displacement of the collar 47 under the influence of the governor, the member 46 is advanced into or withdrawn from the sleeve 28 by a corresponding distance, so that a larger or smaller cross-section of the ports 29 in the sleeve is exposed by the regulating edge 48. Depending upon the size of the exposed flow area a corresponding quantity of control oil flows out of the annular space 30 and the pressure on the mass of control oil which has already been throttled by the device 49 in the feed conduit 34 is changed. Where a large flow area of the ports 29 is exposed there results a small control oil pressure, whereas by reduction of such cross-section the control oil pressure is maintained high. The oil pressure determined by the position of the governor at any time acts through conduit 72 upon the regulating piston 73 (see Fig. 6) which is held in equilibrium by the spring 74. If the oil pressure falls, due to the fact that a larger flow area of the ports 29 has been uncovered due to increase in the speed of the governor, the regulating piston 73 rises under the influence of the spring 74, while pressure oil flows into the annular space 76 through the conduit 75 which is connected with the pump conduit 36, the space 76 surrounding a piston 77. The latter piston slides upon the regulating piston shaft 78 which is provided in its circumference with grooves which upon the upward movement of the regulating piston come into registry with channels 79, so that the pressure oil flows out of the space 76 into the space beneath the piston 77, while the cylinder space 80 above the piston 77 is placed in communication with the space 83, which is under atmospheric pressure, through ports 81, the perforated hollow shaft 78 and the hollow shaft 82 of the piston 77 which slides upon the shaft 78. The piston 77 now moves upwardly until the flow of pressure oil under the piston and the discharge above the piston are checked. The piston is now held in this position and with it the fulcrum 23 of the lever 22 which is pivotally connected with the plunger 17.

If, on the other hand, the control oil pressure in the conduit 72 leading to the regulating piston 73 increases, upon fall in the speed of the turbine, then conversely the regulating piston 73 and the piston 77 are moved downwardly to an extent depending upon the magnitude of the control oil pressure, so that the fulcrum 23 is displaced downwardly, resulting in an increase in the effective quantity of fuel supplied.

In the pressure oil regulation of Figs. 2, 5 and 6, the oil pressure necessary for the pressure stroke of the fuel pump plunger and with it the duration of the injection are regulated by hand. This regulation can be effected also automatically, that is, in dependence upon the other regulating processes of the explosion plant with changes in the output of the plant. Such a mechanism is embodied by way of example in the injection pump J illustrated in Fig. 11. The construction of this pump itself, including its hydraulic drive and its method of operation are entirely the same as in the construction of Fig. 6, reference being therefore had to the description of such figure for an explanation of the structure and operation of the pump shown in Fig. 11. The only difference between the two pump constructions resides in the fact that the fuel pump of Fig. 11 is provided with an adjustable abutment 84 serving to vary the control oil pressure, such abutment being adjusted automatically by the control oil pressure which in turn is controlled by the governor S. The automatic control mechanism is built into the fuel pump shown in Fig. 6, as indicated in Figs. 11 and 13. The details of this automatic control mechanism are shown more clearly in Fig. 13 which shows the parts of the fuel pump under discussion in an enlarged longitudinal section. The numerals 38, 39 again indicate the two sections of the control piston regulating the control oil which in the upper position of the control piston is conveyed from the pump 35 by the conduit 36 into the intermediate space 57 and thence through the transverse bore 4 to the space 45 of the stepped main piston 13, 14, and which in the illustrated lower end position of the control piston, flows through the port 11 into the space 44 under the section 13 of the main piston. This latter control position of the auxiliary piston is shown in Figs. 11 and 13. The auxiliary piston is thus forced into its lower end position through inflow of the control oil into the cylinder space 55 above the larger section 39 of such piston. In the upper end position of the control piston (see Fig. 9), on the other hand, the control oil below the section 13 of the main piston flows off again through the bore 11 and through the radial bores 63 provided in the lower section 38 of the control piston into the space 58 and thence to the oil supply tank 9. The control oil pressure acting in the space 44 below the section 13 of the main piston is determined, as has been described in connection with Fig. 6, by a controllable throttling cross-section 37 which is adjusted by change in the elevation of the abutment 84 (see Figs. 11 and 13). This abutment consists of a hollow shaft which at the end opposite the control piston terminates in a two sectioned piston 85 having an intermediate annular space 86 into which actuating oil is constantly fed by the pump 35 (see Fig. 11). A hollow shaft 87 projects co-axially into the piston 85 and its shaft 84, the shaft 87 terminating at its lower end in a regulating piston 87*a* against which a spring 88 acts from below. The space 89 above the piston 87*a* is under the influence of the control oil fed by the conduit 72, the pressure of such oil resulting from the position at any time of the governor S, as already described hereinabove. The intermediate space 86 which is filled with actuating oil is in communication through at least one radial bore 90 with an inner annular groove 91 lying in the same plane. This groove 91, upon upward movement of the regulating piston 87*a*—hence upon decrease in the output of the turbine or increase in the speed of the governor—is connected through a groove 92 on the shaft of the piston 87*a*, annular space 93, and axial bore 94 with the space 95 under the piston 85, so that the actuating oil entering the same drives the piston 85 upwardly and reduces the throttling area 37. Consequently, the oil pressure acting upon the main piston 13 is reduced until the annular space 91 is again covered by the surface of the regulating piston shaft 87, that is, the connection between the space 86 and the space 95 under the piston 85 is broken. During the connection of these two spaces 86 and 95 the space

