Dec. 2, 1969 C. E. DINES 3,481,538

BOILER CONTROL APPARATUS

Filed May 2, 1968 2 Sheets-Sheet 1

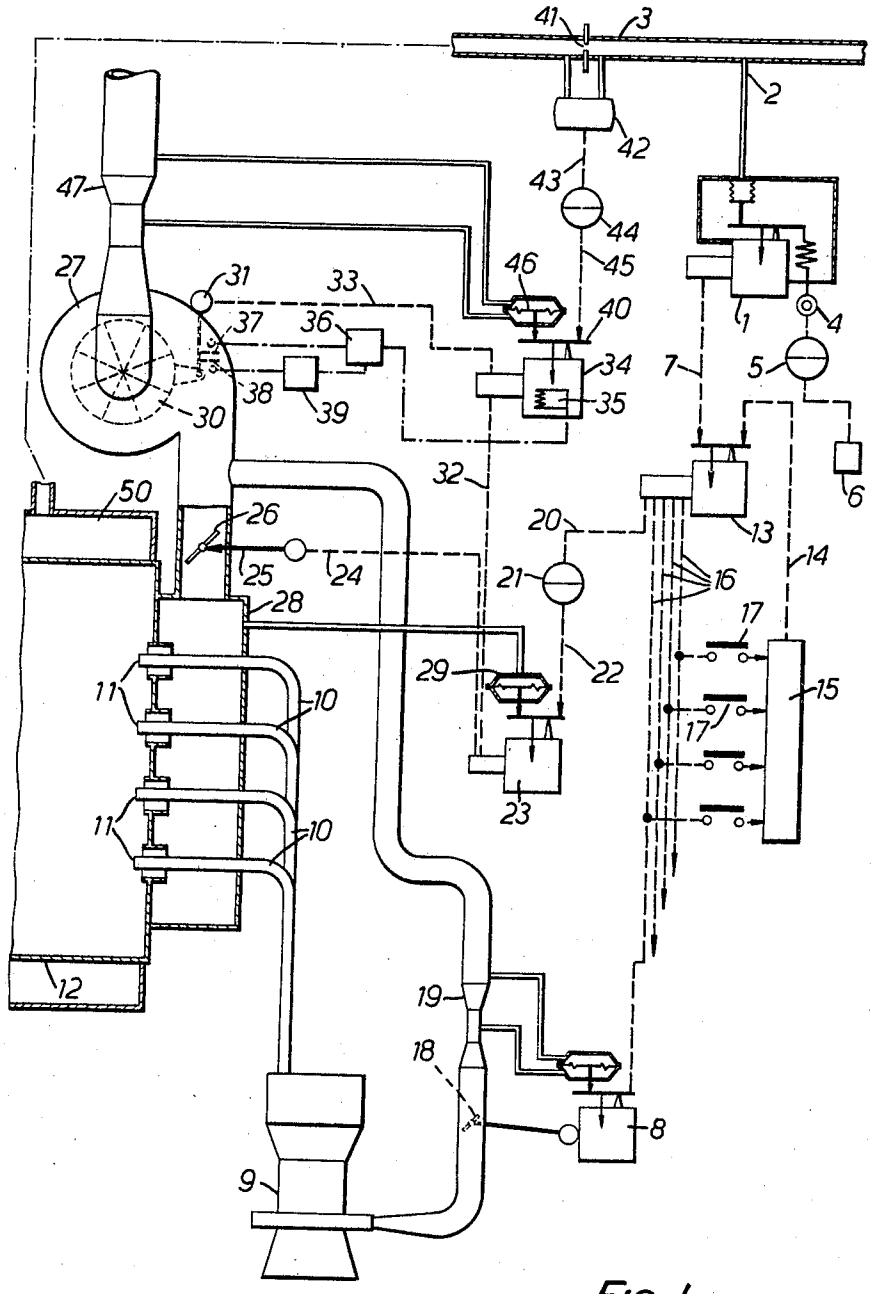


FIG. 1.

