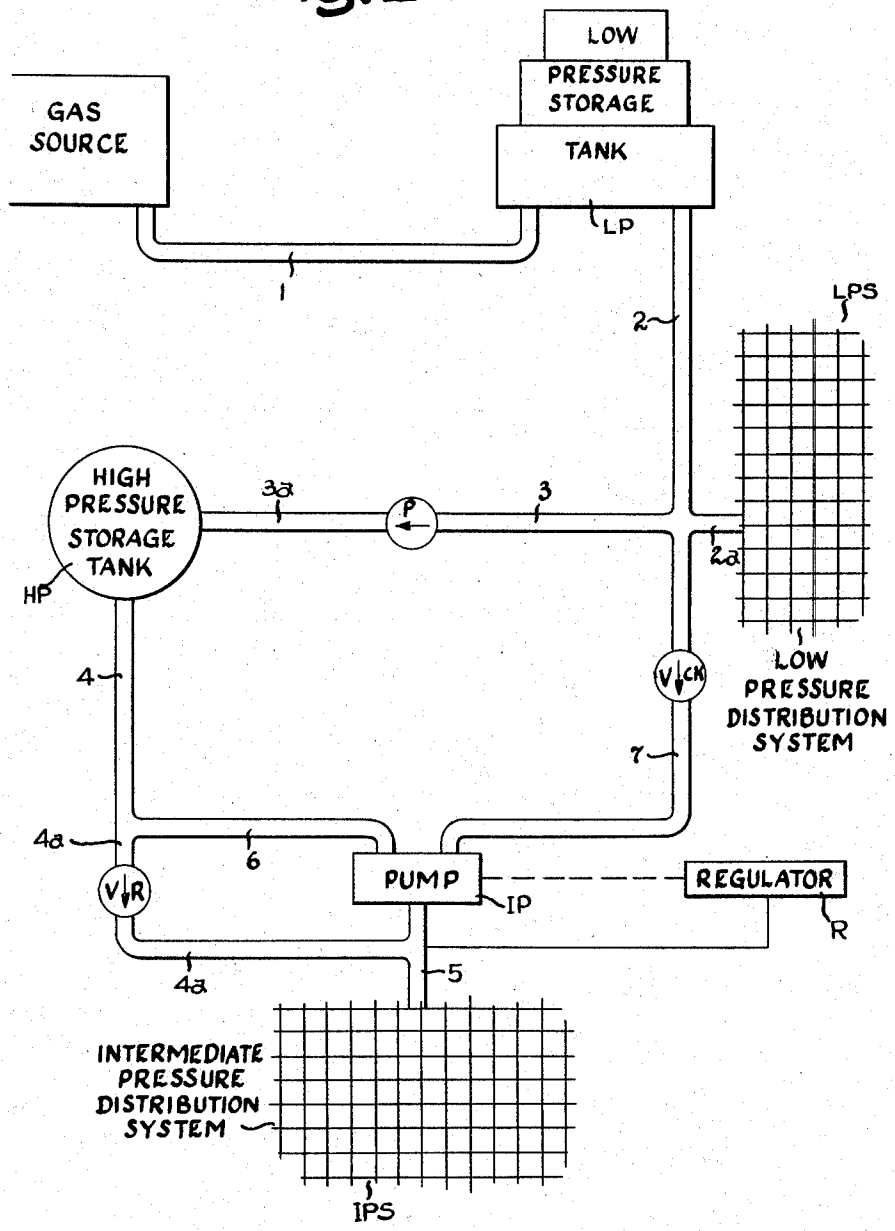
Feb. 10, 1959 T. M. GILBERT 2,873,180

GAS DISTRIBUTION MEANS

Original Filed Nov. 12, 1953 2 Sheets-Sheet 1

Fig. 1



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Original Filed Nov. 12, 1953 2 Sheets-Sheet 2

