Nov. 17, 1953 D. K. SWARTWOUT III, ET AL 2,659,350

FEED WATER REGULATION

Filed March 3, 1948 4 Sheets-Sheet 1

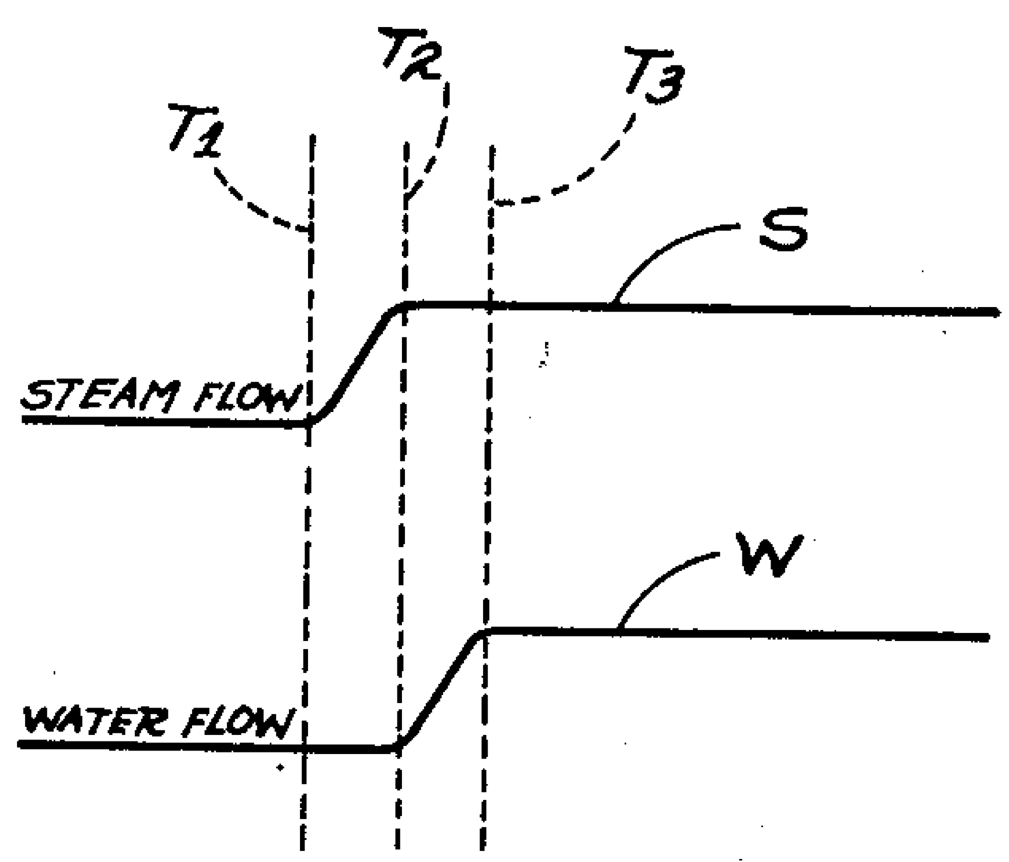

Fig.1

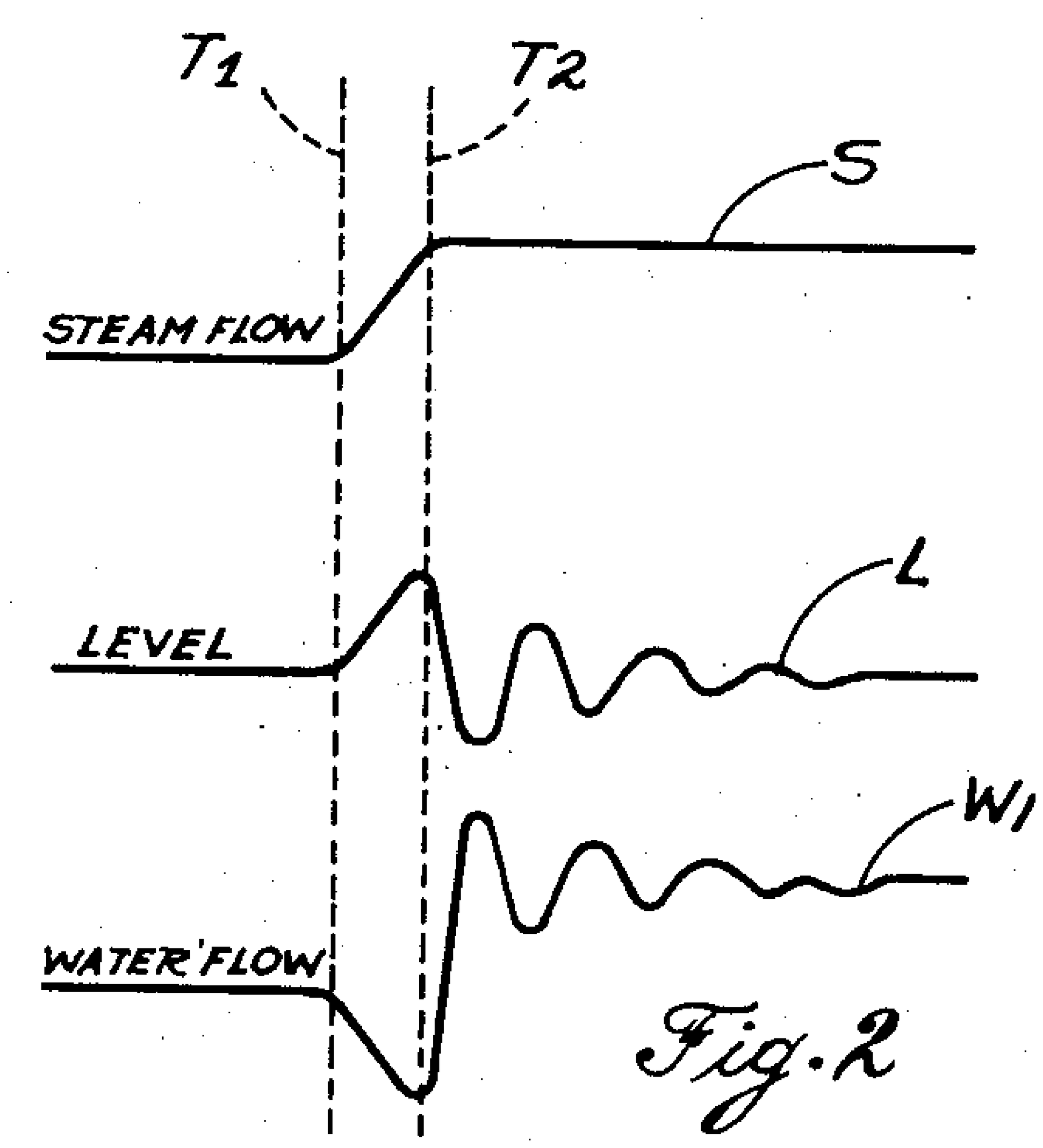

Fig.2

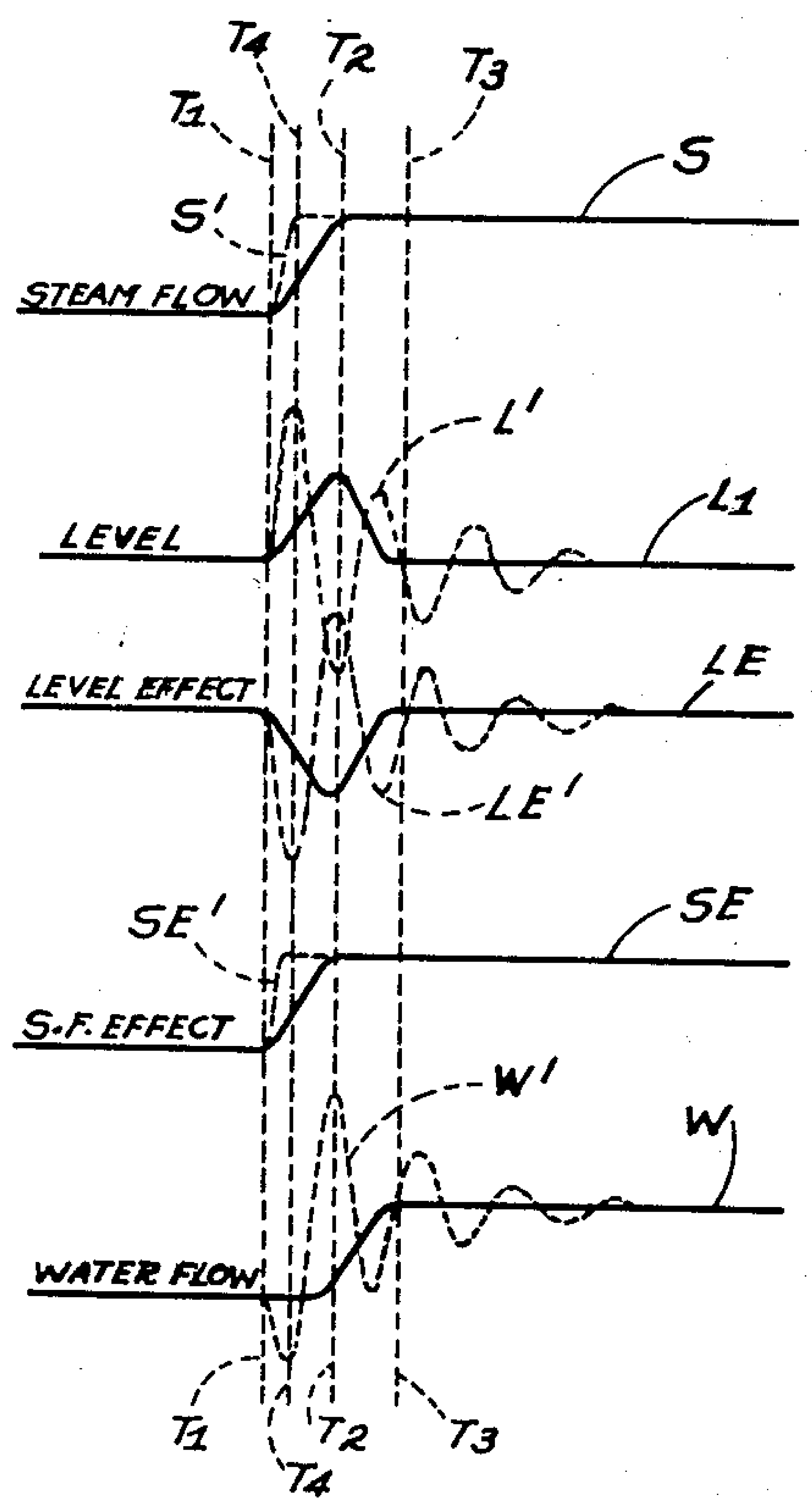

Fig.3

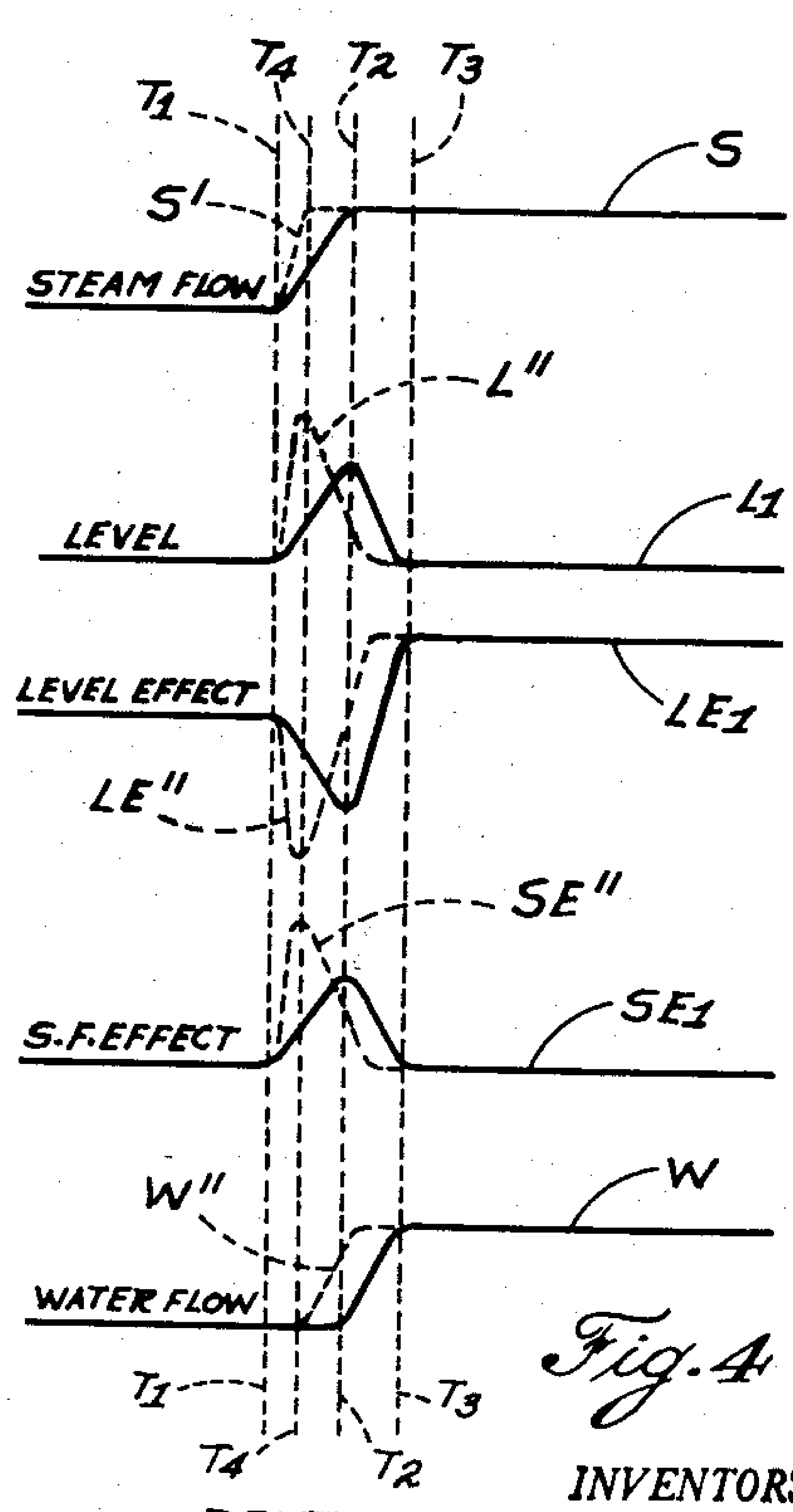

