Fig.1

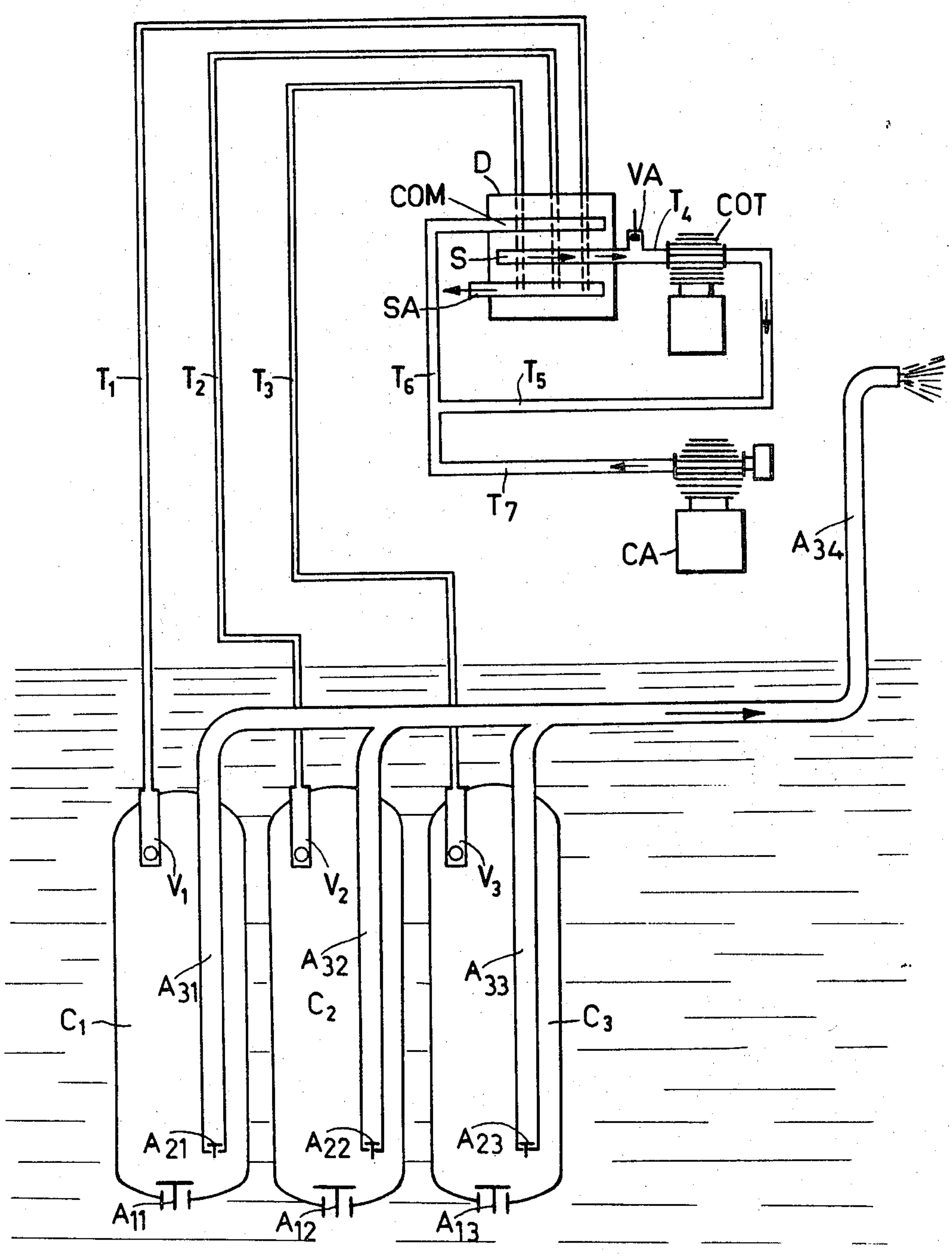

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Fig. 2

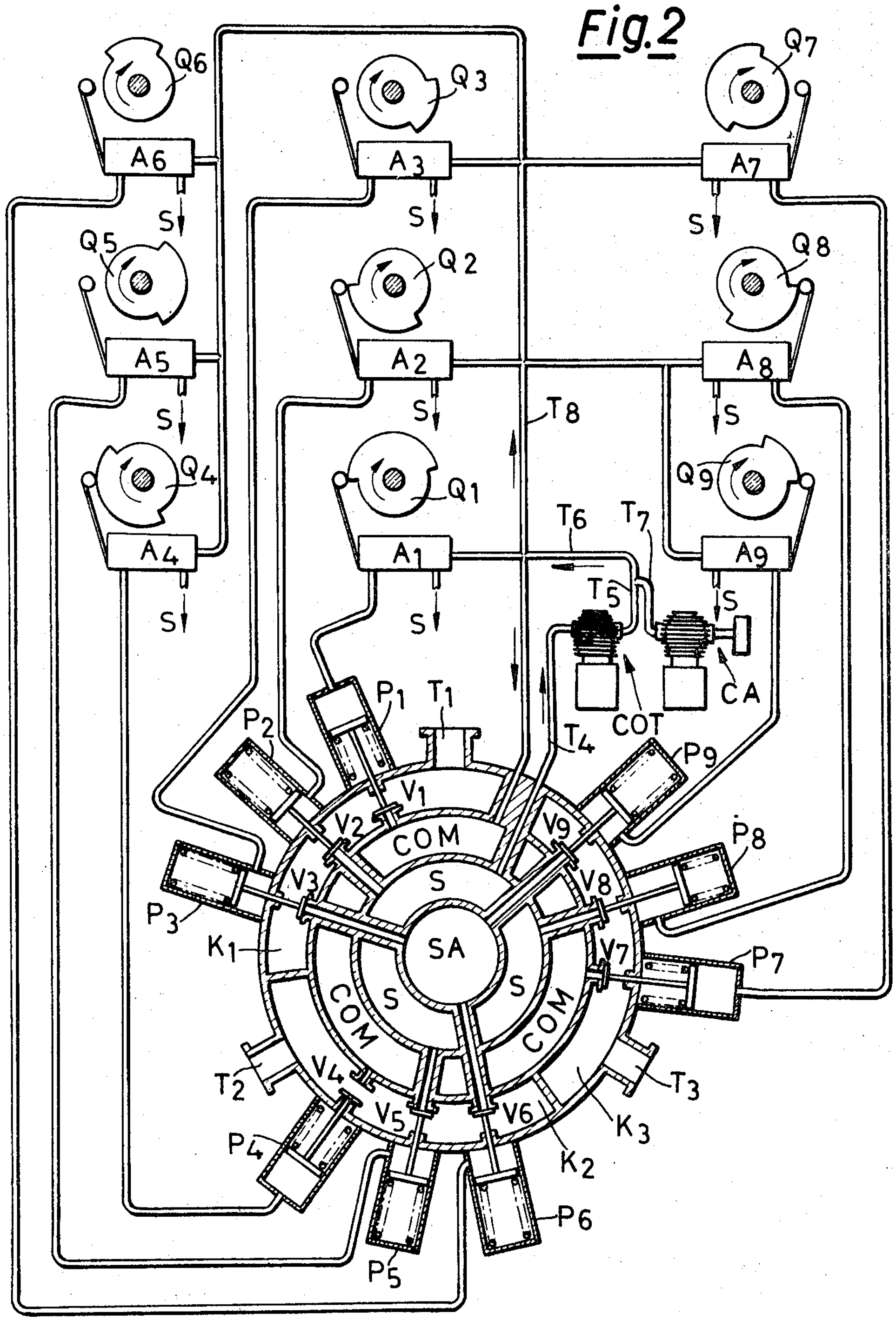

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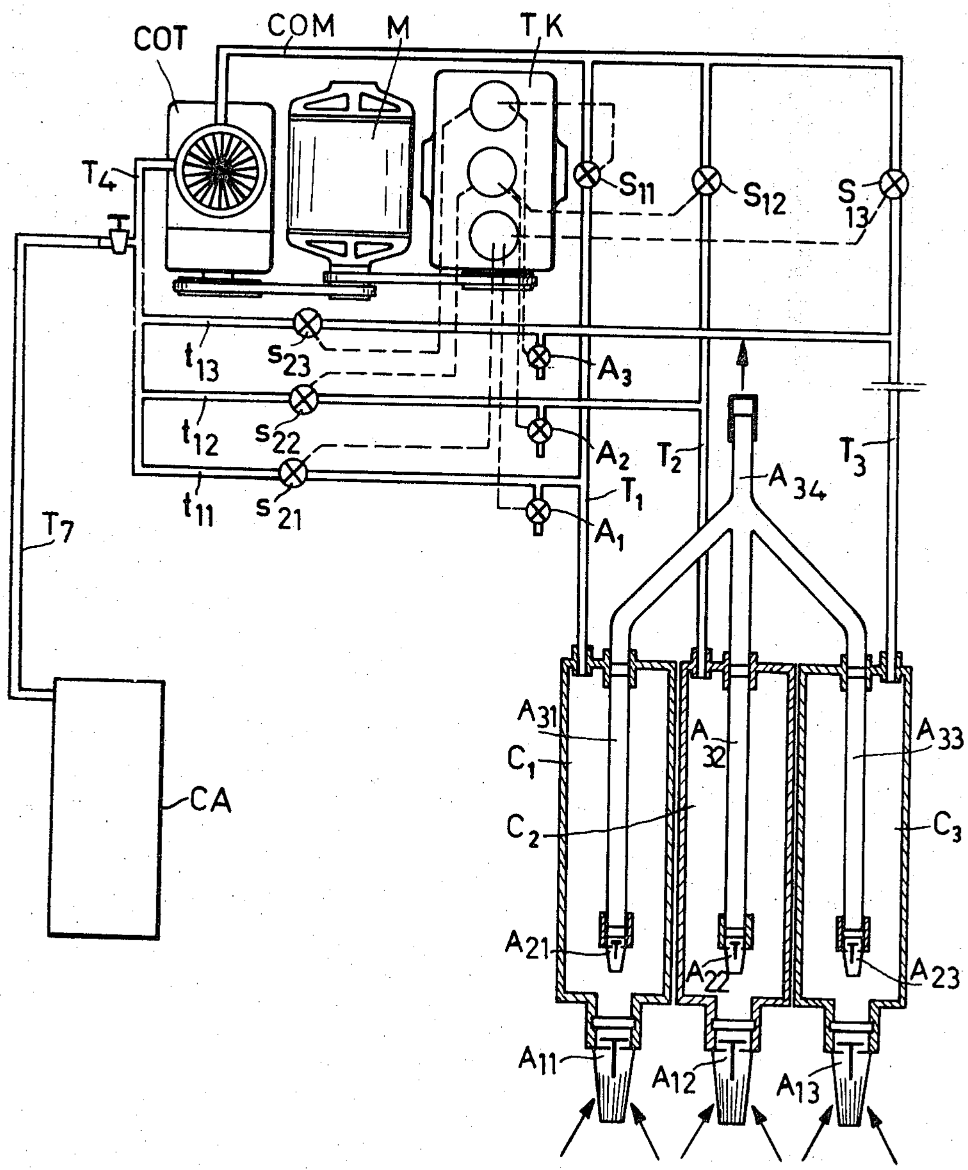
Fig.3



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United States Patent Office

3,552,884

Patented Jan. 5, 1971

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3,552,884

FLUID PUMPING STATION WORKING ON THE COMPRESSED AIR PRINCIPLE WITH PARTIAL RECOVERY AND RE-CYCLING OF THE AIR

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Filed July 15, 1968, Ser. No. 744,772
Claims priority, application Italy, July 20, 1967, 18,634/67
Int. Cl. F04f *1/00, 11/00*
U.S. Cl. 417—122 5 Claims

ABSTRACT OF THE DISCLOSURE

A device for pumping fluids by means of compressed air which is compressed in succession into a plurality of chambers submerged in the fluid to be pumped, comprising an auxiliary compressor for transferring some compressed air from the chamber from which the fluid has been expelled to another chamber which is still filled with fluid.

There are several conventional systems of fluid pumping which are generally covered as follows:

A pump casing in the form of several pump cylinders or cylindrical chambers each with valves which usually operate automatically (a fluid inlet valve and a fluid delivery valve);

An air distributor situated between the pump casing and the compressed air supply;

A compressed air supply generally in the form of a compressor.

Some of these so-called closed cycle systems contemplate recovery of the compressed air by connecting the delivery or discharge duct of the distributor to the suction pipe of the single stage compressor, so as to recycle the air that has already been used in each pump chamber.

The semi-closed cycle compressor must, in this case, be a single stage compressor.