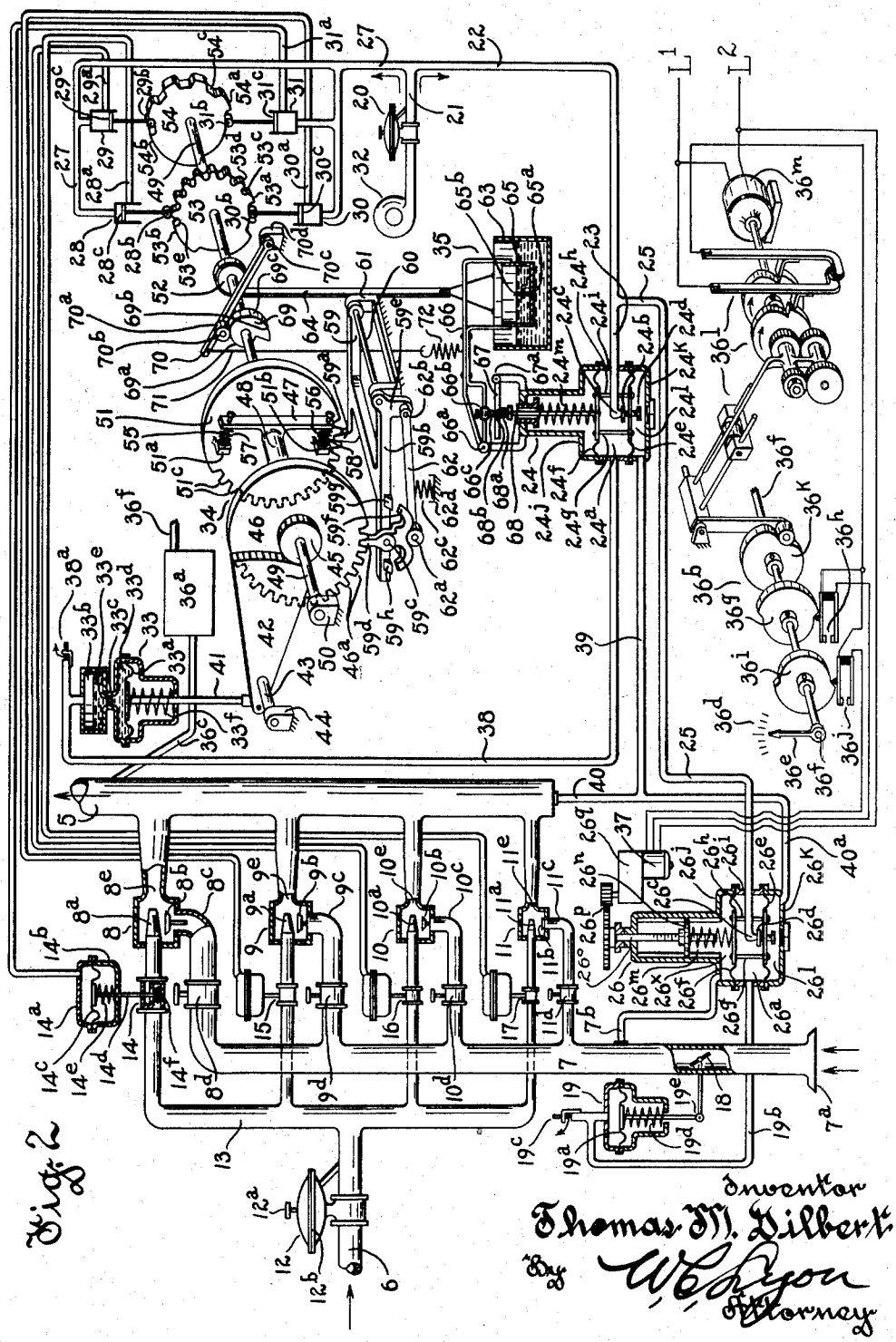


Fig. 2

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2,873,180

GAS DISTRIBUTION MEANS

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Continuation of application Serial No. 391,483, November 12, 1953. This application March 14, 1957, Serial No. 646,172

2 Claims. (Cl. 48—191)

This invention relates to improvements in means for supplying gas to gas distribution systems.

This is a continuing application of my application Serial No. 391,483, filed November 12, 1953, now abandoned.

Modern gas supply systems frequently require gas to be distributed at both low and intermediate pressures. Inasmuch as the peak demands for gas in both the low pressure and intermediate pressure systems often exceed the rate at which the gas is supplied from its source, gas storage equipment must be provided. It has been customary, in such systems, to provide means to store some gas at low pressure to be released directly into the low pressure distribution system and to provide means to store a quantity of the gas at high pressure to be released to the intermediate pressure distribution system through a suitable pressure regulator.

However, the quantity of gas which can be supplied to the intermediate distribution system from the high pressure storage equipment is limited by the capacity of the latter so that a very large and expensive high pressure gas holder is usually required. Moreover, a large amount of energy, which is costly to provide and most of which is not recovered, is expended in pumping gas into the high pressure holder.

Accordingly, a primary object of the invention is to provide improved means for distributing gas.

Another object is to provide means for distributing gas efficiently and at unusually low cost.

Another object is to provide improved means whereby the ratio of the quantity of gas supplied to an intermediate pressure system to the quantity of gas stored at high pressure is increased.

Other objects and advantages of the invention will hereinafter appear.

The accompanying drawings illustrate an embodiment of the invention in the form of a distribution system of a public utility gas company, it being understood that other embodiments of the invention are possible without departing from the scope of the appended claims.

In the drawings,

Fig. 1 schematically shows a gas distribution system constructed in accordance with the present invention; and

Fig. 2 is a partly schematic and partly diagrammatic illustration of an intermediate pressure pump and regulator employed in the system of Fig. 1.

Referring to Fig. 1, the system comprises a low pressure storage tank or holder LP, a high pressure storage tank or holder HP, a pump IP, a low pressure distribution system LPS, and an intermediate pressure distribution system IPS. The system further comprises a high pressure pump P, a regulating valve VR and a check valve VCF.

The pump IP represents a unit of any type which can utilize the energy stored in compressed gas to pump other, lower pressure, gas. It preferably, but not necessarily, comprises multiple rate compressors; which preferably are of the jet compression type. It may comprise,

for example, a multiple rate jet compressor of the type hereinafter described in connection with Fig. 2 and disclosed in United States Patent No. 2,637,638, granted May 5, 1953, to Edwin X. Schmidt, as assignee of Cutler-Hammer, Inc. The character R designates a controller or regulator for pump IP, also shown in the right-hand portion of Fig. 2.

Gas is delivered from a suitable source through a conduit 1 at low pressure to holder LP where it is stored. Some of the gas is permitted to flow to the low pressure distribution system LPS through conduits 2 and 2*a*. Other gas, which flows from holder LP through conduits 2 and 3 to pump P, is pumped by the latter through conduit 3*a* to high pressure tank HP where it is stored at high pressure.

Conduits 4 and 6 connect the high pressure holder HP to pump IP and deliver gas to said pump. There the energy stored in the gas from tank HP is utilized to pump low pressure gas, supplied to pump IP from holder LP through conduits 2 and 7, through a conduit 5 at an intermediate pressure to intermediate pressure distribution systems IPS.

The regulator R controls the rate at which gas is pumped into the intermediate pressure system so that the pressure in said system is maintained at a proper value. The check valve VCK may be incorporated in the pump IP as in the jet compressor hereinafter described in connection with Fig. 2.

A branch conduit 4*a* connects high pressure storage tank HP to conduit 5 and the intermediate pressure distribution system IPS through pressure regulating valve VR. The valve VR is set to open at a pressure below the minimum safe operating pressure of distribution system IPS and to close at a pressure at or above the normal, desired pressure which is maintained in distribution system IPS by pump IP. Thus, in normal operation valve VR remains closed.

The gas supplied by pump IP to distribution system IPS comprises a mixture of high pressure gas from holder HP and low pressure gas from holder LP. Pump P is controlled manually or automatically at selected times to maintain the gas in holder HP at a pressure substantially higher than the discharge pressure of pump IP. Thus the mixture of gas comprises a relatively small proportion of high pressure gas and a relatively large proportion of low pressure gas. If, because of a power failure or for any other reason, pump P ceases or is ceased to operate, pump IP continues operating at maximum efficiency to maintain the intermediate pressure for a substantial period of time, but the pressure in holder HP is diminished as gas is released from it to pump IP. As the pressure in holder HP is decreased, the ratio, in the gas flowing through pump IP, of gas from holder LP to gas from holder HP remains at a maximum for the corresponding nozzle pressure. Check valves in the individual compressor units of pump IP or check valve VCK prevent gas from flowing through pump IP from distribution system IPS to holder LP after the pressure in holder HP is reduced to a value below that required to assure pumping of the low pressure gas against the pressure in the intermediate pressure distribution system.

Should the pumping rate of pump IP fail to meet the demand for gas in the intermediate pressure distribution system IPS, the pressure in conduit 5 would fall below the desired, normal value. Regulating valve VR would then open and gas would be supplied to distribution system IPS directly from holder HP at a pressure not lower than the minimum safe operating pressure of system IPS.

In Fig. 2 the numeral 5 designates a discharge manifold or conduit (also shown in Fig. 1) of relatively large cross

section supplying a combustible mixture of gases to the intermediate pressure distribution system shown in Fig. 1, with conduit 6 arranged to supply high pressure gas to gas pumping units 8, 9, 10 and 11, for pumping low pressure gas from conduit 7 into conduit 5. A regulator 12 of well known form is associated with conduit 6 in a manner to maintain the pressure in the manifold 13, and consequently at the inlet ends of the respective shutoff valves 14, 15, 16 and 17, at a fixed value, which may be preselected by manual adjustment of knob 12*a* to vary the degree of spring loading of the diaphragm of regulator 12, indicated somewhat diagrammatically at 12*b*.

