Dec. 29, 1931. F. KÖHLER 1,838,265

AUTOMATIC CONTROL SYSTEM FOR STEAM GENERATORS

Filed Dec. 16, 1927 3 Sheets-Sheet 1

Fig. 1

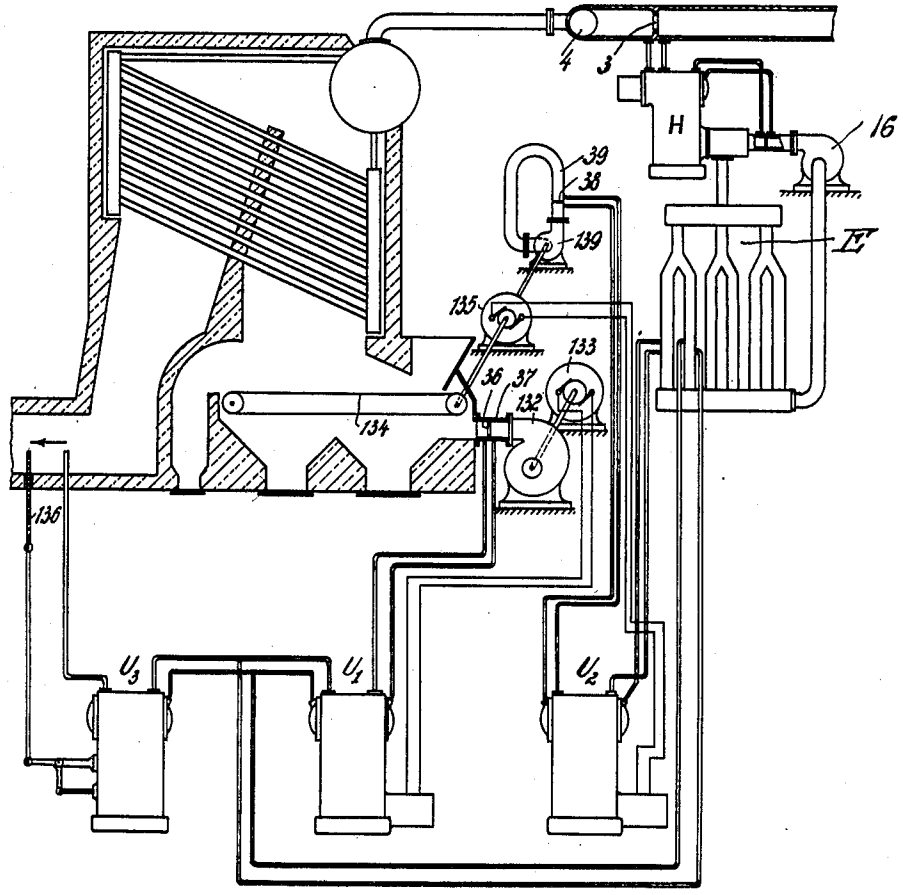

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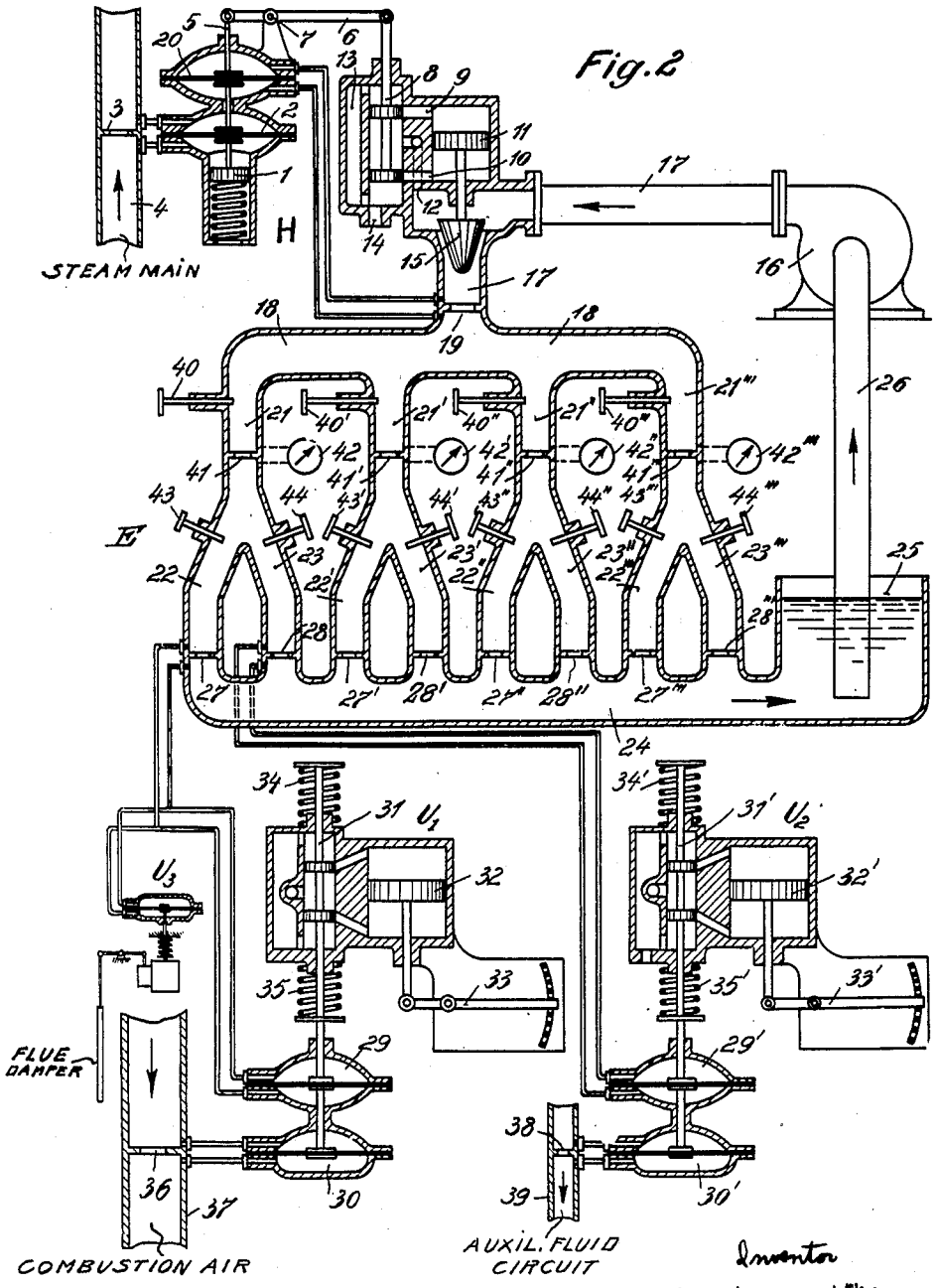
