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PRESSURE EXCHANGERS

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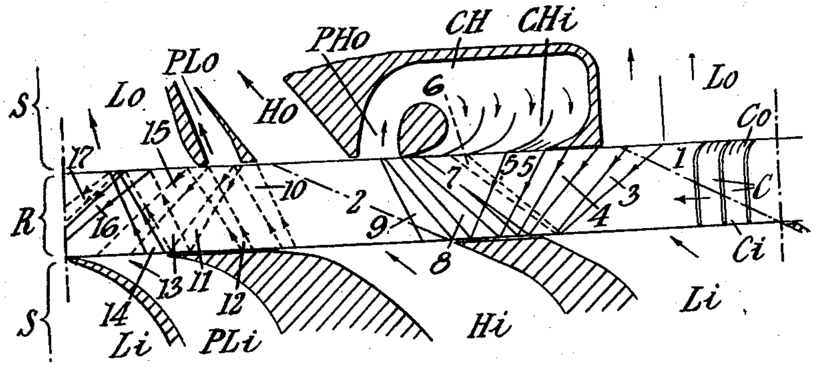

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PRESSURE EXCHANGERS

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4 Claims. (Cl. 230—69)

This invention relates to machines, hereinafter referred to as pressure exchangers, in which each of a plurality of cells serves cyclically to receive gas from a source of lower pressure and discharge it to a pressure-increasing means, and to receive gas from said pressure-increasing means and discharge it to a region of lower pressure. The cells are arranged around the periphery of a rotor mounted to pass over appropriate permanently-open ports in the walls of a stator. (Of course, the terms rotor and stator are used relatively, the one to the other, so that it might be that the "rotor" is stationary in space and that the "stator" rotates about the rotor.) The admission and discharge of the gas to and from the cell in the lower and in the higher pressure stages is hereinafter referred to as "scavenging"; being defined as a condition in which both ports of the cell being open together for a sufficient duration of time, there occurs a displacement of a substantial part of the former contents from the cell, and their replacement by fresh gas.

The pressure-increasing means is conveniently a combustion chamber wherein the received gas is made to burn with a fuel to increase both its volume and temperature.

Conveniently, too, but not necessarily, the motion of the gas into and out of the cell in both of the scavenging stages is unidirectional, so that it is possible to speak of an inlet to and an outlet from the cell, the inlet being on one flank of the rotor and the outlet on the other flank.

When the machine is arranged as an engine, it serves to convert some of the pressure energy from said pressure increasing means into kinetic energy.

It is desirable that immediately before a cell reaches the low pressure stage or the high pressure stage, the gas in in the cell should be accelerated towards that port, usually the cell outlet, from which the gas is to be discharged in said stage. Hereinafter this acceleration is referred to as "prescavenging."

A somewhat fuller exposition of the working of such machines may be found in my copending patent application Serial No. 594,461.

It will be understood that at the instant when one of the ports of the cell is opened, either to a region of higher pressure than that obtaining in the cell or to a region of lower pressure than that obtaining within, then a wave will travel through the cell from that newly-opened port towards the other port, at a velocity comparable with that of the velocity of sound, being in the first case a compression wave and in the second case a rarefaction wave. When the wave reaches the far end, it will be reflected: if the far end is closed, the reflected wave will be of the same sense as the incident wave, compression-compression or rarefaction-rarefaction: while if the far end is open, the reflected wave will be of opposite sense. In the same way waves are generated at the instant of closing of a port which had been open.

It is one of the objects of the present invention to provide for the neutralisation of waves before their existence can operate adversely upon the performance of the machine.

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The following description relates to the accompanying drawing which shows, by way of example only, one embodiment of the invention.

In the drawing is shown a development of the rotor and stator system of a pressure exchanger embodying the present invention, with a rotor R moving from right to left as indicated by the arrow between the two flanking parts of a stator S. The rotor has an array of cells in its periphery; and the stator has a number of ducts whose mouths at fixed positions around the inner periphery of the stator open towards the paths of movement of ports leading into and out of the cells.

The rotor cells

Each of the similar cells C in the rotor R has an inlet port C*i* and an outlet port C*o*, the latter having its adjacent cell walls bent backwards.

