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COMPRESSOR PLANT AND METHOD FOR REGULATING THE QUANTITY OF WORKING FLUID DELIVERED THEREBY

Filed Nov. 24, 1941

Serial No. 420,283

2 Sheets-Sheet 1

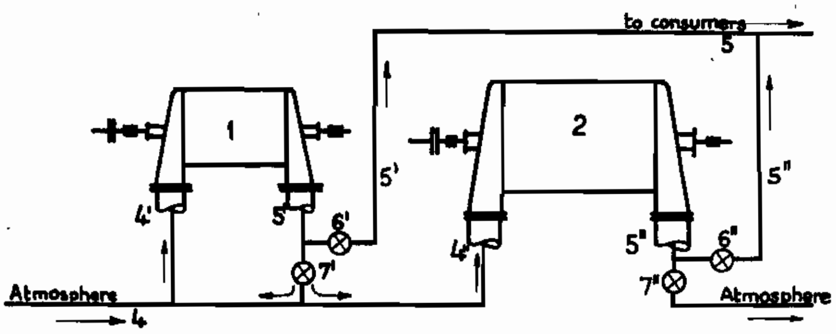

Fig. 1

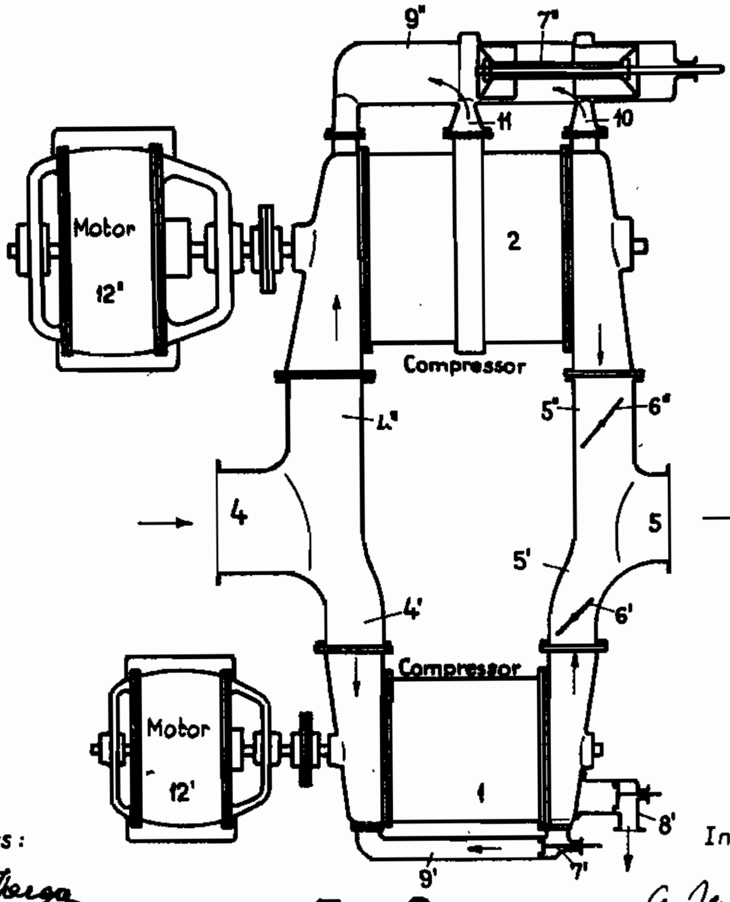

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Fig. 2

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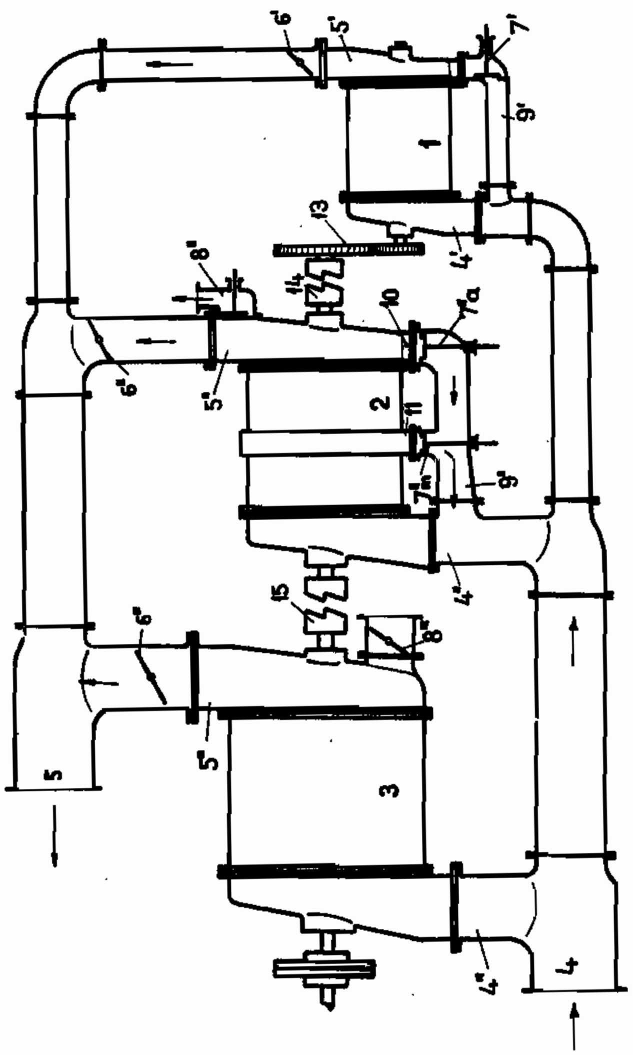

Fig. 3

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COMPRESSOR PLANT AND METHOD FOR REGULATING THE QUANTITY OF WORKING FLUID DELIVERED THEREBY

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In the operation of rotary compressors, the regulation of the quantity of compressed working fluid delivered presents difficulties in those cases in which it is by means of a delivery pipe of practically constant pressure that the working fluid is conducted towards the place of consumption. This is due to the well-known fact, that it is only on the descending section of the pressure-volume characteristic (i. e. on the section in which, with growing pressure, volume decreases) that such compressors operate in a stable manner, and even in this range of operation it is only at or above the working pressure of the delivery pipe that it is possible to work, as otherwise backflow directed towards the compressor would be set up in the delivery pipe. This circumstance substantially limits the range of regulation and this limitation becomes more appreciable still because—in view of other considerations, but also owing to inherent features of construction—the preponderating majority of the compressors concerned possess a so-called "steep" pressure-volume characteristic. This means that the percentage by which the volume of the working fluid delivered diminishes with increasing pressure is smaller than the percentage by which the pressure increases, so that in order to alter the gas volume delivered in a certain proportion the pressure has to be altered in a relatively higher