Fig. 2



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AUTOMATIC CONTROL SYSTEM FOR STEAM GENERATORS

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Fig.4

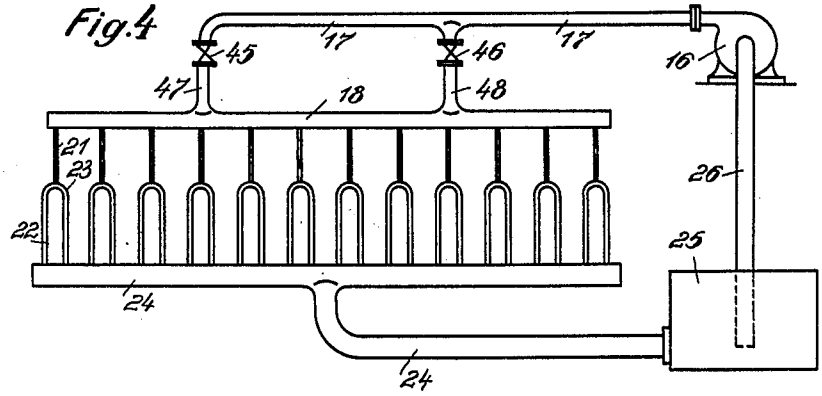
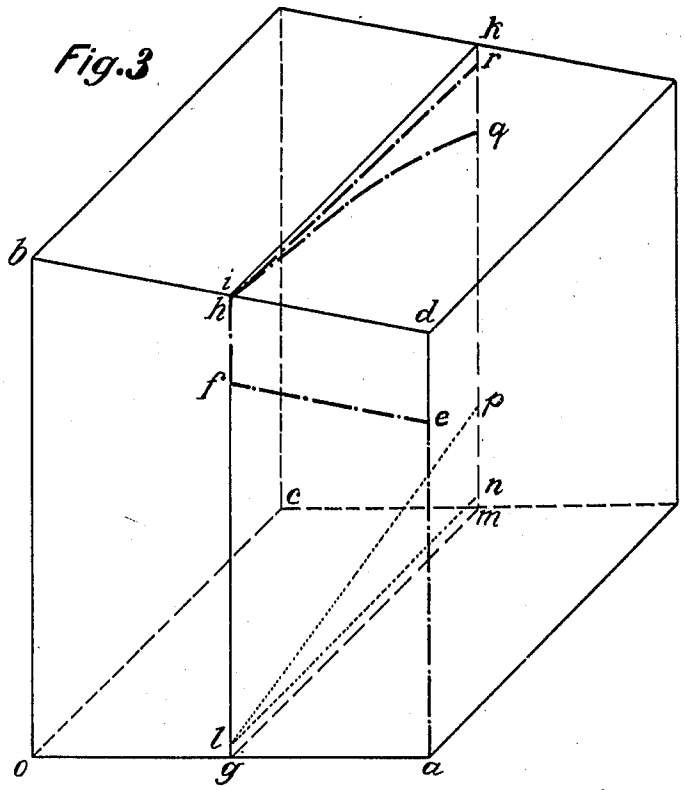


