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Jenny

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[54] **AERODYNAMIC PRESSURE-WAVE MACHINE**

[75] Inventor: **Ernst Jenny,** Baden, Switzerland

[73] Assignee: **BBC Brown Boveri & Company Limited,** Baden, Switzerland

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[51] **Int. Cl.**... **F02c 3/02**

[58] **Field of Search**....................... 60/39.45; 417/64

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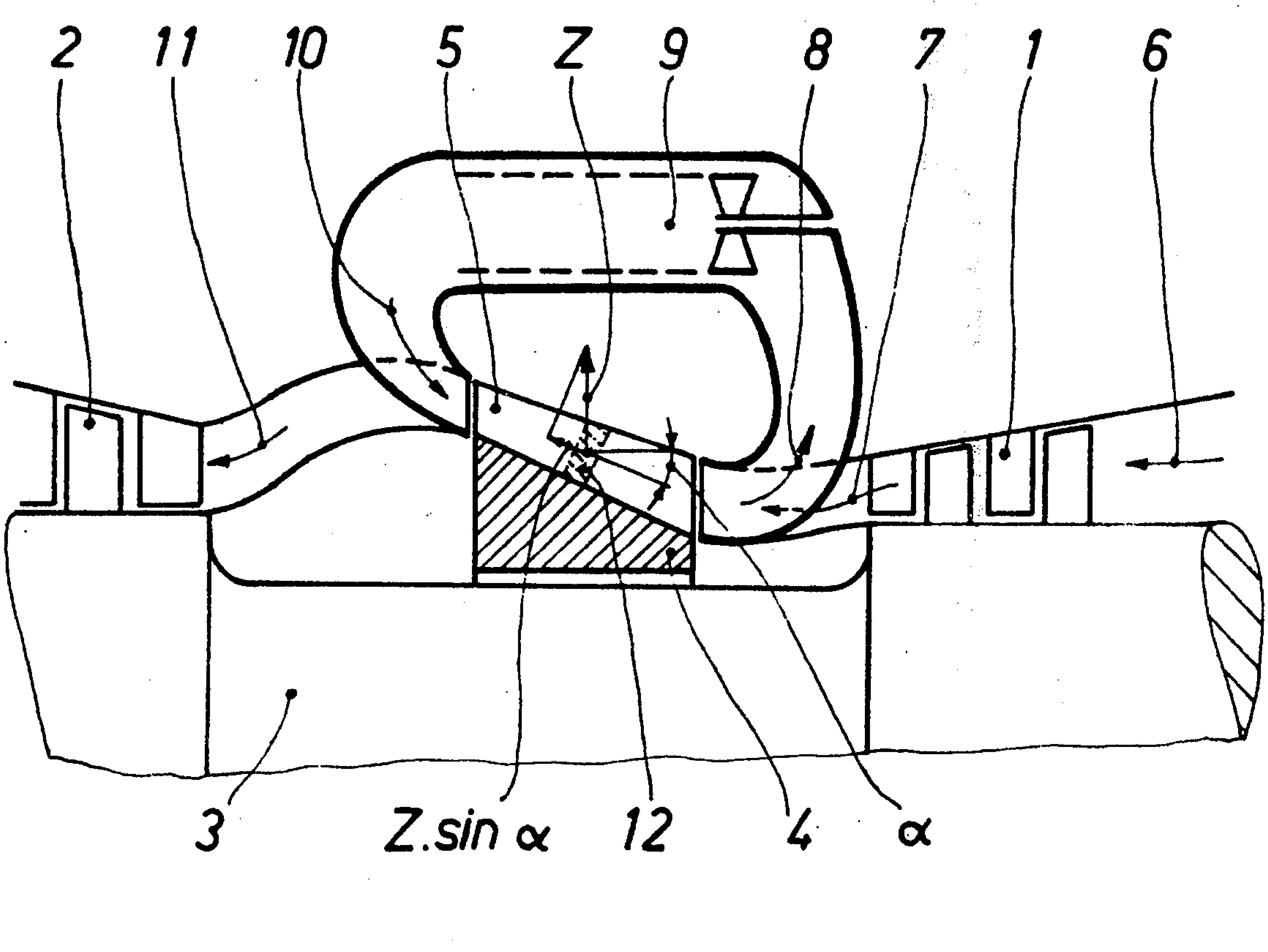
Primary Examiner—C. J. Husar
Assistant Examiner—Thomas I. Ross
Attorney, Agent, or Firm—Pierce, Scheffler & Parker