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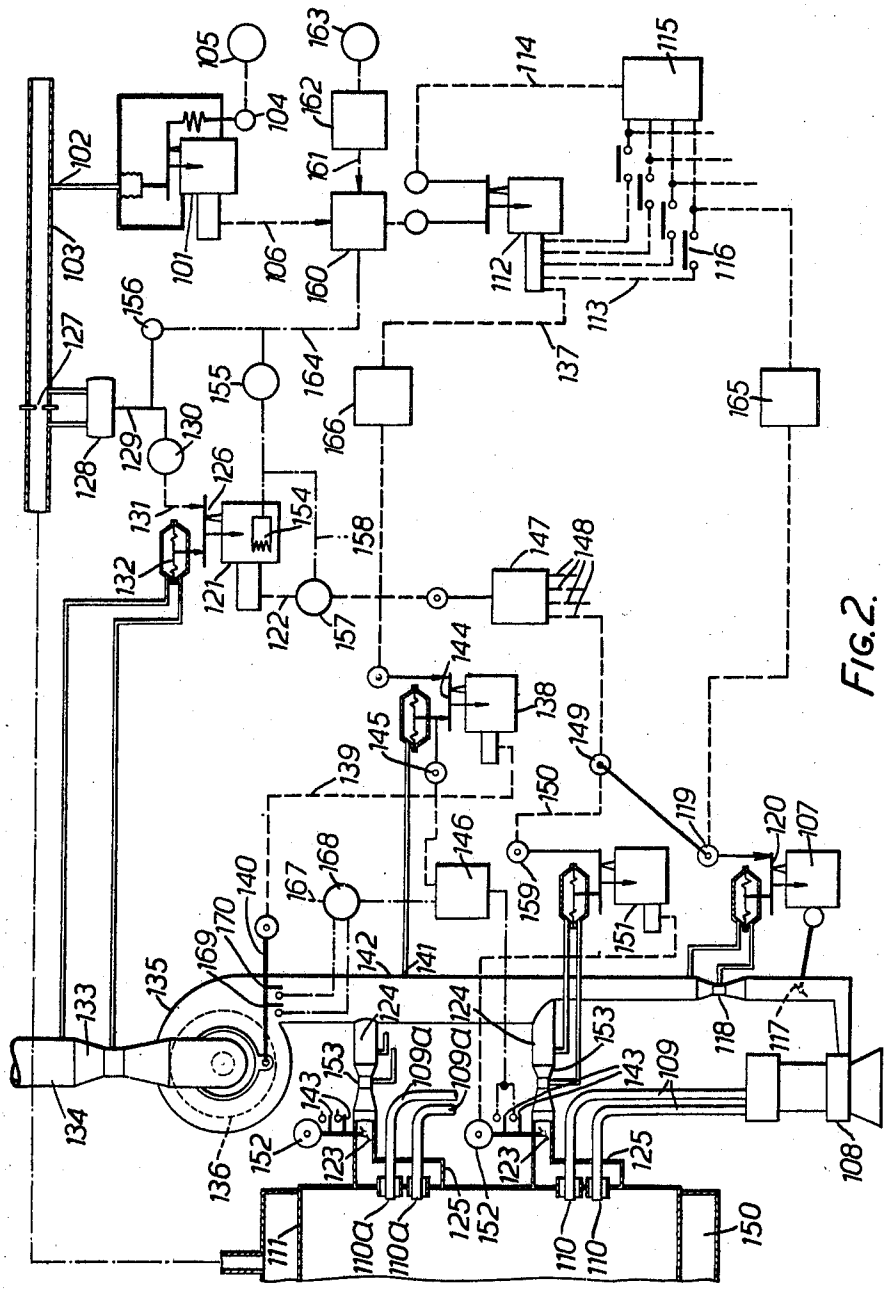


FIG. 2.

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BOILER CONTROL APPARATUS

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U.S. Cl. 236—24.5 15 Claims

ABSTRACT OF THE DISCLOSURE

Control apparatus for a boiler has first control means for controlling the air flow to the combustion chamber of the boiler during start-up and low level boiler operation by moving air constrictor means in dependence on the ratio of a fuel demand signal, and air flow rate, and second control means for controlling the air flow during on-load operation by moving the air flow constrictor means in dependence on the rate of steam output flow-rate of the boiler and air flow rate, the second control means being inoperative to control the flow constrictor in dependence on said steam/air rates until a predetermined level of boiler operation is reached.