Fig.3



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1,838,265

UNITED STATES PATENT OFFICE

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AUTOMATIC CONTROL SYSTEM FOR STEAM GENERATORS

Application filed December 16, 1927, Serial No. 240,590, and in Germany December 18, 1926.

My invention relates to an automatic control system for steam generators or the like.

The object of the automatic control apparatus for the steam generator is to adapt the supply of the fuel and the air of combustion as quickly as possible to the withdrawal of steam and to adjust them substantially in such a manner that changes in the withdrawal of steam are followed by corresponding changes in the supply of fuel and air. It is thus necessary that to each weight of steam demanded by the consumer be apportioned a proportional weight of air and fuel. It may be said that it is necessary that the weight of the steam and the weight of the air as well as the weight of the steam and the weight of the fuel must be balanced against one another upon scales.

When employing scales for a quick acting automatic control apparatus a weighing proper by weights does not come into consideration. It is necessary to find an equivalent as measure for the weights. Such a measure is available in the difference of pressure which is measured by a contraction which in the form of a baffle disc, throttling nozzle or Venturi pipe is inserted in the path of the flowing steam, the air and as will be described later on also of the fuel. The scales to be designed for the control system thus serve for weighing or measuring pressures.

As a rule a plurality of steam boilers are joined to a common steam pipe. It depends upon the service conditions for the time being whether all the boilers take an equal share in the raising of the steam, whether a boiler is banked or cut out altogether, whether one portion of the boilers covers the normal load and the other the peaks and so on. Since such arrangements can only be made by the load dispatcher, it is necessary that the fuel and air regulating apparatus (regulating units) of all the boilers should be in charge of a central control office from which all variations in the regulation are to be effected.

To create such a central commanding point means to provide a main regulator from which the control units of the individual boilers are made dependent. In other words: the control units receive their control impulses not directly from the flow of steam, but from a main controller which responds to the flow of the steam. In principle this main controller is to be designed similar to the control mechanism described before, viz. as scales with the difference only that the flowing steam weight is weighed with the weight of an auxiliary transmitting medium (such as air or oil) flowing from a separate source. The auxiliary flow controlled by the scales then corresponds exactly with the flow of the steam and varies in proportion to it.

As the steam flow measured is composed of the steam flows of the individual boilers, the auxiliary flow is conversely divided into as many parts as there are boilers. From these fractional flows impulses are conveyed to the control units of the individual boilers. Each fractional stream varies, according to the laws of flow proportionally to the flow, of the steam so that the regulating impulses derived from it and produced by choking discs are proportioned to the main impulse derived from the steam flow. An interference with a fractional flow by throttling for instance, varies the quantity flowing in magnitude and thus the absolute value of the derived impulse force of this fractional flow, but the variations remain as before proportioned to the variations of the steam flow. The law of regulation thus maintains its force.

