Nov. 26, 1957 O. J. LEONE 2,814,479

BLAST FURNACE CONTROL SYSTEM

Filed Jan. 12, 1953 4 Sheets-Sheet 1

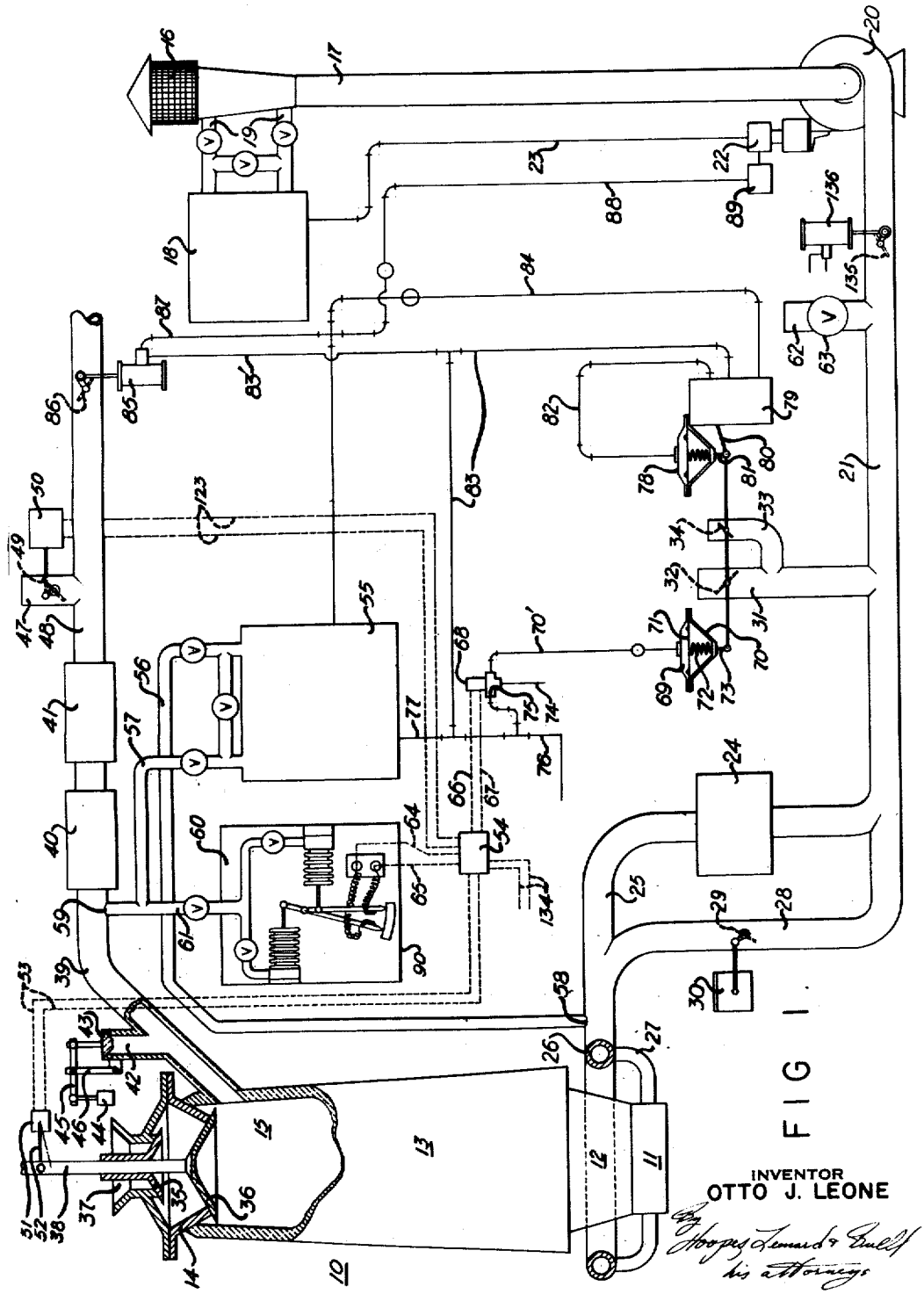


FIG. 1.

INVENTOR
OTTO J. LEONE

By Hoopes, Lemard & Bull
his attorneys

Nov. 26, 1957 O. J. LEONE 2,814,479

BLAST FURNACE CONTROL SYSTEM

Filed Jan. 12, 1953 4 Sheets-Sheet 2

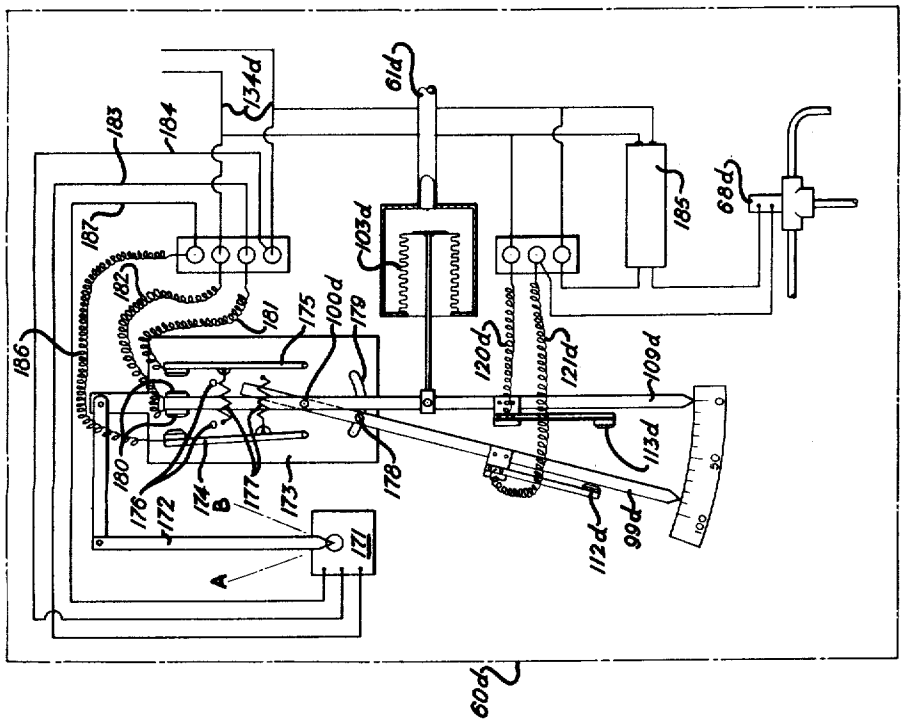


FIG 6

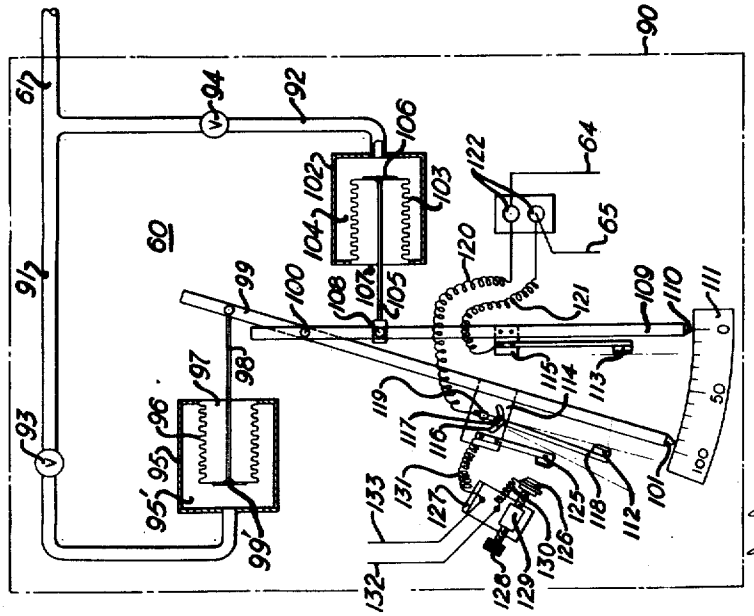


FIG 2

INVENTOR
OTTO J. LEONE
By Rogers, Leonard & Budd
his attorneys

Nov. 26, 1957 O. J. LEONE 2,814,479

BLAST FURNACE CONTROL SYSTEM

Filed Jan. 12, 1953 4 Sheets-Sheet 3

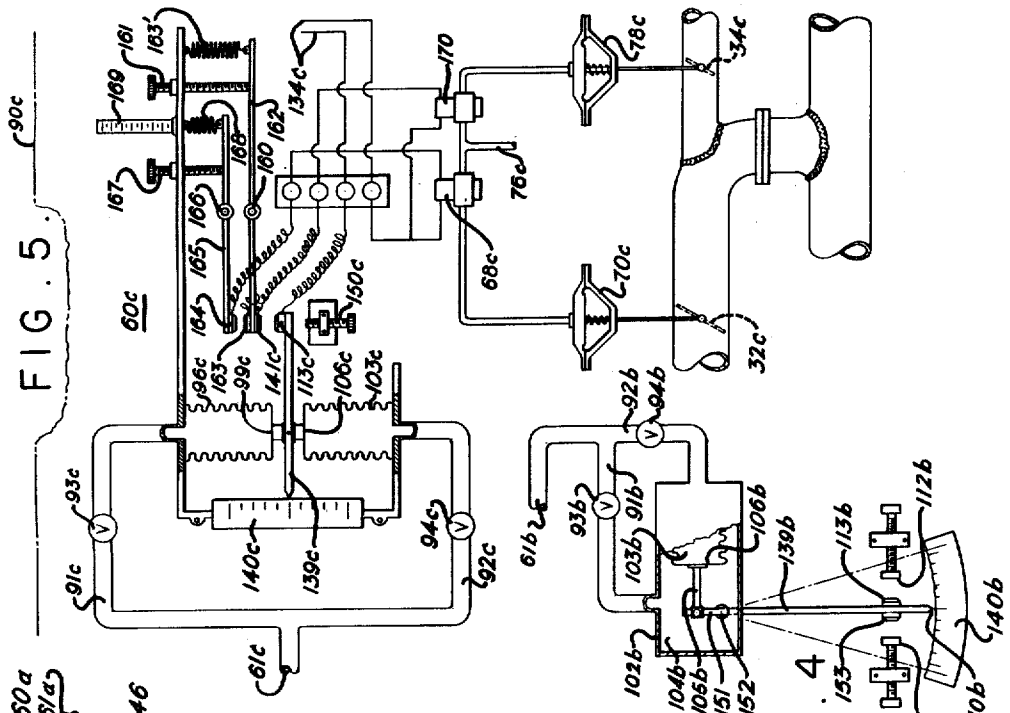


FIG. 5.

