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Wunsch

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[54] **METHOD OF AND APPARATUS FOR OPERATING AN AERODYNAMIC PRESSURE-WAVE MACHINE**

[75] Inventor: **Alfred Wunsch,** Friedberg, Germany

[73] Assignee: **Aktiengesellschaft Brown Boveri & Cie,** Baden, Switzerland

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[52] **U.S. Cl.** **417/64**
[51] **Int. Cl.**...**F04f 11/00**
[58] **Field of Search**....................... 417/64; 60/39.45

[56] **References Cited**

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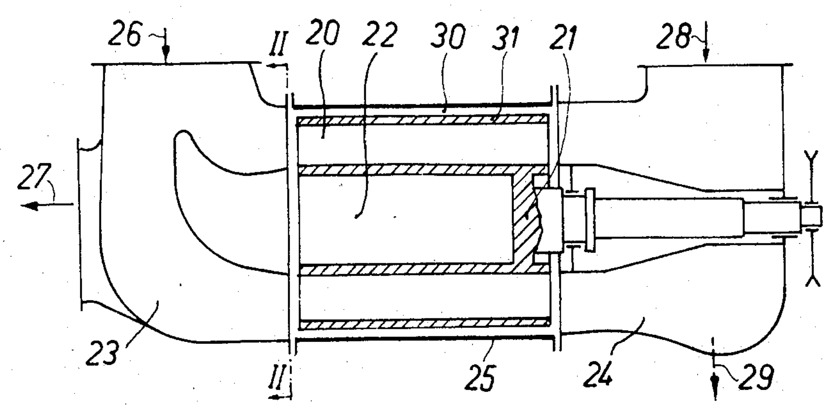
Primary Examiner—William L. Freeh
Assistant Examiner—Leonard Smith
Attorney, Agent, or Firm—Pierce, Scheffler & Parker

[57] **ABSTRACT**

An aerodynamic pressure-wave machine which includes a rotor provided with a circumferential array of longitudinally extending open-ended cells rotates within the middle portion of a casing, the end portions of the casing being provided with high-pressure openings and low-pressure openings confronting the opposite ends of the rotor cells for expansion of an energy-laden gas as it flows through the cells which effects compression of another gas, such as air, as it flows through the cells. Leakage gas flowing from the high-pressure openings to the low-pressure openings is collected, at least in part, and is fed back into the gas-dynamic process for utilization of the energy still contained within them.