In the drawings attached hereto and forming part of my specification:

Fig. 1 represents a schematic illustration of a complete control system embodying my invention,

Fig. 2, the details of the system,

Fig. 3, a three-dimensional diagram showing the conditions prevailing during the regulation, and

Fig. 4, a modification of the system shown in Fig. 1.

Referring to Figs. 1 and 2 of the drawings, it will be seen that the impulse responsive member is designed as combined pressure and quantity gage. It consists of a

spring-controlled piston 1 upon which acts the steam pressure and a diaphragm 2 controlled by a differential pressure measured in front and behind a throttle or baffle disc 3 or contraction in the steam pipe 4. The differential pressure is a measure for the flowing steam quantity. The greater the flow of steam the higher the differential pressure and the more the diaphragm 2 is bent upwards. The motion of the diaphragm 2 is transmitted by a rod 5 to the double-armed lever 6 adapted to rock on the fixed pivot 7 and displaces a pilot piston 8. When the diaphragm 2 and the lever 6 are in the middle position the pilot piston 8 just covers the two ports 9 and 10 each leading into a chamber above and below the servo motor piston 11. If the diaphragm 2 is deflected upwards due to an increased steam flow the pilot piston 8 moves downwards. Oil under pressure admitted through the bore 12 is thus able to pass through the bore 10 under the piston 11 while the oil above the piston 11 is able to flow through the bore 9 into the chamber 13 and hence escapes through the outlet 14. The piston 11 is thus moved upwards and raises the valve 15. This valve controls the passage area of the pressure oil which is conveyed into the pipes 17, 18 by the pump 16. The quantity of the oil is measured by means of the throttle disc 19 by a differential method similar to that by which the quantity of steam flow through pipe 4 is measured as just described. The pressure difference existing on the two sides of disc 19 is utilized as return impulse and acts upon a diaphragm 20 fixed to the piston rod 5, but affected by the pressure difference in such a manner, however, that its force tends to oppose that which the steam flow exerts upon the diaphragm 2. If thus valve 15 is opened to a greater extent due to an increased flow of steam, the oil flow is augmented and thus also the pressure difference measured at the throttle disc 19, whereby the pilot piston 8 is reversed. The latter ultimately reaches its middle position (covering position) again when the impulse emanating from the steam flow just balances the impulse originating from the flow of oil. The quantity of the flowing oil has then changed exactly proportional to the quantity of the steam. The steam flow and the auxiliary flow are again in equilibrium. The main controller or regulator thus sets the auxiliary flow so that it is a true image of the flow of the steam.

After the stream of oil has passed beyond the throttle disc 19 it passes through an energy distributor E where its flow is divided into as many equal streams as there are boilers. The pipe 18 of this distributor branches in the example illustrated into four main branch pipes 21, 21′, 21″, 21‴. Each of these pipes divides into two sub-branches 22 and 23, 22′ and 23′, 22″ and 23″, and 22‴ and 23‴. Finally all these branches unite again into a manifold pipe 24. This pipe communicates with a tank 25 from which the oil is raised again through the riser 26 by a pump 16 and circulated through the system. The flow in each main branch may then be made in image or rather a reverse image of the steam generation of a single boiler. By individual throttle members 40, 40′, 40″, 40‴ each main branch flow may be adjusted independently according to the load desired for the individual boiler, without changing the total flow which is controlled by the main controller as described before. Thus the total flow of the control fluid as an image of the total steam flow from the entire boiler plant is not interfered with by such an individual adjustment. The characteristic of the variations of the fractional flows remain proportional to the characteristic of the variations of the total flow. The throttle members 40—40‴ only vary the ratio of the fractional flows and thus the share of the individual boiler in the total steam generation (load share). If individual throttle discs 41, 41′, 41″, 41‴ cooperating with respectively individual pressure difference gages 42, 42′, 42″, 42‴ are also provided in these fractional paths the share in the load of each boiler may be read off.

It would also be possible to derive the impulses for the supply of the fuel and the air to the individual boilers from these throttle discs 41—41‴. Preferably each fractional path is, however, again divided before deriving the impulse from it, into two sub-branches, forming the corresponding groups 22 to 22‴ and 23 to 23‴. Two equivalent impulses are then obtained of which one is used for controlling the fuel and the other for controlling the air. The impulse for the fuel control is derived from the choke discs 28—28‴ located in the respective branches of groups 23—23‴, the impulse for the control of the air from the choke discs 27—27‴ located in the respective branches of group 22—22‴.