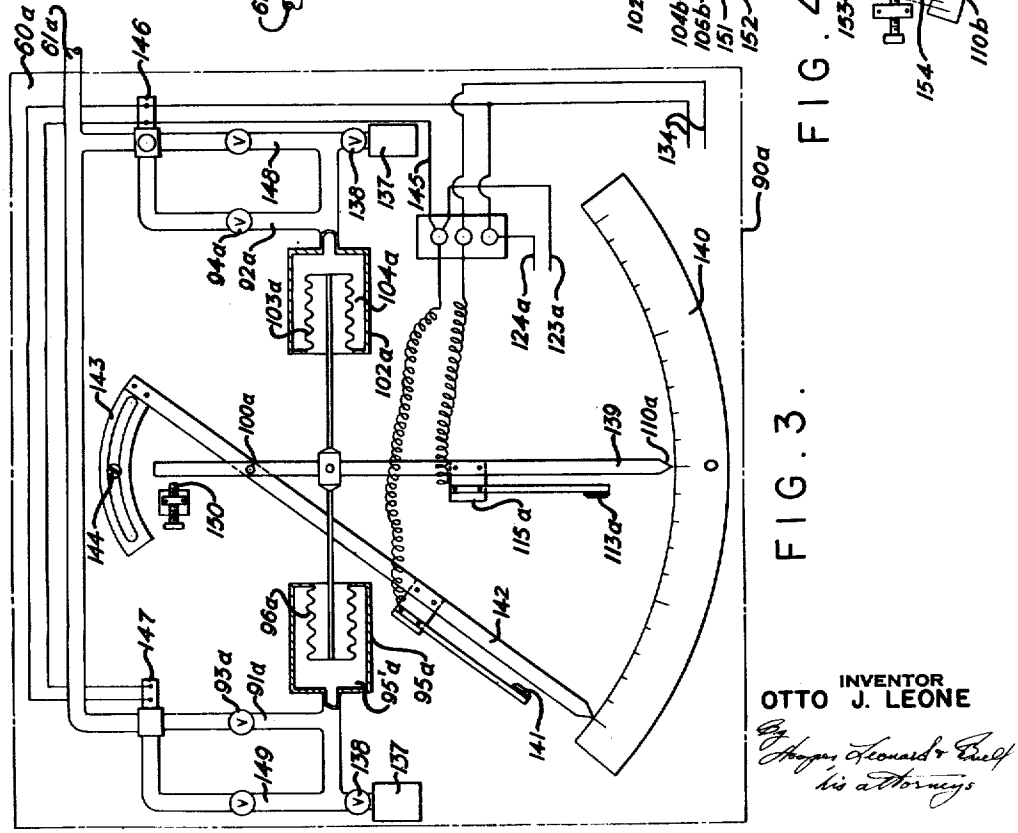


FIG. 4

FIG. 3.

INVENTOR
OTTO J. LEONE

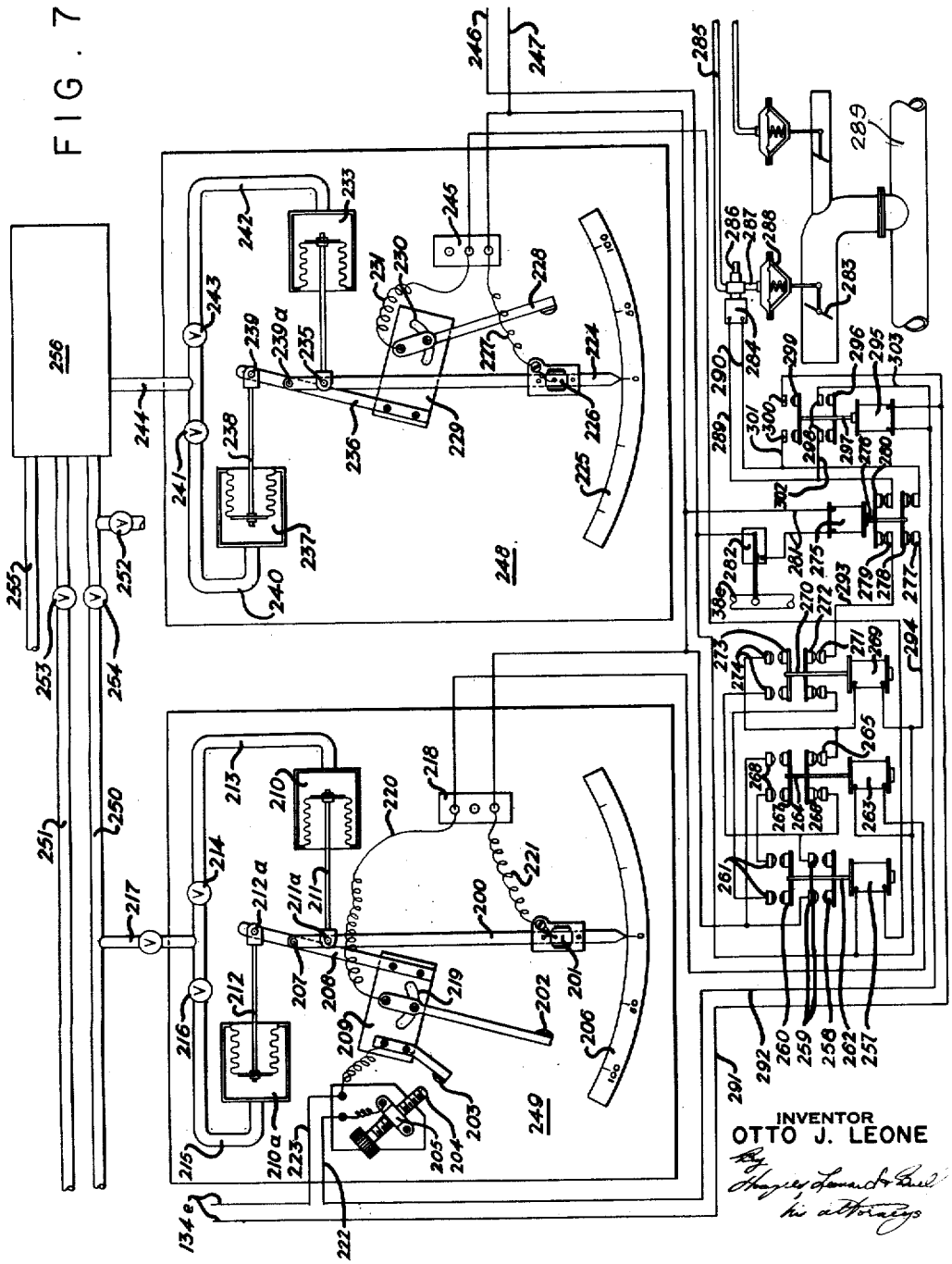
By Hagan, Leonard & Ruehl
his attorneys

Nov. 26, 1957 O. J. LEONE 2,814,479

BLAST FURNACE CONTROL SYSTEM

Filed Jan. 12, 1953 4 Sheets-Sheet 4

FIG. 7



United States Patent Office 2,814,479 Patented Nov. 26, 1957

2,814,479

BLAST FURNACE CONTROL SYSTEM

Otto J. Leone, West Newton, Pa.

Application January 12, 1953, Serial No. 330,753
18 Claims. (Cl. 266—30)

This invention relates to a novel control and detection system for slips and rolls, whether incipient or otherwise, of blast furnaces. Further, this invention pertains to new, quickly responsive control apparatus combinations useful in so controlling blast furnaces.

Blast furnaces are highly individual in their operation and that operation is affected by numerous factors: Among those factors are the nature of the stock charge and its introduction into the furnace; the volume rate, temperature and pressure of the blast air fed to the furnace; the maximum permissible top pressure in the main leading from the furnace; the voids and buoyancy conditions of the downwardly moving stock; the upward gas velocities in the furnace; the presence of a common gas main from a plurality of furnaces or other associated equipment; interruptions due to the casting or to temporary down periods; the kind and response of control instruments that may be used; and human error. Whenever orderly downward movement of a charge of stock in the blast furnace shaft is interrupted by incipient formation of a bridge or a scaffold at some level in that shaft, a tendency for the furnace to hang begins. If continued, the stock below that level may continue to move, forming a cavity therebeneath, and the furnace may be said to be hanging. If the weight of the hanging materials becomes too great for the upwardly moving gases to support, the hanging material falls or "slips" into the cavity below with a violent disturbance of the furnace operation. The phenomenon of "rolling" which may appear without a stoppage of downward movement of charging stock but in which the rate of downward movement of the stock at lower levels appears to be faster than it is at upper levels, would seem akin to hanging and slipping. With such a slip or roll there is a sudden increase in the top pressure of the furnace to a value substantially higher than normal. Such top gas pressure may increase so much that it may cause damage to the furnace equipment and endanger the furnace operators, particularly if bleeder valves, whether power or manually operated, open too late, which they may when there is a severe slip in the furnace. Even when a gas main bleeder valve does operate in time to prevent the top gas pressure from reaching and excessively high value, its opening ejects dust and gases into the atmosphere, which not only represents a loss of furnace production but also constitutes a serious air pollution problem. Such fine solids which in slips or rolls may be caught by a dust catcher usually require sintering and briquetting before that dust can be returned to the furnace.

In addition, such hanging, slips and rolls may create disruption and rearrangement of the solids burden in the furnace shaft and bring about, in severe cases, further troubles in the operation of the furnace and/or a change in the analysis of the hot metal produced.

Reference is made to the differential pressure control principles and system for avoiding hanging and slips in blast furnaces disclosed in my copending application Serial No. 749,238 for United States Letters Patent, filed May 20, 1947, now patent No. 2,625,386.