proportion. Thereby, not only the range of regulation, narrow as it is already, will be rendered more narrow still, but substantial deviations of the pressure from the figure of pressure which it is desirable to maintain constant as far as possible in the delivery pipe will also be caused, which circumstance, seeing that, in view of what has been said above, any such variations of pressure can only be variations above the figure of nominal pressure of the delivery pipe, will also mean an increase in the quantity of power required, and will thus tend to render operation less economical.

According to the invention these difficulties can be eliminated by employing, for providing the desired service, two or more compressors, mutually connected in parallel, the said compressors being operated singly or connected in parallel in the various possible combinations, according to what quantity of working fluid is to be delivered, a number of steps of regulation being thus obtained at the desired pressure. In order to increase, in the manner which will appear from the examples as below, the number of steps of regulation, it is advisable to construct the various compressors so as to possess different output capacities. With this arrangement, the employment of two compressors will already enable three steps to be obtained, whilst the employment of three compressors will enable five or seven steps to be obtained, according to whether in this latter case two of the three compressors or all three compressors are chosen so as to possess different output capacities. At the same time the output capacities of the individual compressors should preferably be so chosen as to enable steps of regulation distributed as uniformly as possible to be obtained within the maximum output capacity of the whole equipment. Transitional regulation (intermediate regulation) between the individual steps can be effected by the methods employed up to now (e. g. by means of throttling, which will not cause any appreciable loss of power or diminution of efficiency).