The stator ducts

As the cell C moves from right to left its inlet port C*i* sweeps successively over the mouths of the following inlet or delivery ducts, namely: low-pressure scavenging L*i*, high-pressure scavenging H*i*, and low-pressure prescavenging PL*i*. Similarly the outlet port C*o* sweeps over the mouths of a number of ducts, all but one being outlet or receiving ducts. They are: the low pressure scavenging outlet or receiving duct L*o*, the high pressure compression delivery duct CH*i*, the high pressure pre-scavenging receiving duct PH*o*, the high pressure scavenging receiving duct H*o*, and the low pressure prescavenging receiving duct PL*o*.

The pressure-exchange cycle

Thus the cycle through which such a cell C passes consists of five stages, of low and high pressure scavenging and pre-scavenging and of compression. More particularly, this cycle is as follows:

(1) Low pressure scavenging: When the cell is at the righthand side of the drawing, its inlet and outlet ports C*i* and C*o* are both open to the respective low pressure scavenging delivery and receiving ducts L*i* and L*o*. This is the low pressure scavenging stage; the outlet L*o* discharges to the atmosphere and the linlet L*i* receives air from the atmosphere either directly or via a fan.

(2) Compression: From the low-pressure scavenging stage L the cell passes to the compression stage where the cell inlet C*i* is closed while the outlet C*o* is open to the delivery duct CH*i*.

(3) High pressure pre-scavenging: In the high-pressure pre-scavenging stage PH, the cell inlet C*i* is open to the high pressure delivery duct H*i* and the cell outlet C*o* is open to the receiving duct PH*o*.

(4) High pressure scavenging: High pressure scavenging exists when both cell inlet and outlet are connected to the respective high pressure ducts H*i* and H*o*. The receiving duct H*o* leads to a combustion chamber (not shown) and the delivery duct H*i* takes from the combustion chamber.

(5) Low pressure pre-scavenging: Beyond the high pressure scavenging stage is the low pressure pre-scavenging stage PL. Here the cell inlet C*i* is at first closed and is then opened to the inlet PL*i*. The outlet is open firstly to the pre-scavenging outlet PL*o*, and then to the low pressure scavenging outlet L*o*.

Wave propagation

At the instant of opening or closing either of the cell ports, a wave is set up in the cell from that port, and travels through the cell, at a speed comparable with that of sound, towards the other cell port, where it is reflected. Such waves are either compression waves or rarefaction waves according to the change occurring at the originating end, and are reflected as either compression waves or rarefaction waves according to the condition obtaining at the reflecting end.

The path of a compression wave in space, i.e. relative to the stator, is shown by a pair of continuous lines and that of a rarefaction wave by a pair of broken lines; the first line of each pair marks the foot of the wave and the second line marks the head. As is known, compression waves tend to grow steeper as they progress, and rarefaction waves to grow shallower, so that the two full lines of a pair converge, while broken lines diverge. A compression wave is transformed into a shock wave when a pair of full lines meet.

The occurrence of a wave may be advantageous or deleterious; and the present invention is concerned with the neutralisation of waves that are deleterious.

A certain wave pattern will exist for one set of conditions only, the condition exerting the most influence on the wave pattern being the rotor speed. In the drawing, therefore, the wave pattern shown is that obtaining when conditions approximate to design values; however, it is so arranged and it is one of the objects of this invention that the change in pattern caused by variation in operating conditions has only a minor effect upon the performance of the machine.

The wave cycle

The following are the waves that are developed in the cell in its cyclic movement from low pressure scavenging through compression, high pressure prescavenging and scavenging and low pressure prescavenging back to low pressure scavenging.

In the drawing, as a cell C moving from right to left approaches the end of the low pressure scavenging stage L the flow of gas through the cell is retarded by waves of compression **3** and **4** travelling from the cell outlet *Co* towards the cell inlet *Ci* and generated by the gradual closing of the cell outlet *Co* to the low pressure scavenging discharge duct L*o*, i.e. the wave **3** by a partial and the wave **4** by the complete closure. The reception of wave **3** at the inlet end *Ci* causes substantial cut-off of the flow into the cell from the stator inlet duct L*i*, but without that reversal of flow into duct L*i* which would occur if no partial closure of L*o* preceded the complete closure, so that waves **3** and **4** coincided and their combined amplitude therefore were greater.