Summary of invention

The control apparatus of the invention is for use in a boiler plant, in particular using pulverised fuel, in which combustion air is supplied to the combustion chamber of the boiler through an air duct containing a forced draught fan and flow constrictor means in the form of movable inlet guide vanes of the fan, and a movable damper downstream of the guide vanes. Under start-up and low level boiler operation, the guide vanes are largely closed so that the damper operates on a relative low air flow.

The control apparatus includes a fuel demand signal generator, in particular controlled by the pressure in a steam output pipe, and a fuel control device responsive to the fuel demand signal. The constrictor means is controlled to maintain a balance between combustion air flow rate and a fuel demand signal.

A second air control assembly is operable to move the flow constrictor means to maintain a balance between combustion air flow rate and steam flow rate. A selector which is responsive to the transition from low-level to on-load boiler operation, operates to render the flow constrictor means responsive to the steam/air rates via the second air control assembly.

The combustion air duct can be branched downstream of the fan to form a number of windboxes each having its own damper and fuel supply.

In particular the fuel supply or each fuel supply is a fuel-pulverising mill supplied with an air flow for carrying pulverised fuel into the combustion chamber.

Description of drawing

Two forms of control apparatus according to the invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings in which:

FIGURE 1 shows combustion start-up and on-load control apparatus for a pulverised fuel boiler plant having a windbox common to all burners of the plant and

FIGURE 2 shows combustion start-up and on-load control apparatus for a pulverised fuel boiler plant having a number of mills each associated with a group of burners and a separate windbox.

Description of preferred embodiment

It will be appreciated that the drawings show, and following descriptions refer to, simplified plant and that in actual plant the auxiliaries may for example include at least two forced draught fans, two or more primary air systems and six or eight mills. It will also be appreciated that the control apparatus for the actual plant would be similar to that described with reference to the simplified plant.

The construction of boiler plant incorporating primary and secondary air flow systems in which the primary air flow controls the fuel output from mills to combustion chambers is well known to those skilled in the art and is therefore not described in detail in this specification.

Individual components, for example, the various regulators, repeaters and summator, of the preferred embodiment will not be described in detail in cases where they are of types well known to those skilled in the art or are of such a nature that their construction is readily apparent to those skilled in the art.

In FIGURE 1 a master regulator **1** is arranged to measure the steam pressure at a point **2** in the steam main **3** from a boiler **50**. A desired steam pressure setting of the regulator **1** is adjusted by a servomotor **4** either manually from a set point station **5** or automatically according to a preset pressure raising routine from a timed programmer **6**. Deviation of the measured steam, pressure from the desired steam pressure causes the regulator **1** to produce an electrical output signal **7** to take corrective action upon a fuel throughput regulator **8** for a fuel mill **9** which via fuel pipes **10** delivers pulverised fuel to burners **11** in a combustion chamber **12**.

The output signal **7**, which represents total fuel demand, is applied to a signal repeater **13**, including a regulator which is connected by a separate output line to each mill. The repeater, in response to the signal **7**, sends a separate equal electrical signal **16** to each mill **9** (one only being shown) which is in operation. By means of an electrical feedback signal **14**, from a summator **15** connected to each repeater line and thus responsive to all the signals **16**, the repeater **13** maintains the sum effect of the signals **16** in balance with the output signal **7**. The feedback signal **14** represents the total value of those signals **16** which are communicated to the summator **15** by electrical closure of electrical switches connecting the repeater output lines to the summator **17**. The switches **17** are relay operated by auxiliary contacts in switchgear (not shown) that controls the running of the mills, each switch **17** being associated with a different mill **9**, and controlled by adjustable time delay relays so that they are closed only when the respective mill is capable of delivering pulverised fuel substantially in accordance with primary air flow demand. The fuel throughput metering system is thus not falsified by mill and fuel pipe purging routines. The feedback signal **14** ensures that the individual signals **16** are each equivalent in terms of fuel throughput to the output signal **7** divided by the number of mills **9** in operation and that the signals **16** become readjusted automatically as mills **9** are brought into or taken out of service.

