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(54) CONTROL SYSTEM FOR VARIABLE-PITCH AXIAL FAN FOR UTILITY BOILER

(71) We, WESTINGHOUSE ELECTRIC CORPORATION, of Westinghouse Building, Gateway Center, Pittsburgh, Pennsylvania, United States of America, a company organised and existing under the laws of the Commonwealth of Pennsylvania, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention generally relates to a control system for an axial-flow fan, and more particularly to a control system for such a fan used with the air flow system of a boiler.

Fans for supplying air for combustion to boilers and for aiding in the removal of combustion-gases are typically provided with a margin of safety which will permit continued operation under adverse conditions which may occur and which may require a greater draft than normally required for the boiler. Thus, the so-called test-block specifications are established which result, in effect, in the selected fans being somewhat oversized in capacity, such as 15 to 20% for example, with respect to normally expected operating conditions. However, during swing load operating periods the boiler may be operating well below its rated capacity.

Thus, in making a selection between an inlet vane controlled centrifugal fan and a variable-pitch axial-flow fan, one factor which is given consideration is the static efficiency of the fans under various operating conditions below rated capacity as well as at rated capacity. While variable-pitch axial-flow fans may have a lower static efficiency than equivalent centrifugal fans at test-block conditions, at a condition of normal 100% boiler load the efficiency differential is reversed. Further, as the boiler load drops progressively below 100%, the efficiency advantage of the axial fan increases progresssively. For at least this reason, a variable-pitch axial-flow fan is considered to be more desirable than an equivalent centrifugal fan in some applications.

However, axial flow fans are more subject to the stall phenomenon resulting from a condition in which the blade attack angle is too steep relative to the mass air flow (and hence velocity). Under the stall condition a static pressure-rise across the fan is excessive for the flow rate, and potential damage from the vibrations associated with a continued stall condition can occur. Therefore it is apparent that prevention of a stall condition of variable-pitch axial fans in the utility boiler draft applications is desirable.

This well known problem of stall in connection with axial-flow fans has been dealt with several ways. One known way of preventing stall in connection with an axial-flow turbo compressor having adjustable inlet guide vanes and adjustable stator vanes and used in blast furnace service is to use a blow-off or relieve valve between the compressor and the blast furnace to vent the discharge pressure to open atmosphere when the pressure is excessive relative to the flow. However, it is considered undesirable in a boiler application to have a relief to the atmosphere since on the forced draft side of the boiler furnace this will create other repercussions, as in fuel-air ratios for example, and on the induced draft side of a boiler furnace it would be combustion gases being blown off before their treatment in the passage to the stack.

In an arrangement for an air conditioning and ventilating system for a building as disclosed in U.S. Reissue Patent 28,946, provision is made for sensing flow rate and static duct pressure in the duct downstream from a fan, which may be a variable pitch axial fan. The arrangement is intended to maintain a flow rate that is correlated with the static pressure to maintain efficient operation without a surging condition. In the system, the temperature changes in the spaces being served control inlet dampers to the served spaces. Accordingly, the system resistance changes in accordance with temperature demands. As the system resistance is increased due to the dampers closing, the flow

will be reduced of course while the discharge static pressure increases. This results in the pitch of the fan blades being changed to give a discharge static pressure that is less than at the first reduced flow, which of course results in a further reduced flow. If that is satisfactory for the requirements, then the system will continue at that same condition. However, if that further reduced air flow is inadequate then the temperature change requirements result in a reduced system resistance; the static pressure will then drop and the flow will increase. Thus, with that control arrangement the temperature changes control the system resistance to which the flow responds automatically in a direction to satisfy the temperature control-needs. In the system the duct pressure is continually being used for readjusting the position of louvers or the pitch of the axial fan blades.

In the described embodiment of the present invention, the blade pitch changes advantageously follow the demand of air for the given boiler load and the static pressure-rise changes across the fan with the different air flow changes is of no consequence and does not influence the control unless and until a stall condition is approached. Then and only then will the relation of the static pressure-rise across the fan to air flow volume become a factor in the control and the normal boiler load control of the blade pitch be overridden and blocked by the stall prevention control.