The waves **3** and **4** are desirable waves, since by them the energy remaining in the cells after scavenging is substantially used to produce a supercharging effect; but the reflected waves **6** and **7** form a rarefaction pulse which if further reflected would be undesirable. They are substantially neutralised on reception at the pre-compression nozzles CH*i* feeding the outlet ends of each cell.

Precompression is effected by introducing gas from duct CH*i* at an elevated pressure so that compression wave **5** is produced. This wave is reflected from the closed inlet *Ci* as wave **8** producing further compression. Although waves **5** and **8** are desirable, the further reflection of wave **8** from the outlet end would be undesirable. By suitable design of the nozzles in precompression duct CH*i* to give sufficient pressure drop the desired neutralisation of wave **8** is effected. The pressure of gas fed to the nozzles is then equal to that of the wave head of wave **8**.

After transit of wave **8** the cell contains stagnant gas at an elevated pressure substantially equal to that in prescavenge receiving duct PH*o*, so that the cell contents are not influenced when the cell is opened to this duct on further movement of the rotor.

Prescavenging is produced by opening the cell inlet *Ci* to the high pressure scavenging delivery duct H*i*, when a compression wave **9** completes the compression process and accelerates the cell contents to scavenging speed. The prescavenging receiving duct PH*o* is so positioned as to receive wave **9** and on arrival this wave causes discharge from the cell to commence. By restriction of the cell outlets preferably by using bent back trailing edges as at *Co* the reflection of wave **9** as a rarefaction wave can be at least reduced.

On passing the wall beyond PH*o*, the cell enters the high pressure scavenging stage H and to prevent the formation of a pressure pulse by temporary flow stoppage the width of the wall is made less than the cell width or less than the width of subsidiary channels if fitted in the outlet end of the cell.

Hot gas enters the cell at its inlet end from duct H*i* and cold gas is withdrawn from the outlet end H*o*; the progress of the interface between the two gases is indicated by line **2**.

At the end of the high pressure scavenging stage the scavenging flow is arrested in two stages by rarefaction waves **10** and **12**. The first wave **10** is produced by partial restriction of the cell inlet caused by the change to a high angle inlet nozzle of the delivery duct H*i*. Wave **12** is produced by complete cut off from delivery duct H*i*. Termination of scavenging in two stages as described is desirable in order to improve the flow conditions at the receiving duct H*o*, especially at lower speeds of operation. Also, the high angle nozzle serves to neutralise any unwanted residual waves received by it.

An important rarefaction wave **11** is produced upon opening the cell outlet *Co* to duct PL*o* at a lower pressure and is supplemented by reflection of wave **10** from the wall between H*o* and PL*o*. In the same way the final rarefaction wave **15** produced by opening the cell to the low pressure scavenging discharge duct L*o* is reinforced by the reflection of wave **12**.

Wave **11** reflects from the closed inlet end as wave **13** and is followed closely by compression wave **14** produced by opening the cell inlet to the low pressure prescavenging delivery duct PL*i*. An undesirable retarding pulse **13, 14** is thereby produced which will be continually reflected from the cell ends during scavenging as indicated for the first such reflection by pulse **16, 17**, and which increases in width as the speed is reduced. Substantial neutralisation of wave **15** by impingement on the nozzles PL*i* is ensured by correct design of the nozzles PL*i*, gas for PL*i* is fed from expansion duct PL*o*.

The dividing wall between PL*i* and L*i* is of narrower width than the cell in order to prevent production of an undesirable rarefaction pulse.

The interface between incoming fresh gas from inlet L*i* and spent gas is shown progressing along a cell by line **1**.

The apparatus and its operations having thus been described, it remains to point out how that apparatus embodies the features of the present invention.

Thus it will be seen that at a number of stages of the cycle, a wave within a cell is substantially neutralised on reaching a cell port by meeting a gas stream which is of appropriate pressure relative to the pressure obtaining in the cell and which comes from a duct of appropriate throat area to which said port is then open. In particular, there occurs a substantial neutralisation of the rarefaction wave **15** when it reaches the inlet port *Ci* of the cell at a moment when that port is open to the low-pressure prescavenging delivery duct PL*i*, said duct PL*i* having a substantial angle of inclination to the normal to the direction of movement of the cell inlet *Ci*, and that inclination being in the direction of movement of the cell port *Ci*.