Valves 14 to 17 are normally closed by springs individual thereto, and go wide open when a preselected degree of fluid pressure is applied at the upper surfaces of their respective diaphragms. The operating means for the valve 14 is shown enlarged and in section, and diagrammatically, as comprising upper and lower fixed housing portions 14*a* and 14*b*, with a diaphragm 14*c* interposed therebetween; a valve rod 14*d* being suitably attached to diaphragm 14*c*, and a coiled spring 14*e* being interposed between the bottom wall of housing portion 14*b* and diaphragm 14*c* to normally bias the valve disk 14*f* against its seat to close the valve; said parts being shown, however, in valve-opening position. It is to be understood that the operating elements of valves 15, 16 and 17 may be of substantially the same size as the corresponding elements of valve 14, with the exception that the valve disks and their seats are preferably of sizes proportional to the sizes of the branch conduits in which they are respectively located.

The gas pumping units 8 to 11, inclusive, are preferably of the ejector or jet compressor type, as shown; the same differing in size or dimensions in the relationship of a geometrical progression, as hereinafter described. The gas which flows through conduit 7 preferably consists of low pressure gas and the enlarged inlet end 7*a* of conduit 7 connected to low pressure holder LP may include a screen or other suitable form of filtering means (not shown).

The branch streams of high pressure gas flow through the jets 8*a*, 9*a*, 10*a* and 11*a* of the respective units, which are provided with check valves 8*b*, 9*b*, 10*b* and 11*b* in the branch conduits 8*c*, 9*c*, 10*c* and 11*c* through which the low pressure gas is supplied. The discharge of each ejector unit enters the discharge manifold 5 and thence passes to the intermediate pressure distribution system. The low pressure gas duct 8*c*, 9*c*, etc., of each ejector unit includes a manually adjustable throttling valve 8*d*, 9*d*, 10*d* and 11*d*, respectively. Gas enters the low pressure gas conduit or duct 7 through a throttling valve 18.

The gas pumping units 8 to 11, inclusive, are preferably of like construction, but differ in their respective sizes, as aforementioned; the sizes thereof being so selected that each unit has twice the pumping capacity of the next smaller unit. Thus, in a four-unit plant like that illustrated in Fig. 2, with the smallest unit 11 of predetermined capacity, the next larger unit 10 will have twice that capacity; the next larger unit 9 will have four times the capacity of unit 11, and the largest unit 8 will have eight times the capacity of unit 11. Accordingly, the units 8 to 11, inclusive, when active individually or jointly in various combinations, are adapted to provide fifteen equal steps of increase or decrease in the pumping rate of the gas; each step corresponding to 6⅔ percent of the total pumping capacity of the entire plant. The aforementioned throttling valve 18, which may be of the butterfly type, in the low pressure manifold 7 is operable automatically by a diaphragm motor 19, in the manner hereinafter described, to maintain substantially constant the difference between the values of the pressures within the low pressure manifold 7 and the aforementioned discharge manifold 5.

From the foregoing it will be apparent that the number of gas pumping units might be increased from four to five, and again sized in geometrical progression; in which case thirty-one rates of gas pumping would be obtained, each increment in flow corresponding to 3.225 percent of the total pumping capacity of the entire plant.

An adjustable regulator 20 of well known form is adapted to control the pressure of compressed air supplied to conduit 21, one branch 22 of which communicates, through conduit 23 under given conditions, with the interior of pilot regulator 24, and through conduit 25 under given conditions, with the interior of pilot regulator 26. The other branch 27 of conduit 21 is adapted to communicate as shown with the four valve mechanisms 28, 29, 30 and 31. In practice I prefer to maintain the compressed air pressure in conduit 21 and in parts associated therewith at approximately twenty-five pounds per square inch. An air compressor is shown diagrammatically at 32.

The housings of valves 28, 29, 30 and 31 communicate, through conduits 28*a*, 29*a*, 30*a* and 31*a*, with the diaphragm motors associated with the aforementioned valves 17, 16, 15 and 14, respectively, to effect opening of one or more of the latter under predetermined conditions, against the normal spring bias thereof to closed position; the biasing spring of valve 14 being shown at 14*e*, as aforestated.

Pilot regulator 24 is adapted for operation in a manner to control the action of a diaphragm motor 33 to effect step by step actuation of the rate scheduling mechanism designated in general by the numeral 34, with consequent control of the aforementioned valves 28 to 31, inclusive.

The hydraulic stablizing means designated in general by numeral 35, is adapted to modify the operation of pilot regulator 24 in a manner to prevent undesirable adjustments of the scheduling mechanism 34 and to prevent hunting.

Calorimetric control means (parts of which are shown at 36*a* and other parts of which are shown at 36*b*) are adapted to control the degree of spring loading on pilot regulator 26, through the medium of a reversible motor 37; the latter being operable automatically in the manner hereinafter described to maintain substantially constant the total heating value per unit volume of the gaseous mixture supplied to discharge manifold 5.

Operation of the gas mixing control system illustrated in Fig. 2 is as follows: Assuming that the system is in operation producing a combustible gaseous mixture of the desired total heating value per unit volume at a volumetric rate which exactly corresponds with the demand for said mixture from the distribution system, and further assuming that the air pressure in conduit 38 (which affords communication between pilot regulator 24 and diaphragm motor 33) is at the desired value predetermined by the setting of pilot regulator 24. Under these conditions the net flow into the intermediate pressure distribution system is zero and the distribution pressure will, of course, remain constant.

In the event of an increase in demand for the gas in the intermediate pressure distribution system corresponding to 3 percent of the maximum capacity of the plant, the net flow into the distribution system would be minus 3 percent, and the distribution pressure would decrease at a rate depending upon the capacity of the distribution system and the maximum capacity of the plant. Said decrease in distribution pressure causes pilot regulator 24 to increase the degree of loading of diaphragm motor 33; which change in loading tends to and finally does (if unbalance of pilot regulator 24 continues long enough) cause a step in the operation of mechanism 34 in a direction to initiate operation of one of the gas pumping units (8 to 11) and to discontinue operation of one or more of the other of said units (if necessary), to thereby produce an increase in the rate of gas pumping corresponding to 6⅔ percent of full plant capacity. Said increase in loading of diaphragm motor 33 also reacts through the medium of hydraulic stabilizer 35 to at least temporarily ef-

fect a decrease in the degree of loading of pilot regulator 24.

