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ORGANIZATION PRINCIPLES OF THE OPERATING PROCESS OF THE CASCADE COMPRESSION UNITS AND SOME DIRECTIONS OF THEIR APPLICATION

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Abstract

In the paper was presented new trend of thermal-power units - operation principle of the cascade thermal compression units of different purposes. In this equipments a working medium compression is carried out owing to supplied heat as a result of internal redistribution of expansion indicator work in the process of cascade mass interchange without the use of mechanical displacers which remove some part of mechanical energy from the power take off shaft. The most important characteristics of cascade thermal-power units was presented.

Keywords*: cascade thermal-power units, cascade pressure interchangers, diesel engine, gas-turbine units, exchange processes*

I. Introduction

A new improvement trend of thermal- power units of wide purpose is connected with creation of cascade compression units of gas- air mediums. The units of cascade- thermal compression (CTC) and cascade pressure interchangers (CPI) are variety of such units.

In CTC units a working medium compression is carried out owing to supplied heat as a result of internal redistribution of expansion indicator work in the process of cascade mass interchange without the use of mechanical displacers which remove some part of mechanical energy from the power take off shaft.

In addition to simplicity and high reliability of the structure, because of absence of mechanical displaces and mobile gas distributed elements discretely controlled, the CTC units are characterized by high efficiency, even while using heat resources with relatively low temperature potential and it stipulates their application attraction as a recovery systems included as components of traditional thermal power plants.

2. Principle of the operating process of the cascade compression units

The operation principle and description of the first CTC units are given in the papers [1-3]. At present serviceable samples of CTC compressor are created, and the diagram is shown in fig.1.

In the process of rotor rotation (fig.1 clockwise rotation), each rotor cell is connected in sequence with a stator head interchange channel through which a working medium enters from contiguous cell of the expansion area. De to cascade compression the pressure in the cell steadily increases up to definite value which depends on thermo-dynamical parameters of the working medium in the beginning of the expansion process. While communicating the cells with the windows of high pressure (HPV) of displacing section under the action of centrifugal forces or forced circulation the displacement of preliminarily compressed in the cell of air charge is replaced by heated air or gases (in the case of use of internal combustion chamber). Due to this fact maximum cycle pressure is fixed in the displaced path and in the cells communicated with it. That pressure exceeds the pressure of cascade compression.

Part of compressed air is removed from the displaced path to the consumer through a branch pipe placed in front of heat source.

In the period of further cell communication with head exchange channels part of the working medium is removed to the contiguous cells of the compression section. And it is accompanied by pressure drop in the considered cells. Thus, the expansion work is spent for air charge compression in the process of cascade mass interchange.

Residual pressure at the end of expansion process, as an indicator of working process perfection, depends on the quaintly of head interchanged channels towards atmospheric one increasing quaintly of channels.