This branching has the advantage that it is possible to individually interfere with the general process from the control station when the heating value of the fuel varies and to alter the ratio of the fuel and the air. For this purpose are provided the throttling elements 43 to 43‴ and 44 to 44‴ which may be adjusted individually or in common in such a manner that the sum of both throttle cross-sections in the two sub-branches of each of the four main branches remains unchanged. In this case the share in the load adjusted for instance by the throttle member 40 of main branch 21 remains unaffected.

The complete control process thus presents the following picture: The main controller or regulator H sets the auxiliary flow and its

flow quantity is proportional to the total quantity of steam delivered by the plant. The auxiliary flow is divided into as many main branches or streams as there are boilers in service. The quantity of the flow of each branch can be controlled by its respective throttle member 40—40″′, which flow remains proportional to the total quantity of the steam and is at the same time a measure for the load share of each individual boiler. Each main branch flow is in turn subdivided without the proportionality in relation to the total steam quantity being interfered with. In each main branch the flow quantity of one sub-branch is a measure for the quantity of fuel, that of the other sub-branch a measure for the quantity of air.

We proceed now to describe the control units on the steam generators themselves.

In assuming in the boiler shown diagrammatically in Fig. 1 one desires to regulate or control:

(*a*) The supply of air by varying the speed of the motor 133 driving the forced draught blower 132,

(*b*) The supply of fuel by varying the speed of the motor 135 driving the travelling grate 134,

(*c*) The pressure in the combustion chamber by adjusting the flue damper 136.

For this regulation there are two impulses available, which must be conducted from the control station to the two control units for air and fuel. Each impulse originates, as described before, from a pressure difference measured at a throttle disc and is a measure for the quantity of steam passing. The regulation demands that a proportional quantity of air and fuel be supplied. If it is now possible to measure the quantity of air and fuel also by means of a throttle disc and to express it by a pressure difference, the regulation may be considered a weighing of pressure forces. The control units at the steam generator should then be designed exactly like the main controller H at the control station.

(*a*) Regulation of the air. In the case of air the metering of the quantities may be carried out easily by, for instance, inserting a throttle disc 36 in the connecting pipe 37 between the blower 132 and the ashpit under the grate 134. The pressure difference measured there is weighed in the control unit U_1 with the impulse derived from the throttle disc 27. The control unit U_1 then operates in exactly the same manner as the main controller H with the difference that the servo motor piston 32 operates here an electric switchgear. As Fig. 2 shows, this control unit U_1 consists of a control diaphragm 29, a return control diaphragm 30, pilot piston 31, servo motor 32 and switch lever 33 which may represent a motor rheostat arm. The design and manner of operation corresponds with that of the main controller H with its two diaphragms 2 and 20, as described before. As the return impulse, produced by the pressure difference on the two sides of throttle disc 36 in the main air duct 37 (Figs. 1 and 2), and acting upon diaphragm 30, counteracts the primary control impulse acting upon diaphragm 29, and balances this primary impulse, pilot piston 31 is returned into its central position (covering position) which is assisted by the springs 34 and 35. The return control impulse being produced by the same means as in the main controller H with respect to the relation of the steam flow to the oil flow, viz. by the pressure difference measurement at throttle discs, everywhere full uniformity in the measurements and consequently full proportionality between oil flow and air flow is attained. By this system of connections acting upon motor rheostat 33, the proper speed of the motor 133 is adjusted and accordingly the blower 132 coupled with it will have an output at which the quantity of air supplied or the pressure difference measured at the throttle disc 36 coincides with the delivered quantity of air in duct 37 or with the pressure difference measured at the throttle disc 27 in the air control branch 22 of the energy distributor E.