The invention in its broad form resides in a control system for an axial-flow fan having variable-pitch blades disposed in use in an air flow system connected to the combustion chamber of a boiler, the system comprising: means which vary the pitch of said blades; means which detect a pressure rise across said fan and for generating a signal in accordance with said pressure-rise; means which detect the air flow rate in said air flow system and generate a signal in accordance therewith; mixing means which mix said pressure-rise signal and said air flow rate signal to produce an output signal; means which feeds signals to cause blade-pitch-increase or decrease to said blade-pitch varying means in normal operation to vary the air flow rate, irrespective of changes in static pressure rise, but in accordance with boiler load changes; means for giving an alarm in response to said output signals from said mixing means indicating pressure-rises exceeding given levels for corresponding flow rates to warn about a predetermined stage of the axial-flow fan before complete stall, and control means for blocking said blade-pitch increase-signal and substituting a blade-pitch decrease signal in response to said output signals indicating a predetermined stage before a stall condition and for reducing the pitch of said blades to a position in which the pressure-rise and flow rate are reduced to a safe level with respect to a stall condition.

The invention will now be further explained by way of example, referring to a preferred embodiment, to be understood in conjunction with the accompanying drawing in which:

Figure 1 is a simplified schematic of the air flow system for a boiler;

Figure 2 is a fragmentary view partly in section and partly schematic illustrating the arrangement for controlling the pitch of a single-stage forced-draft fan;

Figure 3 is a graph illustrating the stall characteristics of a typical variable-pitch axial fan at various blade pitch settings, and with a typical system characteristic curve also shown; and

Figure 4 is a circuit diagram, in block form in part, of the control system arrangement for controlling the induced-draft fan part of the arrangement of Figure 1.

The simplified system shown in Figure 1 includes the boiler furnace 10 with a single-stage forced-draft axial fan generally designated 12 furnishing combustion air to the furnace, and a two-stage induced-draft axial fan 14 for passing the products of combustion from the furnace through dust collectors to the stack. The fan wheel 16 of the forced-draft fan is driven by motor 18 through shaft 20 while the two wheels 22 of the induced-draft fan are driven by motor 24 through shaft 26. The blade pitch of the fan wheels is controlled in accordance with operating conditions of the system and in particular in accordance with the boiler load to provide the proper fuel-air ratio. Control of the blade pitch is by a hydraulic system with the flow of the hydraulic fluid being controlled by the solenoid valve 28 for the forced-draft fan, and valve 30 for the induced-draft fan.

The sensing devices for indicating the operating conditions of the air flow system are schematically indicated in Figure 1, those elements carrying the legend F sensing air flow volume, those with the legend P sensing static pressure and that with the legend T sensing the air flow temperature. Only the induced-draft fan is provided with the temperature sensing means since the range in temperatures of the air passing through that fan will be significantly greater than that passing through the forced-draft fan.

Referring to Figure 2, a typical system for varying and controlling the pitch of the blades of the forced-draft fan wheel 16 is illustrated. A series of blades 32 around the circumference of the hub 34 is rotatably secured to the hub through rotatable blade shafts 36 which have lever arms 38 secured to their radially inner ends. One end of the lever arm is captured at the periphery of an operating disc 40 so that as the operating disc 40 is

displaced to either the left or the right as seen in Figure 2, the lever arm 38 will effect rotation in one direction or another of the blade shaft and hence the blade. A hydraulic actuator mechanism is provided to effect the displacement of the operating disc. The operating disc 40 is secured to the movable hydraulic cylinder 42 provided with an internal piston 44 which is fixed on the shaft 46. In accordance with operation of a multiposition solenoid valve 28, hydraulic fluid is passed through one of the stationary hydraulic lines 50 and withdrawn from the other of the lines which are connected through a rotating union 52 with internal, axially extending passages 54 in the shaft 46. Thus, fluid is forced into the space on one side of the piston 44 and withdrawn from the space on the other side of the piston 44 to effect the movement of the cylinder 42 in one direction or the other. As the cylinder 42 moves in one direction or the other the operating disc 42 moves accordingly and this effects the rotation of the blades through pivoting of the lever arm and blade shafts. While not illustrated since forming no part of this invention, it will be appreciated the hydraulic system includes check valves, pumps, reservoir and other elements conventional in a hydraulic actuating system so that the blades may be held at one pitch, or moved in either direction. The hydraulic system for varying the pitch of the two fan wheels of the induced-draft fan 14 is similar in principle.