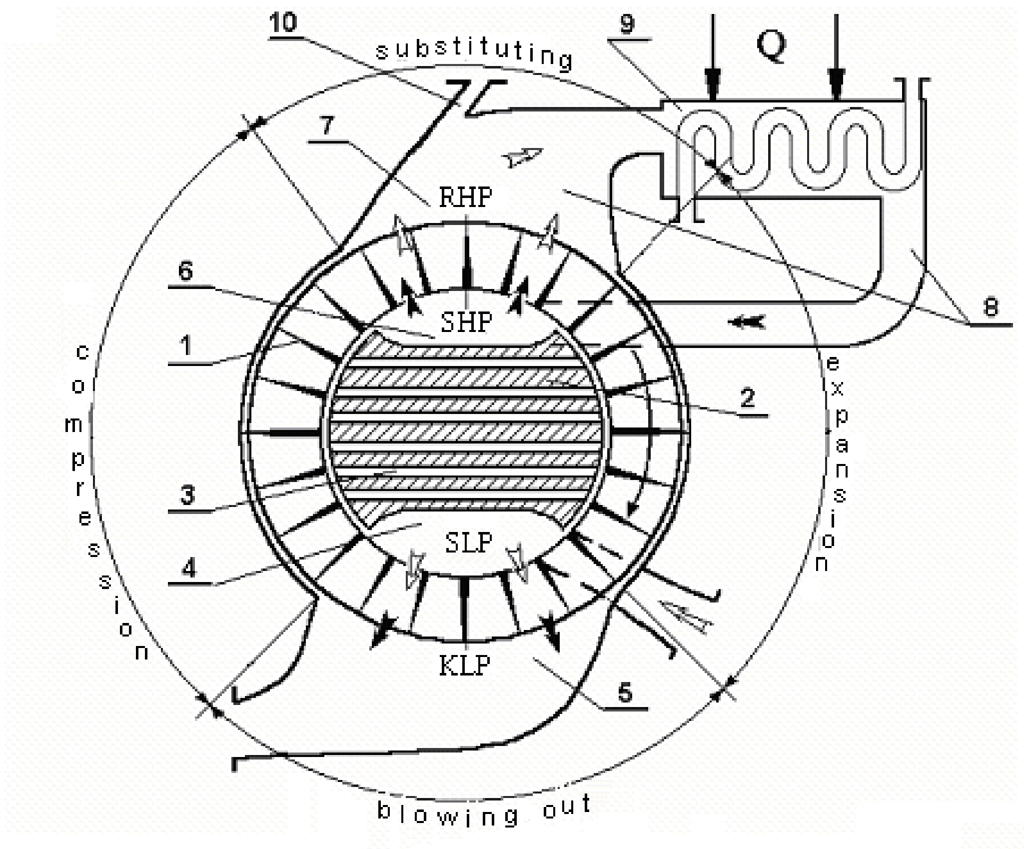

Fig.1. Fundamental diagram of cascade thermal compression compressor. 1 - rotor; 2- stator; 3- head interchange channels; 4, 5- supply window (SLP) and removal low pressure air [KLP]; 6, 7- supply window of high pressure air [SHP] and removal window of high pressure air [RHP]; 8- displayed path; 9- recover heat interchange; 10- brauch pipe of compressed air removal to the consumer.

Blow through the cells by means of air charge, which is implemented in the period of cell connection to the windows of low pressure [SLP] and [RLP], closes a working cycle of the cascade thermal compression unit (CTC).

This compressor arrangement is easily transformed into gas or hot air generator by means of branch pipe placement for take off working medium along displacement path near heat source in the direction of gaseous atmosphere motion.

Concerning railway transport, the use of hot air generator in the heating systems of rolling stock is of great interest. The evident advantage of the CTC heater is its independence in maintaining service ability when de- energizing power network. It gives the possibility to apply it with different types of fuel and any heat source. Thanks to hot air blow by means of CTC unit heat- transfer agent transportation into local zones of the heated object is carried out without the use of drive compressor or fan.

Another direction of the cascade compression unit development is connected with development of pressure change used , for example, for supercharging of internal combustion engines.

In cascade pressure changer (CPC) air pressure as well as in the wave pressure changer (WPC) is carried out as a result of close contact with compressing gas but with quite different working process in the cycle.

Cascade pressure exchanger action is easily determined from the diagram 2. which represents the developed views of rotor with longitudinal cells relatively gas distributed windows. General view of the unit is shown in the fig. 3. Compressing gas supplied through the window of high pressure completely compress already compressed air in the cascade process and displace it to the consumer through the high pressure window. The energy of redundant pressure which is left in the cell of compressing gas after disconnections with the high pressure windows is spent for main compression of fresh charge having analogy with considered cycle of cascade thermal compression.

