Sept. 15, 1959 R. D. PEARSON 2,904,242

PRESSURE EXCHANGERS

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Fig. 1.

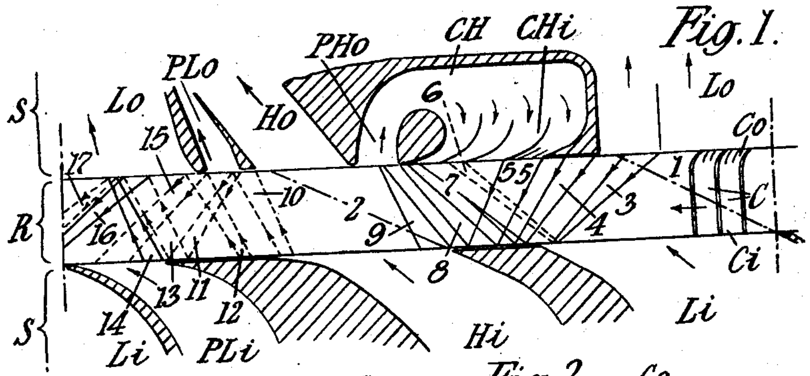
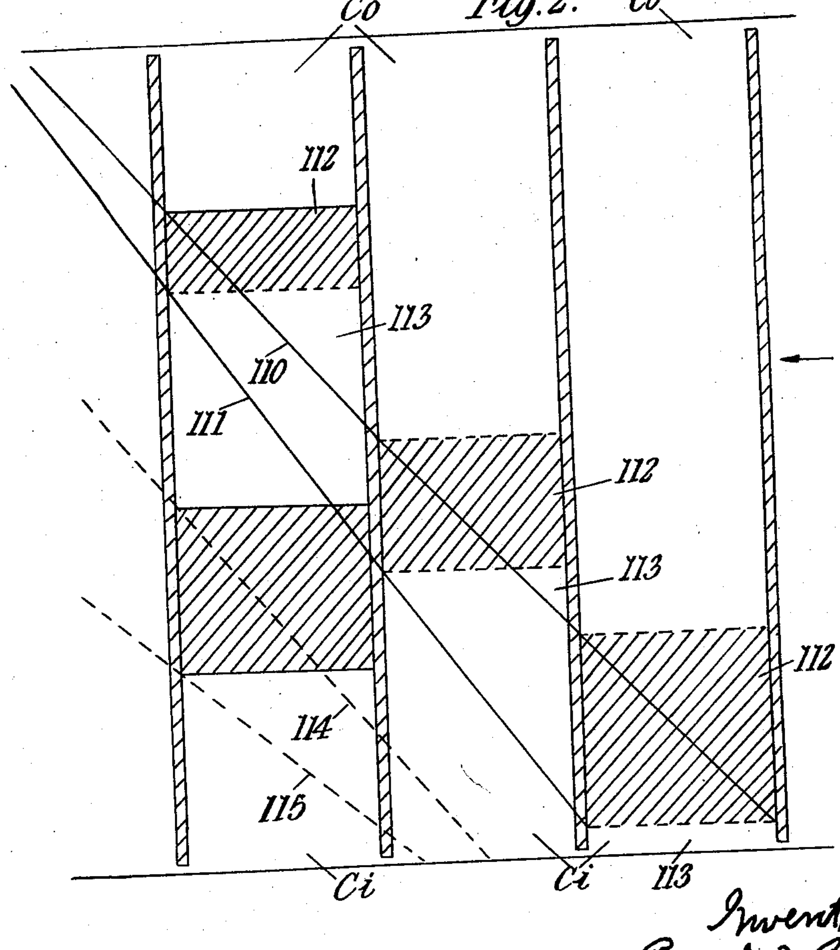


Fig. 2.



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PRESSURE EXCHANGERS

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9 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 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.

One of the objects of the present invention is to provide that a scavenging stage is immediately preceded by what is hereinafter referred to as prescavenging, when the gas within the cell is accelerated towards that port from which it is about to be discharged in the scavenging stage.

The following description relates to the accompanying drawings which show, by way of example only, one embodiment of the invention. In the drawings:

Figure 1 is a developed view of a pressure exchanger in accordance with this invention; and

Figure 2 is a diagram showing the mode of wave representation in Figure 1.

In Figure 1 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 path 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.

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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 pre-scavenging 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 pre-scavenging 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 inlet 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 PI*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 method of wave representation is shown more clearly in Figure 2, showing the progress of a compression wave **110**, **111**, from cell inlet to outlet. The line **110** marks the foot of the wave and the line **111** the head, in relation to the forward wall of the cell. (It has always to be remembered that the cell has a finite width circumferentially of the rotor and that the waves extend over the full cell width.) The cross hatched areas **112** indicate the sloping wave front in which the pressure and particle velocities increase steadily from wave foot to wave head; the particle velocity being in the direction of wave travel though at much lower speed. The areas **113** following the sloping wave front represent a zone in which pressure and particle velocities are steady and must remain so until affected by passage of some other wave front such as rarefaction wave **114—115**.

A pair of waves of opposite sense following one another within a cell-length constitute a pulse; a compression pulse or a rarefaction pulse according as the leading wave is one of compression or of rarefaction. Thus the pair of waves **110, 111; 114, 115**, together constitute a compression pulse.

