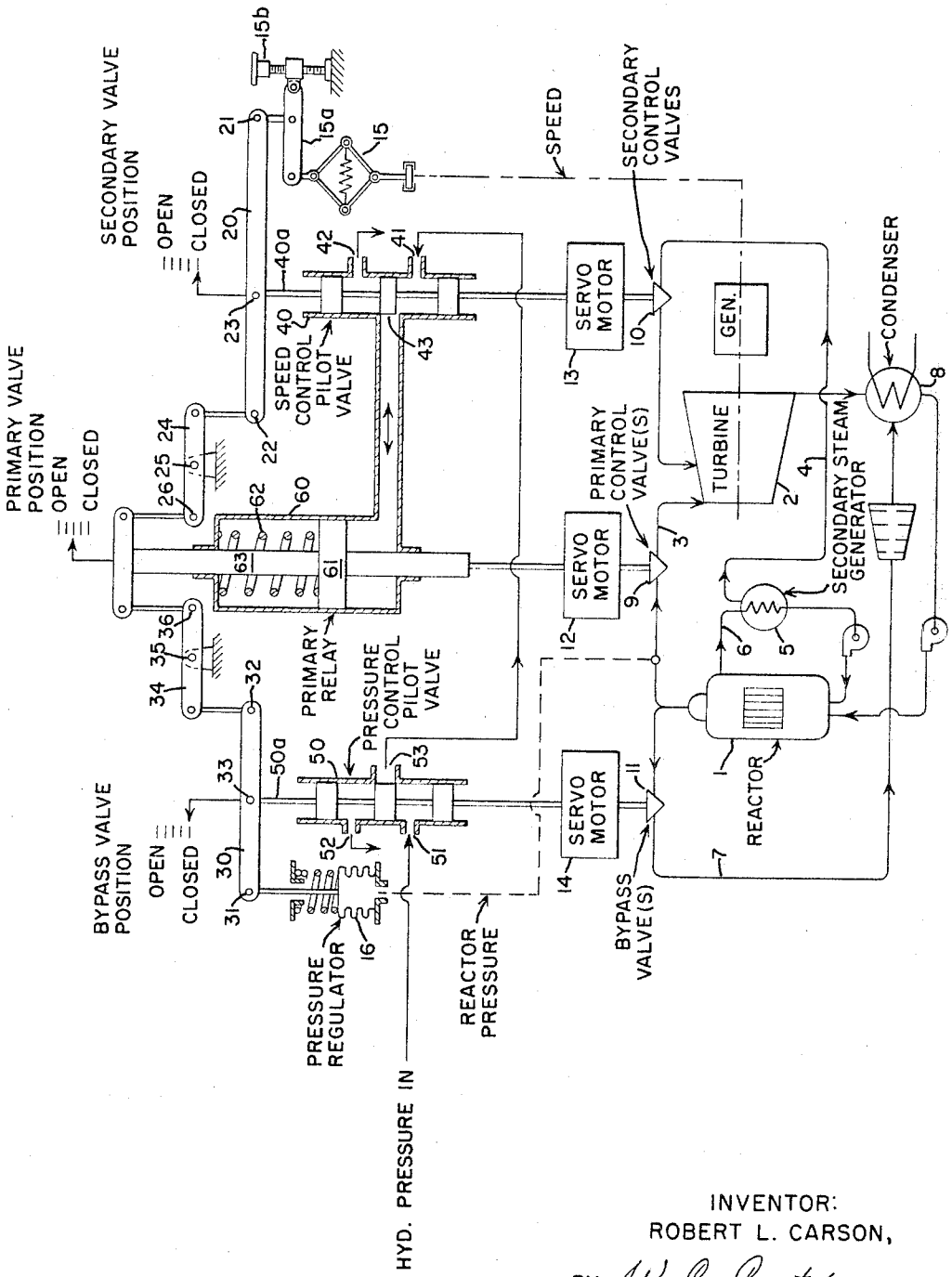
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COMPOUND CONTROL SYSTEM FOR A TURBINE

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COMPOUND CONTROL SYSTEM FOR A TURBINE

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This invention relates generally to a control system for a turbine and in particular to an improved compound control system wherein turbine speed and motive fluid pressure act interdependently to control the speed and pressure in a turbine generator plant.

While the practice of this invention is subject to a wide variety of modifications and variations, it is suited for use with a "dual cycle" boiling water type nuclear reactor plant for supplying steam to a turbine and is so described herein.