The regulator **8** adjusts a primary air flow control damper **18** to produce a balance between the differential pressure of primary air flow measured by a venturi measuring device **19** and the associated signal **16**.

In a start-up mode of operation of the plant, the ratio of combustion air flow to fuel flow is controlled by an electrical signal **20** generated by the signal repeater **13** in parallel with the signals **16** and having a fixed relationship to fuel throughput per mill **9** and therefore to the magnitude of the signals **16**.

A panel-mounted station **21** provides bias of this signal **20** for adjusting the fuel/air ratio to suit variations occurring in the quality of the plant fuel supply. The resulting signal **22** forms a set point for a first air control means in the form of a windbox pressure regulator **23** which generates a control signal **24** to adjust, by way of a servomotor **25**, a low load secondary-air-flow control damper **26**, located in series with a forced draught fan **27**, so that pressure in the burner windbox **28**, as sensed and transduced by the measuring diaphragm **29**, is maintained in balance with the signal **22**.

In order to facilitate adjustment of the combustion air to low flow rates (compared to on-load flow rates) by the damper **26**, the fan inlet guide vanes **30**, which are used to control total air quantities in the normal on-load range, must be positioned for minimal air delivery. The vanes **30** are closed and held closed by a servomotor **31** under the control of the regulator **23** by way of electrical signals **32** and **33** until the throughput rate demanded by the signal **22** increases to result in the damper **26** opening to the limit for effective control. At this point the regulator **23** is arranged to take action on signal **32** so that the demanded windbox pressure is achieved substantially by adjustment of the vanes **30**.

As the boiler throughput is increased and enters the normal operating range, in which combustion can be controlled by means of total combustion air and steam flow measuring loops employing inferential measuring methods, a second air control means in the form of a steam flow air flow ratio regulator **34** is released from a null state by a selector means, in the form of a solenoid device **35**, operated from a switching relay **36**, which is unlatched by a limit switch **37**, at a given position of the vanes **30**. Control of the vanes **30** is returned to the regulator **23**, only when the boiler load is reduced to a level at which a further limit switch **38** is closed and is held closed for an interval, as set by a time delay relay **39**, long enough to cause the relay **36** to become energized thereby to operate the solenoid device **35** to return the ratio regulator **34** to the null state.

When released, the ratio regulator **34** is arranged to add to or substract from the signal **32**, produced by the regulator **23**, as required to control the air flow rate by means of the vanes **30** to achieve a balance of the ratio regulator's measuring element **40**. The element **40** is arranged to compare total combustion air flow with total steam flow measurement. The steam flow is inferred from a differential pressure produced by a restriction **41**, in the steam main **3**, in conjunction with a transmitting device **42** which gives an electrical output signal **43** representing steam flow rate. Bias of the output signal **43** is afforded by a manually operated control station **44** thereby to vary the ratio between steam flow and total combustion air flow to obtain a desired excess air margin to operating requirements. The output signal **45** from the control panel station **44** adjusts the set point of the measuring element **40** of the regulator **34** against which acts differential pressure, representing total combustion air flow rate, produced by a venturi contraction **47** formed in the forced draught fan ducting on the suction side of the fan **27** and transduced by a measuring diaphragm **46**.

In the embodiment of FIGURE 2, a master regulator **101** measures the working pressure at point **102** in a steam main **103** from a steam generator **150**. Deviation from the desired value of steam pressure, as adjusted by a servomotor **104** from a manually operated set point station **105**, produces an electrical output signal **106**, to take corrective action upon fuel throughput regulator **107**, thereby to appropriately adjust throughput of a mill **108** which, via fuel pipes **109**, delivers pulverised fuel to burners **110** in combustion chamber **111**. Fuel pipes **109***a* and burners **110***a* are associated with another mill (not shown) which is also controlled by a fuel throughput regulator (not shown) in response to the output signal **106**.

The signal **106**, representing total fuel demand is applied to a signal repeater **112**, which generates a separate electrical signal **113** for each mill (one only being shown) and which by means of a feed back signal **114**, from a summator **115**, representing the total value of as many of the several signals **113** as are made active by closure of electrical switches **116**, causes the signal repeater **112** to maintain the combined throughput of the active mills in balance with the demand signal **106**.