Again the pressure wave **3** generated at the cell outlet *Co* by flow restriction and reflected as rarefaction wave **6** at the open cell inlet *Ci* is substantially neutralised on again reaching the cell outlet *Co*, and the pressure wave **4** generated at the cell outlet *Co* by the closing thereof to the low pressure receiving duct L*o* and reflected from the closed cell inlet *Ci* as pressure wave **7** is substantially neutralised on again reaching the cell outlet *Co* both neutralisations being due to the meeting of the respective waves at the cell outlet *Co* with a gas stream of appropriate pressure relative to the pressure obtaining in the cell from the duct PH*i* of appropriate throat area to which the cell outlet C*o* is then open.

The compression wave 9 generated at the cell inlet C*i* by the opening thereof to the high pressure delivery duct H*i* is partially neutralised on reaching the cell outlet C*o* by reason of the cell outlet C*o* being of restricted throat area as compared with the cell being then open to the receiving duct PH*o* through which gas is taken to the delivery duct PH*i* to which the cell outlet C*o* is open when the cell inlet C*i* is closed after leaving low pressure scavenging L*i*.

The compression wave 5 generated at the cell outlet C*o* by the opening thereof to the higher pressure delivery duct PH*i* between the low pressure and high pressure scavenging stages L*o* and H*o* and reflected as compression wave 8 from the closed cell inlet C*i* is substantially neutralised on again reaching the cell outlet C*o* because outlet C*o* is still open to said duct PH*i* and by the correct choice of nozzle throat area CH*i* the pressure developed behind wave head 8 is made substantially equal to that at inlet to the nozzles. In other words, the cell outlet is open to the said duct PH*i* for a sufficient duration to allow of the wave 5 to be reflected as wave 8 into said duct PH*i* even at the highest speed of rotation.

The wave-neutralising pocket PH between the low pressure and high pressure scavenging stages is so arranged that the receiving duct PH*o* thereof is open to the cell outlet C*o* when the pressure wave 9 originating with the opening of the cell inlet C*i* to the high pressure delivery duct H*i* arrives at the outlet C*o*, while the delivery duct CH*i* of said pocket is open to the cell outlet C*o* before the receiving duct PH*o*. The pocket PH is shown wholly closed external to the machine but operation is characterised by the same description when a substantial bleed from this pocket for some external use is allowed.

It will of course be understood that the invention may take many other forms than that shown in the accompanying drawing. In particular alternative arrangements giving more efficient working are obtained when delivery duct CH*i* faces the rotor periphery or the cell inlets C*i*.

With peripheral admission a pressure wave will travel radially inwards to be reflected at the closed wall formed by the rotor drum and be substantially neutralised after travelling radially outward to meet the nozzles CH*i*, neutralisation being achieved in a manner similar to that described with reference to Fig. 1.

In order to allow for the effect of linear taper of a cell as measured in the direction of wave travel, a configuration inherent in the use of peripheral admission, it is found convenient to use the same equations defining the required nozzle as for cells of constant section in the direction of wave travel the effective cell cross sectional area for tapered cells being taken at a section one quarter of the distance from the said nozzles to the opposite closed wall.

Also the rarefaction pulse formed by waves 6 and 7 remaining from low pressure scavenging is partially neutralised by the gas stream flowing from nozzles PH*i* although in this case the flow is normal to the direction of motion of the said pulse.

With nozzles CH*i* facing the cell inlets C*i* neutralisation of pressure waves is as described with reference to Fig. 1 except that neutralisation takes place at the cell inlet C*i* instead of cell outlet C*o* after reflection from the closed cell outlets C*o*. Also the rarefaction pulse formed by waves 6 and 7 is substantially neutralised by nozzles CH*i* after its further reflection from the cell outlet C*o*.