The occurrence of a wave may be advantageous or deleterious; and the present invention is concerned with the generation and utilisation of waves that are advantageous. In general, waves are to be generated in the prescavenging stages and utilised there to accelerate the gas in the cell towards that port cell from which they are to be discharged in the succeeding scavenging stage.

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 Figure 1, 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 Figure 1, 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 scavening 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.

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 pre-scavenging 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.

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 imporant 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 a pre-scavenging acceleration of gas in a cell approaching the high pressure scavenging stage H or the low pressure scavenging stage L is effected by changing the condition of a cell port, that is to say opening it or closing it, so as to cause an appropriate wave to be transmitted through the cell. By an appropriate wave is meant: a compression wave such as wave **9** travelling towards the port such as the cell outlet *Co* from which the scavenging discharge is to occur; or a rarefaction wave such as wave **11** travelling away from that port.

The high pressure scavenging stage H is preceded by pre-scavenging in which one cell port namely the cell inlet *Ci* is open to the scavenging inlet duct H*i* and another cell port namely the cell outlet *Co* is open to the receiving duct PH*o* receiving gas from the cell and returning it at least in part to some other point in the cycle namely at the earlier point CHi.

Again, between the low and high pressure scavenging stages L and H a cell port such as Co is open to a delivery duct such as CHi receiving gas from a duct such as PHo into which the cell is discharging through one cell port such as Co when another cell port such as Ci is open to the high pressure delivery duct Hi.

Between the low pressure scavenging stage L and the high pressure scavenging stage H, there occurs a compression in which one cell port namely the cell inlet Ci is closed by the wall between delivery ducts Li and Hi and another cell port namely the cell outlet Co is open to the delivery duct CHi which receives gas from the outlet duct PHo to which outlet duct PHo the cell outlet Co is open when the cell inlet Ci is open to the high pressure delivery duct Hi.

Between the high pressure scavenging stage H and the low pressure scavenging stage L, one cell port namely the cell inlet Ci is closed by the wall between delivery ducts Hi and PLi and another cell port namely the cell outlet Co is open to the receiving duct PLo supplying gas to the inlet duct PLi to which the cell inlet Ci is open when the cell outlet Co is open to the low pressure receiving duct Lo.

In a cell approaching the high pressure scavenging stage there occurs a prescavenging acceleration of the gas: this is effected by opening one cell port namely the cell inlet Ci to the high pressure delivery duct Hi and another cell port namely the cell outlet Co to the receiving duct PHo connecting with the delivery duct CHi to which the cell is open after leaving the low pressure scavenging stage L but before reaching said receiving duct PHo.

The opening of one cell port namely the cell inlet Ci to the prescavenging delivery duct PLi occurs only when the pressure within said port Ci is reduced below that in the duct PLi by the arrival of a rarefaction wave 11 originating at another cell port namely the cell outlet Co with the opening of the cell outlet Co to a duct at lower pressure namely the prescavenging exhaust duct PLo.

It will of course be understood that the invention may take many other forms than that shown in the accompanying drawing. In one modification, the shaping of the wall between nozzles Hi and PLi is such that the duct Hi is not closed off completely until the moment before the cell inlet Ci is opened to the duct PLi; in other words the taper is longer and shallower. Other machines within the invention may have unshrouded cells, that is to say, the cell cavities are open to the rotor periphery, where they sweep a stator surface that may or may not have ducts opening through it.

What I claim is:

1. 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 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 the high and low pressure scavenging receiving ducts and substantially opposite a wall portion between the high and low pressure scavenging delivery ducts.

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 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.

3. A pressure exchanger as in claim 2 in combination with a low pressure pre-scavenging receiving duct in the second wall between the high and low pressure scavenging receiving ducts and substantially opposite a wall portion between the high and low pressure scavenging delivery ducts.

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, 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 further duct in the second wall between the low and high pressure scavenging receiving ducts for delivering gas at high pressure to the cells, and 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.

5. A pressure exchanger as in claim 4 in which the pre-scavenging duct overlaps a portion of the outlet of the high pressure scavenging delivery duct.

6. 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, 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 further duct in the second wall between the low and high pressure scavenging receiving ducts for delivering gas at high pressure to the cells and a low pressure pre-scavenging receiving duct opening through the second wall in communication with the cell opening and positioned between the high pressure receiving duct and the low pressure scavenging receiving duct, said pre-scavenging receiving duct being substantially opposite a wall portion between the high and low pressure scavenging delivery ducts.

7. A pressure exchanger as in claim 6 in which the high pressure pre-scavenging receiving duct overlaps a portion of the outlet of the high pressure scavenging delivery duct.

8. 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, 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 further duct in the second wall between the low and high pressure scavenging receiving ducts for delivery gas at high pressure to the cells and a prescavenging low pressure delivery duct in the

first wall communicating with the cells and positioned between the high and low pressure scavenging delivery ducts, said prescavenging duct being narrower than and in alignment with a portion of the low pressure scavenging receiving duct.

9. A pressure exchanger as in claim 8 in which the high pressure pre-scavenging receiving duct overlaps a portion of the outlet of the high pressure scavenging delivery duct.

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