The switches **116** are relay operated from auxiliary contacts on the switchgear that controls the running of the mills raw coal feeders with suitable time delay so that they are closed only when the respective mill is capable of delivering pulverised fuel substantially in accordance with the fuel demand signal (signal **113**).

Each fuel regulator **107** adjusts the primary air flow control damper **117** so that a differential head is produced by a venturi metering device **118** of a magnitude to achieve a balance with the associated demand signal **113**. The demand signal is transduced by servomotor **119** into a force on a weighbeam **120** which forms part of each said fuel regulator **107**.

In the normal on-load operating range of the boiler, combustion is optimised by means of control by a second air control means in the form of a steam/air ratio regulator **121** which generates an electrical output signal **122** to control, via a transmission and distributional system, dampers **123** which regulate a supply of secondary air in ducts **124**, to windboxes **125** (two only being shown) to achieve balance of its measuring element **126**, which compares total air flow rate with total steam flow rate. Steam flow is inferred from the differential head produced by a restriction **127** in steam main **103**, in conjunction with a transmitting device **128** which gives an output signal **129** in known relationship to flow rate. Proportional bias of this signal is afforded by a manually operated station **130**, so that the ratio to be observed between steam/air flow can be varied to obtain a desired excess air margin. The output signal **131** of the station **130** forms the set point of the regulator **121**, and is balanced by the differential head produced by a venturi contraction **133**, formed in inlet ducting **134** to a forced draught fan **135**, by way of differential pressure transducer **132**.

The power control means of the forced draught fan **135**, in the form of inlet guide vanes **136**, is modulated to maintain sufficiency of delivery pressure for a given mill throughput by a demand signal **137**, which is generated by the signal repeater **112**, in parallel with and as the square of the fuel signals **113**, to form a set point of a first control means in the form of a forced draught pressure regulator **138**. This regulator generates a signal **139** to control, by means of a servomotor **140**, the position of the inlet guide vanes **136**, to maintain pressure at a point **141**, in the hot air main **142**, in balance with the demand signal **137**.

The relationship between the demand signal **137**, and the measured pressure value at point **141**, is modified by reset action initiated from limit switches **143** set on the operating motion of each of the dampers **123**, to observe the desired maximum and minimum states and a given margin of damper travel to afford switching stability.

The reset action is typically applied by ratio adjustment within measuring element **144**, of regulator **138**, as affected by a reversing motor **145**, which is made to run in discrete steps by a rate adjusting means in the form of a pulse generator **146**, that is adjustable in frequency and duration of both made and break periods so that the reset rate can be optimised to the time constants of the forced draught plant.

The groups of limit switches **143**, are integrated in a logic relay system (not shown).

The transmission and distributional system for secondary air, mentioned previously, will now be described.

The output **122**, generated by the steam/air ratio regulator **121**, is in the nature of an error signal in that it

functions to take action on the secondary air supply to prevent departure from a desired steam/air ratio. This action is shared equally among the several secondary air control loops by a signal repeater **147**, which produces the required number of separate electrical signals **148**.

Secondary air to each windbox is controlled by an air flow regulator in the form of a secondary air regulator **151** in approximate ratio with the respective fuel throughput in order to cater, for example, when the number of mills in service is changed. The signal repeater **147** and air regulators **151** together form a distribution means.

To achieve this control, proportional bias is applied to signal **148**, to produce a desired value electrical signal **150**, by a potentiometric divider **149**, the slider of which is driven from the servomotor **119**, that transduces the fuel demand signal **113** into a loading force on the fuel regulator **107**.

Each air regulator **151** controls a damper **123**, in an individual duct **124**, to an independent windbox **125**, by means of a servomotor **152**, to maintain the flow rate, as measured by a pressure difference device **153**, in balance with the respective value signal **150**.

It will be seen that, by imposing the steam/air control mode in this manner on a discrete number of firing units, each having basic fuel and air control loops as described, a fuel/air ratio control mode for start-up and low-load operation is readily achieved.