A disadvantage of the expansion stage as shown in Fig. 1 exists whereby by the reflection of rarefaction wave 11 as wave 13 and the subsequent formation of pressure wave 14 an unwanted rarefaction pulse is formed which becomes increasingly conspicuous as speeds are reduced. This can be minimised by extending the high pressure inlet duct H*i* to a point close to prescavenge duct PL*i* the said duct extension taking the form of a highly inclined nozzle wall.

Further unwanted pulses can in certain cases be prevented from forming by correct choice of duct dividing wall thickness. In particular walls between outlet ducts PH*o* and H*o* and between PL*i* and L*i* are best having widths less than the cell wall spacing such that undesired momentary flow reversal associated with transfer of a cell port between ducts at different pressure is prevented, whilst at the same time the production of unwanted pressure or rarefaction pulses which would occur when momentarily closing such a cell port is avoided. The width of such walls is required to be from 0.2 to .8 of the cell spacing for a wall between PH*o* and H*o* and from zero to .8 of the cell spacing for a wall between PL*i* and L*i* depending on flow velocities.

The invention is not limited to the use of a single precompression delivery duct CH*i* and further advantages can be obtained when a number of delivery ducts are employed. In particular the addition is desirable of at least one delivery duct opening to the cells after low-pressure scavenging but before opening to a main delivery duct of much larger extent. The said first delivery duct is arranged to have a pressure higher than that in the cell but lower than that in any succeeding duct between low and high pressure scavenging whereby a pressure wave is created without creating the excessive initial speeds of gases delivered from the duct nozzles which would occur if the main delivery duct were opened directly to cells leaving low pressure scavenging. The first ducts are so arranged that together with the main delivery duct a single pressure wave of steadily increasing amplitude is formed to be reflected at the opposite closed wall and received again by the said main delivery duct neutralisation of the reflected pressure wave being exactly as described with reference to Fig. 1.

The nozzle angles required to give neutralisation of waves in accordance with the foregoing description are substantially as given by the following equations:

(1) Compression stage CH*i*: Nozzle angle B required to produce a pressure behind wave 8 equal to that upstream of the nozzles.

$$\cos B=\frac{Aw}{An}\cdot\frac{\cos\alpha\sqrt{\frac{2}{\gamma-1}\cdot\frac{aw}{an}}\cdot(Z_w-Z_1)}{\sqrt{\zeta n[(1+Z_n)^2-(1+Z_w)^2]}}$$

where

$$Z=\left[\frac{P}{Po}^{\frac{\gamma-1}{2\gamma}}-1\right] \qquad (\cdot\text{Pressure parameter})$$

and

$$Z_w=Z_1+(Z_n-Z_1)\left[\frac{1+\frac{an}{aw}}{3+\frac{an}{aw}}\right]$$

and

$$\frac{Aw}{An}=\frac{\text{Cell cross sectional area measured normal to axial direction at a point one quarter of the distance from nozzle to opposite wall}}{\text{Nozzle outlet cross sectional area measured normal to axial direction}}$$

"Axial" is replaced by "radial" when duct nozzles are open to the cell periphery.

B=nozzle angle measured from axial direction.

α=cell helix angle measured from axial direction at point of measurement of A*w* except for duct nozzles facing the cell periphery when =zero.

γ=ratio of specific heats for gas at constant pressure and constant volume.

an=speed of sound of gas issuing from nozzles.

aw=speed of sound of gas initially in cells when at the same pressure as that issuing from nozzles.

ζn=nozzle efficiency.
Zo=pressure parameter at any chosen datum.
Z_n=pressure parameter upstream of nozzles.
Z_1=pressure parameter initially in cells at a point not influenced by unwanted pulses.
Z_w=pressure parameter measured at incident wave head near nozzles.

(2) Low pressure prescavenging nozzles PL*i*: Nozzle angle B required to produce neutralisation of a rarefaction wave of amplitude Z_1-Z_w when the gas initially in the cells at Z_1 has the same pressure as that upstream of the nozzles at Z_n, i.e.

$$Z_1=Z_n$$

$$\cos B=\frac{\frac{Aw}{An}\cdot\cos\alpha\sqrt{\frac{2}{\gamma-1}}\cdot\frac{aw}{an}(Z_n-Z_w)}{\sqrt{\zeta n[(1+Z_n)^2-(1+Z_w)^2]}}$$

Using the same symbols but any value for Z_w as defined by the wave point to be neutralised.