In a boiling water reactor plant, water cools the reactor and in doing so, is partially converted to steam which is caused to flow directly from the reactor to a turbine. In a dual-cycle boiling water reactor plant, the coolant is not only used as a direct source of steam, but a portion of it is passed to a heat exchanger or steam generator to provide a secondary source of steam. This steam is necessarily of a lower pressure and is introduced at intermediate or low pressure stages of the turbine system. In addition to the primary steam to the high pressure side of the turbine, and the secondary steam to the intermediate or low pressure side, there is a steam bypass which dumps primary steam directly to the condenser in the event of excessive pressure. Hence there are three sets of valves to position and regulate: primary control valves which admit high pressure reactor steam to the turbine; secondary control valves which admit steam from the secondary steam generator to the turbine; bypass valves which bypass the turbine and put reactor steam directly into the condenser if more primary steam is being produced than is being taken by the turbine.

Patent No. 3,022,235 issued Feb. 20, 1962, to Dale H. Brown and David W. Leiby and assigned to the assignee of the present application, discloses a regulating system of the general type herein disclosed by which the sets of valves are properly coordinated by the interdependent action of a speed responsive and a pressure responsive governing means.

The present invention provides a regulating system of the same general type as above mentioned. However, in addition to this structure, the present invention provides a hydraulic system which is responsive to the signals of the two interdependent governors, and by which those signals are amplified to produce the motions called for. That is to say that, since the signals of the present system are hydraulically amplified to perform the function of opening and closing certain valves, the apparatus and structure by which the signals are sensed and relayed can be smaller than the equivalent apparatus in a system which has no hydraulic amplification.

Accordingly, it is an object of the present invention to provide an improved compound control system for a turbine which operates at comparatively low force levels.

Another object of this invention is to provide an improved compound control system for a turbine which reduces friction and hysteresis, thus providing improved regulation.

These and other objects, features, and advantages of this invention will be readily appreciated from the following description when considered in connection with the accompanying drawing, which is a schematic diagram of the control system of this invention, and shown in working relation to a nuclear powered steam turbine system which is in a state of equilibrium.

Briefly stated, in accordance with one of its aspects, this invention comprises a turbine control system including a primary or high pressure steam valve, a secondary or lower pressure steam valve, a turbine bypass steam valve, a speed governor regulating the secondary valve, a pressure responsive governor regulating the bypass valve, and the speed governor and pressure responsive governor acting together to regulate the primary valve.

Referring now to the drawing, a boiling water nuclear reactor **1** provides steam for turbine **2** directly through a primary steam line **3** and indirectly by way of secondary steam line **4** from steam generator **5** which is a heat exchanger taking heat from reactor coolant loop **6** and giving it up to the steam in secondary steam line **4**. A steam bypass line **7** connects primary steam line **3** directly to the shell side of condenser **8**, allowing steam to bypass the turbine and exhaust directly to the condenser in certain conditions of low turbine load or turbine overspeed. The primary steam line **3**, secondary steam line **4** and bypass steam line **7** are controlled by throttle valves **9**, **10** and **11** respectively, which are in turn actuated by servo motors **12**, **13** and **14** respectively. A centrifugal governor **15** is driven by and controls the speed of turbine **2**. A pressure sensitive governor or pressure regulator **16** is responsive to and controls the pressure of primary steam in line **3**.

Speed governor **15** acts to regulate the speed or load on the turbine by way of a control mechanism which includes an arm **20** which is pivotally connected at one end **21** to an arm **15***a* and at the other end **22** to the end of another arm **24**. Arm **15***a* is actuated by the speed governor **15** on one end and its fulcrum at the other end is adjusted by load reference selector **15***b*. At a point **23** intermediate its ends **21** and **22**, arm **20** is pivotally connected to the spindle of a speed control pilot valve **40** which is in turn directly connected to the input signal of secondary valve servomotor **13**.

Pressure sensitive governor or pressure regulator **16** acts to regulate the pressure of primary steam by way of a control mechanism, similar to that connected to the speed governor, which includes an arm **30** which is pivotally connected at one end **31** to the pressure regulator **16** and at the other end **32** to the end of another arm **34**. At a point **33** intermediate its ends **31** and **32**, arm **30** is pivotally connected to the spindle of a pressure control pilot valve **50** which is in turn directly connected to the input signal of bypass valve servomotor **14**.

Arms **24** and **34** are pivotally connected to fixed structures at points **25** and **35** intermediate their ends. End points **26** and **36** of arms **24** and **34** respectively are pivotally connected to the spindle of a single acting cylinder or primary relay **60** which is in turn directly connected to the input signal of primary valve servomotor **12**. Therefore arms **24** and **34** act as "restoring" linkages for pilot valves **40** and **50** respectively.