(*b*) Control of the fuel. The measuring of the fuel offers greater difficulties. It is not possible to carry out the measurement directly and it is necessary to resort to auxiliary means. When the fuel is supplied to the grate in a layer of definite constant thickness, the quantity of fuel fed forward upon the grate is substantially proportional to the feeding speed of the grate and thus also proportional to the speed of the grate motor. With the grate motor 135 may be coupled an auxiliary pump 139 by which an easily measurable operating medium such as air or a liquid may be circulated. The auxiliary pump should be so designed that the quantity of fluid conveyed is proportional to its speed, for instance as displacement pump in the form of a piston pump or of a rotary vane pump with eccentric casing. If now the quantity of fluid conveyed by the auxiliary pump 139 as well as the quantity of fuel fed forward by the grate is proportional to the speed of the grate motor, the quantity of fluid conveyed by the auxiliary pump is a measure for the quantity of fuel supplied. The measurement of the quantity of fuel is thus referred back to the measurement of a quantity of air or liquid. The throttle disc 38 placed into the circulation path of the fluid is used for this purpose. The control unit U_2 for the fuel may therefore be built accurately like the control unit U_1, which is indicated in the drawings by the use of like reference signs with an index for like parts. Unit U_2 receives the actuating control impulse from the throttle disc 28 in the fuel control branch 23 of

energy distributor E and the return control impulse from the throttle disc 38 in the auxiliary fluid system. The speed of the grate motor 135 is regulated by means of the electric switch gear 33′ which may represent a rheostat, which is operated by the control unit and thus the quantity of fuel supplied is brought into agreement with the delivered quantity of steam in the main 4.

(*c*). Control of the flue damper. The object of the automatic regulation is really accomplished by the correct adjustment of the supply of fuel and air according to the consumption of steam. If it is also demanded that the flue damper should be controlled automatically, this is done for economic and practical operating reasons only. The control is exerted with respect to the pressure in the combustion chamber. An excessively high or low pressure in the combustion chamber is undesirable because due to unavoidable leaks in the brickwork combustion gases might then escape from the combustion chamber towards the outside or cold air might enter the combustion chamber from outside. The pressure in the combustion chamber should therefore generally lie slightly below the atmospheric pressure and should be maintained as uniform as possible. This may be effected in well known manner by adjusting a flue damper in order to control the cross-sectional area of the flue. The position of the flue damper depends generally from the load of the boiler. The higher the load, the greater is the quantity of the products of combustion and the more the flue damper is to be opened. It therefore suggests itself to make the adjustment of the flue damper dependent upon one of the impulses by which the fuel and the air is regulated. According to the laws of furnace engineering the quantity of the products of combustion is proportional to the quality of combustion air and if the same kind of fuel is used, is almost independent of the kind of fuel or its heating value. A variation of the heating value of the fuel causes an augmented or diminished supply of fuel, but it has no effect on the quantity of the products of combustion and consequently the position of the flue damper remains unaffected by it. It would therefore not be correct to make the position of the flue damper dependent upon the fuel impulse but the air regulation is the decisive factor and this regulation is derived from the throttle disc 27. The control unit U_3 which is of similar design as the control units U_1 and U_2 is for this reason connected, likewise unit U_1, with the throttle disc 27.

It is, however, not sufficient that the main controller H merely supervises the flow of the steam, because this flow alone does not determine unequivocally the weight of the steam and consequently the output of the boiler. Unequivocally it is determined by the flow only when pressure and temperature do not vary. The temperature is automatically kept sufficiently accurately constant by a suitable construction of the boiler and superheater. Maintaining the pressure constant demands on the other hand special measures. For this purpose main controller H is provided with the spring controlled piston 1. How the total system operates will now be described with reference to Fig. 3 of the drawings in which in a system of coordinates in space are plotted on the axis *o—a* the stroke of the main controller, on the axis *o—b* the force of the spring or the diaphragm, and on the axis *o—c* the load of the boiler. When starting from an initial state at which the steam pressure has not yet attained its full value and no steam is supplied yet, the main controller is at the end of its stroke at *a* and sets the pilot piston 8 so that the valve 15 is fully opened. The maximum quantity of oil thus flows through the valve and the throttle disc 19 and exerts a higher pressure upon the top of diaphragm 20 which together with the steam pressure acting upon the piston 1 counteracts the spring power against piston 1. This spring power has at first its minimum value *a—d*. The diaphragm pressure resulting from the maximum flow of oil may have the value *d—e*. The steam pressure then rises with the furnace adjusted for full operation first to the value *a—e*, $(a—e)+(d—e)$ being $+(a—d)$., without the main controller moving. If, however, the steam pressure rises beyond the value *a—e*, the controller H moves, but does not yet exert an action upon the position of the valve 15 so long as its middle position has not been reached. Up to the middle position the full flow of the oil is maintained and the steam pressure rises along the line *e—f*, *e—f* being parallel *d—b*, the spring power line. If the diaphragms of controller H pass beyond their central position, the oil flow is diminished because the valve 15 is closed to a greater extent. A reduced oil pressure and an increased steam pressure balance or compensate each other from now so that the controller H substantially maintains its central position. The steam pressure finally attains the value *g—h* and is smaller by the value *h—i* than the mean spring tension *g—i*. The value *h—i* corresponds with an oil flow the action of which on the sub-controllers U_1, U_2 and U_3 is just sufficient to adjust the fuel and air supply necessary for covering the losses of the boiler. Since the boiler losses may be considered as substantially constant over the entire range of loads, it is necessary to add an invariable amount to that quantity of oil which corresponds to the quantity of steam generated so that the supply of fuel and