4 Claims, 8 Drawing Figures



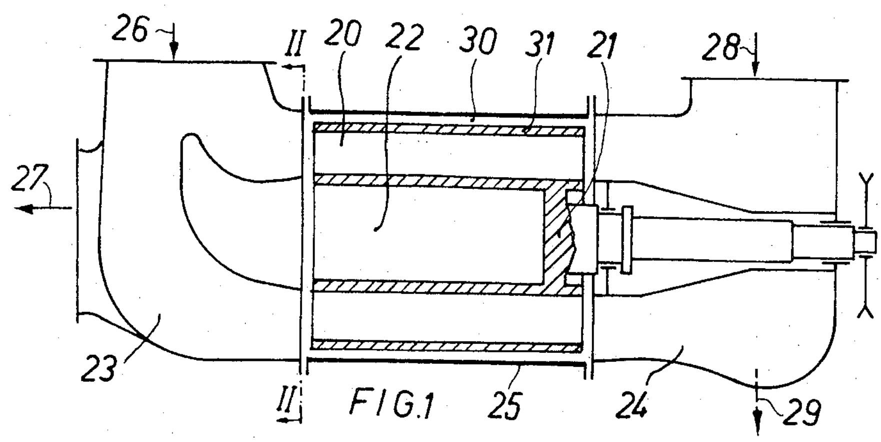


FIG.1

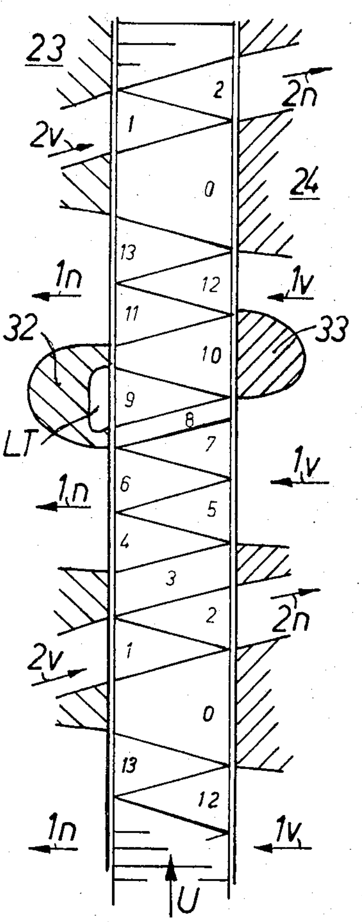
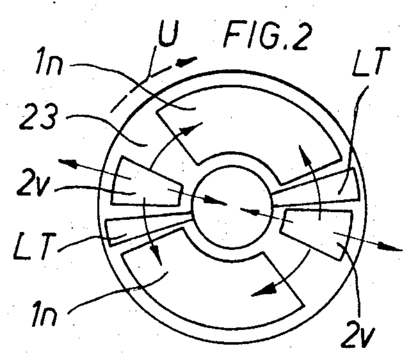


FIG.7



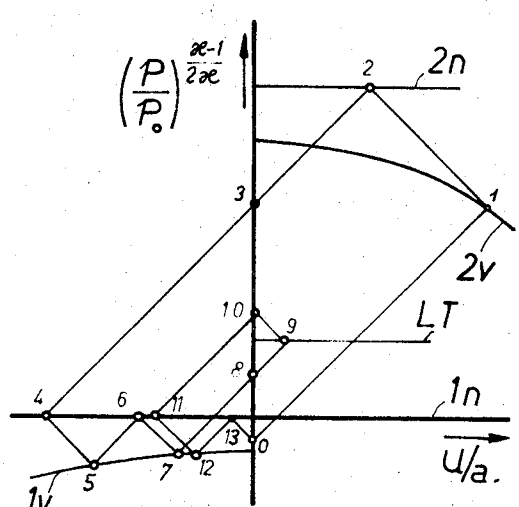
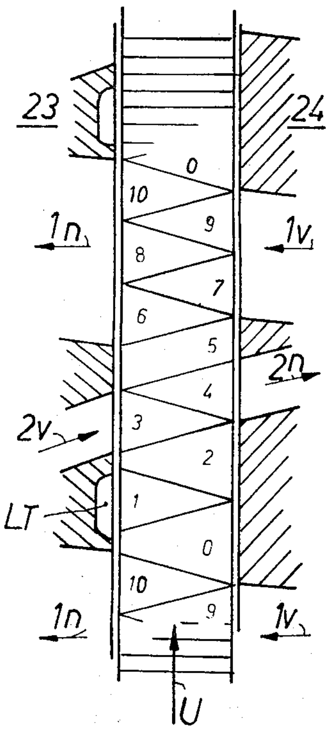


FIG.8

FIG. 3



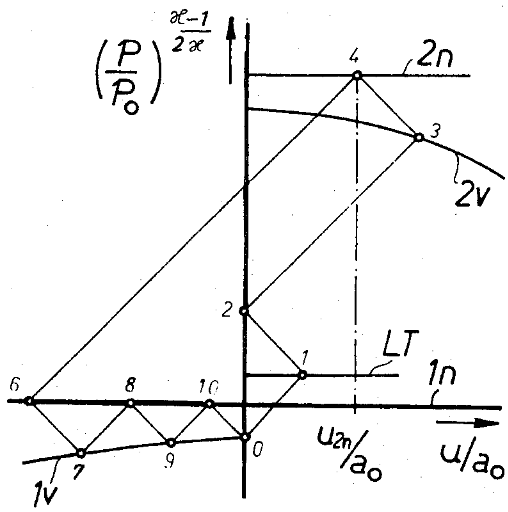
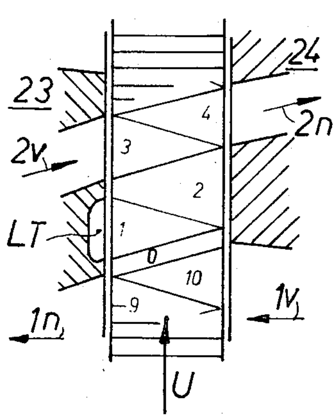