Primary relay **60** includes a piston **61** which is biased in one direction by a spring **62** and in the other by hydraulic pressure. Hydraulic pressure to primary relay **60** is supplied through the aforementioned pilot valves **40** and **50**, these being connected in series as follows. Speed control pilot valve **40** and pressure control pilot valve **50** each have three ports. Pressure port **51** of valve **50** is connected to a hydraulic pressure source (not shown). Exhaust port **52** is vented to an oil reservoir (not shown). Outlet port **53** is connected to pressure port **41** of speed control pilot valve **40**. Exhaust port **42** is vented to an oil reservoir (not shown). Outlet port **43** is connected to the hydraulic side of primary relay **60**.

Directly connected to the spindles **40***a* and **50***a* respectively of each pilot valve **40** and **50** and of the primary relay **60** are indicators which move with their respective spindles relative to stationary indicator scales which read

in terms of the degree of opening or closing of steam throttle valves **9**, **10** and **11**. For the purpose of understanding the invention, the secondary steam control valve **10** can be pictured as moving up and down with the pilot valve spindle **40***a*. Similarly the steam bypass valve **11** can be pictured as moving up and down with pilot valve spindle **50***a*. Therefore each pilot valve spindle performs a dual function of moving a steam valve directly and also controlling oil flow to the primary relay **60**.

The operation of the controlling servomechanism consisting of pilot valves **40**, **50**, primary relay **60** and associated linkages will first be described without reference to the power plant or the steam valves **10** and **11** which are additionally moved by direct action of the pilot valves. Input movements at points **21** or **31** will move pilot valve spindles **40***a*, **50***a* respectively. Since pilot valves **40**, **50** are connected in series to control oil to a common servomotor piston **61** of primary relay **60**, each pilot valve is capable of overriding the other one in a predetermined direction. The connections are such that the pilot valve demanding the lowest position of piston **61** will exercise control. The overridden pilot valve will have its spindle elevated above the controlling position by an amount proportional to the difference between the servomotor position called for by the overridden pilot valve and the servomotor position actually assumed due to the action of the other (overriding) pilot valve. Thus the overridden pilot valve, though inactive insofar as primary relay **60** is concerned, moves by an amount proportional to a deficiency or error in the servomechanism failing to satisfy two input signals at the same time. This error signal can therefore be utilized to control additional valves, i.e. steam valves **10** or **11**, to satisfy the conflicting requirements of two input signals to the same relay **60** controlling primary steam valve **9**.

The operation of the system will now be described. For a reference point, assume an initial or "normal" operating condition as shown in FIG. 1, wherein primary steam pressure is controlled by the pressure regulator positioning the primary valve **9**, and turbine load is maintained by primary steam alone, so that secondary steam throttle valve **10** is closed, bypass steam throttle valve **11** is closed, and primary steam throttle valve **9** is at a point between fully open and closed. Also, pilot valve spindle **50***a* is in a controlling position on port **53** and pilot valve spinde **40***a* is slightly above port **43**, permitting hydraulic fluid to communicate from pilot valve **50** to primary relay **60**.

Assume now that load on the turbine is increased. This is accomplished either by the operator's action in utilizing the load reference selector **15***b* to raise the fulcrum of lever **15***a* with the speed remaining fixed, or by the speed governor **15** raising the left-hand end of lever **15***a* due to a decrease of turbine speed.

It will be understood by those skilled in the art that when the turbine-generator is electrically interconnected with other turbine-generators in a large power system, as is the usual case, so that load is shared by many units, the speed governor **15** is actually sensing speed, i.e. electrical frequency of the total system. Small variations in speed, therefore, become a measure of the load which is added or shed by turbine **2**.

Increase in load, therefore, will cause point **21** on lever **20** to move upward. It will be understood that the foregoing description applicable to a system of interconnected turbine-generators would also be applicable if the unit shown were operating separately and that a decrease in speed, either because of added load or for some other reason, will also cause point **21** to move upward. This action raises spindle **40***a* of pilot valve **40** increasing the opening of port **43**. However, pilot valve **50** is responsive only to regulation by the pressure regulator **16** and since there has been no pressure regulator signal, pilot valve **50** does not move and port **53** remains closed. Therefore, although speed governor **15** wants to increase hydraulic pressure to primary relay **60** to signal servomotor **12** to