Fig.4

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4 Sheets-Sheet 2

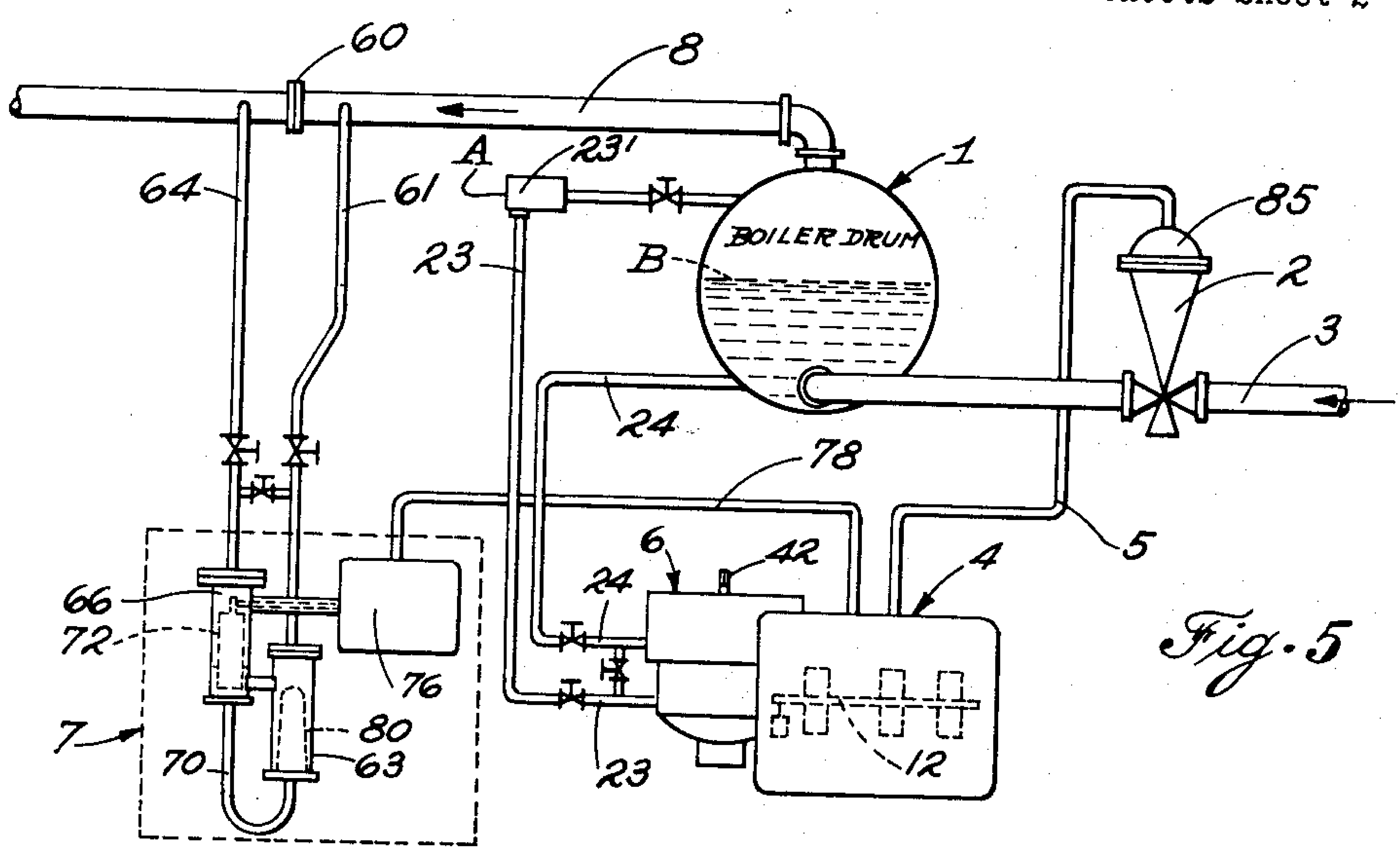

Fig. 5

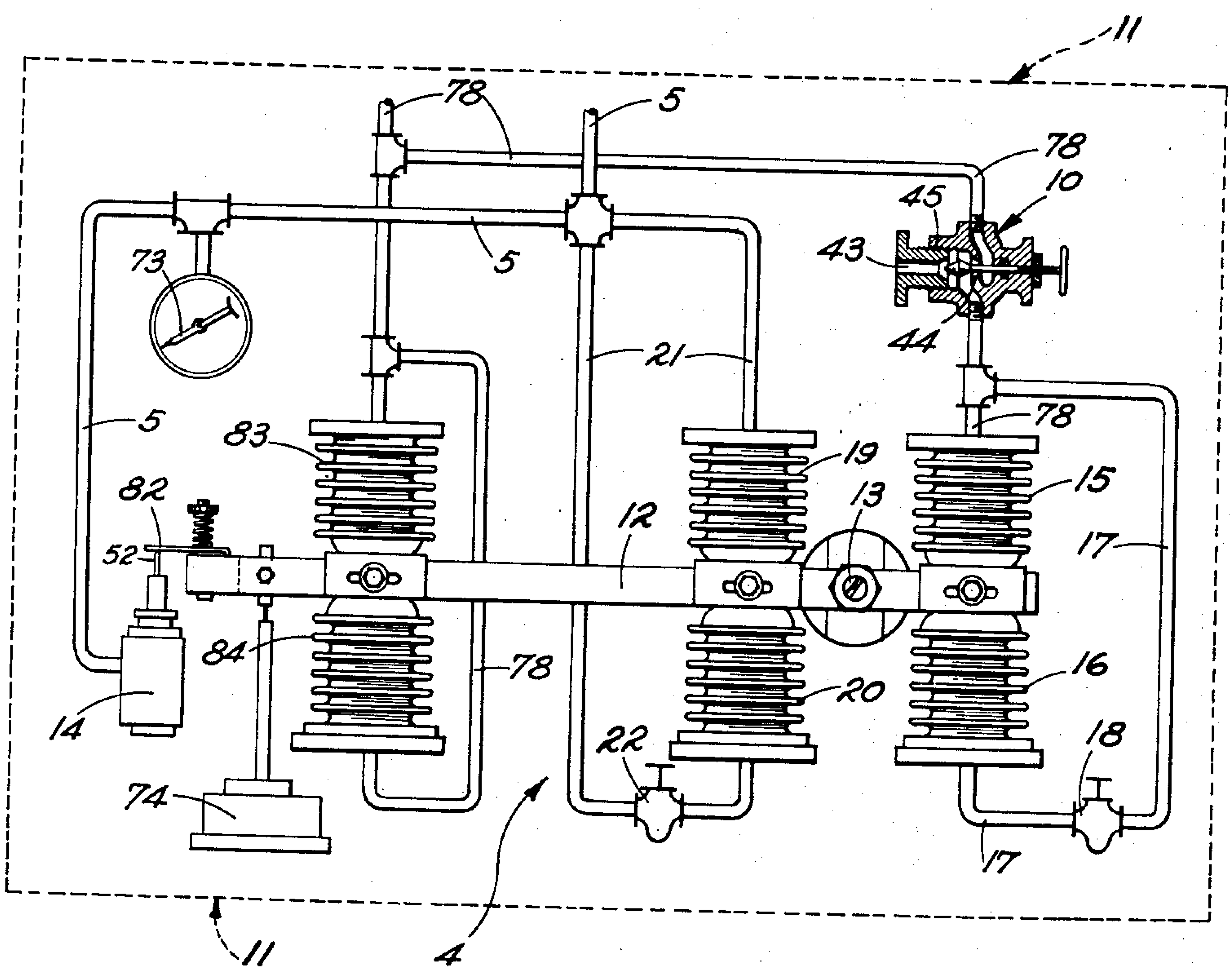

Fig. 6

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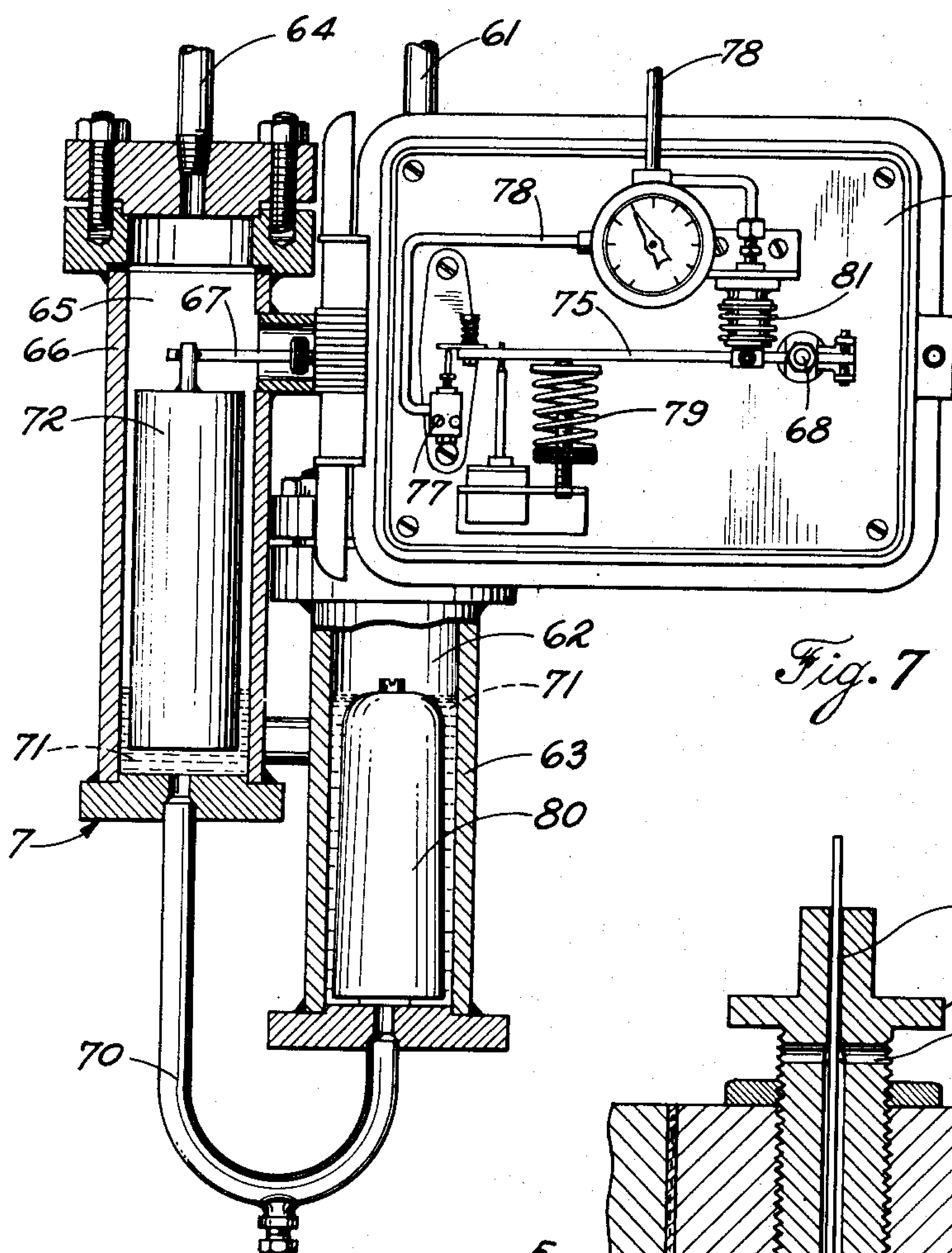