The graph of Figure 3 illustrates values of static pressure-rise across an axial fan corresponding to flow with a typical system resistance curve 56, and the blade-pitch at various settings. The stall line 58 indicates for various pitch settings the static pressures corresponding to flow values which will result in stall. As an example, with a pitch setting at 49° and the system resistance being normal, the static pressure-rise and flow will correspond to that indicated at point 1. Now if there is some untoward occurrence in the system which results in a blockage of air flow, the system resistance changes in an increasing direction and its curve 56 will pivot upwardly from point 1 and to the left as seen in Figure 3. If the change is sufficient, and the pitch setting remains at 49°, the point 2 will be reached and the fan will go into a stall condition. If that stall condition is reached, then even if the system resistance is reduced, the fan will continue to operate in a stall condition, following along the dash line 60 or along one of the similarly sloped dash lines if the pitch setting were other than 49°.

Since the complete shutdown of a boiler owing to a problem with the air system is to be avoided if at all possible, a control system to prevent a stall shutdown is provided. This system contemplates that a stall alarm will occur if the relation of static pressure to flow for a given pitch setting reaches the alarm line 62, and that if remedial action is not taken and the fan more closely tends to stall by reaching line 64, an automatically actuated program takes over to reduce the pitch setting to take the fan farther from the stall condition.

The fan control system for controlling the induced fan 14 is functionally illustrated in Figure 4 and is the same as that for the forced-draft fan 12, except that the temperature sensing and input therefrom may be omitted if desired from the forced-draft fan control system.

For normal operation, the control over blade-pitch through the solenoid valve 30 is sensed from the combustion control 66 in accordance with boiler load demands to AND gate 68 to decrease pitch, and to AND gate 70 to increase pitch. When the fan is operating in a supposedly normal operation in which the tendency to stall is not a problem, there is no signal generated from the stall-computer 72 which will interfere with the normal operation increase and decrease-signals from the combustion control. In normal operation, the lack of signal from the stall computer to the set-reset flip-flop 74 whose output is coupled through inverter 76 to an input to the increase-AND gate 70, will permit either an increase or decrease-signal to the solenoid valve from the combustion control.

Now let it be assumed that an abnormal blockage to air flow occurs and that the static pressure-rise across the fan sensed and signalled from the pressure-difference computer 78 to the stall-computer 72 has risen to a level above the alarm line 62 (Figure 3), but below the stall shutdown line 64, for the volume of air flow signal put out from the flow-computer 80 and as modified by the temperature-curve shifter 82 receiving a temperature indicating signal from the temperature amplifier 84. This will result in the stall-computer putting out a signal of a level which actuates the alarm indicator 86 at a control station and thereby warns that there is a problem in the air system and corrective action should be taken, such as reducing the blade pitch through manual control and also the boiler fuel rate to correspond, so that boiler operation continues at a reduced load while the source of the problem is sought.

However, assume that for some reason the operator fails to take the corrective action necessitated by the alarm, and the static pressure-rise continues accompanied by a reduction in flow to a point on the stall shutdown line 64. Then, the stall-computer puts out a different level signal to the set input of the bistable flip-flop 74, to the inverter 88 and to one input of the OR gate 90 in the

decrease line to the solenoid valve 30. The output signal from the flip-flop 74 through inverter 76 results in blocking the increase-AND gate 70 from passing an increase-signal to the solenoid valve, while the OR gate 90 passes the decrease-signal to the solenoid valve. The flip-flop output signal is also transmitted to an indicating device 92 to inform the operator that the automatic stall prevention system has control of the system. As such, even after the blade-pitch has been decreased to a degree that the signal from the stall-computer 72 is removed, neither the automatic-combustion control 66 nor a manual operation can result in an increase-signal to the solenoid valve because of the flip-flop 74 being in a set condition. This flip-flop functions as an anti-hunt bistable memory device which will maintain the blocking signal to the increase-AND gate 70 until the operator resets the flip-flop with a signal to the AND gate 94 to reset the flip-flop. Since the flip-flop does not prevent a decrease-signal, the boiler controls can continue to protect the boiler, i.e. run back the load further via the forced-draft fan, or preventing a furnace implosion by running back the induced-draft fan.