When operating below the normal on-load range where combustion can be optimised by the steam-air mode, the regulator **121** is disconnected from its measuring element **126** and made to assume a predetermined position. This is effected by a solenoid device **154** which is operated manually from a panel switch **155**, or automatically at a preselected point in the load range by a switching relay switch **156**, the switch being operated from the steam flow transmitter output signal **129**.

The steam/air ratio regulator **121**, when in the fixed position, generates signal **122**, at a constant value which is chosen according to the increase in excess air margin considered necessary to safeguard the uncertainty that exists in the fuel metering system, with respect to calorific value, in the absence of the steam/air mode.

The boiler operator is provided at this time with the means of setting the approximate fuel/air ratio by a panel station **157**, which effects reduction of the standing signal **122**, within a prescribed safe limit. This means is switched into and out of effect simultaneously with the operation of the solenoid device **154**, by the parallel circuit **158**, in order to preserve the ratio setting established in one period of start-up mode operating to the next i.e. excluding the possibility of malfunctioning of the station **157**.

The resulting output signal is re-transmitted by the signal repeater **147** to form the individual basic demand signals **148**, that are modified to suit the individual fuel throughput level by the ratio bias **149**, to produce the respective demand signal **150**, the signal **150** is transduced into a loading force on the appropriate air regulator **151**, by a servomotor **159**, that would perform the squaring function necessary in the example shown where the measured value represents the secondary air flow velocity head.

At start-up of the boiler, the pressure at point **102** in the steam main **103** will be below the set point value applied to the master regulator **101**, depending on the time elapsing since the boiler was shut down. Consequently, the fuel demand signal **106** will be at the maximum value and hence, if applied to the fuel regulators at this time, would result in full loading of the mills as commissioned.

A maximum signal limiting relay **160** is employed which receives an alternative demand signal **161**, and transmits this value to the fuel regulator **107** when it is the lower of the two signals.

The alternative demand signal **161** is generated by a ramp loading device **162**. This device functions to generate an increasing signal at an infinitely variable rate as selected by the operator at station **163**. This station displays the output signal **161**, has setting means calibrated in terms of percentage heat release and means to start and stop the ramping action. The operator is thus able to demand any firing rate that is below the requirements of the steam pressure element and greater than the turn-down limit of the milling plant.

An essential requirement for correct function of the steam/air ratio combustion mode is for the heat release rate to be controlled to maintain substantially constant steam pressure. The availability of the steam/air ratio mode is therefore made conditional upon the existence of the state in which the relay **160** is set to transmit signal **106** to the fuel regulator **107** by an electrical interlock connection **164** with the circuit that controls the operation of the solenoid **154**.

With regard to minimal firing rate, the employment of a mill below the given safe turn-down limit is prevented by a minimum loading limiter **165** in the indivadual signal lines **113** to each fuel regulator **107**. A similar limiter **166**, in signal line **137**, is set to prevent the set point on the forced draught regulator **138** from falling below the value necessary to provide sufficiency of combustion air supply when the mills are operating at minimal throughput, i.e. in the case when the total fuel demand applying from signal **106**, or **161**, becomes less than the given control range of the mills in service.

In order to ensure that the set point on the minimum loading limiter **166** is not falsified by start-up or abnormal operating conditions, readjustment of the ratio between set point signal **137** and the measured value on regulator **138** is inhibited in circumstances which do not permit the secondary air dampers **123** to operate at optimum efficiency.

The resetting arrangement is retained in an existing state by cutting the power supply line **167** to the pulse generator **146**, by using a switching relay **168**. The switching relay **168** is energised by a limit switch **169**, set to close at minimal opening of the fan guide vanes **136**. When energised, the switching relay **168** latches-in and opens its contacts to interrupt the power supply. At the wider opening of the guide vanes which establishes adequate control of fan delivery pressure, a limit switch **170** operates to unlatch the relay **168**, which then restores supply to the pulse generator **146**.

The relay **168** will function similarly from signals derived from other states which may not permit the secondary air dampers to operate efficiently as for instance when the forced draught plant is under manual control.