A general diagram of the invention in case of employing two compressors operated in parallel is represented on Fig. 1, whilst Fig. 2 represents an embodiment, shown by way of example, comprising two compressors likewise, and Fig. 3 one comprising three compressors.

The compressors **1** and **2** employed in the arrangement as per Fig. 1 are connected on the one hand to the suction pipe **4** and on the other hand to the delivery pipe **5**, to which pipes they join on by means of the suction and delivery branches **4'**, **4''** and **5'**, **5''**, respectively. The driving devices of the compressors **1** and **2** may be of any desired kind (mutually dependent or independent), and if the mutual difference existing between the output capacities of the said compressors is such that the output capacity of compressor **1** is smaller and that of compressor **2** greater—for instance twice as great as the output capacity of compressor **1**—it is possible, taking the joint output capacity of the compressors **1** and **2** as 100%, to obtain the first step of regulation, representing an output capacity of **33**, 33% by operating compressor **1** and cutting out compressor **2**, the second step of regulation, representing an output capacity of **66**, 66%, by operating compressor **2** and cutting out compressor **1**, whilst the third step of regulation, representing an output capacity of 100%, is obtained by operating the two compressors **1** and **2** jointly.

If, in accordance with the first step of regulation, the compressor **2** is put out of commission, its delivery branch **5''** has to be shut off, by means of the closing device (valve) **6''** built into the said branch, from the delivery pipe **5** standing under pressure in consequence of the operation of the compressor 1. In the second step of regulation it is the delivery branch 5' of the compressor 1 that has to be shut off, in a similar manner, by means of the closing device 6', from the delivery pipe 5. In case the driving devices of the compressors 1 and 2 are mutually independent, either of these compressors can be put out of commission simply by shutting down its driving device, whilst, in case the driving devices are not independent from each other, the high-pressure end of the compressor put out of commission may be brought into connection—in the case of compressor 2, by opening the closing device 7''—with the atmosphere, or—in the case of compressor 1, by opening the closing member 7'—with the suction conduit 4, thereby ensuring that the compressor put of of commission will, notwithstanding its rotation, require practically no energy for driving it apart from the quantity necessary for overcoming frictional resistances.

In case the various compressors are driven in a mutually independent manner, special working turbines, electric motors, or the like, may be employed for driving them. Fig. 2, which is substantially identical with Fig. 1, represents a set of apparatus comprising driving arrangements of this last-named kind, the electric motors 12' and 12'' being employed for driving the compressors 1 and 2, respectively. After identifying the constructional parts marked in mutual conformity on Figs. 1 and 2, the method of operation of the apparatus will be readily understood without any further explanation, the difference consisting only in that the compressor 1 of smaller output capacity is fitted, in addition to the stop-valve 7' leading back through the duct 9' towards the suction branch 4', also with a stop-valve 8' for discharge into the atmosphere, and, moreover, in that the closing device 7'' of the compressor 2 of larger output capacity, instead of opening a conduit leading into the atmosphere, opens the way through the return conduit 9'' towards the suction branch 4'' of this compressor, the closing device 7'' being of a double type, which, in addition to opening the branch 10 joining on to the discharge branch 5'' of the compressor, and already before opening this branch, also opens the branch 11 joining on to the middle section of the working space of the compressor. The purpose of the constructional details differing from or representing an addition to those represented on Fig. 1 will be explained in what follows.