As may be seen in Figure 3, basically as the flow volume increases, so does the allowable static pressure-rise across the fan. The flow-computer 80 converts the percentage flow to the non-linear curve required and the output from the computer represents the maximum allowable inlet to outlet pressure set point, as modified by the temperature curve shifter 82, which will in effect lower the curves as the temperature rises.

The stall-computer subtracts "pressure out" from "pressure in" as computed by the pressure-difference computer and compares it against the maximum allowable outlet to inlet pressure set point. A pressure-rise greater than the maximum allowable pressure-rise as a function of flow results in a decreasing-signal from the stall-computer. The stall alarm warns of an impending stall, with the second-level stall fan shutdown operating the anti-hunt memory device and actuating previously described corrective action taken at the time there is tendency to stall.

WHAT WE CLAIM IS:—

1. A control system for an axial-flow fan having variable-pitch blades disposed in use in an air flow system connected to the combustion chamber of a boiler, the the system comprising:

means which vary the pitch of said blades;

means which detect a pressure-rise across said fan and for generating a signal in accordance with said pressure-rise;

means which detect the air flow rate in said air flow system and generate a signal in accordance therewith;

mixing means which mix said pressure-rise signal and said air flow rate signal to produce an output signal;

means which feeds signals to cause blade-pitch-increase or decrease to said blade-pitch varying means in normal operation to vary the air flow rate, irrespective of changes in static pressure rise, but in accordance with boiler load changes;

means for giving an alarm in response to said output signals from said mixing means indicating pressure-rises exceeding given levels for corresponding flow rates to warn about a predetermined stage of the axial-flow fan before complete stall, and control means for blocking said blade-pitch increase-signal and substituting a blade-pitch decrease-signal in response to said output signals indicating a predetermined stage before a stall condition and for reducing the pitch of said blades to a position in which the pressure-rise and flow rate are reduced to a safe level with respect to a stall condition.

2. A control system according to claim 1 including:

means responsive to said predetermined stage to indicate to the user that normal operational control is disabled.

3. A control system according to claim 1 or 2 including:

bistable means responsive to said predetermined stage to prevent the user from feeding a blade-pitch-increase signal to said pitch varying means until said bistable means is reset to a normal operating position.

4. A control system as in claim 1 wherein said control means comprises overriding means to override said pitch varying means to prevent further increase of blade pitch when a detected pressure-rise increases just above said predetermined stage;

an indicating means responsive to said overriding means to indicate that the pitch-varying means is being overridden;

additional means to maintain the overridden condition after it is attained, even after a detected pressure-rise drops below said predetermined stage; and

resetting means which may be reset by an operator for deactivating said additional means when the pitch varying means can resume its operation of varying the blade-pitch.

5. A control system for a variable-pitch axial-flow fan in an air flow system for a boiler, substantially as described hereinbefore with respect to and as illustrated in the accompanying drawing.

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1597172 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