Fig. 7

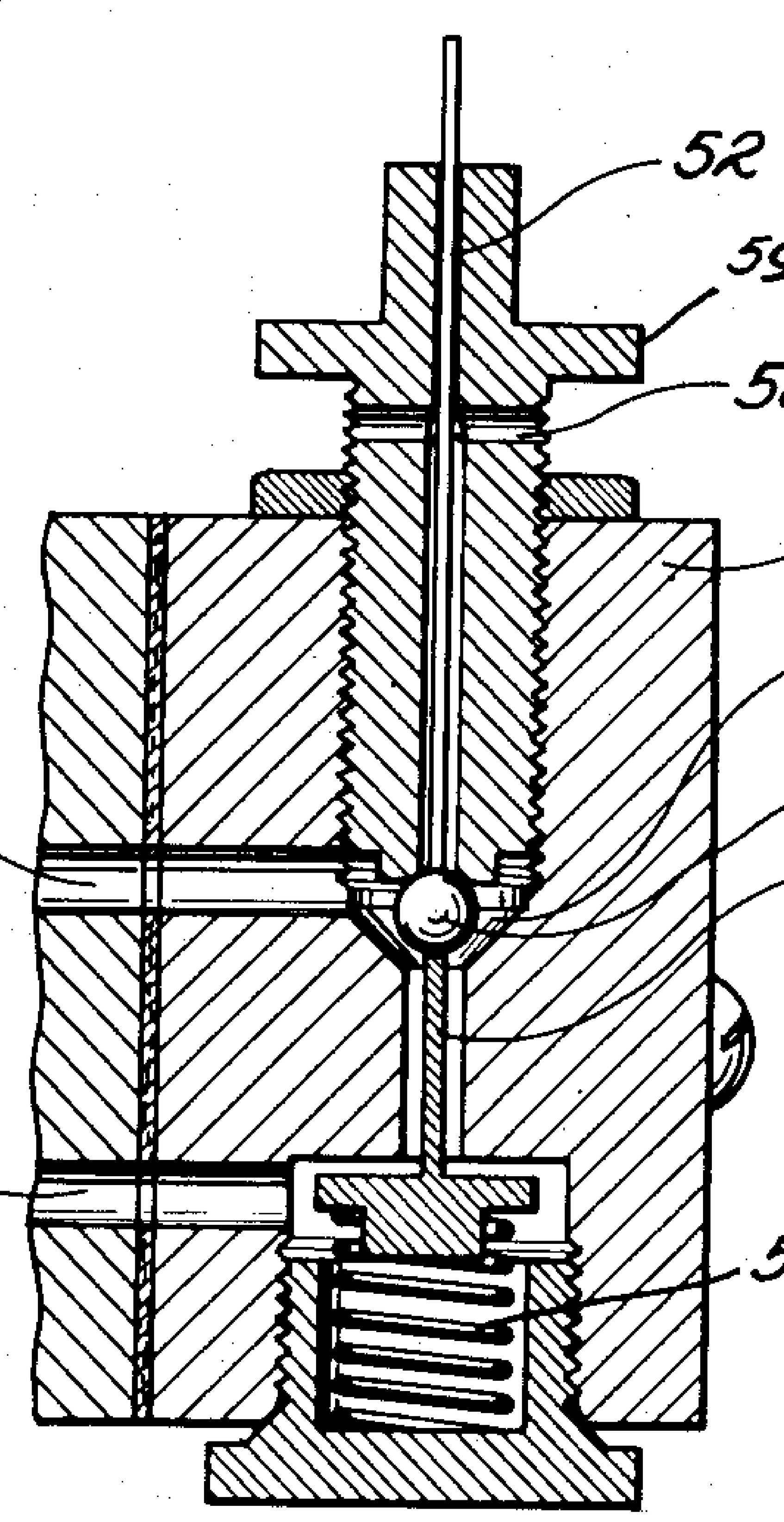

Fig. 10

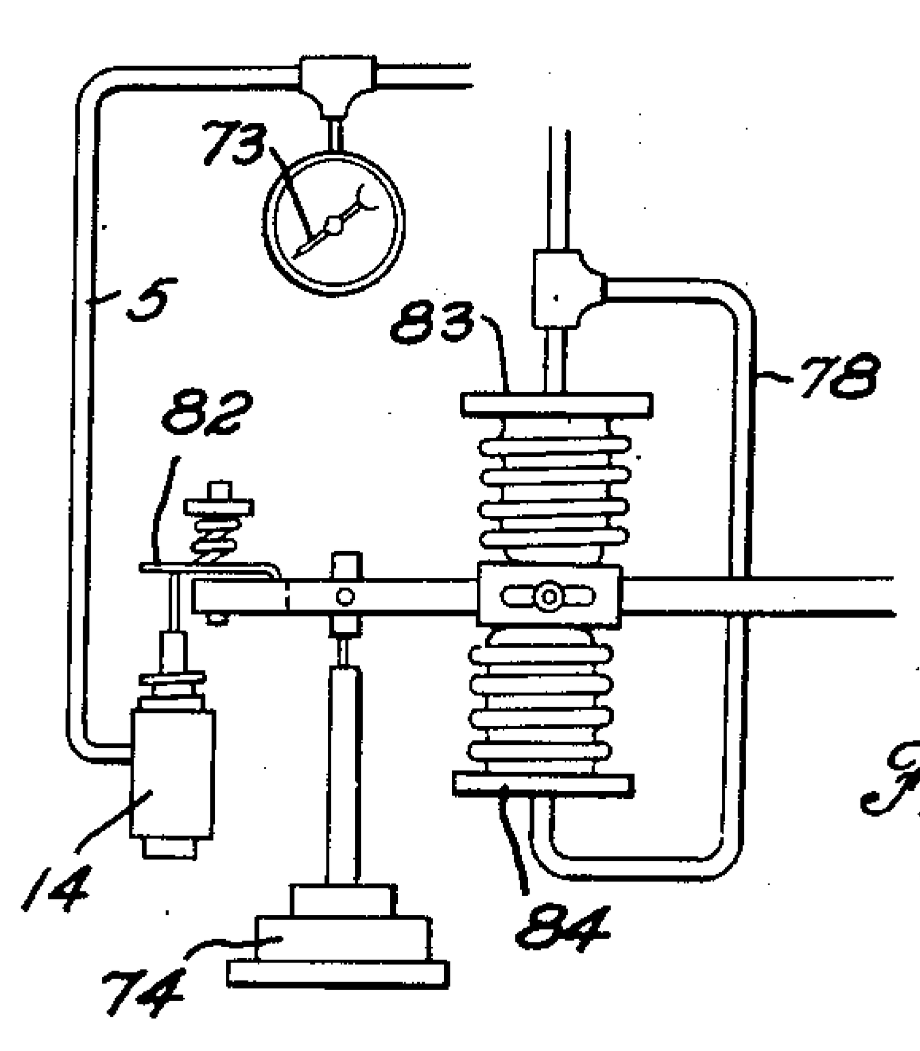

Fig. 12

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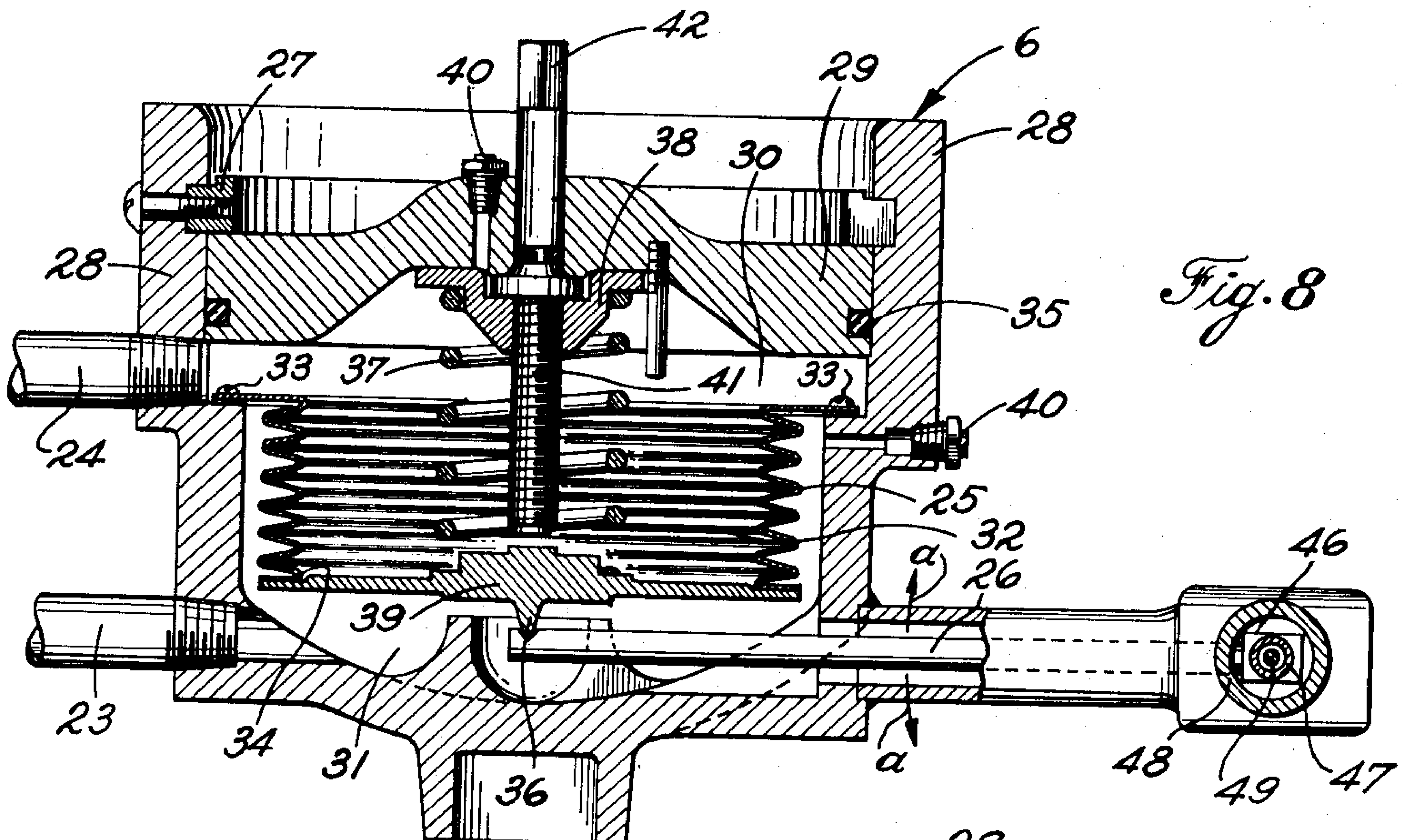

Fig. 8

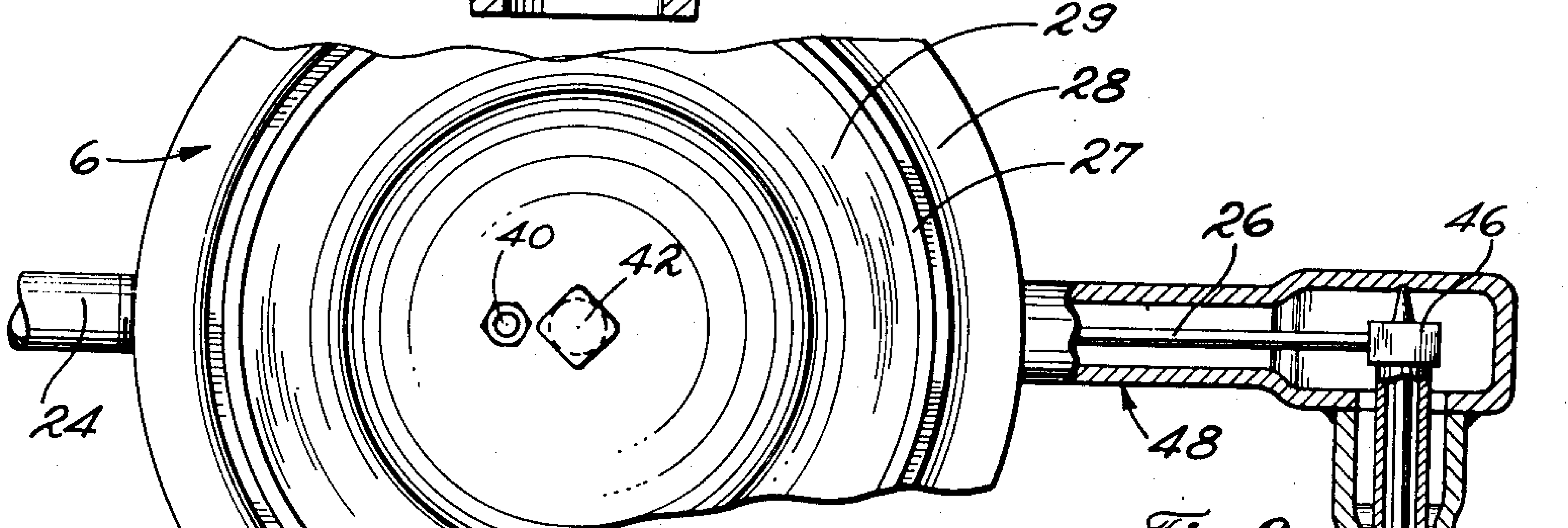
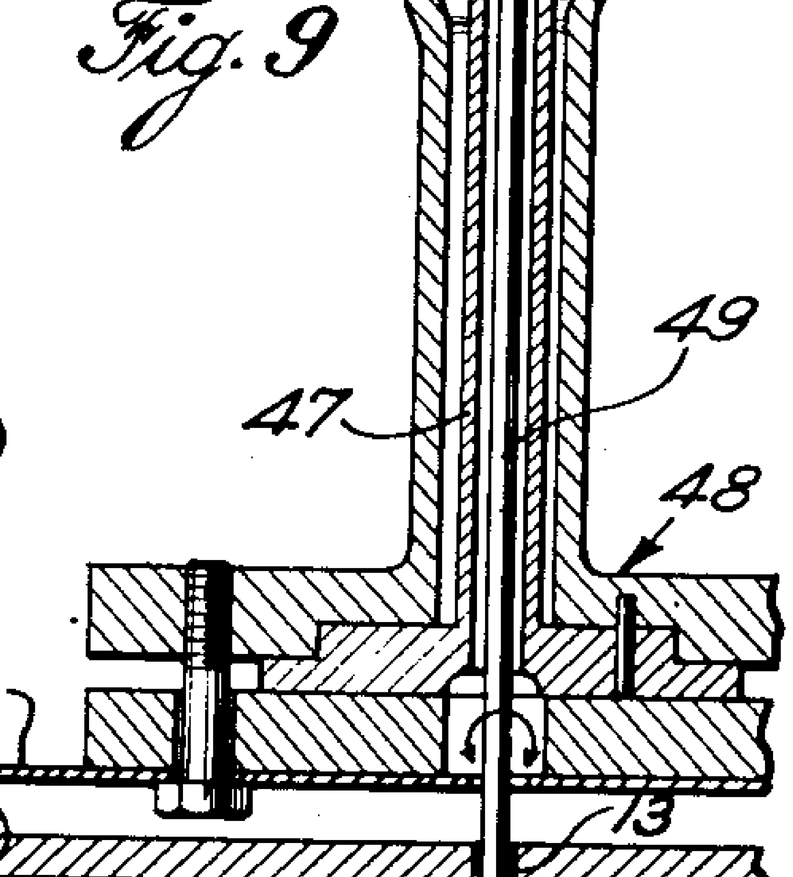

Fig. 9

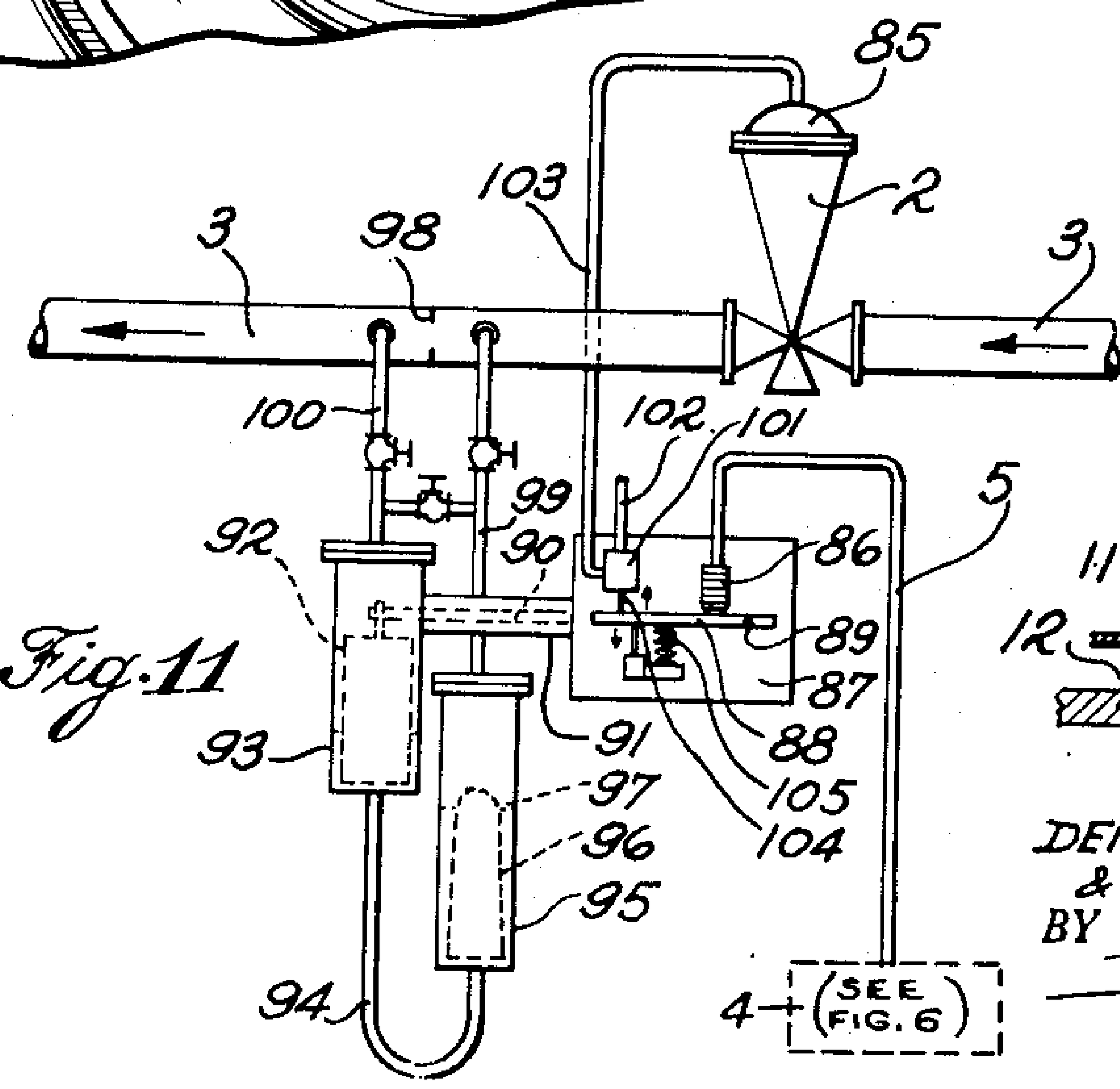

Fig. 11

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FEED WATER REGULATION

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Application March 3, 1948, Serial No. 12,834

13 Claims. (Cl. 122—451.2)

1

This invention relates to methods of control and control apparatus and more particularly to feed water regulation for steam boilers.

A general object of our invention is to provide an improved and simplified method of and means for feed water regulation. Preliminary to mentioning our more specific objects a general problem to which our invention is addressed will be exemplified with reference to the suggestive charts and diagrams of Figures 1 to 4.