It will be appreciated that in a case where the function of regulator **138** is performed by a controller of a type which does not afford the facility for adjusting the relationship between set point and measured value internally, the same effect is to be achieved by a signal modulating device employing similar resetting technique to that described. In such a case a transmitting device would apply the measured value at point **141** to the said controller and, if this device is of the root extracting type, the demand signal **197** would be generated by the signal repeater **112**, in linear relationship to the fuel demand signals **113**.

It will also be appreciated that, in an alternative construction, if the fuel regulator is of a type which does not afford the facility of a servomotor **119** to drive the slider, the slider could be driven by an instrument that measures the differential head produced by the primary air flow device **118**. Differences will thus appear in the desired value signal **150**, which are applied to the several air flow regulators **151**, depending upon differences in the primary air (fuel) distribution pattern.

When operating below the normal on-load range, in an alternative arrangement, the change-over point may be made dependent upon the number of mills operating since the number of idle burners is a limiting factor in the use of the steam/air mode when a large percentage of the

combustion air supply does not enter into the combustion process.

I claim:

1. In control apparatus for a boiler plant, the combination comprising

first air control means, operative during start-up and low load level of boiler operation, to control combustion air flow rate in response to the ratio of fuel flow rate and combustion air flow rate,

second air control means, operative during normal on-load level of boiler operation, to control combustion air flow rate in response to the ratio of steam output flow rate and combustion air flow rate,

sensing means for sensing the load level of operation of the boiler, and

selector means responsive to said sensing means and operable selectively in dependence on the load level of boiler operation to render either the first air control means or the second air control means operative to control the combustion air flow.

2. Control apparatus, for a boiler plant having a combustion air flow duct, a fuel supply and a steam output pipe, the apparatus comprising in combination,

fuel flow control means for controlling the rate of fuel flow to the plant,

first air flow control means for controlling the rate of combustion air flow through the duct during start-up and low-level boiler operation,

second air flow control means for controlling the rate of combustion air flow through the duct during on-load boiler operation,

a fuel demand signal generator for generating and supplying a first control signal to said fuel flow control means, and a second control signal to said first air flow control means,

movable air flow constrictor means in the duct,

the first air flow control means comprising

first means responsive to air flow rate in said duct to generate a first air flow rate signal, and

a first regulator responsive to the ratio of said air flow rate signal and said second control signal to move said constrictor means in a sense to balance the air flow rate signal against the second control signal,

sensing means for sensing the load level of boiler operation,

the second air flow control means comprising

second means responsive to air flow rate in said duct to generate a second air flow rate signal,

means responsive to steam flow rate in said steam pipe to generate a steam flow rate signal,

a second regulator responsive to the ratio of said steam flow rate signal and said second air flow rate signal to move said air flow constrictor means, and

a selector responsive to said load level sensing means to render the second regulator operative to control the air flow constrictor means upon transition from low-level to on-load boiler operation.

3. A method of operating a boiler plant having a fuel supply, a combustion air duct and a steam output pipe which comprises the steps of

generating a fuel demand signal,

controlling the supply of fuel to the boiler plant in dependence on said signal,

measuring the combustion air flow in the air duct and controlling said air flow in dependence on the ratio of the measured air flow and the fuel demand signal, during start-up and low level boiler operation,

generating a control signal indicative of the level of boiler operation,

measuring the steam pressure in the steam pipe and, in response to a said control signal indicative of the transition from low level boiler operation to on-load boiler operation, varying the air flow in the duct to maintain a predetermined ratio between the said steam pressure and air flow.

4. A boiler plant comprising in combination

a combustion chamber,

a boiler heated by the combustion in said chamber,

a steam pipe connected to said boiler,

a fuel supply connected to said combustion chamber,

a combustion air duct connected to supply air to said combustion chamber,

means for generating a fuel demand signal,

fuel supply control means responsive to said fuel demand signal to control the supply of fuel to the combustion chamber,

a first movable air flow constrictor at a first position in said air duct,

first air control means for controlling start-up and low level boiler operation and comprising

means measuring air pressure in said duct downstream of said first position and generating an air flow rate signal, and

a first regulator which responds to the ratio of said fuel demand signal and said air flow rate signal, varies the position of said first constrictor, and generates a control signal indicative of a demand for air flow in excess of that being supplied to the first constrictor,