Furthermore, these systems contemplate the application of a valve adjacent to the suction duct of the single stage compressor. This is a special valve which operates at a preset pressure. When the pressure falls below a certain level, this valve allows the compressor to draw in air from the atmosphere, too, both in order to make up for inherent losses in the system itself, as well as to reach the quantity required for the subsequent pumping stage.

It has been ascertained in practice that such systems have a poor efficiency of air saving, as well as a low saving in energy, especially when operating at low pressures.

In fact, if we compare the performance of an open-cycle system with that of a semi-closed cycle system operating through a single compressor in the conventional way, in order to obtain a delivery of 1,000 litres per minute of water at the various pressures indicated, air consumption is generally as shown in the following chart:

	Open cycle lt./min. air	semi-closed cycle with 1 single-stage compressor
Atmospheres:		
3	4,800	3,500
5	7,000	4,800
7	9,500	6,500

As will be noted, there is a slight increase in efficiency regarding air consumption as the pressure rises.

If we examine the corresponding consumption of energy, however, it will be observed that although a saving in air exists, and this increases with the increase in pressure, in the conventional semi-closed cycle system using one single-stage compressor, the consumption of energy is greater in practice than that obtained when operating with an open-cycle system and a two-stage compressor (these afford higher efficiency than single-stage compressors by virtue of their superior constructional characteristics).

In actual fact, the energy consumption for the same delivery of 1,000 litres/min. at the given pressures is as follows:

	Open cycle, HP	Semi-closed cycle with 1 single-stage compressor HP
Atmospheres:		
3	36 (single-stage)	29
5	44 (two-stage)	54
7	80 (two-stage)	92

The conclusion may therefore be drawn, that a conventional semi-closed cycle system operating with one compressor can, on the whole, guarantee a certain economy in compressed air and energy only when used in plant operating at very low pressures, i.e. up to about 3 atmospheres which is, after all, more or less the top limit of efficiency for single stage compressors in practical use.

The purpose of the invention now to be described, is to create a semi-closed cycle pumping station affording a high economy both in compressed air as well as in energy absorbed, and this high saving will increase even more as the operating pressure increases.

To this end, the essential feature of the plant using this invention is that in addition to a compressor working in combination with a multi-chamber pump, connected to a compressed air supply, it also employs a so-called "transfer compressor" which serves the purpose of transferring compressed air already used by one of the chambers to re-cycle this air by means of a special distributor.

The plant consists of:

(1) A multi-chamber pump casing each chamber being fitted with a fluid inlet valve and a delivery valve as well as a floater-type check-valve at the top of the chamber opposite the air inlet;

(2) A feed compressor for the supply of compressed air; this compressor is single stage for low pressures (generally up to three atmospheres) and two-stage for higher pressures (generally above three atmospheres). The compressor supplies compressed air to the plant, taking in this fresh air from the external atmosphere.

(3) A single-stage transfer or recirculating compressor which transfers the compressed air already used in one chamber, to the next chamber. The period of time during which transfer takes place can be regulated and transfer can be checked when the pressure in the pump chamber that has already operated falls below a given pre-set pressure.

(4) A compressed air distributor which is so constructed that apart from distributing compressed air to the pump chambers in the conventional way, also allows the compressed air discharge duct of each chamber to be connected to the intake of the transfer compressor for a period of time which can be regulated at will. The transfer compressor subsequently sends this compressed air to next pump chamber and after the pressure has fallen below a given level, opens the discharge duct to the atmosphere.

Tests have been effected on a semi-closed cycle pumping station using two compressors as indicated in this invention, and comparisons were drawn between the efficiency of this plant and that of an open-cycle single compressor pumping station. The following results were obtained, using the same units in both cases, namely a delivery of 1,000 lt./min. at the various pressures indicated on the left hand side of the chart:

CONSUMPTION OF COMPRESSED AIR

	Open-cycle, lt./min.	Semi-closed cycle using two compressors: lt./min.
Atmospheres:		
3	4,800 approximately	2,250 approximately.
5	7,000 approximately	3,000 approximately.
7	9,000 approximately	3,400 approximately.
12	15,000 approximately	4,800 approximately.

The increased air economy in proportion to the increase in pressure is quite evident in the above table.