In these figures time is the abscissa and each curve has its own independent ordinates. The several curves must be taken as merely illustrative of the conditions described. These curves omit for simplicity's sake many extrinsic considerations and values known to those skilled in the art.

In Figure 1 we suggest an ideal relation between the steam outflow from a boiler and the water inflow during an increase in load. The upper curve S represents a substantially constant load prior to the time T1 as shown leftwardly of the time line T1 and the lower curve W represents a corresponding substantially constant feed water input during the same time. Between the times T1 and T2 the load is seen to increase rapidly and then continue at the increased substantially constant rate after the time T2, i. e. rightwardly of the line T2. Ideally the water flow is not increased at the same time that the load increases but rather is continued at substantially a constant rate to the time T2 and then increased until time T3 when the rate of feed again corresponds to the load. The delay in time in increasing the feed avoids chilling the boiler while the rate of steaming must be increased, avoids aggravating the surge in water level incident to the increase in load, permits an orderly and desirable reduction in weight or mass of water in the boiler that goes with an increase in load (assuming a substantially constant water level before and after the increase) and permits dissipation of the water level surge before the rate of feed is increased.

In Figure 2 the problem is exemplified in terms of the diagrammatically charted results of single element water level control of feed water. Here the curve S corresponds to the curve S of Figure 1 and represents the same change and rate of change in load between the times T1 and T2. The water flow curve W1 while corresponding to the curve W prior to the time T1 and long after the time T2 at the extreme right of the figure shows the characteristic and often undesirable fluctuations reflecting and contributing to the surges and fluctuations in the water level as represented by the curve L in the same periods of time. That is to say, the initial surge in water level between the times T1 and T2, induced by the increase in load, first pinches down the water flow and then produces a hunting cycle with its well known undesirable effects. While this type of regulation is not necessarily deleterious with boilers having relatively constant loads or not subjected to large swells or shrinks in water level incident to changes in loads, the hazards of wide fluctuations in water level and rate of water feed are well understood and appreciated especially in relatively small drum boilers upon which the loads and the rates of change of load may be great and variable.

2

In Figure 3 we seek to show that phase of the problem that turns more particularly upon the rate of change of boiler load and have undertaken to depict by the curves in Figure 3 the results and effects of the prior and currenly conventional types of two and three element controls where both the changes in boiler load and/or load and feed as well as the changes in boiler water level have their joint and several influences upon the control of the rate of flow of feed water to the boiler. Considering first a two element control, in Figure 3 the curves S and W in solid lines, representing the steam flow and water flow respectively with respect to the times T1 and T2, correspond substantially to the curves S and W of Figure 1 and represent respectively the same conditions, i. e. the increase in load between the times T1 and T2 and the delayed increase in flow of feed water with the load and flow of feed water running substantially constant before and after their respective changes. For illustration we assume these prior art controls may obtain or approach this ideal result for some particular rate of change or rate and amount of change in load. The solid line curve L1 represents the water level under these ideal conditions and shows the characteristic surge reaching a maximum at or about the time T2 and a desirable smooth reestablishment of substantially the initial water level after the change in load. The solid line curve LE is intended to represent the water level effect or more particularly the influences of the water level responsive part of the control upon the flow of feed water. In the instant example, the water level effect or influence is shown as dipping or becoming negative approximately equally and oppositely of the surge in boiler water level, reaching its maximum point of negation at or about the time T2. The solid line curve SE is intended to represent the steam flow or load effect, i. e. the influence exerted upon the flow of feed water by that part of the control responsive to change in load. As shown in the solid line, current practice affords mechanisms in which the steam flow effect may rise with the increase in load between the times T1 and T2 in such a way that the positive influence of the increased steam flow substantially cancels out and balances the negative influence of the surge in water level wherewith to hold the rate of feed substantially constant between the times T1 and T2 with the advantages mentioned above with reference to Figure 1. As suggested in Figure 3 the algebraic sum of the steam flow and water level effects, as shown in the solid line curves, may bring about the smooth desirable increase in feed water up to the point of time T3 and the subsequent smooth substantially uniform increased rate of flow of feed water thereafter. All of this as shown in the solid lines, however, with the conventional prior art types of regulation are dependent upon the coincidence that the rate of change of steam flow just happens to be such in view of the adjustment of the equipment as to bring about the desirable result shown in the solid lines. The problem indigenous to this type of control however is that if the rate of change in load is greater or less than that shown in solid lines, that the water level influence or effect will be different in amount from the steam flow influence or effect since the height of the surge in water level is influenced very greatly by the rate of change in load while the steam flow effect is influenced primarily by the amount of the change rather than the rate of the change.

We have undertaken to depict these conditions in the broken lines in Figure 3. The broken line S' departs from the curve S between the times T1 and T2 and depicts a departure from the condition shown by the curve S in that it shows the same amount of increase in load but a higher rate of change in the shorter period of time, i. e. between the times T1 and T4; the loads being the same as shown in the curve S before the time T1 and after the time T4. This different and greater rate of change in load produces a much greater surge in the water level as shown by the broken line curve L' in its departure from the curve L1. The initial surge which rises very abruptly from the time T1 to the time T4 is seen to give a correspondingly augmented initial negative water level effect as represented by the broken line curve LE' which represents the departures in water level effect from the solid line curve LE as a result of the more rapid increase in load. Thus at the time T4 the water level effect is much greater than was the water level effect at the time T2 under the conditions shown by the solid line curves. However the steam flow effect, as shown by the broken line curve of departure SE' from the line SE, is no greater in magnitude at the time T4 than was the steam flow effect at the time T2 shown in the solid curve SE. The algebraic sum of the water level and steam flow effects is shown in the broken line curve W' which suggests the departures and character of flow of feed water from the solid line curve W and shows a pinching off of the water flow at the time T4. This pinching off of the water flow is often if not always undesirable

and is illustrative of the problem that is indigenous in the prior art methods of control because they fail to distinguish the difference between the effect of the amount of change in load and the effect of the rate at which a change takes place. After pinching off of the flow of feed water from the time T1 to T4 the deficiency in the supply of feed water brings about a sharp dip in the water level as shown by the broken line L' at about the time T2, the corresponding sharp increase in the water level effect as shown in the broken line LE' between the times T4 and T2, and the wide and abnormally large increase in the flow of feed water at about the same time as shown by the broken curve W'. This will be recognized as the beginning of a hunting cycle as shown by the broken line curves L', LE' and W' after the time T2 until a much later time when finally the fluctuations may flatten out and join in the solid line curves on the assumption that the steam flow meanwhile has remained constant from and after the time T4.

Thus we have sought to illustrate this aspect of the problem of feed water regulation arising from the insensitivity of prior art two-element controls with particular respect to the rate of change of load. The conventional prior art three-element control offers no solution to the problem since the curves of Figure 3 substantially represent the critical conditions obtaining in a three-element control as well as in a two-element control. To be sure Figure 3 does not depict specifically a curve suggestive of the influence and effect of the so-called third element responsive to the rate of flow of feed water nor the philosophical particulars of the conventional balance of the steam flow and water feed effects in such controls. Having in mind, however, that the third element is dependent on the flow of feed water and that the mischief of the surge still follows the rate rather than the amount of increase in load. It will be understood that the same kind of problem persists in the three-element control as described more particularly with reference to the two-element control.

In Figure 4 we have suggested in the same diagrammatic and illustrative way one of the objects of our invention in respect to the solution of the problem illustrated and discussed above. Generally speaking our object and solution proceeds on the basis of controlling the feed of water essentially and substantially through the boiler water level whilst the load is substantially constant and then while or incident to the change in load to provide an "impulse" or effect of limited duration and desirable magnitude that is responsive to the rate of change as well as the amount of change in load that will offset the deleterious effects and influences and facilitate the optimum and desirable feed above discussed.

In Figure 4 the solid line curves S, L1 and W correspond to the curves similarly marked in the preceding figures and represent substantially the conditions and effects described with respect thereto. The curve SE1, however, showing a steam flow effect, differs in kind from the curve SE of Figure 3 inasmuch as its value prior to the time T1 is substantially the same as its value after about the time T3 when the cycle provided by our invention incident to a change in load has taken place, and the value of both these flat parts of the curve is preferably zero. The curve SE1 therefore preferably represents a value for the steam flow effect rising from zero at the time T1 to a maximum at or about the time T2 and returning to zero at or about the time T3. This we have called an impulse steam flow effect because in accordance with the objects of our invention we cause the steam flow effect to influence the flow of the feed water substantially only by way of and during an "impulse" over a limited period of time beginning with the change in load and ending shortly thereafter. The several solid line curves in Figure 4 therefore show a transaction involving the increase in load between the times T1 and T2; the surge in water level and the corresponding negative water level effect, curve LE1 tending to pinch off the flow of feed water, but with the impulse steam flow effect offsetting the water level effect up until about the time T2 and thereby maintaining the even flow of feed water as shown by the curve W between the same times. After the time T2 as the surge subsides the water level effect is caused to increase more than the steam flow effect decreases with the result that the water flow is increased in the desired way as shown by the curve W. The means by which the water level effect will increase desirably with an increase in load without much or substantial decrease in water level preferably includes a reset control with, if desired, other improved means to be more fully described herein. The rate of decrease of the steam flow effect with respect to the rate of increase of the water level effect after the load has changed is preferably adjusted to aid in the initiation of the increase in the rate of flow of feed water.

Turning now to the broken line departures from the solid line curves of Figure 4 the facility with which our invention meets a different (increased) rate of change of load is shown. In this instance the broken line S′ is the same as the broken line S′ in the preceding figures and represents the same more rapid rate of increase in load above discussed. The broken line L′′ to the extent that it departs from the solid line curve L1 represents the higher surge in boiler water level resulting from the increased rate of change of load. Inter alia, it shows the surge L′′ rising to approximately the same height at the same time T4 that the surge L′ shows in Figure 3 but as distinguished from the surge L′ described in Figure 3 the surge L′′ of Figure 4 is restrained according to the objects of my invention and is caused to diminish in orderly fashion not falling below the normally desired water level shown by the right part of the solid line L1. That is, the abrupt rise between the times T1 and T4 is followed by an orderly fall down to a normal level shortly after the time T2. Correspondingly the broken line of departure curve LE′′ shows an abrupt departure of the water level effect oppositely of the surge L′′ but an orderly return of the water level effect to the higher substantially constant value shown by the rightward horizontal portion of the line LE1. According to our invention we obtain in this instance a steam flow effect as shown by the broken line SE′′ which is materially different from the steam flow effect SE′ in that the steam flow effect has preferably been adjusted to have a magnitude substantially equal and opposite the water level effect and therefore substantially greater than the effect SE′ because it reflects the abruptness and rate at which the load is increased in much the same way that the character of the surge in water level reflects the same change in conditions. By causing the steam flow effect to be similar to but opposite to the water level effect the smoothness of the water flow is preserved as shown in the line W′′ between the times T1 and T4 since here as in the immediately preceding instance, shown in the solid line curves, the water flow is not subjected to any changing influence during the interval when the load is increasing and the surge rising. Between about the times T4 and T2 the negative influence of the water level effect diminishes rapidly as the surge diminishes and while the positive influence of the steam flow effect diminishes, it is adjustable and preferably adjusted to diminish at a slightly lesser rate whereby a net positive influence is exerted on the flow of feed water to bring about its smooth desirable increase as shown by the broken line W′′. After about the time T2 the water level effect as shown by the rightward part of the line LE′′ becomes positive at a rate and amount of increase greater than the rate and amount of decrease of the steam flow effect, continuing the increase in feed until the feed levels off smoothly at the desired increased rate as shown by the line W′′.