FIG. 4

FIG. 5



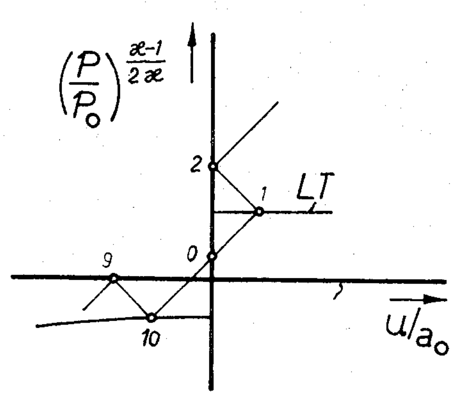


FIG. 6

METHOD OF AND APPARATUS FOR OPERATING AN AERODYNAMIC PRESSURE-WAVE MACHINE

The present invention concerns a procedure for operating an aerodynamic pressure-wave machine, the rotor of which is provided with cells and moves in a casing comprising a middle portion and end portions, such that the end portions each incorporate at least one high-pressure inlet and one low-pressure outlet for a gas giving up energy, and one high-pressure outlet and one low-pressure inlet for a gas to be compressed, each end portion having at least one high-pressure opening and one low-pressure opening, and leakage gas flows from the high-pressure openings to the low-pressure openings; it concerns further a device for effecting the procedure.

In aerodynamic pressure-wave machines, the pressure of one gas is raised by expansion of another gas. The gas-dynamic process takes place under the influence of compression and expansion waves in the rotor cells, which are open at the ends and move past inlet and outlet ducts in the end portions of the casing. The high-pressure and low-pressure openings are separated from each other by a web which is usually only narrow and to which seals can be fitted only unsatisfactorily, if indeed at all. Leakage losses therefore occur due to high-pressure gas flowing either in a circumferential direction straight to a low-pressure opening, or radially, at first into the space surrounding the rotor or into the gap between the rotor shroud and the middle portion of the casing, and from there to a low-pressure opening.

A number of techniques for reducing the leakage are known. All of them are intended to keep the clearance between the rotor and the end portions of the casing small during operation. However, these techniques have the disadvantage that they are relatively costly and their reliability is not always assured.

The present invention adopts a completely different approach. Its purpose is to exploit the unavoidable leakage in a useful manner.

In accordance with the invention this purpose is achieved in that the quantities of leakage gas are at least partially collected and fed to the gas dynamic process so that the energy still contained in them can be utilized.

A pressure-wave machine for effecting this procedure contains at least one leakage-gas recess which is located in one end portion of the casing, the recess being open in the direction of the cells of the rotor, and being fed from spaces filled with leakage gas.

The efficiency of the pressure-wave machine is raised by utilizing the energy in the leakage gas. The characteristic of the machine then alters in a beneficial manner, e.g. for charging road vehicle engines, in that the pressure available for charging and scavenging is increased more in the lower speed range than in the upper range. A pressure-wave machine employing the above procedure is less sensitive to the clearance between the rotor and the end portions of the casing. If this clearance is small, the pressure-wave machine inherently has a high efficiency which is only slightly improved by utilizing the energy of the small quantity of leakage gas. If the clearance is large, the effect of the leakage-gas recess is more pronounced and compensates at least a part of the losses.