[57] **ABSTRACT**

An aerodynamic pressure wave machine for effecting an exchange of energy between two gases, a hot gas being expanded from a higher to a lower pressure level and a cold gas being compressed from a lower pressure to a higher pressure, by means of a celled rotor, wherein the rotor cells are inclined with respect to the axis such that opposite ends of the cells lie on different diameters, the hot gas entering and also leaving at the end of the rotor having the greater cell diameter and the cold gas entering and also leaving at the end of the rotor having the smaller cell diameter. This structural arrangement of the rotor cells is particularly advantageous in a case where the pressure of the compressed cold gas and the hot gas to be expanded differ only slightly in the high-pressure zone, whereas the pressure of the expanding hot gas in the low-pressure zone is substantially higher than the pressure of the cold gas to be compressed. If desired, the radial height of the cells can be varied between one end of the rotor and the other, and the variation in height can be designed in such manner that the cell cross-section area remains constant over the length of the cells.

3 Claims, 3 Drawing Figures



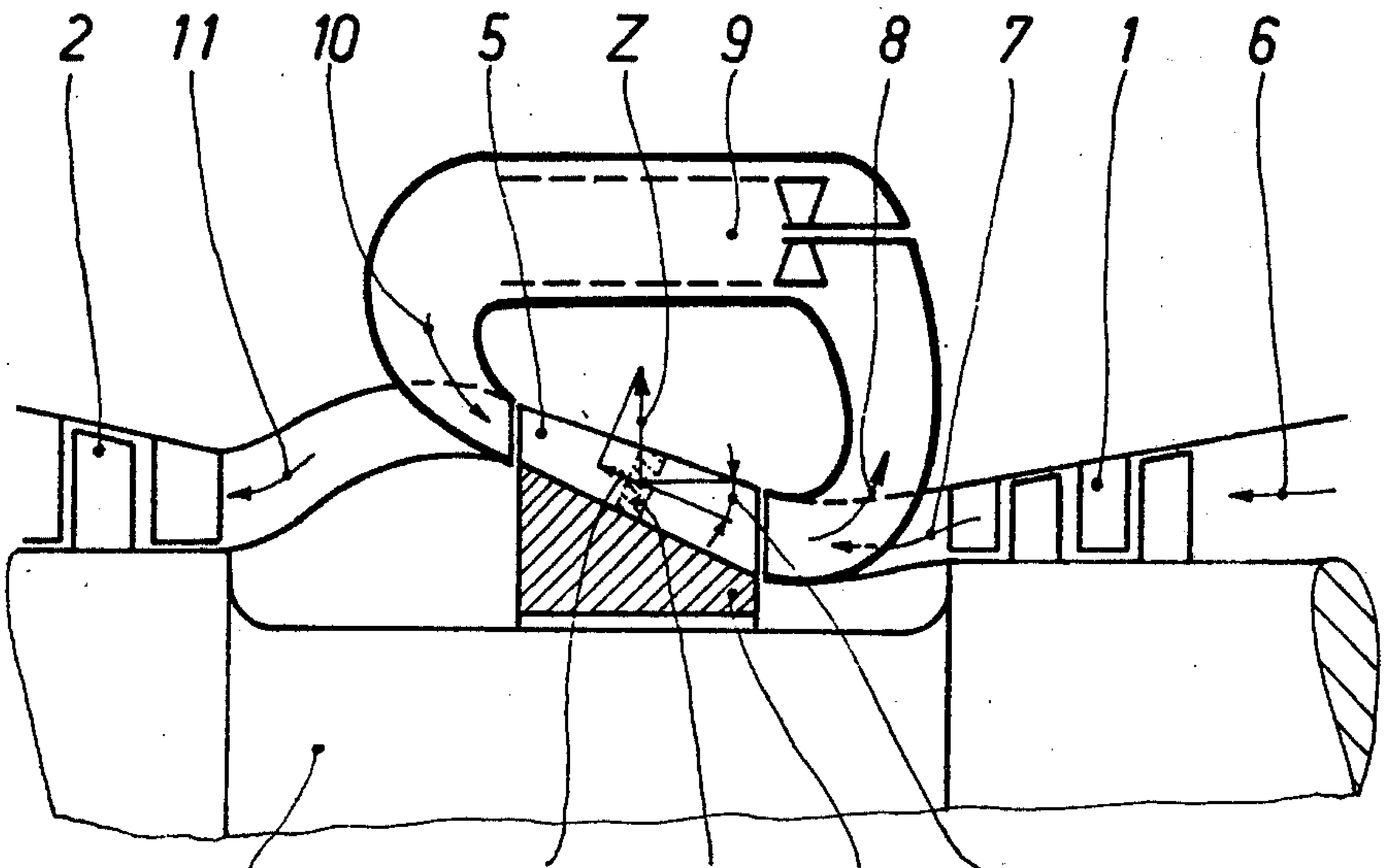


FIG.1

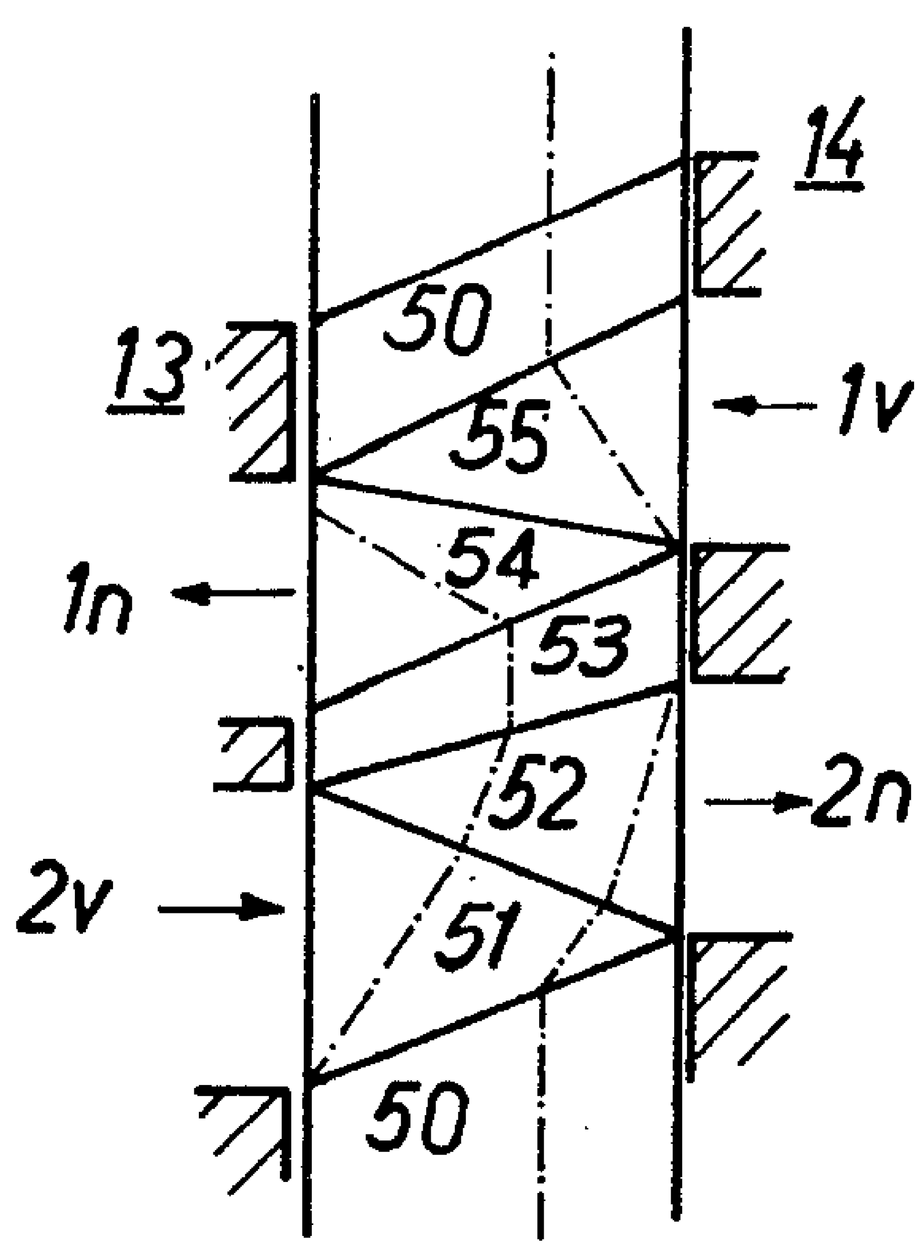


FIG.2

WAVE DIAGRAM

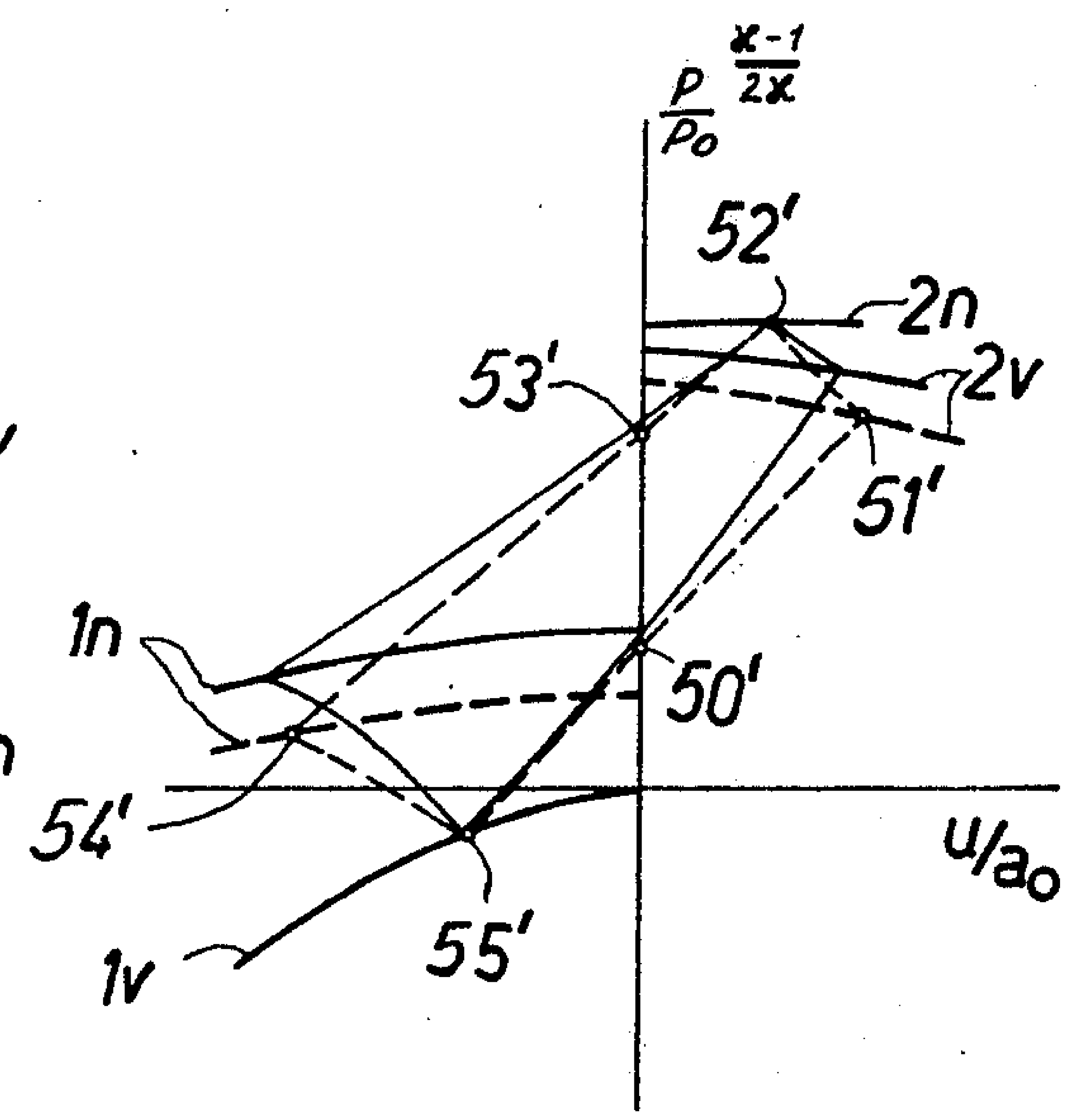


FIG.3

AERODYNAMIC PRESSURE-WAVE MACHINE

The present invention concerns an aerodynamic pressure-wave machine the rotor of which, provided with cells, is located between two side portions, one of which incorporates the inlet and exhaust ports for the hot gas while the other incorporates the inlet and exhaust ports for the cold gas, intended for a process in which the pressures of the compressed cold gas and the hot gas to be expanded differ only little in the high-pressure zone, whereas the pressure of the expanding hot gas in the low-pressure zone is substantially higher than the pressure of the cold gas to be compressed.

In aerodynamic pressure-wave machines, a hot gas is expanded from pressure p_{2v} to pressure p_{1n} and the energy of expansion thus obtained is used to compress a cold gas (termed air in the following, as it is this which is most frequently involved), from pressure p_{1v} to pressure p_{2n}. The indices v and n denote, respectively, before and after passing through the rotor, while **1** and **2** denote the lower and higher pressure levels, respectively.

