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BY A. P. C.

F. GOSSLAU ET AL

REGULATING INTERNAL COMBUSTION ENGINES

Original Filed Oct. 7, 1938

Serial No. 394,322

4 Sheets-Sheet 1

Fig.1

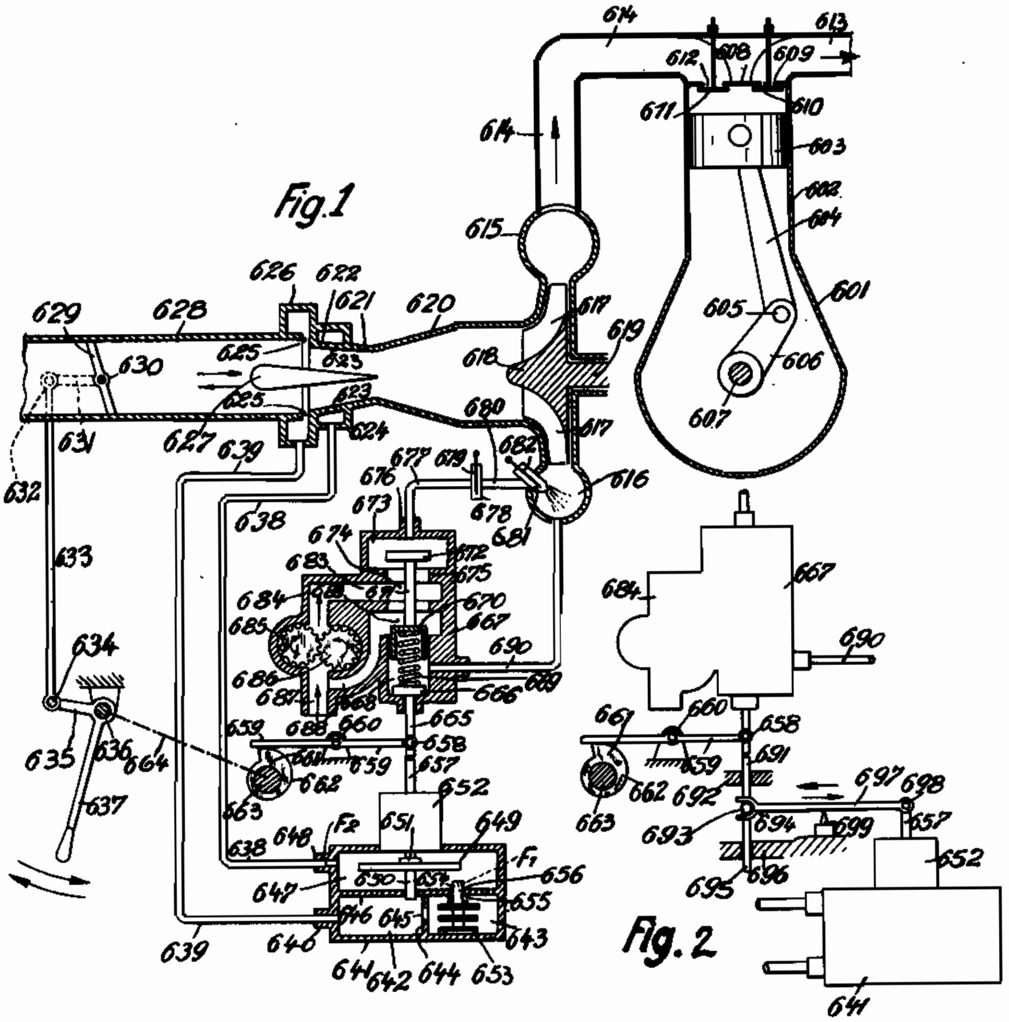

Fig. 2

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Fig. 3

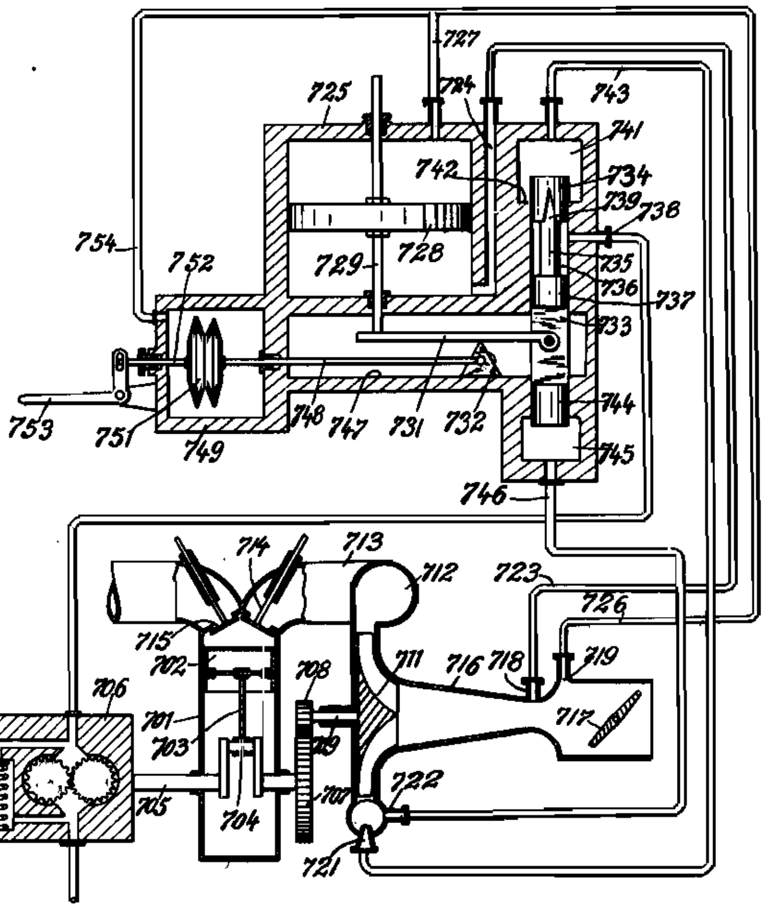
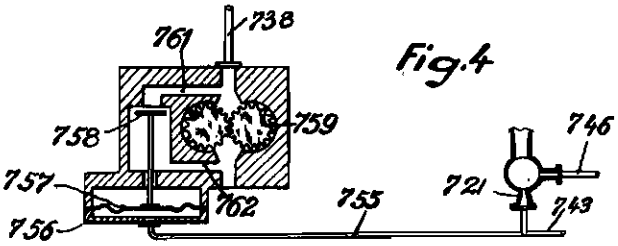