In the embodiment shown by way of example on Fig. 3 three compressors 1, 2, and 3, the driving devices of which are not independent from each other mechanically, are provided; the mutual relations between the various driving devices are such that the compressors 1 and 2 are mutually connected by means of the disconnectable clutch 14 through the tooth-wheel gear 13, whilst the compressors 2 and 3 are mutually connected in a direct manner by means of the disconnectable clutch 15; it is accordingly possible, by putting these disconnectable clutches out of gear, to place each individual compressor, or possibly any pair of compressors, entirely out of commission or to render them independent from each other as to their driving devices, provided that provision is made (in a manner not shown on the drawing) for enabling any compressor which is to be operated but which has been disconnected by means of the clutches 14 or 15, respectively, to be brought into connection with the source of motive power from another side. Considering the constructional parts marked in conformity with, or analogously to, Figs. 1 and 2, it will appear that, as far as the method of functioning of the apparatus is concerned, the addition of the compressor 3 and of the pipe branches 4''', 5''', joining on to it and of the closing device 6''' does not mean any essential alteration as compared to the arrangements described in what precedes, whilst a modification as compared to Fig. 2 is apparent in that, instead of compressor 1, it is the compressors 2 and 3 which, in addition to other closing devices, are also fitted with the closing devices 8'' and 6''', respectively, for discharge into the atmosphere, whilst the return duct 8'' of the compressor 2 contains, instead of the double closing device 7'', two mutually independent closing devices 7''*a* and 7''*m*, for controlling the branches 10 and 11, respectively.

In the case of the arrangement according to Fig. 3, it is possible to provide for all three compressors, or for two compressors only possessing different output capacities. Taking the joint output capacity of the three compressors as 100% and taking the output capacities of the individual compressors proceeding from compressor 1 to compressor 3 as amounting, in order sequence, to, for instance, 15%, 30% and 55%, the following steps of output capacity will be obtained:

Step No. 1: compressor 1 by itself (15%)
Step No. 2: compressor 2 by itself (30%)
Step No. 3: compressors 1 and 2 jointly (45%)
Step No. 4: compressor 3 by itself (55%)
Step No. 5: compressors 1 and 3 jointly (70%)
Step No. 6: compressors 2 and 3 jointly (85%)
Step No. 7: compressors 1, 2 and 3 jointly (100%).

If, on the other hand, the distribution of output capacities is such that for instance compressor 1 is capable of providing 20% of the total output capacity whilst compressors 2 and 3 are, in a mutually equal manner, each capable of providing 40% of the total output capacity, it will be possible to produce the following five steps of output capacity:

Step No. 1: compressor 1 by itself (20%)
Step No. 2: compressor 2 or 3 by itself (40%)
Step No. 3: compressors 1 and 2 jointly (60%)
Step No. 4: compressors 2 and 3 jointly (80%)
Step No. 5: compressors 1, 2 and 3 jointly (100%).

In view of increasing the number of steps produceable it is, accordingly, preferable that all three compressors should possess different output capacities.

In case any compressor put out of commission continues to be kept in rotation, whilst connecting its delivery branch with the atmosphere, or through a return conduit with its suction branch or with the common suction pipe, it is advisable to effect a return towards the suction end from one or more branchings of the working space of the cut-out compressor also, such connection resulting after suitable closing devices are opened. Details of arrangement of this kind are the intermediate branchings 11, already mentioned above, comprised in the arrangements according to Figs. 2 and 3, as well as the double closing members 7'' or independent closing members 7''*m* controlling the junction apertures of the said branchings. The reason why such an intermediate return duct or such intermediate return ducts are desirable is that, in view of the fact that in accordance with the compression in normal operation of the cut-out compressor the throughflow cross-sections in the working space of the compressor diminish towards the delivery end, the velocities will, in case of the compressor running at no-load, become substantially increased towards the delivery end, which circumstance will, in consequence of the increase of the resistance to flow, result in a temperature rise of the working fluid i. e. in increased losses. If now the working fluid is returned from intermediate branching points, these losses will, of course,—owing to the diminution of the throughflow speed behind the branching—become reduced.