A number of examples of the invention are illustrated in the accompanying drawings wherein:

FIG. 1 is a section through a pressure-wave machine;

FIG. 2 is an end portion of the casing viewed at II—II in FIG. 1;

FIGS. 3, 5 and 7 are schematic representations of parts of the development of a cylindrical section at half the cell height through the rotor and through the adjacent parts of the end portions of the casing in different forms; and

FIGS. 4, 6 and 8 are the corresponding wave cycles shown in the pressure/velocity diagram.

FIG. 1 shows the basic construction of an aerodynamic pressure-wave machine with rotor 20 provided with longitudinal cells and mounted in an overhung bearing, such that the rotor hub 21 incorporates cavity 22 and the rotor turns in a casing composed of end portions 23 and 24 and middle portion 25. The energy-containing gas flows into end portion 23 at 26, expends part of its energy in rotor 20 and leaves end portion 23 at 27. The gas to be compressed (usually air, and therefore so termed in the following) flows into end portion 24 at 28, is compressed in rotor 20 and leaves end portion 24 at 29, which is shown as a broken line because this outlet is usually turned at 90° to the plane of the drawing.

FIG. 2 shows end portion 23. Here can be seen the high-pressure inlets 2v and low-pressure outlets 1n for the energy-expanding gas. On leaving the high-pressure inlets 2v the greater part of the energy-containing gas flows into the rotor, but smaller quantities of leakage gas pass into the gap between the rotor and end portion 23. These dissipate, as indicated by arrows, partly in a peripheral direction towards low-pressure outlets 1n, partly radially outwards into the gap 30 between shroud 31 of rotor 20 (FIG. 1) and the middle portion 25 of the casing, and partly radially inwards into the cavity 22 in hub 21, and create a pressure within these spaces.

The pressure in spaces 22 and 30 is lower than in high-pressure inlets 2v because the narrow gap between the rotor and the end portion throttles the flow of leaking gas. However, it is higher than in low-pressure outlets 1n because the gap between rotor and end portion closes off the flow in this direction also.

It is possible to connect pressurized spaces 22 and 30 with leakage-gas recesses LT in end portion 23 by extending these recesses radially beyond the high-pressure and low-pressure openings as far as gap 30 and cavity 22. In the example shown, the recesses LT are located between low-pressure and high-pressure openings when viewed in the direction of rotation of the rotor (indicated by a dashed arrow). They are charged by pressurized gas from reservoir spaces 22 and 30 and in turn feed the rotor cells. The effects of this measure can be seen from FIGS. 3 and 4.

FIG. 3 shows the development of a cylindrical section through the rotor of the pressure-wave machine and a distance/time diagram, while FIG. 4 is the corresponding pressure/velocity diagram as is usually employed in the characteristics method of non-steady gas dynamics.

FIG. 4 shows conditions during the course of the gas-dynamic process, characterized by the pressure ratio (P/P_0) $(H-1/2H)$ and the flow velocity referred to the acoustic velocity u/a_0. The states at the points of intersection of two characteristics are numbered consecutively. In FIG. 3 the areas in which these states exist are denoted by the same numbers. The rotor turns in the direction of arrow U between the two end portions 23 and 24. In the low-pressure zone, the cells are supplied with air from low-pressure inlet lv. An expansion wave between areas 10 and 0 reduces the flow velocity to zero. As soon as a cell comes adjacent to leakage-gas recess LT (which is linked with spaces 22 and 30 pressurized by the leakage gas flows and is also supplied by leakage gas flowing in the peripheral direction) a pressure wave occurs which pre-compresses the cell contents to state 1. Gas flows from leakage-gas recess LT. The pressure wave is reflected from the face of end portion 24 as a pressure wave and again reduces the velocity to zero, so that the cell contents arrive at state 2. Thus, in area 2 the cell contents are precompressed to a pressure which is higher than the intake pressure and also higher than the pressure in the leakage-gas recess.