Fig. 4



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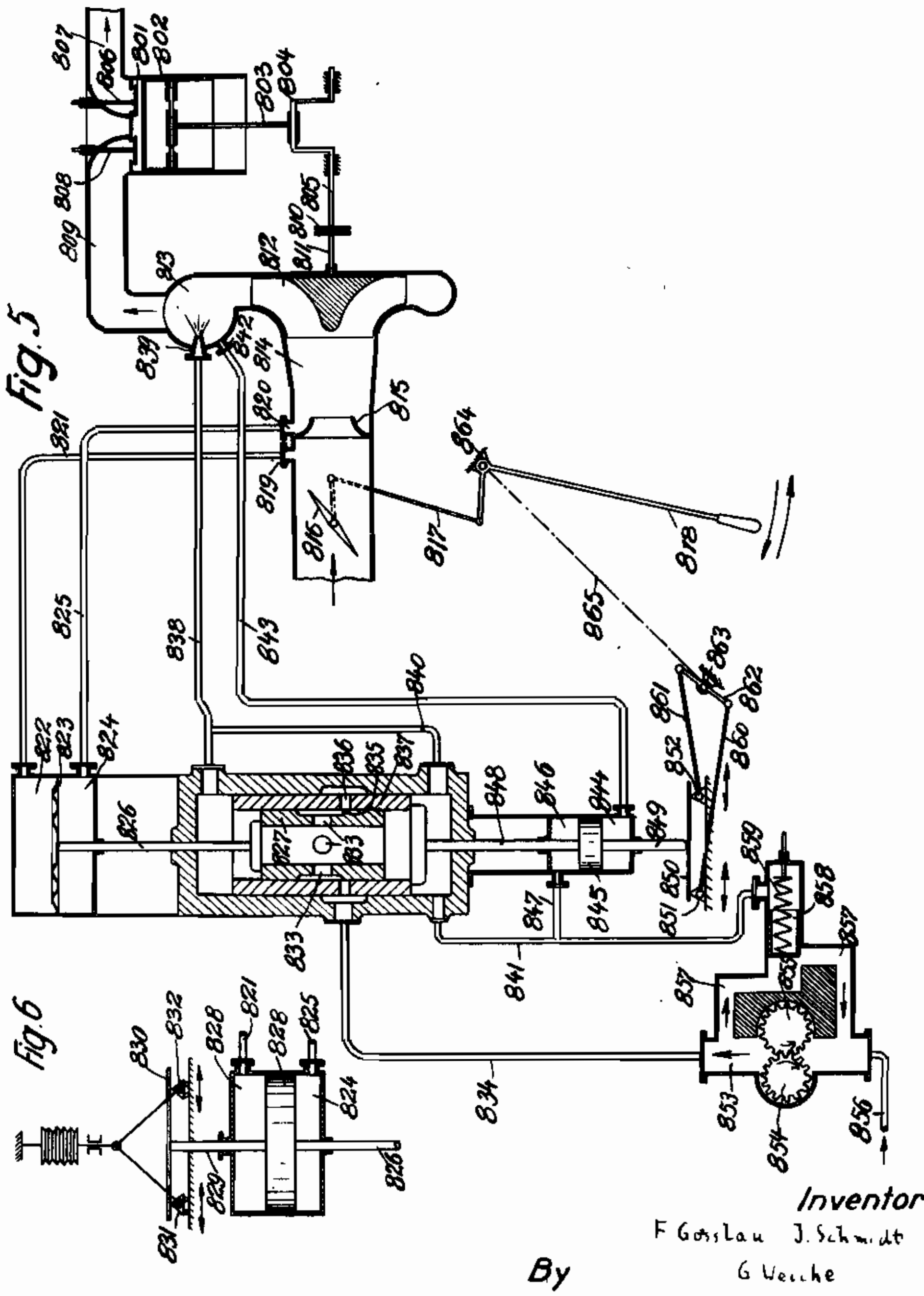

Fig. 5

Fig. 6

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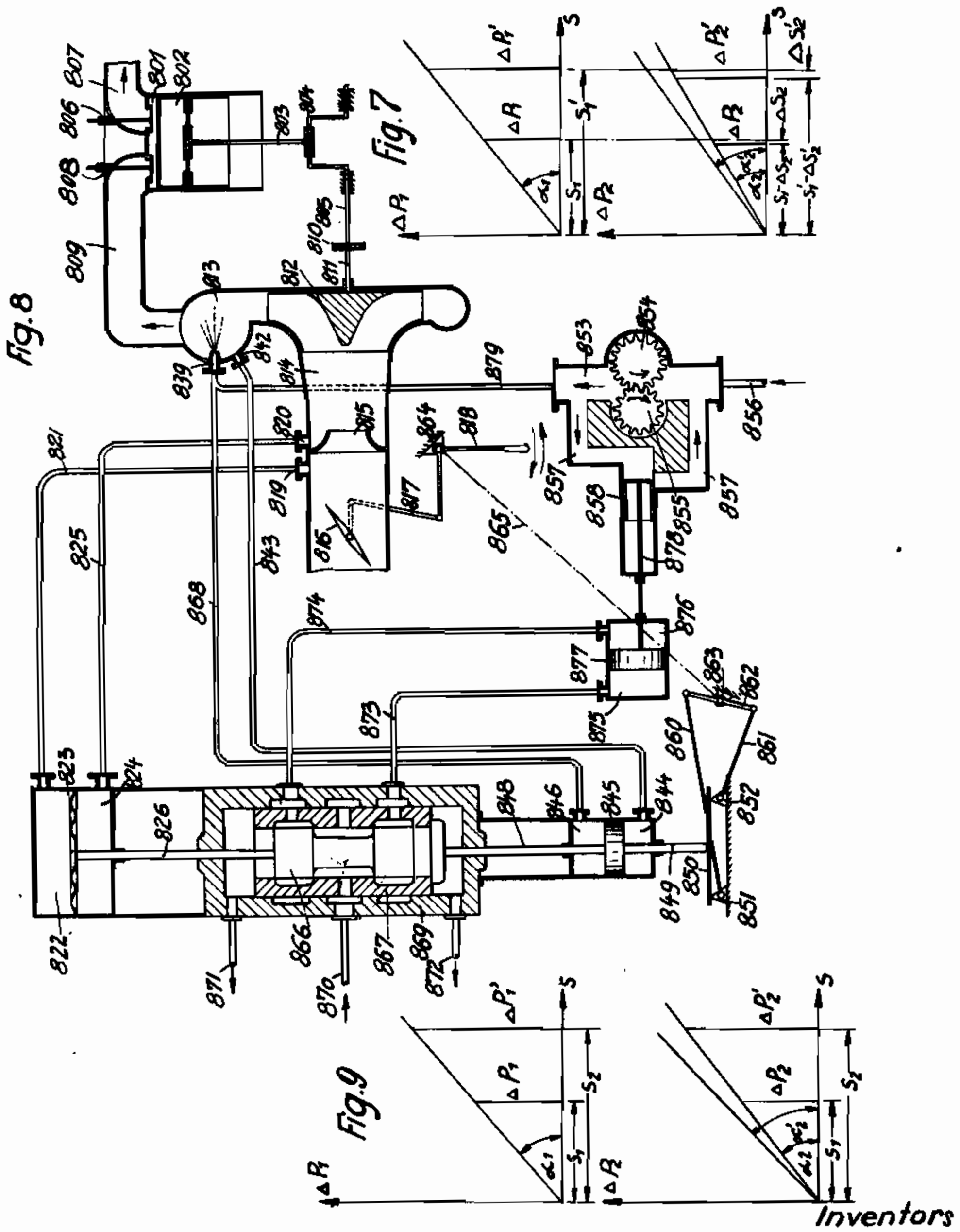

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ALIEN PROPERTY CUSTODIAN

REGULATING INTERNAL COMBUSTION ENGINES

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Application filed May 20, 1941

The present invention relates to internal combustion engines, and more particularly to devices for regulating internal combustion engines.