air is ensured not for the quantity of steam generated only, but also for the boiler losses. This connection will be understood on referring to Fig. 3. The distance *g—l* represents the quantity of oil necessary for covering the boiler losses. The line *l—n* is drawn parallel to *g—m* and above it are entered as ordinates those quantities of oil which are necessary for the quantities of steam produced. Since in the direction of the axis *o—c*, to which runs parallel the line *g—m*, the boiler load is plotted, the steam quantities as well as the quantities of oil rise with the load of the boiler in a straight line *l—p*. From this representation it will be clearly seen that the variations of the oil flow are an accurate image of the variations of the steam flow. The ordinates of the square *g—l—p—m* then represent the total oil quantities necessary. The forces of the diaphragm resulting from them are plotted downwards from the line *i—k* which as line of the mean spring tension is drawn parallel to *g—m*. Their lower boundary line is the parabola *h—q*, since in pressure difference measurements the dependence between quantity and pressure difference follows the law of parabolas. For the function of the forces in the controller H the relation holds good, that the spring power is equal to the sum of the steam pressure and the pressure of the diaphragm originating from the oil flow less the diaphragm pressure originating from the steam flow. From this relation results a course of the steam pressure during the load according to line *h—r*, i. e. the steam pressure drops slightly with the increasing load. By suitable measures it is, however, possible to keep the degree of irregularity as low as possible.

In large boiler plants there are frequently a plurality of steam consuming points which makes it possible to measure the entire quantity of steam by a single throttle disc. In this case as many main controllers are provided as there are steam consuming points, but care must then be taken to equalize load fluctuations not by individual boilers or groups of boilers only, but by all the boilers together. Here also remains the requirement to be able to bank or shut down individual boilers of a battery, when necessary for repairs or cleaning, for instance. For this purpose a collecting pipe is provided into which pass the impulse transmitting streams of oil controlled by the main controller before they are subdivided into the fractional streams passing to the individual boilers.

The arrangement is schematically shown in Fig. 4 of the drawings. Like parts are indicated by like numerals as in the previous figures. Instead of the valve 15 shown in Figs. 1 and 2 two valves 45 and 46 are provided, each adapted to be adjusted by a main controller, not shown, which valves control the flow of oil through the two parallel pipe lines 47 and 48. As this figure shows the pipe 18, into which the pipes 47 and 48 discharge, is not divided, but forms a continuous collecting pipe from which branch the streams 21.

Various modifications and changes may be made without departing from the spirit and the scope of the invention, and I desire, therefore, that only such limitations shall be placed thereon as are imposed by the prior art.

I claim as my invention:—

1. A control apparatus for controlling the supply of operating media for steam boilers in accordance with the steam conditions, comprising means responsive to varying steam conditions, a pilot valve operated by said means, an auxiliary fluid circuit controlled with respect to its flow intensity by said pilot valve, a second auxiliary fluid circuit including a master valve operated by the fluid of said first auxiliary circuit and controlling the flow in said second auxiliary circuit, said second circuit having a plurality of parallel branches, each branch being designed to represent the flow of one of the operating media of the boiler, a flow responsive means in each of said branches and a supply device for each of the boiler operating media, one of said supply devices being assigned to each of said branches and controlled by its pertaining flow responsive means for controlling the boiler operating media in accordance with the flow conditions prevailing in said several branches of the second auxiliary circuit.