96 above the piston 85 is connected with the central bore 98 of the shaft 87 through the ports 97 in the two hollow shafts 84 and 87 which are movable one within the other, so that the pressure oil can escape from the space 96. On the other hand, when the control oil pressure in the space 89 above the regulating piston 87a increases upon decrease in the speed of the governor, the regulating piston moves downward while overcoming the resistance of the spring 88. The control oil now enters from the annular space 86, through a second, higher groove 99, space 100 and bore 101 into the space 96 above the piston 85, while the space 95 below it is connected through a groove 102 and a communicating radial bore in the hollow shaft 87 with its central bore 98. During this connection the piston 85 and with it the abutment for the control piston 38, 39 are moved downward, so that in the lower end position of the control piston, a larger throttling area 37 is created.

As in the described construction the control device for the adjustable abutment of the piston 38, 39 is actuated by the control oil pressure which in turn is regulated by the governor, the latter acting simultaneously through the common conduit 72 upon the control device for the regulation of the quantity of fuel, as described above in connection with Fig. 6, the result is that simultaneously with the change in the quantity of fuel delivered, that is, with change in the output of the machine (turbine), the time or duration of the injection is correspondingly controlled. Thus, upon increase in the quantity of fuel (increase in the output of the machine), when the effective feed stroke of the fuel pump plunger is increased, the duration of injection is, according to the invention, automatically reduced again to approximately the former value, while conversely upon fall in the output, that is, upon increase in the speed of the governor, such duration is increased to the former value. With this construction of the oil pressure regulator, upon change in the output of the machine, both the quantity of fuel delivered and the time provided for the injection are varied automatically in dependence upon the speed of the governor, while the number of working cycles per unit of time (cycle frequency) in the explosion chamber A remains constant. In this form of the invention, upon change in the quantity of fuel injected, there changes also the relative proportion of fuel and air in the chamber, since the quantity of charging air remains uninfluenced by the regulation of the quantity of fuel.