open primary valve **9**, the speed governor is overruled by the pressure regulator. The two must work in concert to open primary valve **9**. Neither the pressure regulator nor the speed governor can do it alone. However, to lower or close the primary valve **9**, either the pressure regulator or the speed governor, whichever requires a lower valve position, will override the other and is able to control it alone. The lifting of pilot valve **40** above the controlling position at port **43** indicates a failure of primary relay **60** to respond to the signal for a load increase. The distance which pilot valve **40** is lifted above the port position is a measure of the error between the load desired by the speed governor and the load carried by the primary valve. This error signal is used to position the secondary valve. When the pilot valve **40** rises more than a predetermined small amount above the port position, the input to servomotor **13** will cause the secondary valve **10** to start to open. In this manner, any portion of the load demand not satisfied by the primary valve will be supplied by the secondary valve. The speed governor **15** thus has unrestricted control of turbine power in response to load, regardless of the condition in the pressure control system. The governor will put steam into the turbine through the primary valve **9** preferentially, but if restricted by the pressure control system, it will automatically open the secondary valve **10** to get whatever power is required to carry whatever additional load is sensed.

Assume now, that the load is returned to "normal" by the removal of the added load. Governor **15** will pull lever **20** down and with it the spindle of valve **40** which, through its signal to servomotor **13** closes secondary valve **10**. The system is once again at the reference condition of FIG. 1.

Assume that the turbine load is further reduced either by lowering the load reference selector **15***b* or by governor **15** sensing an increase in speed. Governor **15** will lower pilot valve **40** until it reaches the controlling position at port **43**. Any further lowering of point **21** will cause the speed control pilot valve **40** to lower the primary relay piston **61**, by venting through port **42**, taking control away from the pressure control pilot valve. Lowering of piston **61** causes point **36** to lower and points **32** and **33** to rise. Point **31** remains fixed because it is positioned only by reactor pressure. When pilot valve **50** rises a small predetermined amount above the controlling position on port **53**, the servo motor **14** will begin to open the bypass valve **11**. Thus the lifting of pilot valve **50** above the port position, which occurs as a result of pilot valve **40** taking control of the primary relay **60**, becomes the error signal which opens the bypass valves. There has been no pressure disturbance and no repositioning of the pressure regulator **16** has been necessary. The lifting of point **33** by levers **30** and **34** has caused the bypass valves to open the amount necessary to maintain constant primary steam flow from the reactor even though the primary steam flow to the turbine has been reduced.

The pressure control system thus has unrestricted control of reactor steam pressure regardless of the condition in the speed control system. The pressure control system will put steam into the turbine through the primary valve **9** preferentially, but if the primary valve is restricted by the speed governor, the bypass valve **11** will be opened automatically by the amount necessary to maintain the desired reactor pressure.

Assume now that the load is increased back to the original level. Governor **15** pushes point **21** up. The piston **61** will rise under control of pilot valve **40** at port **43**. As piston **61** rises, opening the primary valve and increasing primary flow to the turbine, point **36** is raised and points **32** and **33** are lowered. The lowering of point **33** causes lowering of the servomotor **14** and closing of bypass valve **11**. In this manner, the bypass valve is closed by the same amount the primary valve is opened and the flow from the reactor remains constant. When point **33** is lowered to the point where pilot valve **50** is

in a controlling position at port **53**, the bypass valve will be fully closed. The governor **15** will not be able to open the primary valve further because there is no more primary steam available and pilot valve **50** has overridden pilot valve **40**. Any additional load demand from the governor will cause pilot valve **40** to be lifted above the controlling port **43** and the secondary valve will open to satisfy the load requirement.

In the manner which has been described the speed governor has unrestricted control of turbine load, within the limitations of the system capacity, by first opening the primary valve preferentially and then the secondary valve if opening of the primary valve is restricted by other means. The overlifting of pilot valve **40** beyond the controlling port **43** provides the error signal which positions the secondary valve automatically to the position necessary to satisfy the load requirements.

Similarly, the pressure regulator has unrestricted control of the reactor pressure by first opening the primary valve preferentially and then the bypass valve if opening of the primary valve is restricted by other means. The overlifting of pilot valve **50** beyond the controlling port **53** provides the error signal which positions the bypass valve automatically to the position required by the regulator to maintain the desired reactor pressure.

In a modified form of this invention, where there is no secondary steam system, the speed governor **15** will function as described above, except that valve **10** and servo **13** would be eliminated, i.e. the spindle of speed control pilot valve **40** would not be connected to anything other than arm **20**. In this modification, speed governor **15** functions only to oversee primary valve **9** in conjunction with the pressure control system. The pressure regulator would function as described, controlling reactor pressure by opening the primary valve preferentially, and the bypass valve if opening of the primary valve were restricted.