This application is a divisional application based upon certain subject matter contained in our prior copending application Serial No. 233,-728, filed October 7, 1938.

Broadly, it is an object of the invention to provide regulating devices which are adapted to control the fuel supply of internal combustion engines.

More specifically, it is an object of the invention to provide regulating devices which are adapted to automatically keep constant the weight of the air in relation to the weight of the fuel.

It is still a further object of the invention to balance by means of a balance beam the difference of the static and the dynamic pressure of the air passing through the air intake on the one hand, and of the pressure prevailing inside and outside of the fuel injecting nozzle on the other hand, and to thereby control the fuel supply of internal combustion engines.

It is another object of the invention to control the fuel supply of internal combustion engines by balancing by means of a spring the difference of the static and the dynamic pressure of the air in the air intake, and by further balancing by means of a second spring the difference of the pressure inside and outside of the fuel injecting nozzle.

It is still an object of the invention to provide a regulator controlling in turn the fuel supply, said regulator being dependent upon the difference of the static and the dynamic air pressure in the air intake, and further upon the state of the air in such a manner that the regulator depends upon the ratio of the effective air pressure and of the specific volume of the air.

It is still another object of the invention to provide a device which allows a particularly favorable utilization of the fuel reserve of the engine. Our novel regulating device has, for instance, the advantage that aircraft provided with such regulators have a range of flight which is greater than with the use of the hitherto known regulating devices.

It is still a further object of the invention to provide a regulating device which under all service conditions operates free of objection and also, as is required e. g. in the aircraft arts, in a very great height above the earth.

It is still an object of the invention to provide a device which practically never requires operation of the person controlling the engine, for instance of a pilot.

It is still another object of the invention to provide a regulating device which automatically adjusts definite mixture ratios of air and fuel particularly when using various kinds of fuel.

The novel regulator forming an object of the invention is e. g. so constructed that the measuring device influenced by the pressure differences of the air drawn in in the air intake acts upon the spring load of the overflow valve of a pressure pump which feeds the fuel by way of nozzles into the charging pipe.

In accordance with a modification of this construction, the adjusting members of the device for measuring the quantity of air also may be used to alter the internal cross section of the fuel nozzle.

In order to measure the difference of the static and of the dynamic pressure of the air in the air intake Venturi nozzles or throats may advantageously be inserted into the air intake. Instead of the Venturi throat any other known measuring instrument may be used. However, Venturi nozzles have the advantage that practically no throttle losses occur.

These and other objects of the present invention will become more evident in the following description taken in connection with the drawings, in which:

Fig. 1 is a diagrammatic representation of a construction of the regulator which is particularly characterized by a doubly controllable main regulating member.

Fig. 2 is a diagrammatic representation showing in detail a modification of the construction illustrated in Fig. 1.

Fig. 3 is a diagrammatic representation of a further modified embodiment of the regulator wherein the pressure difference prevailing at the fuel nozzle is utilized for effecting the control.

Fig. 4 is a view of a detail of the construction shown in Fig. 3.

Fig. 5 is a diagrammatic representation of a further modification of the regulator according to which the pressure difference in front of and behind an air nozzle as well as the pressure difference inside and outside of the fuel nozzle is utilized for controlling regulator members.

Fig. 6 is a vertical section of a modified detail of the construction shown in Fig. 5.

Fig. 7 shows two regulator diagrams relating to the devices of Figs. 5 and 6,

Fig. 8 is a diagrammatic representation of a modified construction of the device shown in Fig. 5.

Fig. 9 is a regulator diagram relating to the device of Fig. 8.

A particularly simple regulating device according to the invention is obtained by constructing the main regulator controlling in turn the fuel regulator in the following manner. The main regulator is doubly controllable, i. e., on the one hand by the effective pressure of the stowage and quantity measuring device which may be a Venturi tube and on the other hand, by the state and in particular by the density of the air in front of the stowage point of the measuring instrument. Preferably, the doubly controllable main regulator is so constructed that the same operates in accordance with a ratio of the effective pressure Δp to the specific volume v of the air in front of the stowage point of the quantity measuring instrument.

According to a preferred modification of the device for regulating the fuel mixture, the main regulator controlling the fuel regulator is provided with a box filled with air which may be influenced by the state of the air prevailing in front of the Venturi tube or the like, and which in turn controls members, for instance valves, by means of which the effective pressure of the Venturi tube attacking the main regulator may be influenced for instance according to the ratio

$$\frac{\Delta p}{v}$$

According to a modification of this construction the box, influenced by the effective pressure of the Venturi tube, is arranged in a chamber connected to the smaller pressure reducing cross section of the Venturi tube, whereas the box, influenced by the state of the air, is arranged in another chamber separated from the first chamber and connected to the larger pressure reducing cross section of the Venturi tube. Ports are provided in the wall separating the two chambers, which ports, on the one hand, communicate with a pipe connected to the interior of the box, influenced by the effective pressure, and, on the other hand, communicate with a pipe which may be closed by the valve body controlled by the box influenced by the state of air, the size of which may be altered. These ports freely discharge into the space which contains the box influenced by the effective pressure.

Preferably the cross section F_1 of the discharge end of the effective pressure pipe of the Venturi tube connected to the chamber of the box influenced by the effective pressure is invariable, whereas the regulatable cross section F_2 of the valve provided between the two chambers may be altered in accordance with the law; specific volume

$$v = \text{const.}\left(1+\left(\frac{F_1}{F_2}\right)^2\right)$$

The above described regulating device may further be simplified by directly connecting the just described doubly controllable regulator to the regulator controlling the fuel admission, so as to form a single operating unit.

By this construction, the regulating possibilities also are increased and the scope of the regulating range is enlarged.

For instance, with the most simple additional means a more exact adjustment of the regulation of the mixing ratio of air and fuel may be obtained due to the excellent operation of the entire device. To this end it is for instance sufficient to provide an adjustable throttle of a known type in the pipe leading from the fuel pump to the spray nozzle for the mixing device. For the purpose of obtaining further regulation of the mixing ratio of air and fuel it may, moreover, be sufficient to construct the nozzle injecting the fuel into the mixing device so as to be capable of being shut off.