For many thermal processes, a pressure-wave machine is required in which $p_{2n} \approx p_{2v}$ and $p_{1n} > p_{1v}$, and the mass flows of cold and hot gases are approximately equal. If in a gas turbine plant, for example, the pressure-wave machine is located in the flow path before the compressor or after the gas turbine, then $p_{2n} \approx p_{2v}$, since the pressure loss in the combustor is relatively small. The whole mass of the hot combustion gas can expand in the pressure-wave machine and the air is drawn in at a pressure level which is significantly lower than that of the gas leaving. This means that the load on the compressor is reduced, i.e., it consumes less power, and therefore useful power and efficiency are higher.

With the known pressure-wave machines having four inlet and exhaust ports per wave cycle, a greater pressure difference $p_{1n} - p_{iv}$ is attainable only if the pressure difference $p_{2n} - p_{2v}$ is relatively large. An improvement is obtained when a total of more than four inlet and exhaust ports per wave cycle is employed (Swiss Pat. No. 441,868), but this results in a complicated machine.

The object of the invention is to create a pressure-wave machine which is as simple as possible and with which, in contrast to a machine operating in accordance with the known process, the pressure difference $p_{1n} - p_{1v}$ can be increased without at the same time having to increase the pressure difference $p_{2n} - p_{2v}$.

This object is achieved in that the cells of the rotor are inclined with respect to the rotor axis such that opposite ends of the cells lie on different diameters the hot gas entering and also leaving at the end of the rotor having the greater cell diameter and the cold gas entering and also leaving at the end of the rotor having the smaller cell diameter.

Variations of the pressure-wave process are possible by varying the radial height of the cells between one end of the rotor and the other.

Here a special case is possible if the radial cell height decreases with increasing cell diameter in such a way that the cell cross-section area remains constant over the length of the cells.

In the case of a rotor with axis-parallel cells such that opposite ends of the cells lie on the same diameter the different centrifugal forces to which the hot gas and cold air are subjected, owing to their different weights, are of no consequence. In the case of a rotor with having its cells inclined with respect to the rotor axis such that opposite ends of the cells lie on different diameters, however, this difference gives rise to an additional component which is utilized to influence the pressure-wave process in such a manner that the compression ratio of the air is raised and the pressure difference $p_{1n} - p_{1v}$ is increased. Further possible ways of adapting to the particular process are provided by altering the ratio of the diameters on which the two ends of the cells lie, i.e., by changing the angle of slope of the cells, and also by varying or maintaining constant the flow cross-section areas in the cells.

An example of the invention is illustrated by the drawings, in which:

FIG. **1** shows the rotor of a pressure-wave machine located between a driven machine and a prime mover;

FIG. **2** shows schematically the evolution of a cylindrical section at half the height of the cells through the rotor and through the adjacent parts of the side portions of the housing; and

FIG. **3** represents the corresponding wave cycle in the form of a pressure/velocity diagram.

In FIG. **1** an aerodynamic pressure-wave machine, of which only the rotor **4** is shown, is located between the compressor **1** and the gas turbine **2**, which are mounted on a common shaft **3**. The rotor **4** can run at the same speed as the turboset or, as indicated by the gap between shaft **3** and rotor **4**, it can be driven independently of the gas turbine.

The cells **5**, which in the example shown are of uniform cross-section over their length, are inclined with respect to the rotor axis such that opposite ends of the cells lie on different diameters of the rotor. The cells are on an average inclined to the rotor axis by an angle α. The cells do not have to lie along an axial section, but can also curve out from the plane of the drawing, which represents such an axial section. It is characteristic, however, that even with the cells designed in such a modified manner the cells, projected cylindrically onto the plane of the drawing, must have an inclination to the rotor axis. With this form of rotor it is possible, by varying the radial cell height, to increase, reduce or maintain constant the cross-section area over the length of the cells.

The air flows as indicated by the arrow **6** through the compressor **1** to the pressure-wave machine, passes in the direction of arrow **7** through an inlet port **1**v, shown in FIG. **2**, into the rotor **4** at the end with the smaller cell diameter, undergoes the pressure-wave process, which compresses it further, and leaves again through an exhaust port **2**n at the same end of the rotor in the direction of arrow **8**. The air is then passed to the combustor **9** and having been heated by combustion flows in the direction of arrow **10** to the rotor **4** as hot, energy-imparting gas, enters the rotor through an inlet port **2**v at the end with the larger cell diameter, once again undergoes the pressure-wave process and leaves through an exhaust port **1**n at the same end of the rotor in the direction of arrow **11**, whereupon it flows to the gas turbine **2**. (The inlet and exhaust ports referred to are not, however, shown in FIG. **1**).