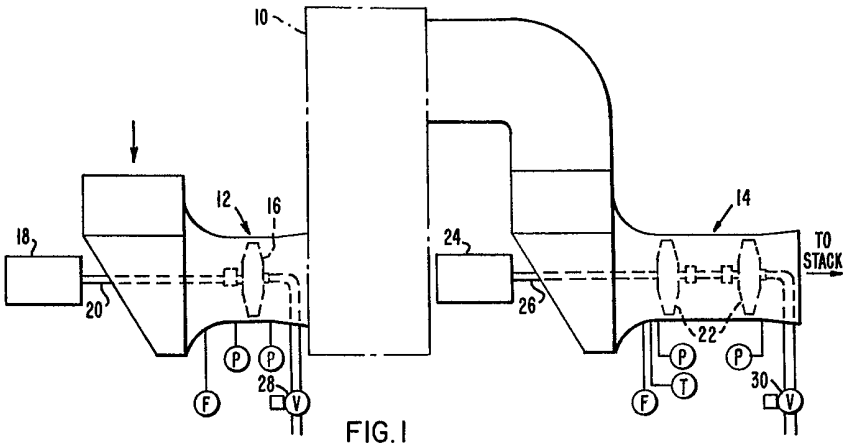


FIG. 1

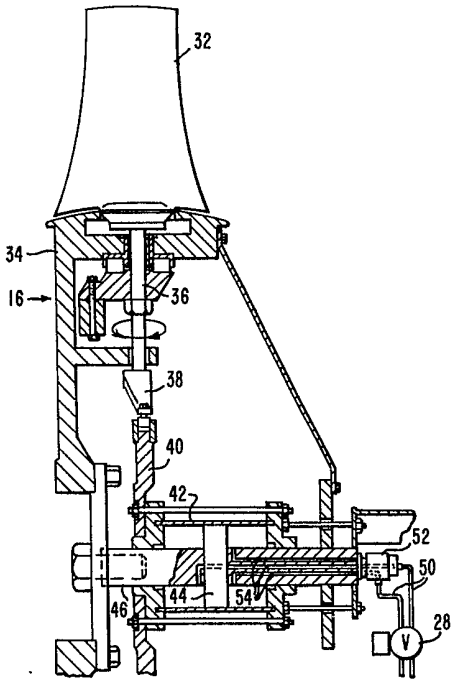


FIG. 2

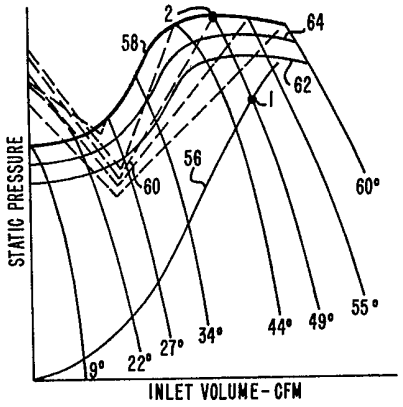
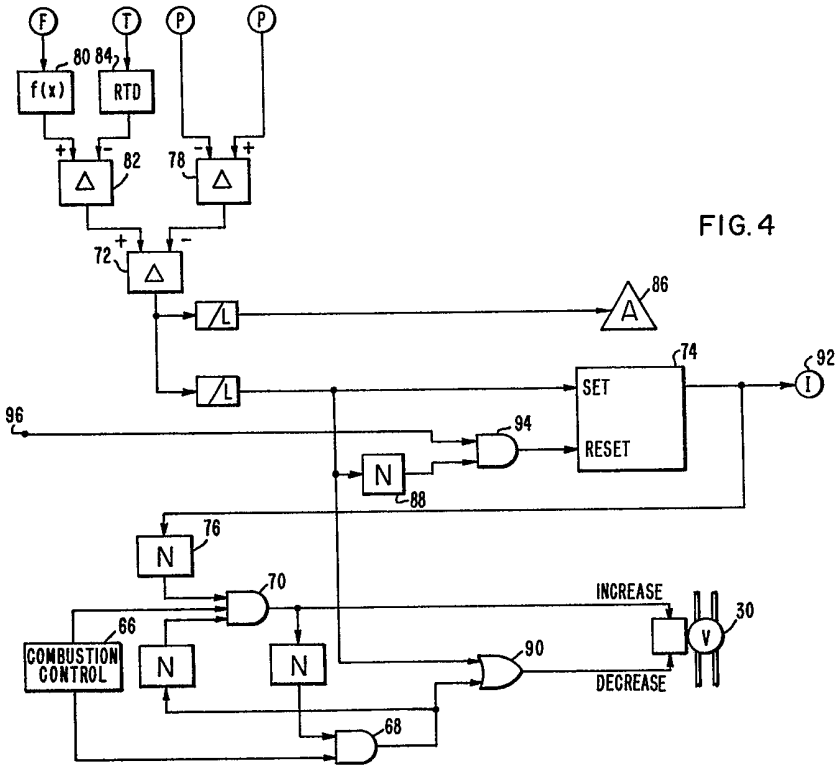

STATIC PRESSURE
INLET VOLUME - CFM
2
64
58
62
1
56
60
60°
55°
49°
44°
34°
27°
22°
9°

FIG. 3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P
80
84
f(x)
RTD
82
78
72
/L
/L
86
A
74
92
I
SET
RESET
96
94
N
88
76
N
70
INCREASE
66
COMBUSTION CONTROL
N
N
90
30
V
DECREASE
68

FIG. 4