I have discovered that, particularly in the case of low pressure blast furnaces with limited permissible top pressures, a mode effective and flexible control is provided by

plural regulation of both the top gas pressure in the gas main and of the pressure of the blast air supplied to the bottom of the furnace shaft through the bustle pipe and tuyeres. Thereby, I can automatically control a blast furnace over a relatively wide range of conditions and variables existing therein without losing the power to maintain the stock in buoyant condition in the furnace so that it moves downwardly with good contact with the blast air supplied and without hanging or packing or building up pressure differentials across any levels in the furnace shaft exceeding those above which hanging, channeling, slipping, or rolling may result.

Further, I have discovered that the rate of increase of top gas pressure as a blast furnace builds toward and/or is in a slip or roll is greater than the rates of change of those pressures that occur in its normal operation, even through a particular furnace may normally have wide swings in its top gas main pressures. A number of new control apparatus combinations are provided herein which include floating members to quickly detect slips and rolls, whether incipient or occurring, and transmit corrective action signals to prevent or arrest such slips and rolls. The consequence is that blast furnaces may be operated for the production of hot metal therein to an extent heretofore unknown without troubles which have always been considered inherent in such operations. Moreover, even in the case of blast furnaces not practicing my differential pressure control, my new rate control principles and control apparatus combinations may be employed by such blast furnaces to quickly restore normal operation after a slip or roll, or a portion thereof, has occurred. Heretofore, after a slip or roll, such an uncontrolled blast furnace might remain in an upset condition for a considerable period, during which the normal production of hot metal therefrom was impeded.

Other objects and advantages will be apparent from the following description and from the drawings, which are schematic only, in which

Figure 1 is one illustrative embodiment of a blast furnace assembly employing various principles of this invention;

Figure 2 is a schematic view of a new pressure controller having a floating member and overtaking rate provisions to detect slips and rolls;

Figure 3 is a schematic view of a new pressure controller which may be used to measure pressure change rates directly and provide a control signal for excessive rates of pressure change;

Figure 4 is a still further embodiment, in schematic form, of a new controller for measuring pressure change rates and initiating control signals for excessive rate changes;

Figure 5 is a schematic view of still another modification of a new pressure controller measuring change rates and capable of providing a plurality of control signals in the event of excessive pressure changes of varying magnitudes;

Figure 6 is a still further embodiment, in schematic form, of a new pressure controller measuring static pressure and providing a floating member for rapid excessive rate response; and

Figure 7 is a schematic view of a new top gas pressure controller in combination with an auxiliary differential pressure controller for highly sensitive pressure change rate detection and response.

Referring to Figure 1 of the drawings, a blast furnace 10 may comprise a hearth 11, a bosh 12, a furnace stack 13 and a top 14. The hollow interior of the furnace 10 comprises a furnace shaft 15. Air for the blast furnace may be drawn in through an intake housing 16 and a conduit 17 to which a blast air volume meter and controller 18 is connected by piping 19 in the usual manner.

A blower 20 is turned by a suitable prime mover and may be regulated as to its volumetric output rate, usually in cubic feet per minute, by a regulator 22 responsive to controller 18 to which it is connected by an impulse line 23. The term "impulse line" herein shall mean the piping used for conducting pressure impulses transmitted by gas or liquid through such piping and/or shall also mean electrical conduits where an electrical impulse is transmitted, whether such impulse lines lead to or away from the controller in question. The term "controller" herein shall include measuring instruments disclosed herein that receive signal impulses such as the existing pressure conditions in the blast furnace assembly and yield a corrective control signal impulse, whether of the indicating, recording or other kind of measuring means.

The outlet of blower 20 is connected to a blast air pipe 21 leading into the stoves 24 for heating the blast air before introducing it through a pipe 25 into the bustle pipe 26 from which branch pipes 27 lead the hot blast or blast wind to the interior of hearth 11 through tuyeres. A by-pass pipe 28 is respectively connected to blast pipes 21 and 25 around the stoves 24 to divert some cold blast air from the stoves 24. A valve 29 linked to a valve operator 30 is usually automatically operated to divert such portion of the cold blast air from pipe 21 as will be required to maintain a generally constant hot blast air temperature at the entrance to the tuyeres near the hearth 11. A pipe 31 leads from the interior of pipe 21 to atmosphere and, with a valve 32 operatively mounted therein, constitutes the principal power-operated blast air pressure relief, or "snort," valve. Usually each blast air pipe 21 is also provided with a manual snort valve 62 having a manually operated valve 63 therein for conventional "snorting" purposes. However, manual snort valves like valve 63 are insensitive and give rise to a great deal of trouble and the possibility that control of the furnace may be lost, particularly when the furnace is "acting up" so that if too much air is bled off or cut back by a furnace operator through pipe 62, the furnace may pack and remain upset for a much longer period than otherwise would be the case. A pipe 33 with a valve 34 therein, connected to pipe 31 inwardly of valve 32, constitutes an auxiliary power-operated snort valve which may be used for modulation. The term "modulation" herein shall mean providing incremental controlling and/or corrective action generally along with the changes in the conditions in the functioning of blast furnace 10 which require controlling and/or corrective action. "Modulation" as so used is to be distinguished from "on-off" controlling as will be understood by those in the field of industrial instrumentation where corrective action is reserved until an extended adverse range has been traversed in the conditions being controlled.

In top 14 of blast furnace 10, a small bell 35 and a large bell 36 are suitably mounted for the periodic introduction of a stock charge through hopper 37 to constitute the burden of furnace 10 in shaft 15. The operation of large bell 36 is performed by means of its stem 38 and such operation alternates with the operation of bell 35. A gas main 39 communicates with the upper part of furnace shaft 15 above the stock level line for the conducting away of the gaseous products of the furnace reaction. Gas being conducted through main 39 away from furnace 10 will usually be caused to pass through a dust catcher 40 to remove stock charge dust entrained in the effluent reaction gases and through a gas washer 41 to provide a relatively clean top gas which then may pass as clean blast furnace gas to stoves such as stoves 24 to heat them or to boilers as a fuel. A bleeder pipe 42 is usually positioned adjacent the top of a blast furnace such as blast furnace 10 communicating with the interior of main 39 to relieve excessive top pressures which may be generated in a blast furnace before such pressures blow the seals of the dust catcher or gas washer, or prevent further charging of stock, or

otherwise tend to adversely affect or to damage the equipment and possibly endanger the furnace operators. Pipe 42 may form a seat for a gas bleeder valve 43 which may be held in normally closed position by weights 44 on a beam 45 pivotally connected to valve 43 and to a bracket 46 attached to the furnace structure. In general, it may be noted that bleeder valve 43, whether power-operated or not, is not a valve which is opened too quickly with the result that in some cases dangerously high top gas pressures in blast furnace 10 may be achieved before valve 43 opens. Even when it does open, dust, representing a loss from the furnace burden, and gases go out into the atmosphere. In many communities, the presence of such dust in the air is regarded as a serious air pollution problem. Even such dust as passes into dust catcher 40 when the bleeder valve 43 operates generally requires sintering and briquetting before it may be returned to the furnace shaft 15.

In the embodiment illustrated in Figure 1, a relief standpipe 47 may also communicate with the interior of main 39 in the portion 48 thereof following washer 41. The upper end of pipe 47 opens into the atmosphere and if gas is discharged therefrom, it is relatively clean gas. A valve 49 linked to an operator 50 controls outward passage through the standpipe 47. If desired, standpipe 47 may be opened and used in lieu of bleeder valve 43 where possible to keep less dust from escaping to the atmosphere.

The embodiment illustrated in Figure 1 is preferably equipped to utilize my differential pressure control across the furnace 10, or any part thereof, as an indication of and for the purpose of controlling hanging and slips, including rolls. Thus, a differential pressure controller 55 may have the opposite sides of the manometer or other differential pressure responsive element therein connected by impulse lines 56 and 57 to a bottom pressure tap 58 and to a top pressure tap 59 respectively. The lines 56 and 57 are respectively high pressure and low pressure lines filled with air and gas for impressing upon controller 55 the current pressure differential existing across furnace 10, that is, in the illustrated embodiment, the difference between the blast wind pressure in pipe 25 and the top gas pressure in main 39. Inasmuch as hanging can occur in a furnace at the bottom, at the top and/or at intermediate levels, the taps 58 and 59 may instead be located so as to span the distance between any desired levels within the interior of shaft 15. Controller 55 may be made more sensitive and responsive to the differential pressures impressed thereon by using a compressed air relay therein connected to an external fixed air pressure source through a pipe 77 which is a continuation of supply line 76.

A novel top gas pressure controller 60 may also be connected by impulse line 61 to top pressure tap 59. Top pressure controller 60 may be electrically connected by wires 64 and 65 through a relay 54 and wires 66 and 67 to a 3-way solenoid valve 68 to admit compressed air into or to exhaust compressed air from a pressure chamber 69 through a pipe 70'. Chamber 69 is in a fast-acting operator 70 to fully open or close valve 32 and is provided with a diaphragm 71 normally pressing chamber 69 to its smallest dimensions under the influence of a spring 72. Linkage 73 connected to diaphragm 71 controls the turning of valve 32 in pipe 31. Solenoid valve 68 is provided with an exhaust port 74 and receives its compressed air through an inlet port 75 connected to a pipe 76 through which compressed air is received from some suitable supply. Normally the solenoid valve is de-energized and chamber 69 is connected to exhaust through port 74 causing valve 32 to close pipe 31.

Valve operator 78 for valve 34 is similar to valve operator 70 but is subject to modulating corrective action hereunder by the use of a valve positioner 79 having an arm 80 connected to the linkage 81 which operates valve 34. Modulating positioner 79 is connected to the upper

pressure chamber of operator **78** by a variable impulse line **82** which is correlated to the action of controller **55** through impulse line **84** connected thereto. A compressed air pipe **83** connects positioner **79** to energy source **76**. Modulating operator **85** for a top gas pressure valve **86**, which is after (in the embodiment shown) gas washer **41** and standpipe **47**, is also at the same time responsive to the control signal action of controller **55** through an impulse line **87** which joins impulse line **84**. A pipe **83'** connects operator **85** to the fixed pressure energy source **76**. In some cases, it is possible, where the speed of the blower **20** can be reduced in modulating fashion by some percentage, to avoid the diversion of cold blast air to atmosphere through pipe **33** and save cost in the course of a differential pressure control action, by combining such blower modulation with the modulation of valve **86**. A relay **89** may receive its variable control signal impulse through an impulse line **88** and be connected to regulator **22** by a further impulse line for such an alternative plural control action, in which event the valve in line **88** will be opened and the one in line **84** closed. Again, in lieu of the use of valve **34** or of relay **89**, a valve **135** on the discharge side of blower **20** may be linked to an operator **136** which may receive control signals from a controller like differential pressure controller **55** to modulate the pressure of the blast wind by setting up a changed orifice in pipe **21** rather than by varying the actual mass rate of blast air supplied by blower **20**. Although the impulse lines from differential pressure controller **55** are pneumatic, it will be evident electrical, pneumatic or hydraulic impulses or combinations thereof may be utilized as control signals with corresponding changes in the instrumentation and equipment employed.