Where such variation in the composition of the mixture in the chamber is not desired, the oil pressure regulation may be so effected, that with change in the quantity of fuel injected (see Fig. 11) the quantity of air supplied is simultaneously changed, so that any predetermined mixture ratio is maintained under all conditions of operation. Two constructions embodying this further development of the invention are illustrated in Figs. 11 and 15 which show such additional regulation. In Fig. 11 the charge of air is varied by regulating the flow of the working medium (steam, gas) which drives the compressor, such medium being fed by the conduit 111, the variation being effected by control of the flow cross-section of the conduit 112 with the aid of a spring-pressed throttling member 113. The latter, like the regulating pistons 73 and 87a of the oil pressure regulating mechanism of the injection pump (see Fig. 11), is under the action of the oil pressure in the conduit 72 which, as already described, is in turn regulated by the output governor S. When the oil pressure in the conduit 72 falls due to the fact that increase in the speed of the main turbine V causes a corresponding movement of the governor, then with simultaneous reduction in the quantity of fuel injected per charge, the quantity of charging air delivered is proportionally reduced by reducing the flow area of the feeding conduit 112 of the auxiliary turbine R with the aid of the throttling member 113 which is pressed toward the left by its spring to an extent corresponding to the fall in pressure in conduit 72. The auxiliary turbine R falls in speed in consequence of the throttling of the working medium charged by the conduit 111, and together therewith the output of the compressor N also falls. Consequently, air of lower pressure, and hence a smaller weight of air per cycle, is charged into the explosion chamber in correspondence with the reduced quantity of fuel injected per cycle. When, on the other hand, the control oil pressure in the conduit 72 rises upon increase in the output of the main turbine and accompanying decrease in the speed of the governor, the reverse of the above events occurs.

As shown in Fig. 15, the quantity of charging air can also be varied in dependence upon the fuel regulation by providing a throttling valve 115 controlled by the output governor through control oil conduit 72, such throttling valve being located in the suction conduit 114 of the compressor N, the quantity of air sucked in by the compressor being then determined by the position of such valve. The control mechanism and the operation of this throttling valve are essentially the same as those of the throttling member 113 shown in Fig. 11.

When for any reason it should be desired to alter the time relationship of the air charging period of the explosion chamber with respect to the other periods or phases of the working cycle, that is, to retard or advance the beginning and end of such air charging period, this may be accomplished with the aid of mechanism disclosed in German Patent No. 563,091, the essential elements of which are illustrated in Figs. 11 and 16. As there shown, the portion of the oil distributor associated with the conduit 12 leading to the actuating piston of the air valve B is modified to receive a sliding ring 116 which is provided with a port 117 in registry with the groove 118 in housing G, the conduit 112 opening into such groove. The port 117 thus controls the communication between the groove 118 (and hence conduit 112) and the pressure and exhaust compartments 119 and 120 defined by the rotating cylinder O. The ring 116 is provided with a gear segment 121 meshing with a pinion 122 on a shaft 123 having a square end 124 (Fig. 11) for engagement by a suitable tool. Upon rotation of the ring 116 by way of the shaft 123 and pinion 122 in the clockwise or counterclockwise direction (Fig. 16), the cylinder O moving clockwise, as shown by the arrow, the instant at which the conduit 12 is brought into communication with the pressure and exhaust compartments 119, 120 is retarded or advanced.

The invention is of course not limited to the embodiments above described, the same having been shown merely by way of example. Thus it is within the scope of the invention to utilize an arrangement in which the explosion chamber is

employed not to drive a turbine but to operate, for example, a heat exchanger or other device.

A method and apparatus for effecting the automatic regulation of output and speed of the turbine in connection with the total arrangement of the turbine plant corresponding to Figs. 11–13 and 15 of the present application is for instance described and claimed in my copending application Serial No. 583,880, which has issued as Patent No. 2,015,072, dated Sept. 24, 1935.

I claim:

1. The combination with an explosion chamber having valve means for charging air into said chamber, of a fuel pump having a pressure oil-operated plunger for charging fuel into said chamber after the admission of air has begun and while the admission of air proceeds, the injection of fuel thus continuing concurrently with the admission of air, apparatus for charging operating oil under pressure to actuate the plunger, means for varying the effective pressure of said pressure oil to vary the rate of injection of the fuel, and timing mechanism for controlling said valve means and said fuel pump and operating to keep the time displacement of the beginnings of air and fuel charging in each cycle substantially constant.

2. The combination as set forth in claim 1, including a pressure oil accumulator, and a conduit for conducting oil under pressure from the accumulator to the pump, said pressure varying means adjusting the pressure of the oil in such accumulator.

3. The combination as set forth in claim 1, including a pressure oil accumulator, and a conduit between the accumulator and the working space of the pump plunger, said pressure varying means comprising a device for throttling the flow of oil in said conduit.