Another very simple additional means for further improving the regulation may consist in providing the air quantity measuring instrument and the device producing the stowage pressure, for instance a Venturi tube, with members for adjusting the size of the cross section of the air flow. For this purpose, for instance, a streamlined body which preferably may be shifted axially and therefore allows an alteration of the narrowest cross section of the tube may be arranged in the interior of the Venturi tube.

The doubly controllable main regulator and the regulator connected thereto and directly acting upon the fuel admission may eventually be connected together by way of a tilting lever, the pivot pin of which is adjustably arranged to allow the setting of a definite mixing ratio of fuel and air.

The regulator directly acting upon the fuel admission preferably is provided with a return pipe which may be controlled by the valve member of the regulator and which serves to return fuel which has been fed in excess to the suction side of the pump. We have found that this construction of the regulator may advantageously be improved by providing the valve member with a special throttle member arranged in the pipe between the fuel pump and the nozzle and serving for influencing, and more particularly for reducing the fuel pressure. Moreover, a spring biasing the valve member and influenced by the pressure prevailing at the injecting point of the nozzle is provided which acts upon this member and tends to shift same in a definite direction.

The just described construction may, for instance, advantageously be used for the following conditions.

The valve member of the fuel regulator which may be a piston, is loaded, on the one hand, by the pressure difference prevailing at the fuel nozzle and, on the other hand, by a spring the tension of which may be altered by the doubly controllable main regulator. The above mentioned valve piston allows return flow of fuel fed in excess to the suction side of the pump in such a manner that the pressure difference corresponding to the tension of the spring is regulated. Now, the pressure at the injecting point of the nozzle may fall substantially below atmospheric, for instance if the motor is strongly throttled. However, as the pressure in the pump always corresponds at each instance to the outer pressure, and would be too high for the just described operating conditions the pressure of the pump is reduced to permissible values and is simultaneously brought into equilibrium with the tension of the spring acting upon the valve piston by means of the throttle member arranged in the pipe between the fuel pump and the nozzle and connected to the valve piston of the fuel regulator.

We have further found that the just described regulator may, with the use of simple means, be constructed for actuation by hand also so that in case the automatic operation fails the device may still be operated.

For this purpose preferably a hand actuated lever is provided which also attacks the control rod of the fuel regulator actuated by the doubly controllable main regulator. The control rod bears positively, for instance by spring action, against the control member rigidly connected to the doubly controllable main regulator in such a manner that the control rod may, by means of the lever, be disengaged from the control member of the main regulator. Preferably, the hand lever is so journalled and linked to the control rod that during operation of the main regulator the lever idles. On actuation by hand, the lever coupled, for instance, to the control lever may be used to prevent an undue drop of the pump pressure and may also be used to limit the ejected quantity of fuel to that value which just still allows operation of the motor. To this end a stop formed as a cam may be provided for the hand lever by means of which the swinging amplitude of the lever may be changed.

With the hand lever it is, moreover, possible to control the pump pressure as far down as to idle running, if for instance at smaller outputs the limit of response of the main regulator should be reached. To this end, the hand lever is connected to the regulator members and is so set that it automatically takes care of the setting of the pump pressure as soon as the lower limit of response of the regulator is reached.

An embodiment of the device above referred to is shown in Figs. 1 and 2 of the drawings.

The internal combustion engine has a crank case 601 to which the cylinder 602 for the piston 603 is connected which, by way of the piston rod 604, is connected to the crank pivot 605 of the crank arm 606. Crank arms 606 may be rotated around the axis 607. Driving gears not shown in the drawings are mounted upon shaft 607 for transmitting the torque to the charger provided with a spiral casing. The charger is, therefore, directly driven by the internal combustion engine. Outlet valve 606 controlling the size of the discharge opening 610 is arranged at the cover 608 of cylinder 602 and in front of piston 603. Inlet valve 611 is provided at the cylinder cover 606 controlling the size of the inlet opening 612. The outlet opening 609 discharges into the exhaust 613. Pipe 614 is connected to the inlet opening 612 the other end of pipe 614 being connected to the spiral casing 615, 616 of the charger. The blades 617 of the charger are mounted on the supporting body 618. The supporting body 618 is rigidly mounted in an overhanging manner upon shaft 616 which, as mentioned before, may be rotated by means of members, not shown in the drawings, by shaft 687 driven by the internal combustion engine.

The charger 615 to 619 draws in the air by way of a tube 620 enlarged like a diffusor. Tube 620 tapers at the end remote from the charger towards its smallest cross section at the point 621 and from this point enlarges again. Radially outwardly directed ports 623 are provided in the wall of enlarged tube-like portions 622, parts 625 being surrounded by an outer annular casing 624. One of the pipes serving to transmit stowage pressure to the regulator is connected to casing 624, as will be described hereinafter.

A shoulder like projection in the form of an outwardly extending enlargement is provided behind the enlarged projection 622 of the stowage pressure producing device and shaped for instance as a Venturi tube. At this place radially outwardly directed ports 625 are provided in the wall which exteriorly are surrounded by an annular casing 626 which is connected with the other of the two pipes for transmitting the stowage pressure to the main regulator, as will be described hereinafter.

A streamlined valve body 627 is arranged in the interior of tube 622 at the portion tapering in the direction towards the charger. Preferably, valve body 627 is formed as a rotary body, the axis of which coincides with that of tube 622. Body 627 is axially displaceable and, when moved towards the charger, the cross section of the annular space formed by body 627 and the surrounding wall of tube 622 is reduced.

Cylindrical tube 628 is connected to tube 622 and extends from the end remote from the point of smallest cross section. Throttle flap 629 is arranged in tube 628 and is pivotally mounted on pin 630. Flap 629 may be rotated by means of a linkage. This linkage comprises of lever 631 rigidly connected, on the one hand, to the throttle flap 629, and, on the other hand, to lever 633 by way of link 632. Lever 633 in turn is connected, by means of link 634, to lever 635. Lever 637 swingably mounted on the pivot 636 is connected to lever 635 and adapted to be actuated by hand.

The pipe transmitting the effective pressure Δp of the Venturi tube 620, 621, 622 upon the main regulator is designated with 638, whereas 639 designates the pipe conducting the pressure in front of the Venturi tube to the main regulator. Pipe 639 discharges by way of connecting socket 640 of regulator casing 641 into chamber 642 of casing 641. By means of wall 644 chamber 643 is separated from the first chamber 642. One or more ports 645 are provided in the wall 644. Wall 646 closes both chambers 642 and 643 against a third chamber 647 provided in casing 641. Socket 646 is provided on the outer wall of chamber 647. Pipe 636 leading from the Venturi tube extends into socket 648 so that the interior space of chamber 647 is connected with the point of the Venturi tube producing the effective pressure.