What I claim is:

1. In a pressure exchanger, a rotor having a plurality of cells arranged peripherally thereof and opening on opposite sides of the rotor, and walls on opposite sides of said rotor each having at least one duct communicating with the openings of the cells, the duct in the first wall being supplied with gas for delivery to the cells and the duct in the second wall receiving gas from said cells, the ducts in the two opposite walls being in operative alignment, whereby the cells in their passage from one duct to the other will be suddenly closed at least at one end to set up a wave in the cell which is then reflected from the opposite end, and means for neutralizing said reflection comprising a further duct communicating with the one end of the cell and a supply of gas thereto at a pressure sufficient to neutralize said reflection and prevent further reflection from said one end.

2. A pressure exchanger comprising a rotor having a plurality of radially extending partitions about the periphery thereof to form a plurality of cells which are open at opposite sides of the rotor, a stator having a wall adjacent each side of the rotor, each wall having ducts therein communicating with the openings in the cells, the ducts in a first wall defining delivery ducts and those in the second wall defining receiving ducts and being substantially in operative alignment with each other, means for supplying scavenging gas at a low pressure to a first delivery duct, means for supplying scavenging gas at a high pressure to a second delivery duct, a low pressure pre-scavenging receiving duct in the second wall between high and low pressure scavenging receiving ducts in the second wall and substantially opposite a wall portion between the high and low pressure scavenging delivery ducts, the wall portion between the low pressure pre-scavenging receiving duct and the high pressure scavenging receiving duct facing said cells and being .2 to .8 of the width between cell walls, such that no undesirable pressure pulse is formed by momentary flow from the high pressure receiving duct to a cell faced by the wall portion, whereby reflections are prevented.

3. A pressure exchanger comprising a rotor having a plurality of radially extending partitions about the periphery thereof to form a plurality of cells which are open at opposite sides of the rotor, a stator having a wall adjacent each side of the rotor, each wall having ducts therein communicating with the openings in the cells, the ducts in a first wall defining delivery ducts and those in the second wall defining receiving ducts and being substantially in operative alignment with each other, means for supplying scavenging gas at a low pressure to a first delivery duct, means for supplying scavenging gas at a high pressure to a second delivery duct, a low pressure pre-scavenging duct in the first wall between the high and low pressure scavenging delivery ducts, said pre-scavenging duct being smaller than and in alignment with a portion of the low pressure scavenging receiving duct and in communication with the cells, the wall portion between the low pressure pre-scavenging duct and the low pressure scavenging delivery duct facing said cells and being .1 to .8 of the width between cell walls such that no rarefaction pulse is produced within the cell faced by the wall portion due to momentary flow from the cell to the low pressure delivery duct, whereby reflections are prevented.

4. A pressure exchanger comprising a rotor having a plurality of radially extending partitions about the periphery thereof to form a plurality of cells which are open at opposite sides of the rotor, a stator having a wall adjacent each side of the rotor, each wall having ducts therein communicating with the openings in the cells, the ducts in a first wall defining delivery ducts and those in the second wall defining receiving ducts and being substantially in operative alignment with each other, means for supplying scavenging gas at a low pressure to a first delivery duct, means for supplying scavenging gas at a high pressure to a second delivery duct and a further duct in the second wall between the high and low pressure scavenging receiving ducts for delivering gas at high pressure to the cells, a high pressure pre-scavenging receiving duct in the second wall in communication with the cells, positioned between the further duct and the high pressure scavenging receiving duct and in communication with the further duct, the wall portion between the prescavenging receiving duct and the high pressure scavenging receiving duct facing said cells and being .2 to .8 of the width between cell walls, such that no undesirable pressure pulse is formed by momentary flow from the high pressure receiving duct to a cell faced by the wall portion, whereby reflections are prevented, and means to neutralize reflections due to closing a cell as it approaches the high pressure second mentioned delivery duct, comprising means for supplying gases at such a pressure to said high pressure prescavenging delivery duct as to neutralize such reflection and prevent further reflection from the cell which is open to the high pressure prescavenging duct.

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