Energy absorbed for the same delivery of 1,000 lt./min.:

	Open cycle, HP	Semi-closed, cycle using two compressors: HP
Atmospheres:		
3	37	17
5	44	29.1
7	70	45.5
12	130	73

It is quite evident, then, that a greater efficiency is always obtained using a semi-closed cycle with two compressors. This increased efficiency regards both compressed air as well as energy consumed and increases even more markedly as the operating pressure increases.

The actual operation of this invention will be easier to understand by following the attached drawings, which give an example of a pumping station using two compressors. The drawings are as follows:

FIG. 1 is a schematic diagram which illustrates such a plant incorporating a mechanically operated distributor.

FIG. 2 is a schematic diagram giving one view of the above mentioned distributor.

FIG. 3 illustrates the same plant but with an electronically operated distributor.

FIG. 1 represents schematically the operation of a fluid pumping station exploiting this invention. It consists of:

(a) A pump casing incorporating three chambers (C1, C2, C3) each one with a fluid inlet valve (A11, A12, A13), with a delivery valve (A21, A22, A23) at the end of the delivery pipe (A31, A32, A33), and a floater-type check-valve (V1, V2, V3) to let compressed air into the chambers through three air ducts (T1, T2, T3), the latter being connected to the distributor generically marked as D.

The delivery pipes (A31, A32, A33) of the three chambers are connected to a single delivery manifold A34.

(b) A feed compressor CA and a transfer compressor COT.

(c) Delivery pipe T5 and delivery pipe T7 which connect the respective compressors COT and CA to delivery pipe T6 and thus to the compressed air manifold (COM) of the distributor.

(d) A distributor D which will be described in more detail later, when FIG. 2 is discussed.

The purpose of this distributor is to connect cyclically pipes T1, T2, T3 to the manifold COM for the delivery of compressed air to one or another of the three chambers C1, C2, C3; or with pipe S which, during the transfer phase, allows the compressed air discharged from one of the chambers to pass into the suction pipe T4 of compressor COT; or with discharge duct SA which discharges into the atmosphere.

Pipe T4 adjacent to compressor COT is fitted with a calibrated spring valve VA so that the transfer compressor COT will suck in air from the atmosphere during the initial pumping stage only, and hence prevents compressed air from entering pipe T4 and possibly discharging into the atmosphere.

When pump chamber C1 has been emptied of its liquid contents through the pressure of the compressed air forced

into the chamber through pipe T1, the compressed air itself (instead of being inefficiently discharged through the same pipe T1 and thus through discharge duct SA of distributor D into the atmosphere, or directly into the atmosphere as in open-cycle, or directly into a compressor as in conventional semi-closed cycle systems), is recovered and sent through manifold S of distributor D, so designed as to allow the passage of this air to the single-stage compressor COT. This compressor thus has the very great advantage of sucking in air which is already compressed and with a subsequently very high efficiency send this air to pump chamber C2 through pipe T2, together with the compressed air supplied by feed compressor CA. The compressed air is delivered through pipe T6 to compression chamber COM of distributor D, and thus to the pre-selected pump chamber.

The advantages will be clearly evident of the transfer of this compressed air through a single stage compressor which, despite the above-normal consumption of energy, due to the extra weight of the pre-compressed air, is able to supply in practice a very large proportion of the compressed air required to run the pumping station, whereas the work done by the supplementary compressor CA is limited to a very low supply of air in order to compensate for inevitable losses in the complete cycle as well as to contribute the necessary amount of air required to carry out the subsequent pumping phase in chamber C2.

As a rule the two compressors (transfer compressor and feed compressor) will displace approximately equal volumes of air which should be about two to two and a half times that of the liquid to be pumped.

It will be evident that the greater part of the work will be done by the transfer compressor, which takes in pre-compressed air, and it is also evident that the very high efficiency of the equipment is due precisely to this fact.

The suction phase of pre-compressed air by the transfer compressor COT will be of limited duration, pre-determined on the basis of prior calculations through estimation.

In effect, only when the air pressure in pump chamber C1 falls below a given level, will the remaining air in this chamber be discharged into the atmosphere through discharge duct SA of distributor D, so that chamber C1 is given sufficient time to fill up again with the liquid being pumped.

The fluid of chamber C1 will rise only to the level of the reversed seat of the floater-type valve V1 which operates with a rubber ball or ball of other appropriate material. The purpose of this valve is to avoid malfunctioning of the system through miss-timing of the distributor. This valve therefore prevents any trouble that might otherwise be created by a too prolonged suction phase of compressor COT, and which might cause a siphoning of liquid from pump chamber C1 through distributor D to compressor COT.