Diaphragm box or bellows 649 is arranged in the interior of chamber 647. Bellows 649 acts by way of centrically projecting intermediate members 651 upon the main regulator 652 and controls the latter in accordance with the effective pressure Δp of the Venturi tube. Diaphragm box 649 is provided with a socket 650, one end of which discharges into the interior of box 649 and the other end of which is tightly passed through wall 646 and discharges into chamber 642 to which pipe 639 is connected which supplies the pressure prevailing in front of the Venturi tube.

Another box or bellows 653 is provided in the interior of chamber 643 which, in a manner known per se, is filled with air and expands in accordance with the state of the air v (specific volume) in front of the Venturi tube. Space 643 surrounding box 653 is, as described above, connected, by way of ports 645, to chamber 642 and also to pipe 639 transmitting the pressure prevailing in front of the Venturi tube.

Bellows 653 actuates control slide 654 which is influenced by spring 655. Slide 654 opens and closes a by-pass 656 provided in the wall between chambers 643 and 647.

If by-pass 656 is opened by control slide 654, a flow is effected from the Venturi tube into chamber 643 and then by way of the variable throttle opening 656 having the cross section F to chamber 847 and then by way of the invariable throttle opening F_2 of the outlet socket 648 back to the Venturi tube 620—622. It may be proven that with this direction of flow the effective pressure Δp of the Venturi tube is reduced in accordance with the ratio

$$\frac{1}{1+\left(\frac{F_1}{F_2}\right)^2}$$

If according to the invention the cross section F_1 of the throttle pipe 656 is so chosen that the just mentioned value

$$1+\left(\frac{F_1}{F_2}\right)^2$$

is proportional to the value v (specific volume of the air), the regulating device operates in accordance with the law

$$\frac{\Delta p}{v}$$

aimed at. In accordance with this value the regulating member sets the pressure differences Δp_{Br} of the fuel pump. Therefore, the weight of the air and the weight of the fuel have a definite predetermined proportion.

The slide 654, moreover, simultaneously serves as a safety member against unduly high effective pressures. In case the effective pressure becomes too high control slide 654 is lifted from box 653 and thereby the pressures in the chambers 643 and 647 is equalized.

Control member 657 which may be a rod projects from regulator 652. Main regulator 652 shown in Fig. 1 directly acts by means of rod 657 upon a control valve of the fuel regulator connected with the fuel pump.

Control member 657 cooperates with its free front face with the front face of a further rod-like control member 665 so that both control members may be positively coupled to each other by means of a spring. Link 658 is connected to the control rod 665 of the fuel regulator. Double-armed lever 659 pivotally mounted upon bolt 660 controls rod 665 by the intermediary of link 658. The free end of double-armed lever 659 cooperates with cam 661 which, for instance, is provided with a spirally extending control face 662 and which may be rotated around axis 663. Control disc 661 is eventually positively connected to hand lever 637 by means of a transmission device 664 shown schematically only. The transmission may be effected in such a manner that by adjusting hand lever 637 cam disc 662 also is adjusted, whereby simultaneously the oscillation amplitude of double-armed lever 659 is determined.

Control face 662 of cam disc 661 corresponds in accordance with the invention nearly to the poorest mixing ratio which still allows operation of the motor. In case the main regulator 652 fails, cam 661 takes care of the control, whereby plunger 865 is lifted with regard to control rod 657 of main regulator 652 which otherwise is positively coupled to plunger 665. By means of cam disc 661 the fuel regulator or the fuel pump are also controlled then, when the limit of response of the main regulator is reached. For instance the regulation of the motor by hand may be set for a range of .25 of 1% of the normai output.

Flanged disc 666 is provided at the end of plunger 685 projecting into the interior of the fuel regulator. Disc 666 is axially movable in cylindrical space 668 of regulator casing 667 against the action of a spring, e. g. coiled spring 669. One end of spring 669 bears against flanged disc 666, whereas the other end bears against the bottom of dish-like piston 670, fixed to rod 671. Rod 671 projects axially from the outer surface of the bottom of piston 670. The free end of rod 671 carries flanged disc 672 serving as throttle member and operating in cylindrical space 673 of fuel regulator casing 667. The diameter of cylindrical space 673 is relatively very much larger than the one of flanged disc 672.

Flanged disc 672 causes an additional throttling of the fuel flowing to the fuel nozzle. By means of flanged disc 572 it is possible to reduce the pressure in front of the nozzle below the outer air pressure. Rod 671 carrying disc 672 is movably arranged in cylindrical space 674 which is partially shut off from cylindrical space 673 by annular projections 675 projecting from the wall of casing 667. The diameter of the interior space reduced by projections 675 practically is as large as the diameter of throttle disc 672 so that the latter may shut off space 673 against space 674.

Outlet socket 676 for the fuel is provided in front of the free front face of throttle disc 672. Pipe 677 leading to the fuel nozzle 681 is connected to socket 676. In pipe 677 a known throttle member 678 having an adjustable throttle 679 is arranged. Pipe 660 connects throttle member 678 with nozzle pipe 681 arranged obliquely to the axis of pipe 660. Nozzle pipe 681 projects through the wall of spiral casing 615, 616 of charger 617, 618 and discharges with its nozzle mouth into space 616 of spiral casing 815. Needle valve 682 is provided in the interior of nozzle pipe 681 and controls and eventually shuts off c. g. the discharge opening. Throttle member 682 e. g. may be adjusted by hand in the same manner as throttle member 679.

Channel 683 provided in socket 684 connected in turn to the pump casing discharges into cylinder space 674 of regulator casing 667. In the example shown the pump is constructed as a geared pump having two gear wheels 685 and 686 which rotate in the direction indicated by the curved arrows and thereby feed fuel as indicated by the straight arrows from the supply pipe 687 into pipe 683 and therefrom by way of pipes 677 and 680 to nozzle 681.

From the supply pipe 687 by-pass channel 688 branches in front of the toothed wheels of the pump. By-pass channel 688 discharges into space 689 provided in the interior of regulator casing 667 adjacent cylindrical space 674. Space 689 is separated from space 674 by annular projections projecting from the walls of casing 667. Overflow piston 670 also partly moves in space 669. Pipe 690 diseharges into cylindrical operating space 668 of overflow piston 670 and the other end of pipe 690 is connected to space 616 of charger casing 615.

Piston 670 is by way of collar-like throttle disc 672 biased with the pressure prevailing in front of the fuel ejecting nozzle 681. The upper side of piston 670 is subjected to the pressure prevailing in the spiral casing of the charger, i. e. behind the nozzle 681. The face of piston 670 influenced by this pressue is also influenced by spring 669, the tension of which may be altered by main regulator 652 by way of the linkage 657, 665, 668.

This last explained action of main regulator 652 upon the linkage 685, 666 and piston 670 is effected directly in the embodiment of the invention shown in Fig. 1. If in this embodiment the mixing ratio between air and fuel is to be altered, then the above described adjustable throttle devices 678, 678 arranged in fuel pipe 677 leading to nozzle 682, and the nozzle control device 681 are used. The mixing ratio between air and fuel may also be altered by axially displacing streamlined valve body 627 in Venturi tube 620, 621, 622.