Thus our general object is defined and served in obtaining the same smooth desirable change in feed water flow whenever the load changes regardless of the rate, direction or amount of the change; it being understood that while we have specifically referred to increases in load and corresponding surges in water level that the same kind of mode of operation obtains in the same beneficent way with respect to decreases in load and shrinkages in water level when the rate of steaming is reduced.

Specific objects of our invention will be mentioned and enlarged upon in connection with the following description of the method and means and particularly the preferred form thereof through which the advantages of our invention may be had and enjoyed. Among the more specific objects of our invention is the provision of method and means for solving the problems herein above stated and discussed and for carrying out our general objects herein above illustrated. A further object is to provide that the mechanism and apparatus be simple and economical of construction and operation and that they be adaptable to widely different conditions of use. More particularly it is among our objects to provide that the mechanisms employed be readily adjustable as for example in respect to the kind and degree of impulse effect to be employed in the control and the constancy or variability of the water level desired to be maintained by the control. A further object is to insure that the results of the control or regulation in terms of the actual flow of feed water respond correctly to the rate and amount intended to be fed.

Our invention though illustrated with respect to boiler feed and water level control is not intended to be necessarily limited thereto but may well be useful in other instances, processes and circumstances.

Other objects and advantages will appear from the following description of a preferred form and embodiment of our invention, reference being made to the accompanying drawings in which Figure 1 is a diagrammatic chart comparing steam flow and water flow in a desirable relation; Figure 2 is a diagrammatic chart comparing steam flow, water flow and boiler water level according to prior practice; Figure 3 is a diagrammatic chart comparing steam flow, water level, water level effect, steam flow effect and water flow under different conditions of rate of change of load according to prior practice; Figure 4 is a diagrammatic chart comparing the same things compared in Figure 3 but with different results obtained with our invention; Figure 5 is a diagrammatic view of control mechanism embodying our invention; Figure 6 is an elevation of the main control apparatus; Figure 7 is a partly diagrammatic side elevation partly in section of the steam flow responsive part of our control; Figure 8 is a sectional view of the water level responsive apparatus; Figure 9 is a somewhat diagrammatic plan view of the linkage between the water level apparatus and the control mechanism; Figure 10 is a longitudinal section of the pilot valve employed in our invention; Figure 11 is a diagrammatic showing of a water flow proportioning control for the feed water valve, and Figure 12 is a fragmentary part of Figure 6 showing the bellows **83** and **84** offset from one another on the lever **12**.

A preferred form of apparatus of our invention is illustrated partly and diagrammatically in Figure 5 and is adapted to control the water level in a steam boiler drum **1** by varying the opening of a main feed water valve **2** located in the water intake pipe **3**. The apparatus includes control mechanism designated generally at **4** which is adapted to produce a control pressure in a conduit **5** which connects with the fluid motor **85** of the feed water valve **2** and to which pressure the valve **2** responds; the valve **2** opening as the pressure increases and being spring closing. A boiler water lever responsive element is designated generally at **6** and a steam flow responsive element is designated generally at **7** which measures and responds to the flow of steam through the steam output pipe **8**. These elements transmit their respective forces and effects to the main control means **4** which in turn synthesizes and converts them into the desired control pressure in the manner suggested above and now to be described.

In Figure 6 is illustrated the proportioning and reset control apparatus **4** responsive in its operation to the water level means **6** and responsive also to the steam flow means **7** particularly to the extent of the "impulses" above mentioned. The apparatus **4** is mounted in a box **11** housing a control lever **12** supported at and fulcrumed about a pivot point **13** and operatively connected to the operating stem of a pilot valve **14** of the supply and bleed type. The pilot valve is adapted to supply fluid under pressure, preferably air, to the conduit **5** which is shown for the sake of simplicity in Figure 5 to lead directly to the fluid motor of the feed water valve **2**. We prefer however to lead the conduit **5** indirectly to the valve **2** by way of the improved means shown in Figure 11 wherewith to cause the flow of feed water to correspond to the pressure from the pilot valve **14**. As shown in Figure 6 clockwise movement of the lever **12** results in an increase in control pressure from the pilot valve **14** and conversely, counterclockwise movement of the lever **12** causes a decrease in control pressure. Clockwise movement of the lever **12** tends to increase the flow of feed water. An increase in boiler water level tends to move the lever counterclockwise, see Figures 5, 8 and 9. Torque from the water level responsive element **6** is preferably applied to the lever at the pivot point **13**.

Also tending to apply torque to the lever **12** is a steam flow effect bellows **15** which acts on the lever to the right of pivot point **13** as shown. The amount of torque exerted by bellows **15** is preferably directly proportional to the magnitude of steam flow and is determined by the pressure

of air within the bellows as supplied by the steam flow element **7** through the conduit **78** subject to manual adjustment by a supply and bleed valve **10** which gives any desired proportion of the pressure from the element **7** to the bellows **15**. The valve **10** may be called the impulse magnitude adjuster. The operation of the element **7** will be discussed more fully below. In order to modify the steam flow effect from one representative of magnitude of steam flow or load to one reflecting the rate of change of steam flow as well as the magnitude of the change and otherwise as will more fully appear, we provide a second bellows **16** preferably in all respects similar to bellows **15** and positioned to act upon the lever oppositely to bellows **15** as shown and connected to the bellows **15** by a fluid conduit **17** having a needle valve **18** interposed therein. The needle valve **18** can be adjusted to restrict the flow of air between bellows **15** and **16** by any desired amount, so that upon a change in pressure in one of the bellows **15** or **16**, air will leak or flow to the other bellows to equalize the pressures therein after any desired determinable period of time. The net effect of bellows **15** and **16** reflects the rate and magnitude of change of steam flow. For example when the needle valve is set so that air can bleed between the bellows at a relatively slow rate and if the steam flow should increase relatively greatly and rapidly, the pressure in bellows **15** would instantaneously greatly exceed the pressure in the bellows **16** and the net torque exerted by bellows **15** and **16** would be relatively large. The increased pressure in bellows **15** would then, however, begin to bleed into bellows **16** but very slowly so that bellows **16** would neutralize bellows **15** only slowly and ony after a relatively long period of time. On the other hand if the rate of flow of steam should increase by the same amount at a very slow rate the increase in pressure in bellows **15** would take place slowly and would be transferred to bellows **16** at substantially the same rate. In the first instance, the net resultant force exerted by both bellows is relatively large and endures, while decreasing, for a long time. In the second case the bellows virtually continuously neutralize each other and their resultant force is relatively small or negligible. The opposed bellows **15** and **16** with the restricted passage between produce a total net effect upon the lever **12** which is proportional to or representative of the rate of change of steam flow and has the characteristic of an impulse whose magnitude and duration measures or reflects the rate at which the load changes as well as the amount of change for a given rate of change. That is to say, if the increase in load were 100 units and came on in an extremely small or least possible minimum time and the maximum torque IP inch pounds was thereupon delivered to the lever **12** substantially instantaneously, assuming the valve **18** permitted no substantial flow from the bellows **15** to the bellows **16** during the time of the substantially instantaneous increase in load, then if the same increase in load came on in a much longer period such as five minutes, a substantially lesser maximum torque, *IP—C*, would be exerted on the lever; C in inch pounds corresponding to the loss of pressure in the bellows **15** due to the bleeding from the bellows **15** to the bellows **16** while the pressure in the bellows **15** was increasing in the five minute period. However if the load were increased by 200 units in the same extremely short time with the bleed valve set as mentioned above substantially twice the torque, 2IP, would be imposed upon the lever, and similarly if the 200 unit increase came on in five minutes the maximum torque exerted would be $2(IP-C)$. This we have undertaken to depict in substance in the rising parts of the impulse curves of SE1 and SE'' in Figure 4. The height of the impulse curves, i. e. the magnitude of the impulses in respect to load changes and/or water level surges or shrinks is readily adjustably controlled by the valve 10, the disposition of the closure element of which in respect to the fixed seat 44 tends to throttle the flow therethrough and in respect to the adjustable seat 45 throttles the desired bleed through the orifice 43 to atmosphere. Closing the orifice 43 puts the whole pressure from the element 7 on the bellows 15 directly. Putting the closure element about midway between the seats tends to put about half the pressure from the element 7 on the bellows 15, and so on. The needle valve 18 in its control of flow between the bellows 15 and 16 facilitates adjustment of the duration of the impulse by controlling the time required to balance or substantially balance the pressures in the bellows 15 and 16 after any unbalancing thereof. An air reservoir, not shown, may be interposed between the valve 18 and the bellows 16 whereby to delay the time equalization without undesirably constricting the passage through the valve 18. With the facility of adjustment afforded by both the valves 10 and 18 my invention provides whatever magnitude and duration of impulse may be desired to meet or offset in whole or in part any surge or shrink effects in substantially any boiler under substantially all conditions of operation. For example, the impulse can be adjusted to substantially exactly neutralize the "surge" effect on the water level control or "over" or "under" neutralize it in respect to rate, time or magnitude; the magnitude depending on the adjustment of the valve 10 and additionally as a matter of choice or design on the size of the bellows 15 and 16 and/or the length of the lever 12 from the pivot point 13 to the points of contact with the bellows compared with the relative strength and mechanical advantage of water level means, whilst the rate and time is facilitated by adjustment of the needle valve 18. It is also within the purview of our invention to provide that either of the bellows 15 or 16 be greater in size than the other or if of like size to be disposed to have contact with the lever 12 at a greater distance from the pivot point 13 than the other. By whatever means the bellows 15 is caused to have a greater influence on the lever 12 than the bellows 16 then correspondingly a residual positive steam flow effect will be imposed and maintained on the lever after the pressure in the bellows 15 and 16 becomes equalized through the connecting conduit 17 and the needle valve 18. For the same reasons if the bellows 16 is arranged or provided to have a greater influence on the lever 12 than the bellows 15 a negative residual steam flow influence will be imposed and maintained on the lever after the fluid pressures in the bellows have become equalized through the connecting conduit and needle valve. While, as mentioned above, we prefer that the bellows 15 and 16 be equal in size and equally spaced from the pivot point 13 for the sake of having a true steam impulse effect characterized by the complete absence of steam flow effect whenever the pressure in both the bellows is the same, we mention the facility with which the impulse effect may be had and enjoyed and additional effects may also be had where the same are desired.