The equipment just described is perfectly trouble-free and can either operate with air-transfer into the pump chamber in advance, i.e. before the preceding pump chamber has been emptied, or, of course, without advance, in which case the various phases are timed so as to obtain maximum efficiency in the system thus reducing the work required of feed compressor CA to an absolute minimum.

Whatever the operating pressure of the plant may be, however, compressor COT must work at the lowest possible pressure ratio in order to obtain the highest possible efficiency of the transfer compressor COT itself. It is a well known fact that the lower the compression ratio (that is, the ratio between the initial absolute intake pressure and the final absolute compression pressure in the compressor) the lower will be the amount of energy consumed to compress a determined quantity of air to a determined final absolute pressure.

There are also no problems whatsoever regarding the initial stages of the pumping operation. After having appropriately timed the distributor, on the basis of a previously estimated calculation, it is quite sufficient to switch on the equipment and the latter will give a slightly lower than normal delivery for a very short time until the predetermined operating pressure is reached; after which, the required delivery volume will quickly be reached and stabilized.

The distributor is fitted with a non-return check valve. As two pump chambers may be in the transfer phase at the same time during the transfer operation, this check-valve prevents a possible transfer of air from the chamber having a higher pressure to the one having a lower pressure.

The mechanicallly operated distribution can be of any kind. For example it could be of the type described in the applicant's U.S.A. Patent No. 3,319,654 which is distinguished by the fact that the compressed air passes through single valves in which the valve shutter is held simply by pressure and is actuated by a piston, which, in its turn, is actuated by compressed air fed in from the air supply duct, or by oil supplied from a special pump through valves operated by a single camshaft.

This mechanically operated device is illustrated in schematic diagram FIG. 2. The annular manifolds are marked COM, S, SA and correspond to those indicated by the same letters in the schematic diagram of the distributor in FIG. 1. K1, K2, K3 indicate the chambers connected respectively to pipes T1, T2, T3. COT and CA indicate respectively the transfer compressor and the feed compressor, which, through their respective delivery pipes T5 and T7 are both connected to pipe T6, and send compressed air to annular manifold COM.

The passage of air between the various chambers of the distributor takes place through three sets of valves, V1, V2, V3; V4, V5, V6; and V7, V8, V9, actuated by three sets of valve pistons P1, P2, P3; P4, P5, P6; and P7, P8, P9. These are one-way, fitted with return springs and are operated by compressed air taken from the same delivery pipe T6, through pipe T8 and valves A1, A2, A3; A4, A5, A6; and A7, A8, A9 actuated by their respective cams Q1, Q2, Q3; Q4, Q5, Q6; and Q7, Q8, Q9 on a single cam-shaft. The angular phase displacement of the respective cams on the cam-shaft is such as to obtain perfect cyclical operation of the distributor and thus of the whole plant.

The distributor works in the following way:

In the diagram, compression valve V1 of the first pump chamber, its piston P1 being actuated through valve A1, is about to close. Valve V4 of the second pump chamber, its piston P4 being actuated through valve A4, is already open due the advance timing. Valve V8 which serves the purpose of transferring compressed air from the third chamber to the first chamber, is also about to close. All the other pistons are closed.

As the cycle continues, after valve piston P1, actuated by valve A1, has sent compressed air to the first pump chamber C1, the valve piston P1 closes. Valve piston P8, actuated by valve A8, and which draws air from chamber C3 transferring it to chamber C1, also closes. Valve piston P2, actuated by valve A2, and which serves to transfer compressed air from the first chamber to the second chamber C2, then opens.

Compressed air is thus forced into chamber C2 through a duct T4 which carries the compressed air from the transfer manifold S to the transfer compressor (COT) inlet, which, in its turn delivers the compressed air through duct T5. This recovered and transferred air is brought up to operating pressure and added to the air fed in through compressor CA is delivered to the manifold COM.

Valve V4, which lets compressed air into the second pump chamber, is already open and all the compressed air collected in manifold COM is thus sent to the second pump chamber.

Together with valve V2, valve V9 also opens, thus allowing the remaining compressed air of the third chamber to be discharged into the atmosphere. Valve piston P9 is, of course, actuated by valve A9. The third chamber is thus empty and can fill up again with liquid.