A modified construction of the power transmitting linkage between the doubly controllable main regulator 652 and the control valve of the fuel pump is shown in Fig. 2. Like parts are designated by the same reference characters in Figs. 1 and 2.

Axially shiftable rod 691 loosely bears against plunger 665 which is attacked by double-armed lever 659 by way of link 656. Rod 891 is provided with ball-shaped member 693 which is surrounded by fork 694 provided at the end of arm 697. Arm 697 is connected, by means of bolt 698 attached to its other end, to control rod 657 of main regulator 652 and bears upon a knife-edge 699. Opposite ball 693 rod 691 continues as rod 695 displaceably arranged in bearing body 696 which also forms a bearing for knife-edge 699.

With the aid of tilting lever 697 the mixing rato between air and fuel may in a simple manner be changed by shifting pivot point 699 of lever 657 for instance upon its bearing.

Another modification of our novel regulating device shown in Figs. 3 and 4 is particularly characterized by its great simplicity and by the fact that it automatically sets the desired mixing ratio independent of the state of the air at each instant.

To this end the invention utilizes the knowledge that with invariable density of air and with a definite mixing ratio the effective pressure of the measuring device for the air quantities bears a certain relation to the pressure difference prevailing in and behind the fuel nozzle. This knowledge is utilized by providing a pressure scale or balance beam influencing the fuel control valve. The pressure scale provided in connection with the fuel mixture regulator is subjected, on the one hand, to the action of the pressure difference of the instrument measuring the air quantities and, on the other hand, to the pressure difference prevailing at the spray nozzle.

A further feature of the invention consists in the use of a control slide relieved of the pump pressure, the control slide being independent of the number of revolutions of the fuel pump or, as the case may be, independent of the characteristic of a spring, i. e. of the spring constant.

In Fig. 3 a single cylinder motor is shown for the sake of simplicity. Piston 702 is arranged in cylinder 781 and is connected by means of piston rod 703 to crank 704 of crankshaft 705. Fuel pump 706 is connected to one end of crankshaft 705. Fuel pump 706 is formed in a known manner as a geared pump and therefore a detailed showing and a description thereof is deemed unnecessary. Gear wheel 707 is mounted upon the other end of crankshaft 705 and cooperates with gear wheel 706 fixed upon shaft 709 of rotor 711 of the air blower. Spiral blower casing 712 is connected to pipe 713 leading to inlet valve 714. The outlet valve is shown at 715. The suction space of the blower is formed as a Venturi tube 716. Throttle flap 717 is arranged in front of Venturi tube 716. Tapping 716 is provided at the point of Venturi tube 716 where the highest air velocity prevails. The air pressure, i. e. the effective pressure, prevailing at tapping 718 indicates the quantity of air flowing through tube 716 in the unit of time. In front of point 718 further tapping 719 is provided at the point, where stowage of the drawn in air begins.

Fuel injecting nozzle 721 is provided in the walls of blower casing 712 and behind nozzle 721 a tapping 722 is provided for measuring the air pressure prevailing in casing 712 behind nozzle 721.

Pipe 723 leads from the tapping of the Venturi tube to channel 724 provided in regulator casing 725. Pipe 726 leads from tapping 719 of the Venturi tube by way of pipe 727 into regulator casing 725. A cylindrical space is provided in casing 725 wherein piston 726 may freely move up and down. Pipe 727 transmitting the stowage pressure discharges into the space above piston 728, and channel 724 carrying the effective pressure discharges into the space below piston 728. Piston rod 729 bears against a balance beam 731 which may be swung around prism 732. The other end of balance beam 731 is connected to slide 733 provided in a cylindrical recess of casing 725. Slide 733 is provided below its cylindrical head portion 734 with a projection 735 of reduced cross section so that an annular space 736 is formed in the cylinder space of casing 725. Below annular space 736 slide 733 enlarges again to form cylinder 737 of a cross section corresponding to that of slide head portion 734.

Pipe 738 branching from fuel pump 708 discharges into annular space 738. Head portion 734 of piston slide 735 carries a lateral groove 738 which in plan view has the form of a triangle. Groove 739 allows the fuel flowing from pipe 736 into space 736 to flow by way of triangular groove 738 into space 741 above slide 736. According to the height of slide 738 with regard to the bottom edge 742 of space 741 more or less fuel may flow into space 741. Pipe 743 leads from space 741 to fuel nozzle 721. The lower end 744 of piston slide 733 also is of cylindrical shape so that it restricts space 745 below slide 733. Pipe 746 leading from tapping 722 in blower casing 712 discharges into space 745.

Pivot 732 around which balance beam 731 may be swung is formed as a prism which may easily be shifted upon surface 747. For this purpose rod 748 is provided which leads into a special fluid-tight casing 749. Rod 746 is connected in casing 749 with a box or bellows 751 acting as barometer. On the other hand, bellows 751 is maintained in its position by rod 752 linked to hand lever 753 which may be fixed in its position. Pipe 754 which, by way of pipe 726, is connected to tapping 719 discharges into casing 749.

The above described device operates as follows:

Supposing e. g. the number of revolutions of the motor increases, while the position of throttle flap 717 remains invariable. Due to the increasing number of revolutions more air is drawn in by Venturi tube 718. Therefore, however, the pressure prevailing at tapping 719 will be higher than that prevailing at tapping 718. Consequently, the upper surface of piston 728 is heavier loaded than its lower surface so that the piston starts to fall. Hence, lever 731 is swung in such a manner that control piston 733 is displaced upwardly. More fuel may now flow from space 738 by way of triangular groove 739 into space 741. The fuel flows into space 741 until the higher pressure built in space 741 is in equilibrium with piston 728.

Simultaneously with the described operations, the pressure ratios prevailing at the fuel nozzle 721 and at the tapping 722 of the blower casing also change. The higher number of revolutions of blower rotor 711 causes an increase of the pressure at tapping 722 which is transmitted by way of pipe 746 into space 745. The increasing pressure in space 745 acts in the same manner as the increasing pressure above piston 728.

With decreasing output or efficiency of the motor, the described operations are performed in the reversed direction, and it is obvious that any change of the operating condition of the motor, which may be caused for instance by adjusting the throttle flap 717, also influences the balance beam consisting of the parts 728, 731 and 733.

The above described operation allows a regulation of the correct fuel mixture ratio only as long as the density of the air is not changed. If the specific volume of the air changes, for instance due to a change of temperature, or due to the fact that the aircraft overcomes great differences in height, then these altered conditions must be considered. For this purpose bellows 751 is provided which is arranged in casing 749. From tapping 719 in front of the Venturi tube the state of the air prevailing in front of the Venturi tube is transmitted to casing 749 by way of pipes 726 and 754. Alterations of the state of the air effect an expansion or contraction of box 751 which, by means of rod 748, displaces prism 732 mounted upon surface 747 to the right or to the left, as the case may be. By this displacement the leverage of the regulator balance beam is altered in accordance with the change of the state of the air.