Hydraulic stabilizer 35 is preferably arranged or adjusted in a manner to exert a force on pilot regulator 24 of sufficient value to temporarily actually reverse the direction of movement of diaphragm motor 33 to a slight degree, under the conditions just mentioned. The controlling effect of stabilizer 35 gradually disappears during the time when the distribution pressure builds up, due to the resultant flow into the intermediate pressure distribution system of 3⅓ percent of the total plant capacity; that is to say, the difference between the increase in the rate of gas pumping (6⅔ percent) and the minus 3 percent of net flow incident to the increase of demand of 3 percent of the total plant capacity. Pilot regulator 24 therefore causes no appreciable movement of diaphragm motor 33 until the net flow gradually builds up the distribution pressure to a value predetermined by the initial degree of loading of regulator 24 unaffected by the action of hydraulic stabilizer 35.

Inasmuch as the position of the diaphragm 33*a* of diaphragm motor 33 is substantially directly related to the pressure maintained by pilot regulator 24, it is, of course, possible to increase the degree of pressure of fluid (from regulator 24) upon the body of liquid in chamber 33*b*, as an incident to each given increase in the rate of gas pumping, while still preventing excessive hunting, by increasing the auxiliary loading effect produced by the hydraulic stabilizer 35. The means for and manner for attaining this result will be described in detail hereinafter.

It is to be understood that under certain conditions the rate of demand for gas may vary rapidly, so that the action of hydraulic stabilizer 35 may not have been dissipated by the time another step (increase or decrease) in the rate of gas pumping becomes necessary. Therefore, two or even three, steps may be taken in quite rapid succession. The stabilizer 35 is therefore so constructed and arranged that the effect thereof is limited to the equivalent of several steps, so that maximum temporary deviation from the desired control point cannot exceed a predetermined value.

If cup 65 is depressed about two steps the rise in liquid level outside of the cup is enough to make the liquid spill over the top thereof. If cup 65 is raised about two steps the fall in liquid level outside of the cup is enough to fall below the bottom of cup 65; so that farther lifting of the cup causes no change in the degree of loading of regulator 24. It is obvious that upon high rates of demand from the intermediate pressure distribution system, when the bucket 63 is high, more lifting and less depressing of the cup 65 than the aforementioned two steps would be required for the release to occur.

The aforementioned calorimetric device, although shown more or less diagrammatically at 36*a*, 36*b*, is to be understood as including well known structural features and operative characteristics of each of the following patents, to which reference may be had for a more complete understanding of said device, namely: No. 1,625,277, granted April 19, 1927, to Horace N. Packard; No. 2,002,279, granted May 21, 1935, to Edwin X. Schmidt; No. 2,415,913, granted February 18, 1947, to Edwin X. Schmidt; No. 965,824, granted July 26, 1910, to Morris E. Leeds, and No. 1,125,699, granted January 19, 1915, to Morris E. Leeds.

Thus the portion 36*a* includes means for withdrawing, through conduit 36*c*, from distribution manifold 5, a continuous sample of the gaseous mixture, the total heating value per unit volume of which is continuously ascertained, and indicated at scale 36*d* by a pointer 36*e* fixed to the shaft 36*f*. A cam member 36*g* attached to shaft 36*f* is operable to effect closure of the "high" direction contacts 36*h*, and a cam member 36*i* also attached to shaft 36*f* is operable to effect closure of the "low" direction contacts 36*j*. Also attached to shaft 36*f* is a cam member 36*k* which cooperates with the various elements designated in general by the numeral 36*l* for regulating the "part time on" during which the heating value adjusting motor 37 may be operated in one direction or the other to adjust the degree of loading of the pilot regulator 26. The elements 36*l* as shown include an electric motor 36*m* connected with supply lines L1, L2, for continuous operation thereof unidirectionally. The specified means for controlling operation of motor 37 are substantially like those shown and described in Patent No. 2,415,913 aforementioned, to which reference may be had. As aforestated, the pilot regulator 26 is primarily responsive to variations in the pressure difference between the suction manifold 7 for the low pressure gas and the pressure within discharge manifold 5.

The pilot regulator 26 includes an assembly comprising a pair of diaphragms 26*e* and 26*f*, the central portions of which are backed by rigid metal plates, and the plates and diaphragms are attached in spaced relationship by a suitable number of rods or studs, two or which are shown at 26*g* and 26*h*. The periphery of diaphragm 26*e* is clamped between a lower housing member 26*k* and an intermediate housing member or ring 26*i*, a lower chamber 26*l* being provided thereby. The periphery of diaphragm 26*f* is clamped between ring 26*i* and the upper housing member 26*j*; thus providing an intermediate chamber 26*a* and an upper chamber 26*x*. The aforementioned conduit 25 extends through ring 26*i* in pressure-tight relationship and terminates in a nozzle 26*c* with which an adjustable seat member 26*d* is adapted to cooperate to effect closure or opening of the nozzle or to permit a variable rate of flow of compressed air through the latter. Conduits 40 and 40*a* afford communication between the aforementioned discharge manifold 5 and chamber 26*l* to subject diaphragm 26*e* to the pressure of the intermediate pressure gas in manifold 5.

A conduit 7*b* affords communication between the low pressure conduit 7 and the aforementioned chamber 26*x*, whereby the diaphragm 26*f* is subjected to the degree of pressure (or partial vacuum) existing in conduit 7. Diaphragm 26*f* is normally subjected to the pressure of a coiled compressed spring 26*m*; the degree of compression of said spring being adjustable by an abutment 26*n* in the form of a traveling nut, whose position is varied upon rotation of a threaded shaft 26*o* in one direction or the other. Shaft 26*o* is adapted to be driven, through gearing 26*p* and suitable speed-reducing gearing 26*q*, by a split-field reversible motor 37, which is subject to control by the aforementioned means 36*b* operable by the calorimeter 36*a*.

The upper surface of diaphragm 19*a* of diaphragm motor 19 is subjected to the pressure of fluid within chamber 26*a* through a medium of a conduit 19*b*; said pressure being adjustably vented to atmosphere by the means shown at 19*c*. Diaphragm 19*a* is loaded for normal movement thereof in an upward direction (to effect full opening of valve 18) by a spring 19*d*; suitable leverage 19*e* being interposed between diaphragm 19*a* and valve 18 for this purpose. By the means aforedescribed a preselected normal differential value of the pressure conditions in conduits 5 and 7 is insured, thus insuring maintenance of proportionality of the flows of high pressure gas and low pressure gas in the active gas pumping units. For the purpose of providing the desired proportionality, initial manual adjustment of valves 8*d* to 11*d*, inclusive, is involved. That is to say, the valves 8*d* to 11*d*, inclusive, are adjusted to compensate for any minor variations in the inherent proportioning characteristics of the respective gas pumping units with respect to each other. The last mentioned normal differential value is automatically varied in accordance with an operation of calorimeter 36*a* to insure maintenance of a predetermined constant total heating value per unit volume of the gaseous mixture supplied to the intermediate pressure distribution system through manifold 5.