Continuing the cycle, after valve V9, its piston P9, actuated by valve A9, has allowed the residual air of the third chamber to be discharged into the atmosphere, and thus allowed the third chamber to fill up with liquid, valve V9 closes, once again actuated by valve A9.

Once valve V9 is closed, valve V7 opens. The latter is actuated by valve A7 working on piston P7 and allows the compressed air to pass into the third chamber.

As can be observed, valve V7 opens before valve V4 closes; valve V4 is the one that allows the compressed air to pass into the second pump chamber C2. The opening phase of valve V7 before valve V4 closes is one of the particulars of the advanced timing; that is, to begin the delivery of compressed air into the next chamber, before the delivery of compressed air into the preceding chamber has terminated. The advanced timing permits an even and uniform flow of liquid.

After the opening of piston P7, actuated through valve V7 to delivery air into the third pump chamber, valve V4 closes. The function of valve P4, as we have seen, is to let air into the second pump chamber C2, the valve piston P4 being actuated through valve A4.

After the closing of valve V4, valve V2 closes. The purpose of valve V2, actuated through valve A2, is to transfer the air from the first pump chamber to the second pump chamber. At the same time, alve V5 closes, actuated through valve A5, the purpose of valve V5 being to transfer the compressed air from the second pump chamber to the third pump chamber.

As mentioned previously the distributor incorporating mechanically operated valves can advantageously be substituted by an electronically operated distributor incorporating electrically actuated valves applied to the tubing connecting the compressors to the various pump chambers. These valves are actuated through electrical impulses received from an appropriately pre-set timer.

FIG. 3 illustrates this second type, which, in addition to the three chamber pump (C1, C2, C3), the transfer compressor COT and the feed compressor CA, also has the electrically operated valves S11, S12, S13 applied to the single delivery pipes T1, T2, T3 which lead in turn to the three chambers respectively, electrically operated valves S21, S22, S23 applied to the suction pipes *t*11, *t*12, *t*13 which are connected to the suction pipes of COT, and with A1, A2, A3 being the electrically operated discharge valves, that permit pipes *t*11, *t*12, *t*13 to be opened to the atmosphere. Finally, M indicates the electric motor that drives the compressors and Timer TK that actuates the valves.

The operating cycle of plant using this type of distributor is identical to the one just described.

If, for example, the cycle starts with the emptying of chamber C1 previously full of liquid, valve S11 opens and S21 and A1 close. The compressed air thus passes from manifold COM into chamber C1 and drives out the liquid through delivery pipe A31. When C1 is empty, S11 closes and S21 opens, whilst S12 has opened in advance of the closing of S11.

Transfer of air then takes place from chamber C1 to chamber C2 until the pressure in C2 falls to the predetermined level. S21 then closes immediately and A1 opens to discharge the residual air into the atmosphere. At this point A1 closes and a new cycle begins.

The same process applies to chambers C2 and C3, the cycle for these being timed through TK.

I claim:

1. A device for pumping fluids by means of compressed gas comprising:

a plurality of submerged chambers, each being provided with a fluid inlet valve, a fluid outlet valve, and a compressed gas supply tube;

means for cyclically controlling the flow of compressed gas to said submerged chambers through said supply tubes comprising a compressed gas distributor;

means for supplying compressed gas to said distributor comprising a two-stage fresh feed compressor, and fresh feed gas tube means passing from said fresh feed compressor to said distributor; and

means to transfer compressed gas already used in a first of said submerged chambers to a second of said submerged chambers simultaneous with the operation of said fresh feed compressor, said compressed gas transferring means comprising a recirculating compressor, recirculator gas tube means passing from said distributor to said recirculating compressor and from said recirculating compressor to said distributor.

2. A device in accordance with claim **1** wherein said recirculating compressor comprises a single stage compressor.

3. A device in accordance with claim **1**, wherein each of said submerged chambers is provided at its upper end with a floater-type check-valve with reversed seat at the end of said gas supply tube.

4. A device in accordance with claim **1**, wherein said distributor comprises means for regulating the intake of compressed gas from said first submerged chamber to said recirculating compressor to effect said transfer of compressed gas for a determined period of time until the pressure in said first chamber is decreased to a predetermined value.

5. A device in accordance with claim **1**, wherein said distributor comprises electrically actuated valve means and timer means to control said electrically actuated valve means.

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