The action of the inclined cells can be explained in the following manner.

Essentially uniform volumes of gases at different temperatures displace each other in the cells. Owing to the inclination of the cells a unit of volume **12** is acted upon in its flow direction not only by the usual pressure forces, but also by a component Z . sin α of the centrifugal force Z. The weight per unit volume of cold air is greater than the weight of the same unit volume of hot gas and is therefore subjected to greater centrifugal force. As compressed air is moved in the direction of arrow **8** to exhaust port **2***n* by the pressure of the hot gas from inlet port **2***v* in the direction of arrow **10,** therefore, the gas must also impart energy to the air which is displaced inwards against the centrifugal force, or in other words to the end of the rotor with the small cell diameter. There is then less energy available to maintain the pressure difference $p_{2n} - p_{2v}$. During the scavenging process, on the other hand, the air entering through inlet port **1***v* in the direction of arrow **7** is thrown outwards, imparting energy to the gas, which can thus be expelled against a higher back pressure through exhaust port **1***n* in the direction of arrow **11.**

FIG. **2** shows the evolution of a cylindrical section through the rotor of a pressure-wave machine with a very simple wave pattern and four ports, i.e., a distance/time diagram, while FIG. **3** is the corresponding pressure/velocity diagram as is normally employed with the characteristics method of non-steady gas dynamics. This diagram shows the condition during the course of the gas dynamic process in terms of pressure ratio $(p/p_o)^{\kappa-1/2\kappa}$ and flow velocity related to the sonic velocity u/a_0. The states at the point of intersection between two characteristics are numbered in sequence from **50′** to **55′**. In FIG. **2,** the regions in which these states obtain are denoted by the same numbers but omitting the primes (′).

The rotor turns in the direction of the arrow U between the two side portions **13** and **14** of the housing. In the low-pressure zone the cells are supplied with fresh air from inlet port **1***v*. A compression wave between regions **55** and **50** retards the flow velocity to zero and thus subjects the contents of the cell to an initial stage of compression. Compression proper begins as soon as a cell opens on the side of inlet port **2***v*. The compressed air is expelled through exhaust port **2***n*, the expanded gas through exhaust port **1***n*, and fresh air is drawn in through inlet port **1***v* until state 0 is reached once again.

In FIG. **3** the changes of state of this process are shown by full lines. Here it can be seen that the characteristics of state are curved by the influence of centrifugal force. For purposes of comparison, the broken lines indicate the changes of state when the cells of the rotor are axis-parallel in the usual way. It is shown that, in accordance with the set objective, with a rotor having inclined cells in accordance with the invention, the pressure difference $p_{1n} - p_{iv}$ is much greater, and at the same time the pressure difference $p_{2n} - p_{2v}$ is reduced.

The improved pressure-wave machine with inclined cells can be used to advantage as a means of charging internal combustion engines if the exhaust back pressure is very high, and also for improving low-pressure scavenging in the pressure-wave machine. It can equally be provided with more than two inlet ports and two exhaust ports per wave cycle, and can also have direction-changing ducts.

I claim:

1. In an aerodynamic pressure-wave machine having a rotor provided with cells extending from one end thereof to the other, the respective ends of the rotor being located between two stationary side portions of the machine, and wherein one of said side portions incorporates inlet and exhaust ports for hot gas to be expanded and the other side portion incorporates inlet and exhaust ports for cold gas to be compressed, the improvement wherein particularly for operation of the machine under conditions where the pressure of the compressed cold gas and the hot gas to be expanded differ but little in the high-pressure zone whereas the pressure of the expanded hot gas in the low-pressure zone is substantially higher than the pressure of the cold gas to be compressed, the cells of said rotor are inclined with respect to the rotor axis such that opposite ends of the cells lie on different diameters, the hot gas entering and also leaving at the end of the rotor having the greater cell diameter and the cold gas entering and also leaving at the end of the rotor having the smaller cell diameter.

2. An aerodynamic pressure-wave machine as defined in claim **1** wherein the radial height of the rotor cells from the inner to the outer boundary walls thereof varies between one end of the rotor and the other.

3. An aerodynamic pressure-wave machine as defined in claim **2** wherein the radial cell height decreases with increasing cell diameter in such manner that the cell cross-section area remains constant over the length of the cells.

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