The operation of the step by step mechanism 34 is as follows: The rate of flow of compressed air through conduits 22 and 23 into chamber 24a of pilot regulator 24 is controlled by movement of valve seat 24b relatively to valve nozzle 24c. Valve seat 24b is adjustably mounted, as by means of bolt 24d, upon the lower diaphragm 24e of the assembly including the upper diaphragm 24f; the diaphragms 24e and 24f being rigidly attached to each other in spaced relationship by a multiplicity of posts, two of which are shown at 24g and 24h. The peripheries of the diaphragms 24e and 24f are clamped between the ring 24f and the top and bottom housing members 24j and 24k; thus forming the aforementioned chamber 24a between diaphragms 24e and 24f, and the chambers 24l between the lower diaphragm 24e and housing 24k. Conduits 40 and 39 afford communication between discharge manifold 5 and chamber 24l, so that the lower face of diaphragm 24e is subjected to the degree of pressure existing in the intermediate pressure distribution system.

The effective areas of diaphragms 24e and 24f are substantially equal when the diaphragm assembly (24e, 24f, 24g, 24h) is in the normal operating position, which is determined by the position of valve seat 24b with respect to said diaphragm assembly and the distance which must separate the valve nozzle 24c from valve seat 24b to satisfy the normal rate of flow out of chamber 24a. The distance just mentioned varies only to a very slight degree as an incident to variations in the degree of pressure in chamber 24a and such variations in distance do not appreciably affect the effective areas of diaphragms 24e and 24f, and therefore the forces exerted by the variable pressure on these diaphragms remain substantially equal and opposite, provided that normal operating positions are properly adjusted. Valve seat 24b is adjustably mounted in the diaphragm assembly, so that by raising or lowering the valve seat in the diaphragm assembly the normal operating position of the diaphragm assembly is either lowered or raised, changing the relative effective areas of the diaphragms. Raising the diaphragm assembly makes the relative effective area of the top diaphragm 24f larger than that of the lower diaphragm 24e, so that an increase in loading pressure in chamber 24a, associated with increase in rate of gas pumping, exerts an upward force on the diaphragm assembly, and thus reduces the loading on the regulator 24. Thus by lowering valve seat 24b in the diaphragm assembly the control point of regulator 24 can be made to become lower as a function of the pressure in chamber 24a, or regulator 24 can be made to depart from full floating type of control and give proportional control in which the controlled pressure is reduced as the maintained pressure in chamber 24a is increased. The stability of control inherent in proportional mode of control provided by this characteristic may in some instances be desirable, particularly in instances where exceedingly long time lags are involved in the system. Under any condition the departure from the control point corresponding to a single step of make will be small so that the control point of regulator 24 is substantially unaffected by the loading pressure in chamber 24a.

Pilot air from chamber 24a passes through conduit 38 to the chamber 33b forming an oil pot, said chamber 33b being adjustably vented to a low pressure point, such as the atmosphere, through an adjustable orifice 38a. A reduced portion of conduit 33c is positioned between chamber 33b and the upper chamber 33d of the diaphragm motor 33; said reduced portion having therein an orifice 33e which affords communication between said chambers 33b and 33d. Diaphragm 33a of motor 33 is biased upwardly by a coiled compression spring 33f. Chambers 33d and 33b contain a sufficient quantity of a suitable liquid, such as mineral oil, to insure the presence of some of the oil in chamber 33b even though diaphragm 33a is in its downward extreme position; and the chamber 33b is of a sufficiently large size to insure that oil will not be forced into conduit 38 when diaphragm 33a is in its upper extreme position.

As the rate of flow of pilot air into chamber 24a is permitted to increase the net flow into conduit 38 and chamber 33b increases, thus increasing the degree of air pressure. The increase in air pressure tends to slightly increase the degree of loading of pilot regulator 24, increases the rate of flow through the orifice or bleeder 38a and causes oil to flow from chamber 33b through orifice 33e into chamber 33d, against the bias of spring 33f at the lower face of diaphragm 33a. As a result the connecting rod 41 is moved downwardly, thereby effecting movement of gear segment 42 in a counterclockwise direction about its pivot 43, which is carried by a fixed support 44. Segment 42 is continuously engaged with gear 45, which is formed integrally with or otherwise rigidly attached to both the latch gear 46 and the drive arm 47 (through the medium of hub member 48); the assembly of gears 45 and 46, hub 48 and arm 47 being free to rotate relatively to shaft 49 under the conditions hereinafter described.

Shaft 49 is freely rotatable in fixed bearings at opposite ends thereof; one of said bearings being shown at 50. Mounted upon and rigidly attached to shaft 49 for rotation therewith are step gear 51, pulley or winding wheel 52, and cam members 53 and 54. Step gear 51 has formed integrally therewith or otherwise rigidly attached thereto a pair of abutments 51a and 51b against which one head portion of each of a pair of studs 55 and 56 (held captive adjacent opposite ends of arm 47) are respectively adapted to abut under the bias afforded by the coiled compression springs 57 and 58, respectively. The arrangement is such that clockwise movement of drive arm 47 about shaft 49 and with respect to step gear 51 will compress spring 58, thus causing stud 56 to exert, through abutment 51b, a clockwise torque upon step gear 51. Stud 55 is simultaneously moved away from abutment 51a. A similar effect, in the reverse direction, is produced by a counterclockwise movement of drive arm 47.

Step latch 59a forming part of a compound lever 59, pivotally mounted upon a pin or rod 60 carried by a fixed bracket 61, is arranged to engage between a pair of the multiple teeth 51c of step gear 51 to lock the latter against rotation. The arm 59b of lever 59 has pivoted thereto at 59c an actuating latch 59d which is normally biased to an intermediate position (not shown) by a roller 62a which is rotatably supported at one end of a lever 62, whose other end is pivotally supported at 62b to a downward extension 59e of said arm 59b. The upward bias of roller 62a is afforded by a suitable coiled compression spring 62c interposed between the lower edge of lever 62 and a fixed abutment 62d.

Actuating latch 59d is arranged to engage between any adjacent pair of the multiple teeth 46a formed peripherally upon latch gear 46, in such a manner that clockwise rotation of gear 46 rotates latch 59d in a counterclockwise direction about pivot 59c until the right-hand lug 59f of latch 59d engages an abutment 59g carried by arm 59b aforementioned, thereby preventing further counterclockwise rotation of latch 59d with respect to arm 59b. Continued clockwise rotation of gear 46 will then force lever 59 to move in a counterclockwise direction about rod 60, thereby causing movement of latch 59a out of engagement with step gear 51. The shape of the teeth in step gear 51 and latch 59a are such that after latch 59a has been moved partly out of the notch between a pair of teeth, the torque exerted by spring 58 will be sufficient to act upon lever 59 to compress spring 62c to the required degree to permit latch 59a to clear the outer end of the particular cooperating tooth of step gear 51, and to also permit latch 59d to clear the outer end of the particular cooperating tooth of latch gear 46; with consequent return of latch 59d to its aforementioned

intermediate position; the same dropping into the next adjacent notch between a pair of the teeth on gear **46**.