I have discovered in applying the principles disclosed in my aforesaid application, that with some blast furnace operations, more especially those with a relatively low maximum permissible top pressure and those of relatively smaller capacity or with relatively inexperienced operators, a highly flexible and greater control effectiveness with relatively more economy in operating costs and less possibility of loss of control, may be obtained by plural corrective action in generally simultaneous or substantially overlapping fashion of the top gas pressure regulating means and of the bottom or blast air pressure regulating means. Still further, I have discovered that the rate at which the top gas pressure rises in a blast furnace constitutes an indication that hanging and slipping may be incipient or under way. Thereby, a new principle is also provided by the use of which blast furnaces, whether or not they employ my pressure differential control, may be guarded against the occurrence of slips and rolls. The following description of the new top pressure controller **60** will preface a description of an operation of the Figure 1 embodiment which will bring out new features in the improvements I have disclosed herein.

Figure 2 is a schematic illustration of essential parts of top pressure controller **60** which, in its commercial form, will be encased in an instrument case **90** for mounting at any suitable control location. Impulse line **61** is provided with branches **91** and **92** in which resistances **93** and **94** are respectively incorporated. Inasmuch as impulse lines **91** and **92** are gas pressure pipes, the resistances **93** and **94** may take the form of valve orifices which may be adjusted to vary the relative resistance in the two branches **91** and **92**. Branch **91** may terminate in a sealed bellows housing **95** fastened to the back of instrument case **90** and having a pressure chamber **95'**. Housing **95** may be provided with a resilient bellows **96** in sealed relation to opening **97** through which a rod **98** extends. Rod **98** is rigidly connected at one end to head **99'** of bellows **96** and is pivotally connected at the other end to a rate arm **99** pivoted about pin **100** which is also fastened to case **90**. A pen **101** at the lower end of arm **99** may be used to mark a recording chart passed thereunder by any suitable clockwork mechanism, for example, which need not be illustrated. Branch **92** in turn communicates with another bellows housing **102** fastened to case **90** and containing therein a bellows **103** which seals the interior **104** of housing **102**. A rod **105** connected to head **106** of bellows **103** passes through an opening **107** for pivotal connection at **108** to a pressure arm **109** pivoted about the same axis pin **100**. End **110** of pressure arm **109** constitutes a pointer pen to record on the aforesaid chart and to indicate top gas pressure, as in inches of water, on a scale **111** adjacent a trace of an arc likely to be described by pen **110**. If resistances **93** and **94** are appropriately selected with the former greater in relation to resistance **94** in this embodiment, as the top gas pressure in main **39** rises, pressure arm **109** and rate arm **99** will move in a clockwise direction about pivot **100**, and depending upon the rate of the top gas pressure change in an increasing direction, arm **109** will tend to overtake arm **99**. That is, if the rate of increase in the top gas pressure in main **39** and hence in impulse line **61** is great enough, such overtaking will take place and will close contacts **112** and **113** respectively mounted on arms **99** and **109**. Insulating brackets **114** and **115** respectively support such contacts on their arms. An arcuately slotted guide **116** cooperates with a machine screw **117** engaging a drilled and tapped opening in finger **118** to which contact **112** is attached so that by loosening screw **117**, finger **118** and thereby contact **112** can be swung about pivot **119** to shift it to a new position wherein it can be held by retightening screw **117** against guide **116**. Any such repositioning enables floating contact **112** to be adjusted to arm **99** and contact **113** which is fixed, in the embodiment shown, on bracket **115**.

Such relative adjustment of the contacts plus proper selection of the respective total resistances in branches **91** and **92** enable controller **60** to be set for closure engagement of contacts **112** and **113** upon the occurrence of an increase in the rate of change of the top gas pressure increases which indicates incipient slipping conditions. The new structure of controller **60** is a further provision which enables the rate arm **99** to float under relatively unvarying pressure conditions a prescribed angular distance from pressure arm **109** irrespective of the position of pressure arm **109** along its pressure-measuring scale, until a rate of change of the top gas pressure occurs which is sufficiently high to indicate the potentiality or presence of slipping or rolling conditions. Moreover, where as in the case of human error, or loss of pressure differential control during casting, or reduction of blast air volume for a sufficient time, a slip has actually occurred, contact **112** will be overtaken by contact **113** to bring into play that much more quickly the corrective action exerted by controller **60**. Lead wires **120** and **121** from the respective contacts through terminal posts **122** and wires **64** and **65** energize, extremely quickly, the valve operator **70** to open inlet port **75** to pipe **70'** closing off exhaust port **74** and depressing diaphragm **71** to open valve **32**, quickly dropping the cold blast air pressure enough to supplement or override as required the continuously acting differential pressure modulating controlling exercised through controller **55** via top gas pressure valve **86** and, for example, bottom air pressure valve **34**. Hence, if a slip has not occurred, there will usually be no engagement between contacts **112** and **113**, whereas on the other hand, if incipient slip or slip or roll conditions have occurred, the overtaking rate principle embodied in controller **60** will quickly restore normal operations in the blast furnace to the modulating control of differential pressure controller **55**.

In operation, the embodiment illustrated in Figures 1 and 2 is so constructed and arranged that the differential pressure controller **55** by impulses through the lines **84** and **87** will modulate the top gas pressure in

main 39 including portion 48 by action of valve 86 and correspondingly modulate, in inverse manner, the blast air rate and consequently the blast air pressure by movement, for example, of auxiliary power-operated snort valve 34. For example, if furnace 10 tends to "stiffen" as indicated by an increase in the pressure differential across taps 58 and 59, controller 55 will move valve 86 in a closing direction in accordance with the increase in the pressure differential. Substantially simultaneously therewith, since an increase in the top gas pressure in main 39 tends to produce at least an immediate increase in the pressure of the blast air fed to the furnace, valve 34 is inversely moved in an opening direction to an extent that insures with the top gas pressure increase a flexible control of the rising pressure differential to arrest it before it reaches a value indicating the presence of bridging or scaffolding material in shaft 15 constituting a hanging situation, or the presence of gaseous lifting velocities of an order passing upwardly through shaft 15 which promote such hanging and/or the early stages of rolling, thereby keeping the pressure differential within that range which will maintain an orderly stock movement in shaft 15 under "buoyant" descending conditions. By means of such plural regulation at the top and bottom of the furnace or by means of such regulation in materially chronologically overlapping relation, over-all control effectiveness appears to be improved in a number of respects. In the first place, the corrective increase in top gas pressure need not be as great as would otherwise be required without coincident modulation at the bottom. Further, under the new system the rate of blast air fed into furnace 10 remains high without requiring excessive "cut back" in the air rate and thereby in the pressure with consequent loss of production of hot metal and a tendency, at times at least, to "swing" the furnace operation in terms of variation in the pressure differential across the furnace enough to tend to be upsetting to proper functioning. Under the new plural control modulation operation also, it would appear that the average blast air pressure will be lower for the same average blast air volume rates with consequent lower costs per unit of blast air supplied. Moreover, modulation of the top gas pressure retains it better as a working control than if it alone were increased to its maximum allowable limit and appears to require less of a cut back in the blast air rate than would otherwise be the case.

Conversely, as the pressure differential across furnace 10 eases, that is as it drops into the normal operative range, valve 34 will move toward closure position in pipe 33 while valve 86 will move in an opening direction to lower the pressure differential and keep the descending stock in orderly descending relatively buoyant relation to the ascending air and gases. If the pressure differential drops below the buoyancy range conducive to orderly downward descent of the stock charge in the furnace shaft 15, the furnace burden may pack, in which event the supplying of blast air to the furnace must be continued until enough coke is burned out to create a cavity in the vicinity of the fusion zone so that descent can begin again and the control system acquire or regain fully effective mastery of the operation. Packing generally is less likely than hanging and slipping or rolling because of the tendency in blast furnace operation to keep the blast air as high as possible to keep the hot metal production up. Therefore, under the automatic plural control system disclosed herein, the descending stock in the furnace shaft between the hearth and the stock level, with the variable voids constituting a variable orifice therein, can be flexibly controlled and orderly buoyant forces maintained thereon so that neither the whole burden nor any part thereof either hangs or packs.

Each blast furnace has its own individuality due to the great number of variable factors that are involved in its functioning. Nevertheless, any blast furnace can have determined thereon the maximum pressure differential that may be maintained with stable operation and orderly stock descent in the furnace shaft, either by reviewing prior furnace operation pressure records if they exist, or by operating the furnace so that slipping and rolling occur and noting the pressure differential. With that last-mentioned pressure differential in hand for the particular furnace, the upper pressure differential control setting on a controller like controller 55 may be set at any lower pressure differential figure which will not force the blast furnace to hang and slip or roll. Similarly, a lower pressure differential setting for a controller like controller 55 may be obtained, if it cannot be calculated from existing records of prior operations of the furnace, by operating the furnace under conditions, such as too low a volume rate for the blast wind, which will cause the furnace to pack, whereupon the lower pressure differential control setting mentioned may be set at any figure above that which may be so induced.