Acting on the lever 12 are also a proportioning bellows 19 and a reset bellows 20. The bellows 19 is connected to the control pressure conduit 5 so that it is exposed at all times to the control pressure emanating from the pilot valve 14. Thus when the water level changes and/or when the steam flow changes, the resulting torque on the lever will cause or tend to cause a change in control pressure and so cause a corresponding change in force exerted by the bellows 19. The reset bellows 20 is preferably similar in all respects to bellows 19 and mounted to bear directly oppositely thereof on the lever 12. It is connected to bellows 19 by a conduit 21 having an adjustable needle valve 22 therein so that the pressure in bellows 20 will lag behind that in bellows 19 at a rate determinable by adjustment of the valve 22. An air reservoir may be interposed between the valve 22 and the reset bellows 20 for the reasons mentioned in reference to the valve 18 and the bellows 16. As those skilled in the art understand, the proportioning and resetting operation of the bellows under the determinable influence of the valve 22 permits that the control as a whole have, inter alia, a desirable sensitivity or lack thereof, a desirable throttling range, freedom from hunting and an asymptotic return to the control point as well as the elimination of non-lineal characteristics of the pilot valve. While we prefer that the bellows 19 and 20 be equal in size and acting equally distant from the pivot point 13, we are not unmindful that advantageous characteristics of operation may be had when desired by modifying the relative influence of the proportioning and resetting bellows. Thus if the resetting bellows be given a slight advantage over or a little disadvantage with respect to the proportioning bellows the water level control point can be held substantially wherever desired throughout the whole range of boiler loads; causing, when the reset has an advantage, the water level to be held at a greater height at higher loads. The coaction of the resetting function with the steam impulse effect is well illustrated in the operation in the period of time between the flattening out of a "surge" and the ending of an impulse. For example, if the impulse effect be adjusted to outlast the surge for a short time following an increase in load, there will be a small net clockwise though diminishing torque on the lever from the bellows 15 as the surge falls and approaches the water level which existed before the change in load. This initiates an increase in control pressure via the pilot valve 14, a corresponding increase in pressure in the proportioning bellows 19 and the beginning of the bleed into the reset bellows 20 and the opening of the feed valve 2 and an increase of flow of feed water, see Figure 4. The increased feed offsets the fall of water level but with the reset bellows pressure now increasing as the net impulse pressure 15—16 is decreasing there is a smooth transition and maintenance of a decreasing net component of clockwise torque that increases the feed to meet the new load until the water level means, responding to an increase in level, adds its counterclockwise torque to that of the proportioning bellows to balance the system and establish the control pressure at the desired increased amount to effect the necessary increased feed. Meanwhile if the reset bellows has had a small advantage over the proportioning bellows the water level will not necessarily have returned to its original level at all but will have come out of the surge smoothly and directly to its new desired water level as for example an inch or so higher than that obtaining prior to the surge. It will be understood that the values given are merely illustrative and may be taken in reference to the fact that equally opposed proportioning and reset bellows may in a given instance hold the water level to about a 1'' fall from no load to full load. What we have termed the small advantage that may be given the reset bellows may, of course, in varying degree be employed merely to reduce the ordinarily expected 1'' fall as well as bring about an actually higher level at the higher loads. Depending on the size of the drum, advantage or disadvantage of the reset bellows relative to the proportioning bellows may be used to modify the water level from no load to full load substantially as much or little as may be desired, it being entirely practicable to have the level 6'' or a foot more or less higher or lower at full load than no load as may be desired. With our invention the facility of smoothness of control will always be of the same kind within any reasonably desired range of water levels and the determinable control points thereof.

The water level element **6** may take any one of a number of forms but we prefer that it take the form shown in Figure 8, which determines the water level by measuring the differential head between the points A and B, see Figure 5. The respective heads are led by conduits **23** and **24** to opposite sides of a diaphragm or bellows **25** which is connected to a lever **26** in such a manner as to rock the lever in a vertical plane about the axis **13** as shown by the arrows *a* whenever the relative heads change, i. e. whenever the water level changes. By the linkage shown in Figure 9 movement of the lever **26** applies torque to the control lever **12** at the pivot point **13**. The element **6** comprises a housing consisting of a body **28** and a cap member **29**; the latter preferably being removably secured in fluidtight relation in and to the former as by a split ring **27** and an O ring seal **35**. Pressure from the steam space of the drum and the constant water head of the conduit **23** with its condensate reservoir **23'** is led to the chamber **31** below the diaphragm **25** and boiler pressure and the variable and controlled head from the water space of the drum and conduit **24** is led to the chamber **30** above the diaphragm. The diaphragm **25** preferably takes the form of a bellows which has its interior exposed to the pressure in chamber **30** and its exterior exposed to the pressure in chamber **31**. The flanged upper end **32** of the bellows is fixedly secured and sealed tight to the body as by bolts **33**; its lower closed end comprising the plate **39** is free to take a position determined by the difference in chamber pressures and to move in response to changes in the differential head between the chambers **30** and **31**. Vent screws **40** facilitate bleeding air from the chamber whenever necessary. A short stub projection **36** extending from the plate **39**, as shown, bears against the lever **26** and transmits movement of the bellows thereto. In order to adjust the element **6** for various water levels at control points we provide a compression spring **37** interiorly of the cap member **29** and confined between the adjustable member **38** and the plate **39**; the spring acting through the plate **39** and projection **36** on the rod **26**. In order to adjust the force of the spring the end member **38** threadedly receives a screw threaded adjusting stud **41** which has a projecting wrench head **42**. The water level at which it is desired the boiler operate may be set for control by compressing spring **37** more or less, the force of the spring opposing the greater constant head of the conduit **23** and reservoir **23'** and supplementing the lesser head from the boiler water level. The net resultant of the differential head and the spring pressure is transmitted to the lever **26** and thence to the control mechanism **4**.

For example, if it be desired to raise the control point for the water level, the compression of the spring **37** is reduced with the result that the smaller force of the spring transmitted to lever **26** and thence to the control lever **12** tends to rotate the lever **12** clockwise and raise the left end of the lever **12** from the pilot valve **14** to increase the control pressure and rate of feed. This raises the water level until the increased head thereof added to the reduced spring pressure brings the control pressure back to normal.

The movement of lever **26** acts to adjust the position of control lever **12** by exerting torque upon the lever through the more or less conventional torque tube arrangement shown diagrammatically in Figure 9. The lever **26** is secured to a pivotally mounted block **46** and thus to the closed end of a torsionally yieldable tube **47** the opposite open end of which is flanged and secured as by welding or otherwise to a fixed housing part **48** which is in effect an extension of the body **28** enclosing the lever **26** and tube **47**. The housing **48** is rigidly secured to the casing **11**. A shaft **49** secured to the tube at its closed end adjacent the block **46** extends out from the tube to connect with the control lever **12** at point **13**. The inside of the tube **47** is at atmospheric pressure, the outside at boiler pressure. Movement of lever **26** in response to change in spring adjustment or in response to change in water level causes twisting of tube **47** and rotation of the shaft **49** as is well understood. Actual movement of the parts is quite small since but a very small fraction of an inch is required to move the pilot valve between its extreme positions. This small movement is freely facilitated through the torque tube and attendant mechanism and housings without frictional losses or impairment.

The leftward, as viewed, end of the control lever **12** is adapted to bear against the stem **52** of pilot valve **14**, Figures 6 and 10, and thus operate the valve to vary the control pressure in conduit **5**. Preferably the pilot valve is of the supply and bleed type. The stem **52** together with lower separate stem part **53** and spring **54** is adapted to control the position of ball **55** within the chamber **56**, the position of ball **55** determining the pressure in conduit **5** by dividing the stream of compressed air which enters the valve at inlet port **57** between conduit **5** and the vent passage **58** in the threaded plug **59** which leads to atmosphere. It will be seen that when the stem **52** is pressed downwardly by the control lever **12** the pressure in conduit **5** will be decreased and when the stem is allowed to rise upwardly under the influence of spring **54** the pressure in conduit **5** will be increased. The extreme limits of travel of the ball **55** is adjustable by positioning the plug **59** and locking the same with a lock nut as shown.

To produce a pressure in bellows **15** corresponding to steam flow we preferably utilize the steam flow element **7** shown in Figure 7 which measures the pressure drop across an orifice 60 in the steam line 8. Pressure from the high pressure side of the orifice is led by a conduit 61 to a chamber 62 within a mercury pot 63, and pressure from the low pressure side of the orifice is led by a conduit 64 to a chamber 65 within a higher mercury pot 66. The pots are connected by a U-conduit 70 and have a common mercury pool 71. A movable float or mass 72 preferably of constant section floats or is buoyed upwardly on the mercury in pot 66 and takes its position within the cylinder according to the mercury level therein which level is a function of steam flow. The "float" 72 is suspended from the left end of a lever 67 which is pivotally supported about an axis 68 preferably through a torque tube connection such as shown in Figures 8 and 9; the axis also supporting a lever 75 in a control box 76. The lever 75 is supported leftwardly of the axis 68 by spring 79; the latter also supporting the "float" 72 in the mercury pool. The left end of the lever 75 acts upon a pilot valve 77 similar to valve 14 to vary the pressure in conduit 78 leading to bellows 15. In order that the pressure in conduit 78 be truly a linear function of steam flow several corrections are made. As is well-known the pressure drop across an orifice is not a linear but is a squared function. We correct for this therefore by providing a fixed mass 80 of varying cross-section in cylinder 63 as shown. This cross-section is such as to cause the mercury level in pot 66 to change linearly with steam flow. For this reason, the cross-section of float 72 is uniform so its position or buoyancy is proportional to steam flow. In order to correct for possible non-linear characteristics in the pilot valve 77 we provide a proportioning bellows 81 connected the conduit 78 and acting to oppose spring 79. The pressure in bellows 81 is thus insured as corresponding directly and linearly to steam flow, and hence the pressure in bellows 15 is also proportional to steam flow.

In some cases, as mentioned above, it may be desirable to vary the water level with the load, carrying, for example, a proportionately high level for high loads. To do this other than by the means heretofore mentioned and independently thereof we provide a third pair of bellows 83 and 84 preferably identical in size and positioned on opposite sides of the lever 12 at unequal distances from the pivot point 13 as shown with exaggeration in Figure 12. The bellows at all times are preferably subjected to pressures equal to that in bellows 15 or as supplied directly by the conduit 78. By reason of the unequal lever arms, the bellows bias the lever in the desired direction and by the desired amount. In order to provide a slightly higher water level at high loads it is practicable to impose a modest clockwise torque on the lever 12 by the net effect of the bellows 83 and 84, and accordingly the bellows 84 is placed slightly farther to the left, as viewed in Figure 12, than bellows 83. The bias therefore is in the direction to increase the control pressure and the degree thereof for any particular setting of the bellows is directly proportional to the pressure therein. If on the other hand it should be desired to lower the level for high steam loads the position of the bellows on the lever relative to the axis 13 can be reversed wherewith to bias the lever oppositely. When the bellows 83 and 84 are equal and oppositely disposed equal distances from the axis 13 as shown in Figure 6 no bias or effect therefrom is imparted to the control and the water level is not affected by the pressure in these bellows. When the bellows 83 and 84 are subjected to the steam flow effect pressure and given different advantages on the ever 12 the results are analogous to those discussed above in connection with modifying the relative advantage of the bellows 15 and 16 on the lever. The bellows 83 and 84 may however be connected to the conduit 5 wherewith to be subjected to the control pressure for the feed valve and the results thereof will be analogous to the "over" or "under" resetting described with relation to the relative position of the reset bellows 20 and the proportioning bellows 19; the bias from the bellows 83 and 84 in the latter instance following the control pressure immediately rather than with the tendency to lag incident to the needle valve 22.

Preferably the main control 4 is provided with a pressure gauge 73 for showing the control pressure, a dash pot 74 to dampen movement of the lever 12, and the lever 12 preferably has a spring pressed extension 82 to shield the pilot valve from excessive pressure should the lever move substantially more than the limited travel of the pilot valve; the extension yielding when and if the lever moves counterclockwise beyond the closed position of the valve.