Actual compression of the cell contents then begins from this pressure level as soon as a cell becomes exposed to high-pressure inlet 2v. The normal cycle of the pressure-wave machine then follows. Compressed air flows through high-pressure outlet $2n$, expanded gas flows through low-pressure outlet $1n$, and air is drawn in through low-pressure inlet lv until state 0 is reached once again. For a given exit velocity u_{2n} of the compressed air, the leakage-gas recess causes a higher pressure to be attained than without pre-compression, i.e. if the principal compression were to start direct from state 0.

Another possible comfiguration of the pressure-wave process with utilization of leakage gas is shown in FIGS. 5 and 6. In this example the pressure wave between states 10 and 0 is not an expansion wave, but a compression wave. The inlet flow velocity of the air at the end of low-pressure inlet lv is reduced to state 0 by the confronting face of end portion 23, whereupon leakage-gas recess LT causes pre-compression by two pressure waves up to states 1 and 2. This reduction of the air inlet velocity creates a higher pressure in leakage-gas recess LT and its effect is increased accordingly.

Another possible way of utilizing the energy contained in the leakage-gas is to use it to improve scavenging of the cells in the low-pressure zone. The corresponding pressure-wave process is illustrated in FIGS. 7 and 8. The leakage-gas recess LT, which again is connected to pressurized spaces 22 and 30, is contained in an additional web 32 twoards the end of the low-pressure outlet ln, where the flow velocity is already low. Web 32 in end portion 23 must be supplemented by a further web 33 in end portion 24. By introducing the leakage-gas into the gas-dynamic process, the pressure in the cells rises to state 10, giving rise to a higher flow velocity in areas 11 and 12, and hence to better scavenging in the low-pressure zone.

The leakage-gas collecting recesses can also be located equally effectively in end portion 24 or in both end portions. Furthermore, the inlet and outlet for one gas must not always be at the same end, i.e. in the same end portion. The leakage of the gases will then tend to mix, in which case it is of no significance at which end they are introduced into the gas process. It is only important that the leakage-gas should not flow unchecked into the cells and to impair the process, but should be fed to the cells with the aid of the leakage-gas recesses at an accurately defined point, and in this way improve the process.

The leakage-gas recesses can be employed in almost all aerodynamic pressure-wave machines, and can be combined with special-purpose devices, e.g. a deflecting recess in accordance with German patent 1 162 631.

I claim:

1. An aerodynamic pressure-wave machine comprising a cylindrical rotor provided with a circumferential array of longitudinally extending open-ended cells and which is mounted for rotation about its axis within the middle portion of a cylindrical casing with a radial clearance gap therebetween, the end portions of said casing facing the opposite ends of said rotor including at least one high-pressure inlet opening and one low-pressure outlet opening for an energy-laden gas giving up energy in the cells and at least one high-pressure outlet opening and one low-pressure inlet opening for a gas such as air to be compressed within the cells, each end portion of said casing having at least one high-pressure opening and at least one low-pressure opening which are spaced circumferentially apart, means providing a gas-leakage collection recess in at least one end portion of said casing opening in the direction of and in communication with the cell ends and which extends radially to the clearance gap between said rotor and casing for collecting leakage-gas flowing in a circumferential direction between a high-pressure opening and a low-pressure opening in a axial clearance gap existing between the end portion of said casing and the corresponding end of said rotor and flowing also in a radially outward direction to said radial clearance gap existing between the periphery of said rotor and the middle portion of said casing, the leakage-gas so collected serving to charge said recess and being thereafter discharged therefrom into said rotor cells to give up its energy.

2. The invention as defined in claim 1 wherein the leakage-gas so collected in said recess is discharged therefrom into said rotor cells to achieve a pre-compression of the gas to be compressed.

3. The invention as defined in claim 1 wherein the leakage-gas so collected in said recess is discharged therefrom into said rotor cells to improve scavenging thereof in the low-pressure zone.

4. The invention as defined in claim 1 wherein the hub portion of said rotor is provided with an axially extending cavity opening to the end of the rotor at which said gas-leakage collection recess is located, and said recess extends in a radially inward direction to establish communication with said cavity which latter likewise functions to receive gas leakage from said high-pressure opening.

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