The returning of the working fluid from the delivery end of the compressor put out of commission or from an intermediate point of its working space, in consequence whereof a certain quantity of working fluid will flow repeatedly through the compressor put out of commission referred to, will, particularly for this last-named reason, result in the temperature rise, just mentioned, of the working fluid. This will, however, notwithstanding the drawback mitigated by the return from the intermediate branching, also result in a certain advantage, so that the loss itself caused by this phenomenon will, in addition to the mitigation produced by means of the returning, be mitigated also owing to a further reason, which latter mitigation will take effect also if no intermediate returning is employed at all. Notably, if the working fluid becomes heated up in consequence of the repeated no-load throughflow, this will cause its density and thus the amount of energy absorbed by it, which must counted as a loss, to become reduced. Advantageous use may be made of this circumstance also in connection with the balancing regulation between the various steps; notably, this regulation can also be effected in such a manner that the closing devices of the apertures for discharge into the atmosphere, or for return are—for the purpose of producing throttling—opened, partly only, also at those times when the compressor in question is not shut down, which will enable the transitional regulation between the various steps to be effected with a relatively slight loss. Accordingly, in order to effect such a regulation, the various closing devices, for instance in the arrangement according to Fig. 2 the valves 7', 8', or the double valve 7'', or, in the arrangement according to Fig. 3, the closing devices 7', 7a'', 7m'' 8'' and 8''', respectively, (in the first place the closing devices effecting the return of the working fluid) may in ordinary operation also be operated as throttle-valves, and should be constructed in accordance with this function.

At the occasion when the working fluid is being partly returned, either in order to place any compressor out of commission or for the purpose of the regulation between steps referred to, any excessive temperature rise should be limited as far as possible, which purpose can be achieved either by means of the natural cooling-down of the working fluid, or by means of cooling the latter artificially. The artificial limitation of temperature, effected for this purpose, can be produced by means of a simple type of equipment, for instance by allowing a part of the working fluid flowing back to escape into the atmosphere, and replacing this deficiency by means of suction from the atmosphere, in which case the quantity of fresh working fluid thus drawn-in will figure as the cooling medium of the quantity of hot working fluid returned into the current of working fluid. In the case of the embodiment according to Fig. 2, this should, accordingly, in the case quoted by way of example of effecting the regulation of compressor 1, be understood to mean that the throttling devices 7' and 8' are kept open in the necessary extent simultaneously by means of a control mechanism not shown on the drawing, in which case the replacement of the quantity of working fluid discharged into the atmosphere through the closing device 8' will be effected automatically through the suction conduit 4 and through the suction branch 4' of the compressor.

The arrangements represented on the figures having the character of examples, it will of course be possible to vary at will, in accordance with the purpose aimed at in each case, the number of compressors connected in parallel, and the mutual distribution of their output capacities, as well as the arrangement and the control, taking place partly in mutual dependence, of the closing devices for producing the various steps of regulation as well as the transitions between these steps. In order to ensure the uniform distribution, referred to precedingly, of the steps of output capacity, it is advisable that—as apparent also in connection with the examples described—the output capacity of the compressor having the greatest output capacity should be at least twice that of the compressor having the lowest output capacity, or even greater. Similarly the arrangements for driving the individual compressors or for driving them in mutual dependence, possibly from a common source of power, may be of any desired kind and of the most varied kinds. It will, however, in the same way as in the case of the examples described, be important in each case that the compressor disconnected from the service should be relieved of all pressure (it being possible to ensure this either by stopping the rotation of the compressor, or, in case of the compressor continuing to rotate, by connecting its delivery and with the suction end or with the atmosphere), since with the delivery end completely closed the maintenance of the pressure in the compressor put out of commission would cause a disadvantageous temperature rise and a deterioration of the efficiency.

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