As mentioned above we prefer that the conduit 5 carrying the control pressure to or for actuating the fluid motor 85 of the feed water valve 2 should not lead directly to the diaphragm chamber or fluid motor 85 of the valve, as shown in Figure 5, since such a direct connection as is known to those skilled in the art does not necessarily produce a flow of feed water through the valve proportional to the control pressure. The departures from a true and direct proportion between the control pressure and the flow of feed water through the valve come about because of, among other things, variations in water pressure ahead of the valve, non-linear characteristic of valve ports, spring build-up, diaphragm stiffness, packing gland friction and the like. To obtain a true and direct proportional relationship between the control pressure delivered from the pilot valve 14 to and through the conduit 5 and the flow of feed water through the feed water valve 2 we have provided a mechanism, which may well be called a flow positioner, disclosed in Figure 11 wherein the conduit 5 connected to the control mechanism 4 shown in dotted lines is diverted from a direct connection with the diaphragm chamber 85 of the feed water valve 2 and terminates in an expansible bellows 86, one end of which is fixed in relation to a control panel 87 and the free end of which bears on a lever 88 pivotally mounted about a horizontal axis 89 whereby an increase in control pressure conducted through the conduit 5 to the bellows 86 induces or tends to induce the counterclockwise movement of the lever 88 about the axis 89. The lever 88 is fixedly connected through the axis 89 to a second lever 90 extending substantially parallel therewith which is also fixedly connected to the axis 89 whereby the levers 88 and 90 move together about the axis 89. The lever 90 is preferably enclosed in a housing 91 which preferably corresponds to the housing 48 shown in Figure 9 embracing the lever 26 and preferably has a torque tube connection to the axis 89 substantially the same way that the lever 26 is connected to the shaft 49 and pivoted with respect to the axis 13. The remote end of the lever 90 is connected to the "float" 92 which may correspond to the "float" 72 of Figure 7, being disposed in a mercury pot corresponding to the pot 66 of Figure 7 which communicates through the tube 94 with the second mercury pot 95 having a graduated mass 96 therein all substantially corresponding to the pot 63 and mass 80 shown and described in Figure 7. The pots 93 and 95 contain a mercury pool 97 corresponding to the mercury pool 71 of Figure 7. The pot communicates via a conduit 99 with the high pressure side of an orifice 98 in the feed water line 3 adjacent to and down stream of the feed valve 2. The pot 93 communicates via the conduit 100 with the feed water line on the downstream or low pressure side of the orifice 98. For the reasons mentioned in connection with the description of Figure 7 the pressure drop across the orifice 98 and its displacement of the mercury pool 97 taken with the shape of the mass 96 and the buoyant effect of the mercury in the pot 93 with respect to the "float" 92 tends to raise or lower the float 92 and hence swing the levers 90 and 88 in linear relation to the flow of feed water through the orifice 98. A pilot valve 101 corresponding substantially to the pilot valve disclosed in Figure 10 is acted upon by the leftward end of the lever 88 but in this instance the pilot valve is turned upside-down with its air supply conduit 102 coming in at the top and its control pressure taking off from the left side as viewed via the conduit 103 which leads to the diaphragm chamber 85 of the feed valve. The pilot valve 102 has its actuating stem 104 corresponding to the stem 52 of the pilot valve 14 in contact with the leftward end of the lever 88 whereby clockwise rotation of the lever 88, as viewed in Figure 11, tends to close the pilot valve and reduce the pressure in the conduit 103. A spring 105 adjustably opposes the action of bellows 86.

Therefore when the pressure from the pilot valve 14 as transmitted by the conduit 5 increases, requiring an increase in feed water the lever 88 will be moved counterclockwise under the influence of the bellows 86 opening the pilot valve 101 and increasing the pressure in the chamber 85 of the feed valve 2. This movement of the lever 88, however, tends also to depress the "float" 92 in the mercury pot 93 while the increased pressure in the motor 85 and corresponding opening of the feed valve 2 increases the flow of feed water through the orifice 98, lowering the level of the mercury pool in the pot 95 and raising the mercury level in the pot 93. Both the initial depression of the "float" and the raising of the level of the pool in the pot 93 increases the buoyancy of the "float" tending to rotate the lever 88 clockwise against the increased pressure in the bellows 86, and these tendencies and forces come to balance only when the flow of feed water corresponds to the pressure in the bellows 86. That is to say any change in the pressure in the bellows 86 will move or permit the movement of the lever 88 in the direction of the change and thereupon change and continue to change the pressure in the motor 85 until the rate of flow of feed water corresponds to the pressure in the bellows 86 regardless of the pressure or changing pressure in the motor 85. Similarly while the pressure in the bellows 86 remains constant any change in the rate of flow of feed water affects the mercury pool 97 and thereby the torque on the lever 88 whereby to cause a corrective change or the necessary corrective changes in the pressure in the motor 85 to restore the rate of flow of feed water to properly correspond with the pressure in the bellows 86, i. e. the control pressure emanating from the main control 4 reflecting the conditions and circumstances above described.

The operation of the several parts and whole of our invention has been in a large measure discussed above. In illustrative summary it will be recalled that we provide a determinable and adjustable steam impulse effect which can be tailored to fit the characteristics and peculiarities of substantially any boiler or condition; the impulse being advantageously useful to offset or neutralize the deleterious effects of changes in load at different rates of change and the characteristic swells or shrinkages of boiler water level incident thereto. In the operation of our invention the impulse effect is peculiarly able to take cognizance of the rate of change in boiler load while not being unresponsive to the magnitude of the change. Features of the operation of our invention include proportioning and resetting actions in conjunction with the utilization of the steam flow and water level effects as the same are employed to control the rate of feed whilst the actual rate of feed is always proportioned to correspond to the intended rate in terms of the synthesis of the controlling effects. A characteristic of the operation of our invention may be and preferably is that the regulation of the feed is substantially exclusively responsive to deviation from a desired water level so long as the boiler load remains substantially constant, but when the water level surges or shrinks due to changes in load wherewith to tend to influence the water level control deleteriously, the impulse provided by our invention is brought forward in such appropriate magnitude and duration as to bring about a beneficent control of the flow of feed water according to the objects of our invention. It is also a characteristic of the operation of our invention that while the impulse effect may and preferably does operate only in about the period of a change in load, the operation may also be characterized by retaining in the character of the control any desirable bias reflecting the load whereby to establish different water levels at different loads when the same may be found advantageous in the operation of any boiler.

While we have illustrated and described a preferred form and embodiment of our invention both with respect to method and apparatus along with certain modified forms thereof, changes, additional modifications and improvements will occur to those skilled in the art who come to understand our invention without departing from the spirit and fundamentals thereof and/or the broad teaching of this specification and therefore we do not care to be limited in the scope of our patent to the forms and embodiments herein specifically disclosed or in any manner other than by the claims appended hereto.

We claim:

1. The method of feeding water to a steam boiler which comprises maintaining a substantially constant rate of feed while the load is substantially constant, creating a first effect independently of boiler drum pressure initially substantially directly proportional to the rate of change of boiler load, creating a second effect substantially proportional to the swell or shrink in boiler water level due to change in load, balancing said effects against each other to neutralize said effects and maintain the said substantially constant rate of feed while the load

is changing and while the said water level is swelling or shrinking, and after the load has changed causing the first effect to diminish entirely but more slowly than the second effect and changing the rate of feed directly from said constant rate only in the direction corresponding to the direction of the change in load.

2. The method of claim 1 with the step of controlling the rate of feed substantially exclusively in respect to boiler water level after said first effect has expired so long as the load is substantially constant.

3. The method of feeding water to a steam boiler which consists in influencing the rate of flow of feed water substantially exclusively in response to boiler water level conditions while the boiler load is substantially constant, creating an effect independently of changes in boiler drum pressure corresponding to the rate of flow of steam from the boiler, modifying said effect when the load changes to an impulse substantially proportional to the rate of change of flow of steam from the boiler, exerting said impulse in opposition to the water level responsive influence while the load is changing, continuing to exert said impulse for a limited time after the load has changed and thereby initiating a change in rate of flow of feed water in the direction of the change in load preliminary to returning the control of the flow of feed water to the exclusive influence of said water level conditions.

4. The method of claim 3 with the step of biasing said water level responsive influence in proportion to the rate of flow of steam from the boiler independently of said impulse.

5. Apparatus for controlling the water level of a steam boiler comprising a control lever and a pilot valve operatively connected to said lever and supplying fluid under pressure to a fluid pressure system adapted to influence the flow of feed water and being adapted upon movement of the lever to vary the pressure within said system, means connected to said lever and adapted to exert a force upon said lever proportional to the change in said water level, a first bellows having fluid supplied thereto by said pilot valve and forming a part of said fluid pressure system and adapted to exert a force on said lever in a direction opposing the force exerted by said level control, a restricted fluid passage, a second bellows connected with said first bellows by said restricted fluid passage and adapted to oppose said first bellows and asymptotically neutralize its effect, means producing a second fluid pressure proportional to steam flow, a third bellows having fluid supplied thereto by said second means and disposed to act upon said lever in a direction tending to neutralize the change in force exerted by said first means resulting from a change in water level, a second restricted fluid passage, and a fourth bellows opposing said third bellows and connected thereto by said second restricted fluid passage and adapted to negative the effect of said third bellows when the flow of fluid through said second restricted fluid passage has substantially equalized the pressures in the said third and fourth bellows.

6. The combination of claim 5 with a third means responsive to the rate of flow of feed water, a second lever actuable thereby, a second pilot valve actuable by said second lever to produce feed valve actuating pressures, a fluid motor connected to said first pressure and acting on said second lever in opposition to said third means.

7. The combination of claim 5 with fifth and sixth opposed fluid motors acting with respectively different advantage on said lever and connected to respond to said second fluid pressure.

8. Apparatus according to claim 5 in which said fluid pressure system also comprises a fifth bellows having fluid supplied thereto by said pilot valve, said apparatus also comprising a feed water valve actuating fluid motor, a source of fluid pressure independent of the pressure in said system, fluid connections between said source and said motor, a second pilot valve in said connections influencing the pressure in said motor, a second lever operatively engaging said second pilot valve, said fifth bellows exerting a force on said lever corresponding to the pressure in said system, and means responsive to the rate of flow of feed water urging said lever in opposition to the force exerted by said fifth bellows.

9. Apparatus according to claim 5 with means for changing the proportional relation of said second fluid pressure to steam flow.

10. Apparatus according to claim 9 with means for changing the restriction in said second restricted fluid passage.

11. Boiler feed water regulating mechanism comprising a pressure actuated feed water valve, a source of fluid pressure, fluid connections between said valve and said source, a pilot valve in said connections influencing the actuating pressure for said feed valve, a member movable in response to changes in boiler water level and moving said pilot valve, a fluid motor responsive to said actuating pressure connected to said member to oppose motion thereof that tends to change said actuating pressure, a second fluid motor connected to said member in opposed relation to said first motor, means producing a fluid pressure corresponding to the rate of flow of steam from the boiler, means conducting said last named pressure to said second motor, a third fluid motor opposing said second motor, and restricted pressure conducting means connecting said third motor to said last named fluid pressure.

12. Boiler feed water regulating mechanism comprising a pressure actuated feed water valve, a lever pivotally mounted on an axis and movable about said axis in response to changes in boiler water level and influencing the actuating pressure for said valve, proportioning and reset fluid motors actuated by said valve actuating pressure and acting in opposition to each other on said lever to influence movement of said lever about said axis, means producing a second fluid pressure proportionate to the rate of flow of steam from the boiler, a pair of impulse fluid motors actuated by said second fluid pressure and acting in opposition to each other on said lever to influence movement of said lever about said axis, means delaying the response of said reset motor to said valve acting pressure, and means delaying the response of one of said impulse motors to said second pressure; the other of said impulse motors and said proportioning motor responding immediately to said second pressure an said valve actuating pressure respectively and acting on said lever in opposition to each other.

13. The mechanism of claim 11 with a second member movable in correspondence with the rate of flow of feed water, a second pilot valve actuable by said second member to produce immediate feed valve actuating pressures, a fourth fluid motor responsive to the actuating pressure influenced by the first pilot valve and acting upon

said second member in opposition to movement of said second member induced by the rate of flow of feed water.

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