It is to be understood that when step gear **51** is released the load exerted on stud **56**, through spring **58**, is likewise released. Such unloading tends to make rod **41** of diaphragm motor **33** move an additional amount. Inasmuch as some time is required for lever **59** to drop latches **59***d* and **59***a* into the respective gears **56** and **51**, orifice **33***e* and the aforementioned body of oil are provided. The sudden change in the degree of loading upon the lower face of diaphragm **33***a* would result in substantially instantaneous movement of said diaphragm, except for the fact that any movement of diaphragm **33***a* immediately results in the establishment of a pressure drop of high value through orifice **33***e*, thus reducing the pressure upon the upper surface of diaphragm **33***a* and insuring a rate of movement sufficiently slow to provide ample time for the latches **59***a* and **59***d* to fall into place. Orifice **33***e* will also affect the normal rate of movement of rod **41** as a function of change in pressure in conduit **38**; but such change in pressure occurs very slowly, and the effect of a suitable orifice for preventing over-travel is substantially nil under these conditions.

Movement of step gear **51** through one step in the manner just described results in rotary movement of wheel **52** and cams **53** and **54** through a corresponding angle, with consequent operation of one or more of the valve mechanisms **23** to **31**, inclusive, in a manner to effect application of pressure to, or release of pressure from, the upper surfaces of certain of the operating diaphragms of valves **14** to **17**, inclusive (see diaphragm **14***c*); which valves are normally spring-biased to their respective closed positions. With cams **53** and **54** in the positions thereof shown in Fig. 1, gas pumping units **8**, **9** and **10** are in operation (step number 14). One farther step of clockwise movement of gear **46** would result in a corresponding degree of angular movement of cams **53** and **54**, whereby units **8**, **9** and **10** would be maintained in operation and valve mechanism **28** would be permitted by cam **53** to operate to bring in the gas pumping unit **11**, thus providing for full capacity operation of the entire plant.

Said last mentioned step of gear **46** in a clockwise direction would also effect a proportional degree of lifting of a bucket **63**, which is suspended by a belt or tape **64** attached to wheel **52**. Bucket **63** is partially filled to a predetermined level with a suitable liquid, such as mineral oil. A cup **65** is so positioned within bucket **63** that the normal level of the liquid will be between the bottom wall and the upper edge of the cup in any operative position of bucket **63**. As shown, cup **65** is rigidly attached to a lever **66**, which is pivoted at **66***a* to an extension of the pilot regulator **24**. A slider **66***b* is mounted to slide upon a part of lever **66**; said slider preferably including a roller **66***c*, which is continuously engaged with a counter-lever **67**, which is pivoted at **67***a* to another extension of pilot regulator **24**.

A rod **68**, which is preferably adjustable in length (as by means of the threadedly connected elements **68***a* and **68***b*), is interposed between counter-lever **67** and the upper surface of the backing-plate of diaphragm **24***f*. Rod **68** is so adjusted in length that with the diaphragm assembly in its normal position counter-lever **67** and the portion of lever **66** carrying slider **66***b* will be substantially parallel to each other, whereby slider **66***b* may be moved toward or farther away from pivot **66***a*, to change the degree of amplification of the force exerted by cup **65** upon rod **68** without any required change in the relative position of cup **65**.

Cup **65** and lever **66** normally tend to jointly exert a clockwise torque, with a resultant downward force upon the aforementioned assembly of diaphragms **24***f* and **24***e*, which is additional to the manually adjusted force produced by spring **24***m*. A step of movement of wheel **52** in the clockwise direction raises bucket **63** and (through the medium of the liquid in the latter) tends to lift cup **65**, thus reducing the degree of force exerted by rod **68** upon the diaphragm assembly **24***e* and **24***f*, **24***g*, **24***h*. Such movement of bucket **63** raises the level of liquid in the annular space between bucket **63** and cup **65**. The temporarily increased displacement of the liquid in bucket **63** by cup **65** determines the degree of reduction in the loading of pilot regulator **24**.

Cup **65** is provided with an orifice or opening **65***a* which provides for gradual equalization of the level of the liquid inside of cup **65** with respect to that outside thereof. Suitable means is preferably provided for adjusting the size of orifice **65***a* so that the rate of decrease in auxiliary loading of regulator **24**, as an incident to a step movement, may be readily adjusted in accordance with conditions in a given installation, in respect of capacity of the distribution system, increment in flow for each increase in the rate of gas pumping, and provision of the desired distribution pressure. In Fig. 2 I have shown, by way of example, an adjustable screw **65***b* for varying the size of orifice **65***a*.

Similarly, in the event of a step of movement of wheel **52** in a counterclockwise direction, the displacement of liquid by the cup **65**, is decreased, thus increasing the degree of force applied by rod **68** to diaphragm assembly **24***e*, etc., the orifice **65***a* acting as aforedescribed to effect gradual equalization of the level of the liquid inside the cup **65** with respect to that outside thereof, as aforedescribed.

With respect to the effect of net flow (that is to say, the rate of gas pumping minus the rate of demand for the gas from the intermediate pressure distribution system) upon the degree of pressure of the gas in the distribution system, I have hereinabove pointed out that the distribution pressure should preferably be increased at a rate substantially proportional to the increase in the rate of demand, thus providing for proper determination of the most desirable rate of gas pumping.

With fifteen steps of variations of equal value in the rate of gas pumping, as provided by the fifteen-step mechanism hereinabove described, each step of increase or decrease in the rate of gas pumping represents a change in the rate of gas pumping corresponding to six and two-thirds percent of the total capacity of the plant. It is therefore possible to set the rate of gas pumping within six and two-thirds percent of the instantaneous rate of demand, so that the rate of rise or fall of pressure in the intermediate pressure distribution system can be maintained between zero and a rate depending upon the relationship between the volumetric capacity of the distribution system and the total plant capacity.

For example, with a distribution system having a volumetric capacity equal to one-half of the maximum hourly capacity of the plant, the change in rate of gas pumping corresponding to six and two-thirds percent of the maximum rate of gas pumping would be 13.3 percent of the capacity of the distribution system per hour. In one hour the distribution pressure would therefore change 13.3 percent of one atmosphere, or at a rate of: (.133) (408), divided by 60, inches of water per minute; or, in general, with a distribution system having a volume in cubic feet equal to Vd times the maximum hourly capacity of the plant in cubic feet per hour, the maximum rate of net flow of 6⅔ percent of maximum capacity will cause a change in pressure at a rate of $0.453/Vd$ inches of water column per minute. The minimum rate of change would, of course, be zero, and in normal operation of the system the rate of change would vary between zero and the above mentioned maximum determined by the value of Vd, which as will be understood may be determined by dividing the volumetric capacity of the distribution system by the maximum volumetric capacity of the plant per hour. The minimum rate of pressure change could, of course, be zero if the net flow were zero, but it is to be under-

stood that in general the rate of gas pumping will seldom correspond exactly with the rate of demand. Therefore the pressure will usually be changing in one direction or the other.