My discovery that the rate of top pressure change across a blast furnace in an increasing direction is greater in the course of incipient or actual slipping or rolling conditions, and in the course of such slipping and rolling, constitutes another principle utilizable in controlling blast furnaces. That new principle is incorporated in top gas pressure controller 60 and is combined in the embodiment of Figure 1 with the control action of differential pressure controller 55. Thereby, if despite the modulation control exercised by controller 55, the furnace continues to stiffen and the build-up in the top gas pressure exceeds a rate normally to be expected, contact 113 will overtake contact 112 as described and operate the main power-operated snort valve 32 to achieve a much more rapid release of blast air and the lowering of the blast air and differential pressure. Further, that overtaking will occur in approximately the same length of time no matter where the top gas pressure is at the instant the slip build-up conditions begin. In other words, as shown in Figures 1 and 2, if the top gas pressure is at 60 inches of water in lieu of being at 15 inches of water before the accelerated rate build-up described, the angular distance between arm 109 and arm 99 will be approximately the same. However, once the slip or rolling top gas pressure build-up rate begins, arm 109 will move to overtake arm 99 and close the contacts 113 and 112. Valve operator 50 may also be connected to relay station 54 by electric lines 123 in the event that anyone may wish to open valve 49 upon the occurrence of a slip bringing contacts 112 and 113 into closure engagement. Generally, the described controlling action of valve 32 is to be preferred without recourse to valve 49.

In calibrating a controller like top gas pressure controller 60 for a particular blast furnace, the angular distance between the arms 99 and 109 with the respective resistances and bellows operative thereon will be set so that overtaking occurs when the rate of increase in the top gas pressure exceeds some predetermined value. Generally, the bellows themselves like bellows 96 and 103 will be provided with the same range calibration to make it simpler to use in the differential mode described. Such bellows or other diaphragm elements are preferred in giving fast, low inertia response to pressure changes. That predetermined value in turn may readily be ascertained by preliminary operation of a furnace in a stable manner and noting the pressure swings of arm 109 so that the adjustment and operation of arm 99 relative thereto may be made so that the contacts 112 and 113 do not engage in the course of such normal swings. Thereby, an abnormal rate change, indicating slip or rolling build-up or occurrence, will cause overtaking and contact and constitute an appropriate calibration of controller 60. In that connection, the bell closing operations of certain

blast furnaces affect the top gas pressure. Thus, there is a rise in the top gas pressure in main **39** upon the closing of large bell **36**. If desired, a switch **51** connected to stem **38** by a switch arm **52** and electrically connected to relay station **54** by electric wires **53** may be used upon the operation of bell **36** to make controller **60** insensitive to the pressure existing at tap **59** when bell **36** is moving.

In some cases, as shown in Figure 2, a top gas pressure controller like controller **60** may be provided with a maximum top gas pressure limit switch. Such a switch may have a movable contact **125** mounted on bracket **114** and a fixed contact **126** mounted on a bracket **127** fixed to the back of an instrument case like case **90**. Contact **126** may have the rearward part thereof threaded and made to be turned by a thumbpiece **128**. The threaded portion of contact **126** may be engaged by a nut **129** on bracket **127** so that the fixed position of contact **126** can be adjusted for the particular blast furnace with which the controller is to be used. Extensible electric wire leads **130** and **131** are in electrical contact with a pair of wires **132** and **133** which may be connected to operator **50** in the Figure 1 embodiment to operate the relief valve **49** as a safety measure if valve **32** has also been opened by the engagement of contacts **112** and **113**. On the other hand, a parallel connection from wires **132** and **133** may be made to operator **70** of valve **32** so that upon the engagement of contacts **125** and **126** without engagement between contacts **112** and **113**, both snort valve **32** and top pressure relief valve **49** may be opened. An outside electric power supply may be conducted to the electrical wiring shown in Figure 1 through the pair of wires **134**.

It may be noted that even if a blast furnace is operating without any differential pressure controller like controller **55**, the utilization of a top gas pressure controller like controller **60** has great utility because with a slip or rolling rate of increase in the top gas pressure being higher than rates of top gas pressure increases in the course of normal or stable operation, such blast furnaces instantly respond in a corrective manner if a floating contact like contact **112** and an overtaking pressure contact like contact **113** upon engagement are caused to instantly operate, for example, a power-operated snort valve like valve **32** to relieve the distress of the furnace and drop the tendency of the top gas pressure to reach such excessive proportions that it may open a relief valve like valve **43** or cause actuation of valve **49**.

The new overtaking rate principle disclosed herein is incorporated in various other new control apparatus combinations schematically illustrated in Figures 3, 4, and 5. The parts therein generally corresponding in construction and functioning to parts in the new controller shown in Figure 2, have the same reference numerals applied thereto with the addition of the letter "*a*" in the case of the Figure 3 structure, of the letter "*b*" in the Figure 4 structure, and of the letter "*c*" in the Figure 5 structure.

In Figure 3, under a steady top pressure exerted through impulse line **61***a*, arm **139**, which is not a pressure-measuring arm but one which measures a rate of change of pressure, remains at the zero mark on an arbitrary scale **140**, assuming bellows **96***a* and **103***a* have the same range calibration. If, however, the top gas pressure rises, arm **139** will swing around pivot **100***a* in a clockwise direction. Conversely, when that pressure falls, arm **139** will swing around in a counterclockwise direction. In the case of a rate of change portending an incipient or actual slip, that rate of change will be high enough to make contact between contact **113***a* and a fixed contact **141**. Contact **141** is connected to a preset arm **142** connected to the back of instrument panel **90***a* by a slotted bracket **143** and machine screw **144**. The preset position of contact **141** will be set far enough away from the zero position on scale **140** to require for engagement an increase in the rate of increase of the top gas pressure exceeding the normal rates of increase in the top gas pressure of the blast furnace to which controller **60***a* is applied. When contacts **113***a* and **141** engage, electrical impulse lines **145** energize solenoid valves **146** and **147** so that the exhausting of chamber **104***a* proceeds very slowly through line **148** instead of branch **92***a* as arm **39** is returned in a counterclockwise direction toward its zero position as the top gas pressure falls. At the same time, the retraction of bellows **96***a* will proceed correspondingly slowly by virtue of the reduced opening to chamber **95'***a* through line **149** when the energization of solenoid **147** shuts off branch **91***a*. Such slow return acts in the manner of a time delay with respect to corrective action signals transmitted, for example, through the lines **123***a* and **124***a* which may be connected in the manner described in connection with lines **64** and **65**. Conversely, if there is a decrease in the normal rate of decrease of the top gas pressure, arm **139** will move in a counterclockwise direction to the right of the zero mark on scale **140** giving a visual indication and recording in whatever rate units the scale is marked in for that decrease. An adjustable stop **150** fastened to case **90***a* may be employed to limit the counterclockwise rotation of arm **139** or to act as a contact for corrective action in the event of an excessive decrease in the rate of decrease of the top gas pressure. A tank capacitance **137** and valve **138** may be used in conjunction with each bellows assembly for response flexibility and wider range of adjustment. Such flexibility is great enough to provide a means for an extensive range in presetting the factors for operation of the new rate principle set forth herein.

In Figure 4, the new rate principle may be practiced by means of a single bellows housing **102***b* having therein a bellows **103***b* and having opposite sides of the bellows subjected to the differential pressures exerted respectively through the branches **91***b* and **92***b* with the aid of suitably adjusted resistances **93***b* and **94***b*. Head **106***b* may be pivotally connected to a rigid link **105***b* the other end of which is pivoted to a crank **151**. Crank **151** is rigidly secured to shaft **152** journaled in housing **102***b*. Shaft **152** extends through housing **102***b* and pressure-tight stuffing glands so that chamber **104***b* remains pressure tight. Arm **139***b* is attached to journal **152** outside of housing **102***b*. A rate arm **139***b* is provided with contacts **113***b* and **153**. Contacts **113***b* and **153** are adapted to respectively engage adjustably preset or fixed contacts **112***b* and **154**. Thereby, as in the case of the embodiment of Figure 3, an increase in the rate of increase of the top gas pressure, for example, beyond that which is normal, will bring contacts **112***b* and **113***b* into engagement for corrective action such as that described in connection with the embodiment in Figure 2. The movement of contact arm **139***b* past the zero position on scale **140***b* toward contact **154** is not significant insofar as it may indicate a decrease in the rate of decrease in the top gas pressure. However, contact **154** can be adjusted very close to the zero position of contact **153** so that if a seal-in relay (not illustrated) circuit is included and energized by engagement between contacts **112***b* and **113***b*, the effect of that engagement can be retained until said seal-in relay circuit is de-energized by engagement between the contacts **153** and **154**.

Although the various contacts which have been described, other than those in connection with the new device in Figure 3 when gas may be trapped in the housings **95***a* and **102***a* by virtue of the operation of solenoids **146** and **147**, are "make-and-break" contacts, it will be evident to those to whom this disclosure is made, that such contacts may be electrically connected to suitable seal-in switches to retain engagement between the respective contacts where needed to give time for the action of the equipment being correctively controlled until either a predetermined time has elapsed or the predetermined corrective action is sufficiently under way. Thus, in the case of the embodiment in Figure 4, if con-

tacts **112***b* and **113***b* should engage midway between the first and second left-hand division after the zero mark on scale **140***b* and then separate, such a seal-in or lock-up electrical relay arrangement might be provided to continue the control signal initiated upon such engagement of the contacts **112***b* and **113***b* until pointer pin **110***b* has returned a predetermined distance toward the zero mark on scale **140***b*.