4. The combination as set forth in claim 1, including a piston associated with the plunger to actuate the same, an auxiliary piston for controlling the fuel pump, a conduit for supplying oil under pressure to the auxiliary piston to operate the same, and passageways controlled by said auxiliary piston for connecting the first-mentioned piston alternatingly with a space of higher and a space of lower oil pressure, and means for varying the pressure between the auxiliary piston and the first-mentioned piston and operating independently of the means for controlling the pressure of the pressure oil.

5. The combination with an explosion chamber, of means for charging air into said chamber, a pressure oil-operated fuel pump for charging fuel into said chamber after the admission of air has begun and while the admission of air proceeds, the injection of fuel thus continuing concurrently with the admission of the air, said pump including a plunger and a main piston for operating the latter, timing mechanism for the air charging means and the fuel pump operating to keep the time-displacement of the beginnings of air and fuel charging in each cycle substantially constant, and means for varying the pressure of the operating oil to vary the duration of injection of the fuel including an auxiliary piston arranged to connect the main piston alternatingly with a space of higher and a space of lower oil pressure, means for adjusting one of the end positions of the auxiliary piston, and means controlled by the auxiliary piston in its end position for varying the flow area for the pressure oil which actuates the main piston, whereby the oil pressure acting upon the main piston may be adjusted to any desired predetermined value and the duration of the fuel feed by the pump correspondingly varied.

6. The combination with an explosion chamber, of means for charging air into said chamber, a fuel pump for charging liquid fuel into the chamber after the admission of air has begun, the injection of fuel continuing concurrently with the admission of the air, said pump including a plunger and an oil-operated mechanism for actuating the same, means for varying the pressure of the operating oil to vary the duration of the feed of a charge of fuel by the plunger to vary the duration of injection of the fuel, and timing mechanism for said air charging means and fuel pump operating to maintain the time-displacement of the beginnings of air and fuel charging in each cycle substantially constant.

7. The combination with an intermittently operated explosion chamber having an air inlet valve for charging combustion-supporting air into the chamber during each cycle, of a fuel pump for charging fuel into the chamber during the admission of air and comprising a cylinder, a plunger movable in said cylinder, a fuel conduit for delivering fuel into said cylinder, means for reciprocating the plunger with constant length of stroke, a by-pass connected with the cylinder and adapted to withdraw controlled amounts of fuel for regulating the quantity of fuel discharged per cycle into the chamber, and mechanism for varying the speed of the pump in accordance with the quantity of fuel to be charged into the chamber per cycle so as to proportion the duration of the fuel injection to the duration of the air charging period independently of the amount of fuel charged.

8. The combination with an explosion chamber having valve means for charging air into said chamber, of a fuel pump for charging fuel into said chamber, means for actuating the air valve means, timing mechanism associated with said means and with said fuel pump to effect beginning of the injection of fuel after the admission of air has begun, the admission of fuel and air occurring thereafter concurrently, means for varying the amount of fuel charged per cycle, and mechanism acting on the pump for causing change in the rate of feed of the fuel into the explosion chamber inversely with the change in the amount of fuel charged per cycle, whereby in an engine operating with approximately constant cycle periods, the fuel injection extends over approximately the same portion of the air charge period in spite of changes in the quantity of fuel introduced per cycle.

9. The combination with an explosion chamber, of means for charging air into said chamber, a fuel pump for charging liquid fuel into the chamber after the admission of air has begun, the injection of fuel continuing concurrently with the admission of the air, said pump including a plunger and mechanism for actuating the same, mechanism for varying the rate of actuation of the plunger to vary the duration of the feed of a charge of fuel by the plunger into the explosion chamber, and timing mechanism for said air charging means and fuel pump operating to maintain the time-displacement of the beginnings of air and fuel charging in each cycle substantially constant.

10. The combination as set forth in claim 8, in-

cluding a shaft driven by the gases generated in the explosion chamber, a governor connected to said shaft, and means controlled by the governor for simultaneously regulating the charges of fuel and air fed into the explosion chamber per cycle in a manner to maintain approximately constant, the ratio of fuel to air.

11. The combination as set forth in claim 8, including means for varying the pressure of the air charged into the explosion chamber in correspondence with variations in the charges of fuel fed thereinto.

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