It is apparent that the compound control system of this invention is suited for use with power sources and powerplants other than the illustrated dual cycle boiling water reactor plant.

The specific embodiment described herein is presented as an example and it will occur to persons of ordinary skill in the art to make modifications within the inventive concept herein disclosed. Accordingly, it is intended that the invention be not limited by the details in which it has been described, but that it encompass all within the purview of the following claims:

What is claimed is:

1. A control system for a turbine supplied with motive fluid from a pressure source comprising:

(a) a primary valve connected to control flow of motive fluid from said pressure source to said turbine,

(b) an additional valve connected to control motive fluid from said source so as to adjust any unbalance between motive fluid flow generated by the pressure source at a given pressure and motive fluid flow required by the turbine at a given load,

(c) first means responsive to motive fluid pressure including a first pilot valve controlled thereby,

(d) second means responsive to the speed of said turbine including a second pilot valve controlled thereby,

(e) a primary servomotor controlled jointly by said first and second pilot valves and arranged to move said primary valve toward a more open position upon increase in motive fluid pressure or decrease in turbine speed respectively, said pilot valves being connected so that the pilot valve requesting the lowest primary valve position overrides the other pilot valve to exercise sole control over the primary servomotor while the overridden pilot valve moves in an unrestricted manner, whereby the motion of the overridden pilot valve indicates the potential unbalance in motive fluid flow between pressure source and turbine, and

(f) an additional servomotor connected to actuate said additional valve to correct said unbalance in response to movements of the overridden pilot valve.

2. The combination according to claim **1** where said additional valve is a valve causing motive fluid to bypass the turbine and where said additional servomotor is connected to be actuated by the first pilot valve.

3. The combination according to claim **1** where said additional valve controls a supplementary source of motive fluid from the pressure source to the turbine and where said additional servomotor is connected to be actuated by the second pilot valve.

4. A control system for a turbine comprising:

(a) a primary valve controlling the flow of primary motive fluid from a pressure source to said turbine,

(b) a secondary valve controlling the flow of secondary motive fluid from said pressure source to said turbine,

(c) a bypass valve controlling the flow of motive fluid in a line from said pressure source bypassing said turbine,

(d) first means responsive to motive fluid pressure including a first pilot valve controlled thereby,

(e) second means responsive to the speed of said turbine including a second pilot valve controlled thereby,

(f) a fluid motor operatively connected to said primary valve and controlled jointly by said first and second pilot valves and arranged to move said primary valve toward a more open position upon increase in motive fluid pressure or decrease in turbine speed respectively, said pilot valves being connected in series so that the pilot valve requiring the lowermost primary valve position overrides the other pilot valve to exercise sole control over the fluid motor while the overridden pilot valve moves in an unrestricted manner, whereby the motion of the overridden pilot valve indicates the potential unbalance in motive fluid flow between the pressure source and turbine,

(g) said first pilot valve being further operatively connected to said bypass valve, the movement of said first pilot valve controlling the degree of opening of said bypass valve, and

(h) said second pilot valve being further operatively-connected to said secondary valve, the movement of said second pilot valve controlling the degree of opening of said secondary valve.

5. A control system for a turbine comprising:

(a) a primary valve controlling the flow of primary motive fluid from a primary pressure source to said turbine,

(b) a secondary valve controlling the flow of secondary motive fluid from a secondary pressure source to said turbine,

(c) a bypass valve controlling the flow of motive fluid in a line from said primary pressure source bypassing said turbine,

(d) means responsive to the pressure of said motive fluid controlling said bypass valve,

(e) a first pilot valve controlled by said pressure responsive means,

(f) means responsive to the speed of said turbine controlling said secondary valve,

(g) a second pilot valve controlled by said responsive means,

(h) means to open said primary valve comprising a single-acting fluid cylinder operatively connected thereto, the power stroke of said cylinder causing opening of said primary valve,

(i) said first and second pilot valves connected in series, said second pilot valve controlling fluid flow to said fluid cylinder, said first pilot valve controlling fluid flow to said second pilot valve,

(j) said first pilot valve being further operatively con-

nected to said bypass valve, the movement of said first pilot valve controlling the degree of opening of said bypass valve, and

(k) said second pilot valve being further operatively connected to said secondary valve, the movement of said second pilot valve controlling the degree of opening of said secondary valve.

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