Figure 5 illustrates a modification of a new controller like, for example, controller **60***c*, in which the rate of change of the top gas pressure is measured by "bucking" or opposing the movements or displacements of two pressure responsive bellows **96***c* and **103***c*. Heads **99***c* and **106***c* are joined to a pointer **139***c* and thereby to each other to indicate increasing rates of increase and decreasing rates of decrease of top gas pressure on a rate scale **140***c* by a translatory movement of arm **139***c*, which will be proportional to the rate of change of the top gas pressure change. Arm **139***c* carries a contact **113***c* for engagement with a contact **141***c* pivotally mounted at **160** in case **90***c* of controller **60***c*. An adjustment screw **161** bears against rocking support **162** for contact **141***c* to hold contact **141***c* in a fixed position relative to case **90***c* and to arm **139***c* when at the zero position on scale **140***c*. A spring **163'** holds support **162** against screw **161**. A second contact **163** is mounted on the other side of support **162** and is in electrical engagement with contact **141***c*. A contact **164** is supported on a rocking support **165** pivoted to instrument case **90***c* at **166** and is adjustably fixed in position in the same manner as support **162**, by adjusting screw **167** and spring **168**. A scale **169** may be used for the purpose of indicating rates of change in pressure corresponding to the respective adjustment of the screws **161** and **167**. For an increase in the rate of increase of the top gas pressure in a blast furnace to which instrument controller **60***c* is applied, which is normal, arm **139***c* will move upwardly as shown in Figure 5 but will not cause contacts **113***c* and **141***c* to engage. However, for conditions indicating an incipient slip or the actual occurrence of a slip, that increase in the rate of increase will be excessive and contacts **113***c* and **141***c* will engage and set afoot corrective action, in this case, for example, and by way of illustration, through a solenoid valve **170**, which functions in the manner of solenoid valve **68***c* but is connected so as to regulate an open cycle or fully "on-off" diaphragm operator **78***c* for valve **34***c*. Under conditions of a still greater increase than the described abnormal rate of increase in the top gas pressure, the upward thrust of arm **139***c* in response thereto will not only bring contacts **113***c* and **141***c* into engagement but will also engage contacts **163** and **164** whereupon solenoid **68***c* will operatively connect valve operator **70***c* to the compressed air in line **76***c* and open main power-operated snort valve **32***c* to increase the relief that would be afforded by opening valve **34***c* alone.

Figure 6 is still another embodiment schematically illustrating a controller which may be used, for example, as a top gas pressure controller, in place of controller **60**. Parts of the new device shown in Figure 6 corresponding generally in construction and function to parts of controller **60** are given the same reference numerals with the addition thereto of the letter "*d*." Thus, a reversible motor gear reducer set **171** may be utilized to cause an arm **172** to rock, for example, between positions A and B, thereby rocking a plate **173** about the pivot **100***d*. Plate **173** is provided with pivotal contacts **174** and **175** pivotally connected to plate **173** and held in preset position against stops **176** by springs **177**. Floating arm **99***d* is connected to plate **173** by a screw clamp **178** passing through arm **99***d* and an arcuate slot **179**. Hence, the oscillation of motor **171** rocks plate **173** and arm **99***d* to a corresponding extent. The contacts **174** and **175** act as "follow-up" switches in conjunction with the common contact **180** on both sides of the upper end of pressure arm **109***d* above pivot **100***d*. A clockwise movement of pressure arm **109***d* occurs upon an increase in the top gas pressure exerted through impulse line **61***d* and switch **180—175** will tend to maintain the arm **99***d* in floating relation to arm **109***d*, regardless of the angular position of arm **109***d* about pivot **100***d*. For example, if there is a normal increase in the top gas pressure and right-hand contact **180** engages contact **175**, motor **171** will be energized to move arm **172** clockwise toward its limit position B through the respective electrical connections that are illustrated as leads **181** and **182** and wires **183** and **184**. Such engagement of contacts **180** and **175** tends to move the upper part of arm **109***d* into central position between the contacts **174** and **175** and maintain contact **112***d* floating relative to contact **113***d*. On the other hand, under the new rate principle disclosed herein, an incipient slip or roll or an actual slip or roll will send the rate of increase in the top gas pressure so high that arm **109***d* will overtake arm **99***d*, closing contacts **112***d* and **113***d* because of the relatively slower oscillating movement of motor **171**. Engagement between contacts **112***d* and **113***d* will energize solenoid **68***d*, for example, in the manner described earlier. In the new structure of Figure 6, a conventional time-delay device **185** may also be incorporated so that upon the engagement of contacts **112***d* and **113***d*, even though that contact is momentary, timer **185** will produce such delay as may be necessary in the time that the solenoid in valve **68***d* must remain energized to effect corrective action. Such timed delay or other holding as by seal-in relays may be applied to the other momentary types of contacts set forth herein where it is desirable to incorporate such a duration factor in the operation of the new system and apparatus or parts thereof. In the event of a decrease in the top gas pressure which causes bellows **103***d* to move to the right in housing **102***d*, arm **109***d* will swing in a counterclockwise direction engaging left-hand contact **180** and contact **174** to energize motor **171** through leads **182** and **186** and wires **184** and **187** to swing arm **172** in a counterclockwise direction toward its limit position A to maintain the general floating character of contact **112***d* relative to contact **113***d* until overtaken by that contact.

Figure 7 shows a mode of control of the opening of the air blast pressure relief valve that utilizes the combined measurement of the top gas pressure and of the differential pressure through the furnace in such manner that (assuming the big bell limit switch circuit **282** to be open, and the high pressure contacts **203** and **204** of the top pressure instrument **249** to be open) a closing of the contact **201** on the pressure arm **200** with the high rate contact **202** will not energize the 3-way solenoid valve coil **284** to operate the valve **283** to open, unless during the time that the circuit between contacts **201** and **202** is closed during an increase in top pressure, contact has also been made in the differential pressure control instrument **248** between the contact **226** on the arm **224** and the low rate contact **228** by a decrease in differential pressure, and further the coil **284** cannot become energized to open valve **283** unless the closure between the contacts **201** and **202** has occurred at precisely the same time or before the contacts **226** and **228** have closed. The advantage of this arrangement is that the distance between contacts **201** and **202** in instrnument **249** may be set much closer than otherwise. The distance between contacts **226** and **228** in the differential pressure controller **248** would be set far enough apart that **226** and **228** would contact each other to close this part of the circuit only at magnitudes in the movement of the pointer arm **224** that result from slips. Preferably the instruments **248** and **249** are selected for almost equal sensitivity, if the same pressure change were impressed in the respective pressure lines **217** and **244**, and with equal settings of the restrictions **216** and **214** and of the restrictions **241** and **243**. These restric-

tive needle valves may then be set so that the pressure arm 200 (of 249) on an increasing top pressure will move faster than will the differential pressure arm 224 (of 248) for the same rate of change of pressure.

Referring to Figure 7, 249 is the top gas pressure controller, of which 210 and 210*a* are pressure responsive bellows connected to a common top gas pressure line 217, by means of branch pressure tubes 215 and 213. Each of the pressure tubes contains a restrictive or needle valve, 216 and 214 respectively, which are manually adjustable to provide any desired value of resistance to the flow of gas as the impressed gas pressure changes. By means of a link 212 changes in length of the pressure bellows 210*a* are transmitted to a high rate contact arm 208 at a pivot connection 212*a*, the movement of link 212 causing arm 208 to rotate about a fixed shaft 207. Similarly, bellows 210 causes a pressure-measuring arm 200 to rotate about the fixed shaft 207 in response to gas pressure changes in line 217, by means of the motion link 211 which is pivoted to pressure-measuring arm 200 by a pin 211*a*. A calibrated scale 206 may be provided to indicate the value of the top gas pressure.

An electrical contact 201 mounted on an insulated base is attached to arm 200 and moves with it. Similarly, a high rate contact 202 is attached adjustably by a slot 219 to an insulated base 209 which is attached to the high rate arm 208. Flexible leads 220 and 221 connect the contacts 202 and 201 to terminal connecting screws on a terminal block 218 which is of insulating material.

Referring further to the top pressure instrument 249, the insulating block 209 may also carry a second high contact 203 which also moves as the high rate arm 208 is moved by pressure changes. Cooperating with the contact 203 is a fixed-position contact 204 which may be manually set in bracket 205 so that the contacts 203 and 204 will close an electrical circuit if the pressure arm 200 reaches some high predetermined pressure value on the scale 206. The contact mechanism 204 is mounted on an insulated block support. When contacts 203 and 204 close the circuit 292 is also closed, to energize the solenoid 284, and to apply air pressure to valve operator 288 which opens the relief valve 283.

The differential pressure controller 248 is built similar to the top pressure controller 249, except that it is equipped with a low rate contact 228 that moves with contact arm 236 instead of a high rate contact and arm as in the case of instrument 249. The difference in operation between 249 and 248 then is such that, whereas contacts 201 and 202 are closed by an increase in the common pressure supply at 217, the contacts 226 and 228 are closed by a decrease in the pressure supplied at 244.

The bellows 237 and 233 may be similar to 210 and 210*a* or they may be of different ranges; this in itself does not matter much provided the response rate of instrument 248 is adjusted to make it faster or slower than that of instrument 249, but preferably slightly slower. This can easily be done by watching the movements of pointers 224 and 200, during a slip in the furnace, for example, and adjusting the restrictive needle valves 216, 214, 241, and 243, as well as any other resistances in the pressure system, such as any valves in lines 217 or 244, until arm 224 moves slower than arm 200 during a slip. A calibrated scale 225 may be used, or the markings may be arbitrary as it is not necessary to know the true differential measure, but only to be able to set the distance between contacts 226 and 228 so that they will close during a slip.

In practical operation of blast furnaces the differential pressures are usually as much as 10 to 14 lbs. higher than the top pressure. Rather than to make the calibration of the bellows 237 and 233 in instrument 248 the same as the ranges for bellows 210 and 210*a* in 249, and in order to adapt the differential pressure controller 248 to commercially available differential transmitting or integrating devices such as those operating on compressed air, and which send out output air pressure signals to the receiver that vary from 0 to 17 lbs. per sq. inch gage, for example, it may be preferable to use higher calibration ranges in 248 than in 249. With reference to top pressure instrument 249, if the top gas pressure is to be directly impressed on the instrument through pipe 217, the calibration or range characteristics of both bellows should be such that at the maximum top pressure to be indicated or recorded, the pressure arm pointer 200 will be moved from the no-pressure or zero reference position on the scale to the maximum calibration mark on the scale 206. A typical range for the top pressure controller 249, on the furnaces that are now equipped with differential control, for example, would be a range of 0 to 150 inches of water. The bellows 233 and 237 of the differential instrument 248 would have air pressures of 0 to 17 lbs. per sq. inch impressed at the pressure connection 244 if used to operate from standard commercial pneumatic instrument differential transmitters.

The position of the differential pressure transmitter is shown as 256 in Fig. 7. The differential pressure measured through the furnace is connected to the measuring element of the differential transmitter 256 by means of the top pressure impulse line 250 and the blast pressure impulse line 251, in which are also located shut-off valves 254 and 253 respectively. An equalizing valve, not shown in Fig. 7, may also be used if desired. By closing the valve 254 in line 250 and opening a valve 252 to atmosphere, the calibration of instrument 256 may be easily checked by impressing known air pressures from line 251. A compressed air supply line 255 furnishes compressed air for the operation of the pneumatic transmitter 256 and to line 244.