By this arrangement, therefore, a uniform mixing ratio of air and fuel independent upon the output of the motor and the prevailing barometric pressure is always assured.

Now, as is well known, a change of the fuel mixing ratio is desired with a change of the output of the internal combustion engine. This change of the fuel mixture ratio also can be obtained with a device according to the invention, and for this purpose lever 753 is provided. By adjusting lever 753 pivot point 732 of the balance beam is displaced and thereby the fuel mixing ratio is altered.

In Fig. 4 a device is shown which serves to improve the regulation. Pipe 755 leads from nozzle 721 into casing 756 below diaphragm 757. Casing 756 forms part of fuel pump 706. Valve 758 is connected to diaphragm 757. If valve 758 is opened, the fuel fed by geared wheels 759 flows no longer by way of pipe 738 into space 736, but first of all by way of channels 761, 762 back to the other side of geared wheels 759. If the pressure prevailing in box 751 increases, valve 758 is throttled and the feed pressure of the pump is increased.

A particularly suitable modification of the regulating device using control members arranged as a balance beam, will now be described. In this construction an air piston and a fuel piston are provided, the arrangement being such that a relatively small space only is required.

With the regulator according to the invention the fuel mixing ratio may directly be changed at the regulator and, besides, the size of the two piston surfaces may be chosen independent from each other by arranging the two cylinders on a common axis which saves considerably in space. This is effected by providing two springs, one of which may be bent by a piston actuated in dependence upon the effective pressure at the air nozzle, and the other of which may be bent by a piston actuated in dependence upon the effective pressure at the fuel nozzle. The resulting piston forces do no longer directly act upon each other. The problem of bringing the regulator members to an equilibrium again after the regulation has been effected, that is to say the return movement, is effected by the fuel pressure adjusted in accordance with the new effective air pressure.

In Figs. 5 to 9 to embodiments as well as additional details and corresponding regulator diagrams are shown.

For the sake of simplicity, in the embodiment of the invention illustrated in Fig. 5 one cylinder 801 only has been shown of the aircraft engine. Piston 802 reciprocates in cylinder 801 and is connected by means of rod 803 to crank 804 of crankshaft 805. Outlet valve 808 is provided in cylinder 801 which, when opened, connects the cylinder space by way of pipe 807 to the exhaust not shown in the drawings. Inlet valve 888 provided in cylinder 801 effects the admission of the fuel air mixture supplied by pipe 808. By means of flange connection 810 or a suitable gear shaft 811 is connected to crankshaft 805. Shaft 811 carries rotor 812 of a centrifugal blower serving as a charger, spiral casing 813 of which is connected to pipe 809 so that the charger presses the mixture into pipe 809. Air is drawn in by the charger by way of pipe 814 in which air nozzle 815 is provided. Throttle flap 816 is arranged in front of air nozzle 815. Flap 816 may be opened and closed by lever 818 by the intermediary of linkage 817. Tapping 819 is provided in front of nozzle 815, while tapping 820 is arranged directly behind nozzle 815. Tapping 819 is constantly connected by way of pipe 821 to closed space 822 above diaphragm 823, whereas the tapping 820 is connected by way of pipe 825 to closed space 824 arranged below diaphragm 823. The entire circumference of diaphragm 823 is clamped in so that the diaphragm acts as a spring. Rod 826 is connected to diaphragm 823 and attacks slide 827 and thereby displaces slide 827 in dependence upon the effective pressure at the air nozzle 815.

Instead of diaphragm 823 piston 828 shown in Fig. 6 may be used. Piston 828 also adjusts rod 826 and thereby slide 827 in dependence upon the effective pressure at the air nozzle. In this case piston 828 is provided with a second rod 829 which causes bending of spring 830 during the displacement of piston 828. Bearings 831, 832 of spring 830 may be shifted towards the right and towards the left so that by altering the effective length of spring 830 an alteration of the constants of spring 830 may be effected. The purpose of this construction will be described hereinafter.

Slide 827 is provided with openings 833 which allow the fuel to flow from pipe 834 into the interior thereof. Moreover, slide 827 has a control edge 835 by which the fuel pressure is regulated so that the cross section of supply openings 836 is controlled, openings 836 being provided in sleeve 837 surrounding slide 827. The fuel reaching the interior of slide 827 then flows through pipes 838 and 840 to fuel nozzle 839 which e. g. is arranged in the spiral casing of charger 813. Pipe 841 is placed under the pressure of the fuel injected by nozzle 839.

Tapping **842** is provided in the spiral casing of charger **813**. By means of tapping **842** the pressure prevailing behind fuel nozzle **839**, i. e. the counterpressure occurring during injection of the fuel, is transmitted into chamber **844** by way of pipe **843**. Piston **845** is provided above chamber **844** above which in turn chamber **848** is provided. Chamber **848** is connected to pipe **841** by way of intermediate pipe **847**. Pipe **841** carries, as stated above, a pressure coinciding with the fuel pressure prevailing in front of fuel nozzle **839**. Piston **845**, therefore, is subjected to the influence of the pressure difference prevailing in front of and behind fuel nozzle **839**. Rod **846** is attached to piston **845** and is rigidly connected to sleeve **837** surrounding slide **827** so that sleeve **837** is adjusted in accordance with the alteration of the effective pressure at the fuel nozzle. Rod **849** is provided on the side of the piston opposite from rod **848**. Rod **949** bears upon spring **650** and bends the latter more or less in accordance with the position of piston **845** and in dependence upon the displacement of bearings **851**, **852**. In the same manner as resilient diaphragm **823** or spring **838** balances the effective pressure at the air nozzle, spring **850** balances the effective pressure at fuel nozzle **839**.

Fuel is supplied to pipe **834** by means of a fuel pump which in a known manner is constructed as a geared pump **853** having gear wheels **854**, **855** rotating in opposite directions. Pump **853** is supplied with fuel from the fuel tank by way of pipe **856**. Return pipe **857** returns the fuel fed in excess to the suction side of pump **853**. Piston **858** is inserted in return pipe **851**. Piston **858** is influenced on the one hand by the pressure prevailing in pipe **841**, i. e. the pressure in front of the fuel nozzle, and on the other hand is influenced by spring **859**.

Fuel pump **853** feeds fuel under the pressure p_p to throttle point 835/836 where the pressure is reduced to $p_p-\Delta p=\Delta p_D$ that is to say to the pressure prevailing in front of the fuel nozzle. If the pressure of spring **859** is made equal to f, then in the pressure return pipe **857** of fuel pump **953** is equal to $p_p=p_p-\Delta p+f$, and accordingly $\Delta p=f=$ constant which in a well known manner increases the exactness of regulation.