It may also be noted that if the demand is steady at one percent of total plant capacity above one particular step of gas pumping, the plant will (in order to average a constant pressure) operate on this step (six and two-thirds percent minus one percent divided by six and two-thirds percent) or eighty-five percent of the time, and fifteen percent of the time on the next higher step. With the demand half-way between two steps or rates of gas pumping the period of operation on each step above and below the desired value should be the same in order to maintain a constant average pressure.

The customary method of control of a multi-unit system of this general type utilizes a mode of control known as proportional-position-action control in which there is a continuous linear relationship between value of pressure and the rate of gas pumping. More specifically, for each successive decrease in pressure there is a definitely related increase in rate of gas pumping. Such a system inherently tends to be stable, but it also inherently tends to maintain a lower pressure as the rate of gas pumping increases. When associated with a step-by-step action such usual method also includes the additional disadvantage that the running time on any particular step is decreased.

Maintenance of a lower pressure as an incident to each increase in the rate of gas pumping is definitely objectionable in a distribution system, because the increased pressure drop from the gas mixing plant to the various different points of consumption (as an incident to the increased rate of demand) makes it very desirable to maintain a higher pressure at the plant as the demand increases. Such a system would, in general, be unstable and cause hunting; and an important phase of the present invention resides in the novel method of and means for preventing instability and excessive changing of the rate of gas pumping.

One suitable means for insuring the desired degree of increase in the distribution pressure (as represented by the degree of pressure in distribution manifold 5), as an incident to an increase in the rate of demand for the gas, is illustrated in Fig. 2, and comprises a known form of cam member **69** having an operative low point **69***a* and an operative high point **69***b* with a cam surface **69***c*, therebetween; said surface **69***c* being spaced radially outwardly from shaft **49** at a uniformly increasing rate from point **69***a* to point **69***b*. In practice the low and high points are angularly spaced only slightly less than 180 degrees from each other. Member **69** is keyed or otherwise non-rotatably attached to shaft **49** at such a rotary angle that when all of the units of the plant are inactive a portion of the cam surface **69***c* adjacent the high point **69***b* thereof will underlie a roller or similar member **70***a* rotatably supported by pin **70***b* upon a lever **70** pivotally supported at **70***c* upon a suitable fixed member **70***d*. A flexible wire or cord **71** has one end thereof attached to lever **70** adjacent the free end of the latter; the other end of cord **71** being attached to the hooked upper end of a coiled tension spring **72**, whose lower end is attached to the aforementioned lever **66** carrying cup **65**. Thus with the various elements of the system in their respective initial positions the degree of tension of spring **72** will be at a maximum, thereby reducing to its minimum normal value the degree of loading of regulator **24**. As shaft **49** rotates step-by-step in a clockwise direction cam surface **69** will act to gradually decrease the tension of spring **72**.

The condition wherein all of the gas pumping units **8** to **11** inclusive, are inactive may occur when the system is employed for "peak shaving," or as a means for maintaining a desired distribution pressure where another or main supply of combustible gas may be insufficient in quantity to satisfy the maximum possible demand. However, when a system like that disclosed in Fig. 2 is employed as the sole supply of combustible gas to a distribution system, normally either the smaller gas pumping unit **11** or any one of more of the units **8** to **11**, inclusive, will be in operation at any given time, depending upon the instantaneous rate of demand as reflected by variations in the distribution pressure after each automatic setting, or resetting, of the parts of the system.

If it be assumed that all of the gas mixing units **8** to **11**, inclusive, are inactive (as an incident to lack of demand for gas in the distribution system) the latch gear **46** will have been rotated in a counterclockwise direction to one of its extreme positions; the shaft **49** and cam members **53** and **54** being moved simultaneously therewith. Upon a drop in the distribution pressure the parts aforedescribed will act to initiate operation of the smallest gas pumping unit **11**, thus supplying to manifold **5** a combustible gas at a volumetric rate corresponding to one-fifteenth of the maximum capacity of the entire system (step 1). If the demand is not satisfied unit **10** will be rendered active, and operation of unit **11** discontinued, thus doubling the volume of gas supplied to the distribution system (step 2). Always assuming that the demand is not satisfied, the units will further be operated as follows: Unit **10** will be continued in operation and unit **11** will be actuated (step 3); unit **9** will then be actuated, and operation of units **10** and **11** discontinued (step 4); unit **9** will be continued in operation and unit **11** will be actuated (step 5); unit **9** will be continued in operation, actuation of unit **10** will be effected, and operation of unit **11** discontinued (step 6); units **9** and **10** will be continued in operation and unit **11** will be actuated (step 7); unit **8** will then be actuated and operation of units **9**, **10** and **11** discontinued (step 8); unit **8** will be continued in operation and unit **11** will be actuated (step 9); unit **8** will be continued in operation, unit **10** will be actuated, and operation of unit **11** discontinued (step 10); units **8** and **10** will be continued in operation, and actuation of unit **11** will be effected (step 11); unit **8** will be continued in operation, actution of unit **9** will be effected, and operation of units **10** and **11** discontinued (step 12); units **8** and **9** will be continued in operation, and actuation of unit **11** effected (step 13); units **8** and **9** will be continued in operation, actuation of unit **10** effected, and operation of unit **11** discontinued (step 14, which is the condition of the system illustrated in Fig. 1); and upon a further demand for gas units **8**, **9** and **10** will be continued in operation, and actuation of unit **11** effected (step 15).

Cam members **53** and **54** are cooperatively shaped and arranged with respect to each other and to the pairs of valves **28**, **30** and **29**, **31** as to provide the aforedescribed sequence of operation of units **8** to **11**, inclusive, as an incident to the aforedescribed step-by-step rotation of shaft **49** in a clockwise direction from one extreme position to the other. More particularly, valves **28**, **29**, **30** and **31** have rollers **28***b*, **29***b*, **30***b* and **31***b*, respectively, associated therewith for actuation by the various cam formations. Thus, with all of the units **8** to **11** inactive, the points **53***a* and **53***b* of the high portions of cam member **53** will respectively engage rollers **28***b* and **30***b* to effect closure of valves **17** and **15**; and the points **54***a* and **54***b* of cam member **54** will respectively engage rollers **29***b* and **31***b* to effect closure of valves **16** and **14**. Upon the first step of clockwise movement of shaft **49** (with corresponding movement of cam members **53** and **54**) the cam depression or valley **53***c* will be alined with roller **28***b*, to permit downward movement of piston **28***c* to an extent sufficient to afford communication between conduits **27** and **28***a*, thus effecting full opening movement of valve **17**, to initiate operation of gas pumping unit **11**. Under

the conditions just mentioned the other pistons 29*c*, 30*c* and 31*c* will be retained in their inner extreme positions, whereby closure of the other valves 14, 15 and 16 is insured.