Fig. 7 also shows electrical relays operating from coils 257, 263, 269, 275, and 295, that are connected into the electrical control circuit between the coil of solenoid valve 284 and the instrument controllers 248 and 249. These relays may be enclosed in a common relay and junction control box or housing, for example, similar to the relay or junction box designated as item 54 in Fig. 1. Power supply lines 246, 247, and 134 are shown to the instruments and to the relays and solenoid valve.

The relay equipped with coil 257 is energized when contact 226 touches contact 228 on a decrease in differential pressure as measured by the counterclockwise movement of differential pressure arm 224 in instrument 248. This relay has two sets of normally open contacts that are closed by the movement of an armature 262 when coil 257 is energized. One set of contacts is shown as 258 and 259, the other set as 260 and 261.

The relay equipped with coil 263 operates to energize the coil when contacts 201 and 202 touch each other in the top pressure instrument 249. This relay has a set of normally closed contacts 265 and 266, and a set of normally open contacts 267 and 268, which are connected to a common armature 264. When coil 263 is energized the normally closed set of contacts 265 and 266 is moved to open-circuit position, while at the same time the normally open set of contacts 267 and 268 is moved from the open to the closed-circuit position.

The relay using operating coil 269 is equipped with an armature 270 having one set of normally closed contacts 271 and 272 and one set of normally open contacts 273 and 274. This relay is so interlocked with the relays operated by coils 257 and 263 and with the solenoid relay coil 284 (and if the normally closed contacts 277, 278, 279, and 280 of the interlocking relay coil 275 which operates from the big bell rod movement, to be described later, are closed) that the circuit through wires 293 and 294 to the solenoid valve coil 284 cannot be energized unless both sets of contacts 201 and 202 and 226 and 228 energize relay coils 263 and 257, respectively, and if coil 263 is energized at precisely the same instant or before coil 257 is energized. That is to say, in order for the coil 284 to be energized (with the aforementioned

contacts **277**, **278**, **279**, **280** closed), relay coil **263** must already be in the energized position when relay coil **257** is energized. If relay coil **257** is energized (by closing of contacts **226** and **228**) before relay coil **263** is energized (by the closing of contacts **201** and **202**), then it is impossible to energize solenoid coil **284** by closing the circuit through lines **293** and **294**. It may be seen, therefore, that the circuit through lines **293** and **294** can only be closed if the top pressure increases at almost the same time that the differential pressure decreases, and only if the changes are great enough that there will be a period when both sets of contacts **201** and **202**, and **226** and **228**, respectively, will be closed. The relative time of closure of each pair of contacts does not matter; one pair may be closed for a longer or shorter time than the other, but it is necessary that for some time at least, both pairs will be simultaneously closed. The relative periods of closed circuit by the closing of each pair of contacts **201** and **202**, or of **226** and **228**, may be controlled to some degree by the settings that will be made by the respective restrictive needle valves **216** and **214**, or **241** and **243**. Alternately a timer may be used to control the time that either or both circuits are closed, in a manner similar to that shown in Fig. 6 if it is desired to control the time duration that the control circuits are closed once the contacts are made, or after the contacts are opened once they have been closed.

Figure 7 shows a means for interlocking the closing stroke of the big bell operation during charging to prevent possible accidental opening of the valve **283** by the increase in top pressure, if by some chance it may be found on some furnaces that at times the rate of top pressure increase (as the top pressure returns to normal after the closing stroke of the big bell operation to charge materials into the furnace) were fast enough to open valve **283** even though there was no slip. The limit switch **282** and the relay coil **275** are energized by electric current supplied from power source lines **246** and **247** when the contact circuit in limit switch **282** is closed. By operating a lever-operated type limit switch **282** from the movement of the large bell rod **38***e*, in a manner similar to that shown in Fig. 1, the limit switch **282** closes its contacts to energize relay coil **275** through wire **281**, which in turn moves relay armature **276** to open the normally closed contacts **277**, **278**, **279** and **280** in circuits **293** and **294**. By setting the limit switch **282** to open the circuit in lines **293** and **294** as soon as the big bell starts to close, and by again closing the limit switch contacts when the big bell is in the closed position again, any accidental operation of valve **283** by energizing solenoid coil **284** from the closing of contacts **201** and **202**, and **226** and **208**, respectively, will be prevented. However, in case a slip should occur during this interval, the top pressure arm **200** must travel sufficient distance as the result of the pressure increase that it will cause the extreme high pressure contact **203** to touch the fixed position high rate contact **204**, which will then close a circuit from power source lines **134***e* which are also wired to operate the solenoid valve coil **284** by means of an interlocking relay whose contacts are so connected to the solenoid valve coil **284** that the coil may be energized to cause valve **283** to open independently of any control action in effect at the time in circuit lines **293** and **294**, or due to energizing the relay coil **275** due to the operation of the limit switch **282**. When contacts **203** and **204** close due to a high rate of increase of top pressure, as may be caused by a slip, they cause the circuits to be closed between the wires **222** and **223**, and cause electric power to flow by means of the wires **291** and **292** which carry electric current from the power source **134***e* to the interlocking relay coil **295** having an armature **297** and its associated normally open sets of contacts **296** and **298**, and **299** and **300**. Connecting wires **301** and **302** convey the electric power from two sets of relay contacts to the circuit of solenoid coil **284**, by connecting contact **298** through wires **302** and **303** to the wire **289** leading to one terminal of coil **284**; the lead **301** connects contact **300** to provide a current flow path to the other terminal of the coil **284** by virtue of its being attached to the wire **290**. Any closure of the contacts **203** with **204** will result in the coils **295** and **284** being energized and thereby causing the valve **283** to quickly bleed blast air to atmosphere. To energize the circuit shown in Figure 7, one line of an electric power source may be connected to line **247** and also to line **223**, while the other line of the power source may be connected to line **246** and to line **291**. While it is believed that the need for a limit switch **282** and the interlocking of the relay coil **275** and its contacts will not be necessary for any furnaces with which the differential pressure control method has been used, it is mentioned in case the need for such a provision should ever arise.

Referring to the description of the 3-way solenoid valve **284** and the relief valve operator **288**, a source of air pressure may be supplied to the diaphragm of the air-operated motor **288**, by energizing the valve solenoid coil **284** so that air pressure will pass through the valve body to the air motor unit by means of the connecting pipe **287**. With the coil **284** of the solenoid valve in a de-energized state, the valve port into which the air pressure supply line **285** is connected is normally closed; at the same time the port **286** is opened to atmosphere; the port into which pipe **287** is connected is open whether the solenoid valve is energized or de-energized.

In connection with the differential controller **248** in Fig. 7, while it has been described as a pressure receiver connected by pressure transmitting pipe **244** to a differential pressure transmitter **256**, the differential pressure transmitter may be replaced by the differential pressure controller **55** shown in Fig. 1. In that case the air supply line **255** in Fig. 7 is equivalent to pipe **77** in Fig. 1; the pressure line **244** in Fig. 7 would then be connected into a controlled air pressure line equivalent to pipe **84** in Fig. 1. It is to be understood also, that while I have used the basic mechanism of Fig. 2 as the top pressure controller **249** and the differential pressure controller **248** of Fig. 7, any of the mechanisms shown in the Figs. 3, 4, 5 or 6 may be incorporated in the instruments **249** and/or **248** in place of the type of mechanisms shown in Fig. 7. And, as shown, parts **221**, **209**, **219**, **220**, **211***a*, **212**, **212***a*, **207**, **215**, **213** and **218** in basic mechanism **249** function in the manner of parts **227**, **229**, **230**, **231**, **235**, **238**, **239**, **239***a*, **240**, **242** and **245** in controller **248**, respectively.

As an alternate to interlocking the differential pressure measurement between pressure lines **250** and **251**, as indicated by the pressures in pressure line **244**, with the top pressure measurement in lines **250** and **217** in Fig. 7, I may also take the pressure for operating the instrument **248** directly from the blast line **251** only, and in this way to influence the operation of the solenoid valve **284** and valve **283** by the interconnected control action of the top pressure and of the blast pressure. For this purpose the pressure pipe **253** may be connected directly to the connecting pipe **244** of instrument **248**. While this alternate method may not respond quite as fast as by interconnecting differential pressure with top pressure, it may nevertheless be used in a similar manner. Any reference to the use of interconnected control actions between the top pressure and differential pressure will therefore be understood to be substantially the same as the effect of interconnecting the control actions between the top pressure and the blast pressure.

Various embodiments and practices of this invention have been disclosed herein without limitation of the invention thereto and various other modifications may be made without departing from the spirit of this invention or the scope of the appended claims.

I claim:

1. In a control for a blast furnace, in combination, a

pressure tap responsive to the top gas pressure in said furnace, means including a diaphragm member connected to said pressure tap and substantially solely responsive to changes in said pressure in said blast furnace, a contact movable by said diaphragm member in a particular direction in accordance with increases in said pressure, and a second contact spaced from said first mentioned contact in said direction, said spacing being sufficiently distant so that normal rates of increase in said pressure will not bring said contacts into engagement where as abnormal increases in the rate of increase of said pressure will, and means operative upon the engagement of said contacts to provide a differential of pressure across said furnace conducive to orderly downward movement of stock in said furnace.

2. In a control for a blast furance, in combination, a pressure tap responsive to the top gas pressure in said furnace, means including a diaphragm member connected to said pressure tap and substantially solely responsive to changes in said pressure in said blast furnace, a contact movable by said diaphragm member in a particular direction in accordance with increases in said pressure, a second contact spaced from said first mentioned contact in said direction, means for maintaining said spacing generally uniform under any relatively steady value of said pressure, said means further being adapted to maintain said spacing sufficiently distant so that normal rates of changes in said pressure may change said spacing at the time being without bringing said contacts into engagement, and means operative upon the engagement of said contacts to provide a differential of pressure across said furnace conducive to orderly downward movement of stock in said furnace.