a second movable air flow constrictor in said air duct at a second position upstream of said first position and movable in response to said control signal,

second air control means for controlling on-load boiler operation and comprising

means measuring air flow rate entering said second constrictor,

means measuring steam flow rate in said second constrictor,

means measuring steam flow rate in said steam pipe,

a second regulator connected to said air flow rate- and steam flow rate-measuring means and said second flow constrictor and which, when operative, responds to the ratio of steam flow rate and air flow rate to vary the position of said second constrictor, and

a selector connected to the second regulator and responsive to the position of the second movable air flow constrictor, at the transition from low-level to on-load boiler operation, to render said second regulator operative to control said second air flow constrictor.

5. A boiler plant according to claim 4 comprising

a forced draught fan in said air duct,

said second air flow constrictor comprising movable fan-inlet guide vanes, and wherein

said first air flow constrictor is a movable damper.

6. A boiler plant according to claim 4 wherein the fuel supply comprises a supply of pulverised fuel and a supply of air for carrying the pulverised fuel into the combustion chamber.

7. A boiler plant according to claim 6 wherein the fuel supply control means is operative to control the fuel-carrying air supply.

8. A boiler plant according to claim 4 wherein said combustion air duct is divided downstream of said second constrictor into a plurality of windboxes, said fuel supply comprising a plurality of fuel supply units each associated with a separate one of said windboxes, and a plurality of said first air control means each associated with a separate one of said windboxes.

9. A boiler plant according to claim 4, wherein the means for generating a fuel demand signal is responsive to steam pressure in said steam pipe.

10. A boiler plant comprising in combination

a combustion chamber,

a boiler heated by said combustion chamber,

a steam pipe connected to said boiler,

a fuel supply connected to said combustion chamber,
a combustion air duct connected to supply air to said combustion chamber,
means for generating a fuel demand signal,
fuel supply control means responsive to said fuel demand signal to control the supply of fuel to the combustion chamber,
a first movable air flow constrictor (**123**) at a first position in said air duct,
a second movable air flow constrictor (**136**) in said duct upstream of said first constrictor,
first air control means for controlling start-up and low level boiler operation and comprising
means measuring air pressure in said duct upstream of said first position and generating an air flow rate signal, and
a first regulator (**138**) which responds to the ratio of said fuel demand signal and said air flow rate signal and to the position of said first constrictor to vary the position of said second constrictor,
a second air control means for controlling on-load boiler operation and comprising
means (**132**) measuring air flow rate entering said second constrictor,
means (**128**) measuring steam flow rate in said steam pipe, and
a second regulator connected to said air flow rate- and steam flow rate-measuring means and which, in a first operative state, emits a constant control signal and, in a second operative state, emits a variable control signal dependent on the ratio of steam flow rate and air flow rate,
means (**151**) connected to the second regulator and responsive to the rate of the air flow rate through the first constrictor and said constant or variable control signal to move the first constrictor, and
a selector (**154**) connected to the second regulator

(**121**) and effective in response to a predetermined fuel demand signal (**164**) indicative of the transition from low level to on-load boiler operation to render said second regulator (**121**) operative to emit said variable control signal thereby to control said first air flow constrictor.

11. A boiler plant according to claim **10** comprising
a forced draught fan in said air duct,
said second air flow constrictor comprising movable fan-inlet guide vanes, and wherein
said first air flow constrictor is a movable damper.

12. A boiler plant according to claim **10** wherein the fuel supply comprises a supply of pulverised fuel and a supply of air for carrying the pulverised fuel into the combustion chamber.

13. A boiler plant according to claim **12** wherein the fuel supply control means is operative to control the fuel-carrying air supply.

14. A boiler plant according to claim **10** wherein said combustion air duct is divided downstream of said second constrictor into a plurality of windboxes, said fuel supply comprising a plurality of fuel supply units each associated with a separate one of said windboxes, and a plurality of said first constrictor control means (**151**) each associated with a separate one of said windboxes.

15. A boiler plant according to claim **10** wherein the means for generating a fuel demand signal is responsive to steam pressure in said steam pipe.

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