If the resulting force ΔP_1 acts upon diaphragm **823** or upon piston **828** respectively, slide **827** is shifted downwardly about the distance s_1 out of its exit position, i. e. out of that position which corresponds to the effective pressures 0 at the air nozzle and at the fuel nozzle. The throttle openings of the outer slide **837** are just perfectly closed in the exit position by control edge **835** of inner slide **837**. If $tg\alpha_1$ is the spring characteristic of diaphragm **823**, then $\Delta p_1=tg\alpha_1.s_1$. If the inner slide has moved downwardly for the distance s_1, then, under the influence of the fuel pressure built up due to the fact that by the movement of the inner slide **827** the fuel throttle has been opened and the fuel pressure acts behind piston **845**, the outer slide **837** moves downwardly for the distance $s_1-\Delta s_2$, until the throttle opening is again so large that the new fuel pressure corresponding to the new position of slide **837** is balanced by spring **850** having the spring constant $tg\alpha_2$. The mixing ratio λ is represented at this point by the expression

$$\lambda=\frac{G_L}{G_B}=C_1\sqrt{\frac{\Delta p_1}{\Delta P_2}}=C_2\sqrt{\frac{\Delta P_1}{\Delta P_2}}=C_2\frac{s_1 tg\alpha_1}{(s_1-\Delta s_2)\,tg\alpha_2}$$

If the effective pressure at diaphragm **823** is increased to ΔP_1 by altering the position of the air throttle **816**, slide **827** is moved about the distance s_1 from its exit position. Under the influence of the effective pressure of the fuel increased by changing the cross section of the throttle, the outer slide **837** follows about the way $s_1'-\Delta s_2'$, $\Delta s_2'$ being greater than $\Delta s_1'$, since now a larger weight of fuel per second is to be throttled about the same value ΔP=constant.

In this case the mixing ratio is:

$$\lambda=C_2\sqrt{\frac{s_1' tg\alpha_1}{(s_1'-\Delta s_2')\,tg\alpha_2}}$$

The mixture, therefore, has become poorer or weaker because $\Delta s_2'$ is greater than $\Delta s_1'$. This non-uniformity may, however, be kept within small limits, as the regulating way, i. e. the amount of relative movement of the two slides, on which this non-uniformity depends is very small.

The above mentioned calculations are diagrammatically shown in Fig. 7.

The non-uniformity mentioned above may also be utilized to compensate deviations from a mixing ratio aimed at. This deviation is due to the compressibility of the air and leads e. g. to an enrichment of the mixture when the measuring is effected by a Venturi tube. By a corresponding formation of the cross section of throttle **836** in an axial direction, the regulating ways, and thereby the non-uniformity of the regulator, may be altered and in this manner the influence of the compressibility of the air may more or less be compensated.

As has already been mentioned above, bearings **851**, **852** of leaf spring **850** are displaceable. For this purpose bearing **851** is fixed to rod **860**, and bearing **852** to rod **861**. Rods **860** and **861** are connected to the ends of rod **862** which may be swung about fixed bolt **863**. The swinging of rod **862** is effected in dependence upon the adjustment of lever **818**, swinging bolt **864** of which may be connected to bolt **863** for instance by shaft **965**.

When lever **818** is shifted, rod **863** is swung and, thereby, the distance of bearings **851**, **852** from each other is altered by means of rods **860**, **861**. Consequently, the free bending length of spring **850** and therefore the constant $tg\alpha_2$ of spring **850** is altered.

If the regulator is to be used for service in great heights with a variable state of the drawn in air, preferably not the diaphragm **823**, but the piston **828** shown in Fig. 6 is used. In this case, bearings **831**, **832** of leaf spring **830** may shiftably be arranged and may be controlled in dependence upon the state of the air (for instance a piston controlled by a measuring box or bellows influenced by the state of the air may effect the displacement of the bearings in a manner, similar to that of the bearings **851**, **852** in such a manner that the constant $tg\alpha_1$ of spring **830** always is adjusted in dependence upon the state of the air.

Fig. 8 shows a modified construction in accordance with the invention, and the same reference characters are used to designate elements shown in Fig. 5. These elements need not be described again. As in the case of the example shown in Fig. 5, the pressure difference at the air nozzle **815** acts upon diaphragm **823** which carries rod **826**. Control piston **866** is attached to rod **826** and cooperates with sleeve **867** surrounding piston **866**. In the same manner as sleeve **837** of Fig. 5 sleeve **867** is connected to rod **848**. Sleeve **867** is influenced by piston **845**. The space below piston 845 is, by means of pipe 843, placed under the pressure prevailing behind fuel nozzle 839, whereas space 846 above piston 845 is, by means of pipe 868, placed under the pressure of fuel nozzle 839. Sleeve 867 may be displaced in cylinder 869 which, in a known manner, is provided with an inlet pipe 870 and two outlet pipes 871, 872 for pressure oil. In accordance with the position of piston 866 and of sleeve 867 pipes 870, 871, 872 may be connected to pipes 873, 874 which in turn are connected to spaces 875, 876 in front of and behind piston 877, respectively. Piston rod 878 is attached to piston 877 and acts upon piston 858 controlling in the manner described above the quantity of fuel returned to the suction side of fuel pump 853. The pressure side of fuel pump 853 is, by pipe 879, directly connected to fuel nozzle 839.

The operation of this device will now be explained in connection with Fig. 9.

If the pressure P_1 is built up at diaphragm 823, control piston 866 is moved downwardly about the distance s_1. Hereby pressure oil pipe 870 is connected to pipe 873, and pipe 874 disconnected to oil outlet 871. Piston 877 therefore is displaced towards the right and displaces, by way of rod 878 piston 858 towards the right. As only a small amount of the fuel fed by pump 853 is allowed to return by way of pipe 857, the pressure in pipe 879 leading to nozzle 839 is increased. Now, as the difference of the pressures in front of and behind fuel nozzle 839 acts, by way of pipes 843, 868, upon piston 845 the latter together with control sleeve 867 is shifted downwardly against the action of spring 850, until piston 866 and sleeve 867 again occupy their original relative positions and thereby again shut off the supply of pressure oil to servo-motor 877. Consequently, sleeve 867 also must move downwardly about the distance s_1. The following equation results from Fig. 9:

$$\frac{\Delta P_1}{\Delta P_2}=\frac{s_1 tg\alpha_1}{s_1 tg\alpha_2}=\frac{tg\alpha_1}{tg\alpha_2}$$

$$\lambda=C_2\sqrt{\frac{p_1}{P_2}}=C_2\sqrt{\frac{tg\alpha_1}{tg\alpha_2}}=\text{const.}$$

Thus an absolute isodrome-regulation is obtained.

The alteration of the mixing ratio again is effected by altering the spring elasticity constant from $tg\alpha_2$ to $tg\alpha_2'$ e. g. by altering the free bending length of spring 850.

Of course, the influence of the variable state of air may also be considered by an arrangement according to Fig. 6 in exactly the same manner as with the construction shown in Fig. 5.

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