2. A control apparatus for controlling the supply of operating media for steam boilers in accordance with the steam conditions, comprising a device responsive to varying steam conditions, a pilot valve operated by said device, an auxiliary fluid circuit controlled with respect to its flow intensity by said pilot valve, a second auxiliary fluid circuit including a master valve operated by the fluid of said first auxiliary circuit and controlling the flow in said second auxiliary circuit, said second circuit having a plurality of parallel branches, each branch being adjustably designed to represent the flow of one of the operating media of the boiler, a flow responsive means in each of said branches and a supply device for each of the boiler operating media, one of said supply devices being assigned to each of said branches and controlled by its pertaining flow responsive means for controlling the boiler operating media in accordance with the flow conditions prevailing in said several branches of the second auxiliary circuit.

3. A control apparatus for controlling the supply of operating media for steam boilers in accordance with the steam conditions, comprising a device responsive to varying

steam conditions, a pilot valve operated by said device, an auxiliary fluid circuit controlled with respect to its flow intensity by said pilot valve, a second auxiliary fluid circuit including a master valve operated by the fluid of said first auxiliary circuit and controlling the flow in said second auxiliary circuit, said second circuit having a plurality of parallel branches, each branch being designed to represent the flow of one of the operating media of the boiler, a flow responsive means in each of said branches, a supply device for each of the boiler operating media, a third auxiliary fluid circuit having individual control means for each of said supply devices, said individual control means being operated respectively by said flow responsive means in the branches of said second auxiliary fluid circuit, for controlling the boiler operating media in accordance with the flow conditions prevailing in said several branches of the second auxiliary circuit.

4. A control system for regulating the supply of operating media for generating a resulting main fluid, comprising a device responsive to the variations in conditions of the main fluid to be regulated, an auxiliary fluid circuit, means for maintaining continuous fluid circulation therethrough, said device having valve means adjusted in direct proportion to the variations in conditions of the main fluid for controlling the flow in said auxiliary circuit to continuously proportion the flow therein to the prevailing conditions of the main fluid, and auxiliary flow responsive devices in said auxiliary circuit continuously adjusted in direct proportion to the variations in flow in said auxiliary circuit for regulating the supply of the operating media in accordance with the flow variations in the auxiliary circuit.

5. A control apparatus for controlling the supply of operating media for steam boilers in accordance with the steam conditions, comprising a device responsive to varying steam conditions, an auxiliary fluid circuit including a master valve controlled by said responsive device, and controlling in turn the flow in said auxiliary circuit, said auxiliary circuit having a plurality of parallel branches, each branch being designed to represent the flow of one of the operating media of the boiler, a flow responsive means in each of said branches and a supply device for each of the boiler operating media, one of said supply devices being assigned to each of said branches and controlled by its pertaining flow responsive means, for controlling the boiler operating media in accordance with the flow conditions prevailing in said several branches of said auxiliary fluid circuit.

6. A control apparatus for controlling the supply of operating media for steam boilers in accordance with the steam conditions, comprising a device responsive to varying steam conditions, an auxiliary fluid circuit including a master valve controlled by said responsive device, and controlling in turn the flow in said auxiliary circuit, said auxiliary circuit having a plurality of parallel branches, each branch being adjustably designed to represent the flow of one of the operating media of the boiler, a flow responsive means in each of said branches and a supply device for each of the boiler operating media, one of said supply devices being assigned to each of said branches and controlled by its pertaining flow responsive means, for controlling the boiler operating media in accordance with the flow conditions prevailing in said several branches of said auxiliary fluid circuit.

7. A control apparatus for controlling the supply of operating media to a plurality of steam boilers in accordance with steam conditions, comprising means responsive to varying steam conditions, an auxiliary fluid circuit including a master valve controlled by said condition responsive means, and controlling the flow in said auxiliary circuit, said auxiliary circuit having a plurality of parallel branches, each branch being designed to represent the steam production of one of the boilers, each of said parallel branches having a plurality of sub-branches, each sub-branch being designed to represent the flow of one operating medium of its pertaining boiler, a flow responsive means in each of said sub-branches and medium supply means respectively continuously controlled by said flow responsive means, whereby the rate of supply of the boiler operating media for each boiler is controlled in proportion to the rate of flow of the auxiliary fluid in the sub-branches, and whereby the rate of total steam production of all boilers is in accordance with the rate of flow in the auxiliary fluid circuit.

In testimony whereof I affix my signature.

FERDINAND KÖHLER.