3. In a blast furnace control system, in combination, pressure taps respectively communicating with different levels of said blast furnace, said blast furnace having a blast air supply, a pressure differential controller connected to said pressure taps, pressure regulating means including valves respectively adjacent the top and bottom of said furnace, an impulse line extending between said controller and said pressure regulating means to transmit signals for corrective regulation of the pressure differential existing across said pressure taps by selective modulation of at least one of said valves, a top gas pressure controller responsive to an excessive increase in any rate of increase in the top gas pressure as communicated by any of said signals, valve means connected to said blast air supply to said blast furnace, and a second impulse line extending between said top gas pressure controller and said last mentioned means to open said valve means and thereby augment or hasten the corrective action of said pressure differential controller whenever said excessive increase occurs.

4. In a blast furnace control system, in combination, a pressure differential controller responsive to pressure to control the pressure differential between the top and bottom of said furnace, a top gas pressure controller responsive to a predetermined rate of increase in the top gas pressure of said blast furnace, said last mentioned controller having a member movable in response to said predetermined rate and a member floating in closely spaced relation thereto for engagement by said first mentioned member upon the occurrence of such predetermined rate of increase, and a second differential pressure controller adapted to measure a predetermined decrease among any rates of decrease of said pressure differential and to transmit a corrective control signal to said first-mentioned pressure differential controller in the event of such engagement and the occurrence of such a predetermined decrease.

5. In a blast furnace control system, apparatus comprising, means operative to measure the differential pressure across the blast furnace, means responsive to said differential pressure in accordance with said measurements to keep said differential pressure within a range conducive to orderly downward movement of the furnace burden by performing at least one selective modulating action among actions for raising the top gas pressure and lowering the blas air pressure, means responsive substantially solely to any excessive rate of increase in said top gas pressure as indicative of abnormal conditions among the rates of increase in said top gas pressure, and means operative upon the occurrence of any such excessive rates of increase to reduce the blast air pressure at the time being.

6. In a blast furnace control system, apparatus comprising, means operative to indicate the differential pressure across the blast furnace, means responsive to said differential pressure in accordance with said indications to keep said differential pressure within a range conducive to orderly downward movement of the furnace burden by performing at least one selective modulating action among actions for raising the top gas pressure and lowering the blast air pressure, means responsive substantially solely to any excessive rate of increase in said top gas pressure as indicative of abnormal conditions among the rates of increase in said top gas pressure, means operative upon the occurrence of any such excessive rates of increase to reduce the blast air pressure below that existing at the time of said occurrence, and means responsive to the cessation of any such excessive rates of increase to return control to said second-named means.

7. In a plural control for a blast furnace having a blast air pipe, in combination, pressure taps respectively communicating with different levels of said blast furnace, a power-operated auxiliary snort valve connected to the blast air pipe at the bottom of said furnace, a valve in the gas main leading from the top of said blast furnace, a differential pressure controller connected to said pressure taps, an impulse line extending from said controller to transmit signals varying in accordance with the pressure differential existing across said pressure taps, means to integrate the corrective action of both said valves by the modulation thereof concurrently and in accord with said signals, and means to measure excessive rates of increase in the top gas pressure of said blast furnace and transfer corrective action control to said last mentioned means from said controller upon the occurrence of such a predetermined rate of increase in said top gas pressure.

8. In a plural control for a blast furnace, in combination, pressure taps respectively communicating with differential levels of said blast furnace, a blower to supply blast air to said furnace, means to regulate the speed of said blower, a valve in the gas main leading from the top of said blast furnace, an operator connected to said valve to modulate the same, a differential pressure controller connected to said pressure taps, an impulse line extending from said controller to transmit signals varying in accordance with the pressure differential existing across said pressure taps, said means and said operator being connected to said impulse line to generally concurrently proportion the corrective action of both said means and said valve with said signals, and a top pressure controller adapted to sense rates of increase in the top gas pressure of said blast furnace and to take over corrective control action upon the occurrence of such rates of increase in said top gas pressure beyond a predetermined rate of increase.

9. In a pressure instrument, a movable contact swingably responsive to the rate of change of a pressure, said movable contact having a zero position for a steady pressure, a second contact spaced from said zero position by a distance greater than the amplitude of the swings of said movable contact under normal operating conditions wherein such a pressure is exerted, and means for engaging said contacts when said rate of change is greater than a predetermined quantity.

10. In a pressure instrument, a movable contact responsive to a pressure, a second movable contact, means for maintaining the second movable contact in relatively

uniformly spaced relation to the first mentioned contact, said means being operative at a rate less rapid than the response of said first mentioned movable contact when a change in pressure occurs, and means for causing said first-mentioned movable contact to overtake and engage said second movable contact when an excessive rate of change in pressure occurs.

11. In a pressure instrument, a pressure impulse line, a flexible diaphragm member connected to said impulse line and responsive thereto through a branch line, a second flexible diaphragm responsive to the pressure in said impulse line and connected therethrough to a second branch line, said branch lines being in parallel and having different fluid flow resistances respectively therein, the first mentioned of said diaphragm members being connected to a pressure responsive contact arm, the second of said diaphragm members being connected to a further pressure responsive contact arm to independently move said further pressure responsive contact arm, said contact arms having a common axis, and means for changing the angular relation between said respective contact arms upon the occurrence of rate changes in the pressure in said impulse line.

12. In a pressure instrument, a pressure indicating impulse line, opposed diaphragm members connected to said impulse line for operation thereby at respectively different rates, a contact arm connected to both said diaphragm members, means for moving said diaphragm members and said contact arm in accordance with a rate of change in the pressure in said impulse line, a first contact for engagement by said contact arm upon the occurrence of such change, means for delaying the return of said contact arm immediately following the end of such change, and a second contact for engagement by said contact arm when said rate of change exceeds a predetermined magnitude.

13. In a pressure instrument, a pressure impulse line, a bellows housing, a bellows in said housing, a branch line connected to said impulse line and to the interior of said housing exteriorly of said bellows, a second branch line connected to said impulse line and the interior of said bellows, fluid flow resistances of unlike magnitudes in said branch lines, a contact arm linked to said bellows responsive to rates of change in pressure in said impulse line, said contact arm being pivoted, and other contacts on each side of said contact arm, and means to cause at least one of said other contacts to be engaged by said contact arm upon the happening of an excessive rate of change thereby moving said contact arm a greater distance in that direction.

14. In a pressure instrument, a pressure impulse line, an axially movable bellows connected to said impulse line through a branch line, a pivoted contact arm connected to said bellows, a second flexible bellows connected to said impulse line through a parallel branch line, a second contact arm connected to said second bellows about said pivot, said respective bellows being connected to their respective contact arms at approximately the same distance from said pivot, said respective branch lines having fluid flow resistances of different magnitude respectively therein, a third contact, one of said contact arms being operated through said branch line having a lower resistance therein and being on the outside of the other of said contact arms opposite to said third contact, and means to cause the outside contact arm to overtake and contact said other contact arm upon a change in pressure in said impulse line beyond a predetermined magnitude causing movement toward said other contact arm, and both said contact arms will move toward said third contact to cause engagement thereof upon a still further change in pressure in said impulse line beyond said predetermined magnitude.

15. In a pressure indicating instrument, a pressure impulse line, axially movable members in opposed relation, a contact arm connected to both said members, said members being respectively connected to said impulse line by branch lines having differential resistances therein to enable said contact arm to measure rates of change of pressure in said impulse line, at least a pair of contacts in alignment with said contact arm, said pair of contacts being spaced from said contact arm and from each other whereupon a rate of change of pressure of one magnitude in said impulse line will bring said contact arm into contact with the nearer of said pair of contacts while a greater rate of change of pressure will bring said contact arm into contact with both said pair of contacts.

16. In a pressure indicating instrument, a pivoted contact arm, a diaphragm member connected to said contact arm to move it, an impulse line connected to said diaphragm member to move said contact arm in response to changes in pressure in said impulse line, a follower plate pivoted about the same axis as said contact arm, movable contacts on said follower plate on each side of said contact arm, a reversible motor to oscillate said follower plate generally in accordance with the movements of said contact arm, a second contact arm attached to said follower plate in angular relation to said first mentioned contact arm, and a contact on said last-named contact arm to engage said contacts on said follower plate respectively.

17. In a control for a blast furnace, in combination, pressure taps respectively communicating with different levels of said blast furnace, a power-operated snort valve connected to the blast air pipe at the bottom of said furnace, a valve in the gas main leading from the top of said furnace, a differential pressure controller connected to said pressure taps, an impulse line extending from said controller to transmit signals varying in accordance with the pressure differential existing across said pressure taps, means to operate at least one of said valves in response to said signals to maintain said pressure differential within a range conducive to orderly downward movement of stock in said furnace, and means to indicate an excessive rate of increase in the top gas pressure of said blast furnace and to operate said snort valve in response to said indication to provide a differential pressure across said furnace within said range.

18. In a pressure indicating instrument, a diaphragm member movable in response to a variable pressure condition in a system, a movable contact connected to said member to indicate said pressure condition, a second member generally movable at a rate different from the rate of movement of said first-named member, said members being interconnected to indicate movements of said first-named contact at least beyond a predetermined distance for normal variations in said pressure condition, and a second contact in positioned relation to said first-named contact to coact therewith to provide a signal impulse upon the occurrence of a predetermined abnormal rate of variation in said pressure condition when said first-named contact moves beyond said predetermined distance.

References Cited in the file of this patent

UNITED STATES PATENTS

Re. 20,092	Mason	Sept. 1, 1936
2,005,773	De Florez	June 25, 1935
2,031,502	Powell	Feb. 18, 1936
2,041,014	Norton	May 19, 1936
2,083,046	Burke	June 8, 1937
2,092,560	Runaldue	Sept. 7, 1937
2,228,769	Klinker	Jan. 14, 1941
2,436,444	Merrick	Feb. 24, 1948
2,479,616	Hasselhorn	Aug. 23, 1949
2,529,875	Howard	Nov. 14, 1950
2,625,386	Leone	Jan. 13, 1953
2,633,858	Eckman	Apr. 7, 1953
2,656,429	Tietjen	Oct. 20, 1953

FOREIGN PATENTS

575,562	Germany	Apr. 29, 1933
530,377	Great Britain	Dec. 11, 1940