Upon the next step of clockwise movement of shaft 49 roller 28*b* will ride up onto the raised or hill portion 53*d* of cam 53, thus effecting movement of piston 28*c* to its inner extreme position (like the position thereof shown in Fig. 2) to interrupt communication between conduits 27 and 28*a*, and to vent the latter to atmosphere, thus providing for reclosure of valve 17 under its normal spring bias to discontinue operation of unit 11. At the same time the cam surface 54*a* will have moved out of alinement with roller 29*b* and the latter will be freed to move into the next adjacent portion of the depression or valley 54*c* formed in the periphery of cam member 54, thus permitting outward movement of piston 29*c* to afford communication between conduits 27 and 29*a*, thereby effecting full open positioning of valve 16, against its normal spring bias, to initiate operation of gas pumping unit 10. Under the conditions just mentioned the rollers 30*b* and 31*b* will be engaged by the raised portions 53*b* and 54*b* of cams 53 and 54. With unit 10 only in operation the distribution manifold 5 will be supplied with a volume of the gas corresponding to two-fifteenths of the maximum capacity of the system. In the next step of increase in the rate of gas pumping the units 10 and 11 will be operated jointly, to provide three-fifteenths of the total plant capacity; and in the next step of increase, operation of unit 9 will be effected and operation of units 10 and 11 will be discontinued; and so on.

If the demand for the gas is or becomes of sufficient magnitude to require operation of all of the units 8 to 11, inclusive, jointly, the units will be operated automatically in the step-by-step manner aforedescribed; the calorimetric device having supervision of the proportionality of the constituents of the gaseous mixture supplied by each unit under all conditions, to insure maintenance of a constant desired total heating value per unit volume of the combustible gas.

With reference to Fig. 2 it will be noted that the various elements of the system are in the respective positions thereof which provide for operation of the system at fourteen-fifteenths of its maximum capacity, units 8, 9 and 10 being in operation and unit 11 being inactive. Upon a predetermined degree of reduction of the pressure within the intermediate pressure distribution manifold 5, as an incident to a demand for the gas greater than that being supplied by the active units, the elements of the system will respond automatically to effect another step of rotation of shaft 49 in a clockwise direction, whereupon the depression or valley 53*c* in cam member 53 will be alined with roller 28*b*. As a result piston 28*c* will be free to move outwardly to afford communication between conduits 27 and 28*a*, with consequent operation of unit 11, as aforedescribed; the other units 8, 9 and 10 continuing in operation. The system will then be operating at its maximum capacity.

It will be apparent that most of the gas supplied to the intermediate pressure system IPS comes from holder LP rather than from holder HP. Thus, for a given amount of gas supplied to the intermediate pressure system IPS, a system which embodies the invention does not require that as much gas be pumped to high pressure, and in cases where such pumping is not or may not be continuous, does not require a high pressure holder of such large capacity as prior systems do. Also, inasmuch as less high pressure gas is released to the intermediate pressure distribution system a pump P of smaller than usual size may be employed. Thus a substantially smaller capital investment is required to provide a system embodying the invention than is required to provide other systems of equal capacity.

I claim:

1. In a system for distributing at low pressure and at intermediate pressure gas supplied at low pressure, in combination, a gas source, a low pressure gas storage tank connected to said source, a high pressure gas storage tank, a conduit connecting said low pressure tank to said high pressure tank, a compressor pump in said conduit for compressing gas received from said low pressure tank and storing the same in said high pressure tank at high pressure, a low pressure distribution system connected to said low pressure tank for receiving gas and distributing the same at low pressure, an intermediate pressure distribution system connected to both said low pressure tank and said high pressure tank for receiving gas therefrom, and means responsive to flow of gas from said high pressure tank into said intermediate pressure distribution system for pumping low pressure gas from said low pressure tank into said intermediate pressure distribution system and maintaining the gas pressure in said intermediate pressure distribution system at a predetermined value, said means comprising a pumping device having a plurality of jet type compressors operating at maximum efficiency and of sizes to afford a change in the rate at which gas is pumped into said intermediate pressure distribution system in the manner of a geometrical progression, a low pressure conduit having a check valve therein connecting said low pressure tank to said pumping device, a high pressure conduit connecting said high pressure tank to said pumping device for supplying high pressure gas to operate said pumping device, an intermediate pressure conduit connecting said pumping device to said intermediate pressure distribution system for supplying gas at an intermediate pressure, regulating means responsive to variations in the pressure of the gas in said intermediate pressure distribution system from said predetermined value for rendering selected one of said jets operative dependent upon the direction of said pressure variations to maintain said predetermined value of gas pressure, a by-pass conduit connecting said high pressure tank to said intermediate pressure distribution system for admitting high pressure gas directly to said intermediate pressure distribution system, and a normally closed regulating valve in said by-pass conduit operable to open in response to variable downstream pressure for supplying gas from said high pressure tank into said intermediate pressure distribution system at a pressure not lower than said predetermined value when said pumping device is unable to maintain said predetermined value of pressure in said intermediate pressure distribution system.

2. In a system for distributing at an intermediate pressure gas supplied at low pressure, the combination with a gas source, a low pressure gas storage tank connected to said source and a high pressure gas storage tank connected to said low pressure tank, of a compressor pump between said tanks for compressing gas received from said low pressure tank and storing the same in said high pressure tank at high pressure, an intermediate pressure distribution system connected to said tanks, and means responsive to flow of gas from said high pressure tank into said distribution system for pumping low pressure gas from said low pressure tank into said distribution system and maintaining the gas pressure in said distribution system at a predetermined value, said means comprising a high-pressure-gas-responsive pumping device having a plurality of jet type compressors operating at maximum efficiency and of sizes to afford a change in the rate at which gas is pumped into said distribution system in the manner of a geometrical progression, a conduit having a check valve therein for admitting gas from said low pressure tank to said pumping device and therethrough to said distribution system, means responsive to variations in the pressure of the gas in said distribution system from said predetermined value for rendering

predetermined ones of said jets active in accordance with said pressure variations to maintain said predetermined value of gas pressure in said distribution system, a by-pass conduit connecting said high pressure tank directly to said distribution system, and a regulating valve in said by-pass conduit operable to open in response to down-stream pressure variations for supplying gas from said high pressure tank directly into said distribution system at a predetermined pressure when said pumping device is ineffective to supply a sufficient quantity of gas to maintain said predetermined pressure.

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