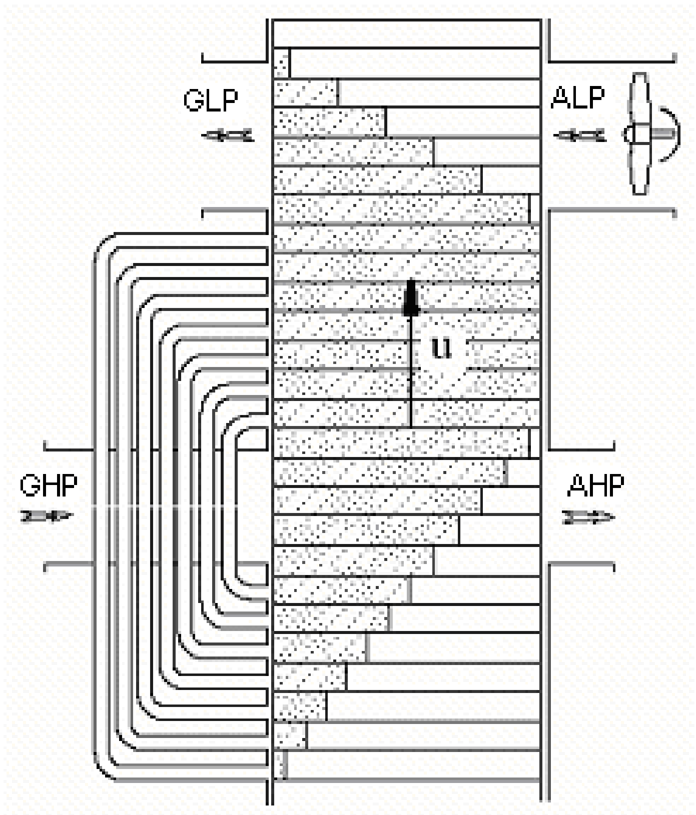

Fig. 2. Unrolling a rotor for windows stator

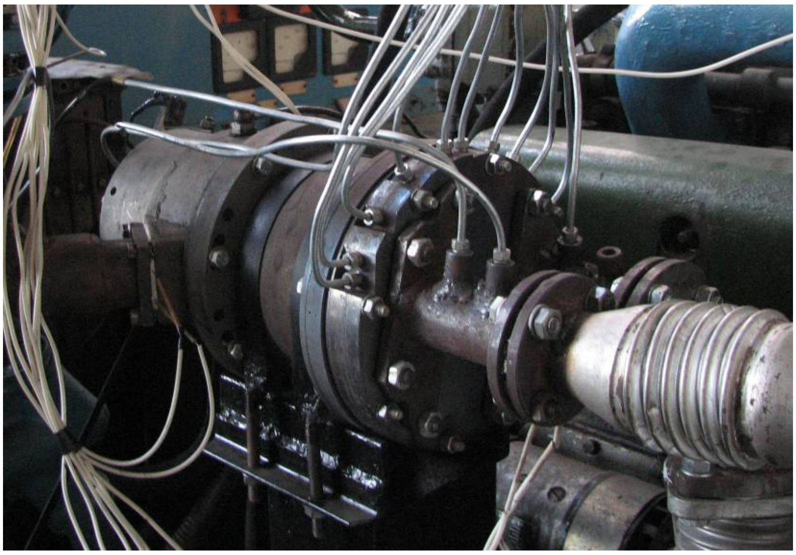

Fig. 3. General type of cascade exchanger of pressure

The advantages of the cascade pressure exchange (CPE) relatively wave pressure exchanger are stipulated by the following.

Wave nature of energy exchange and super- charging of compressed air pre- determines high sensitivity of the working process of wave pressure exchange to the nature of interaction of primary waves with leading edges of gas distributed windows which are easily destroyed when frequency departure of rotor rotation or parameters of compressing gas from calculated values. Impulse charge compression is accompanied by losses which are connected with energy dispersal of formed waves in the result of their interaction and reflection in boundary sections of the cell.

A great influence on wave pressure exchange efficiency is produced by imperfection of displacing compressed air through a window of high pressure .Increase of compressed air which is left in the cell after its separation with high pressure windows causes almost proportional efficiency decrease, which is analogous to negative influence so called “dead” volume in piston compressor.

Taking into consideration the presence of stirring zone of compressing and compressed gases in the cell it is problematic to realize full displacement of compressed air charge, excluding throwing of compressing gas in the low pressure window. These factors are especially displayed when increasing exchange head with frequency change of rotor rotation.

In cascade pressure exchanger in comparison with wave one, air compression is realized in more rational quazi- stationary processes with insignificant amplitude of formed waves.

In this case dissipation phenomena of wave interaction of gas mediums not only do □eveling but there considerably reduce negative influence of displacement imperfection of compressed air (“dead” volume) on efficiency action of the changer.

Indeed, compressed air energy left in the cell after separation with air of high pressure window participates in the process of cascade mass changer and together with the energy of compressing gas in the cell is spent for further pressure of fresh charge.

Higher effectiveness of exchange processes of cascade pressure exchange is confirmed by comparison of gas medium rates in the windows of high pressure. As insignificant part of compressing gas is used for complete compressing of preliminarily compressed in the process of mass exchange air in cascade pressure exchange, practical equality of volume costs of pressed and pressing medium takes place. In this case the ratio of mass costs at slight pressure excess of pressing gas Pg_1, relatively pressure of supercharged air roughly corresponds to inverse ratio of temperatures of these mediums.

$$\frac{G_k}{G_{g1}} \approx \frac{T_{g1}}{T_k} \qquad (1)$$

Pay attention to the fact that wave pressure exchange, which operates in the system of internal combustion engine, realized the balance of mass costs of compressed and compressing mediums (G_k=G_{g1}) and in the modes of maximum effectiveness provides some excess of pressure P_k relatively P_{g1}. However, the factor of considerably high relative productivity cascade pressure exchange prevails and reflects higher effectiveness of exchange processes. The efficiency of pressure exchanger without the costs for a drive is expressed by the expression

$$\eta_{cpe} = \frac{G_k}{G_{g1}} \cdot \frac{\acute{I}_{g1}}{\acute{I}_k}, \qquad (2)$$

where:
H_k, H_{g1}- correspondingly situated heat overfall of the blowed air compressing gas.

For a ideal cascade pressure exchange cycle taking into consideration the equality of volume costs and leakage absence of compressed and compressing mediums and after some simplification we receive:

$$\eta_{cpe}^{id} = \frac{k\left(k_g - 1\right)\cdot\left(1 - \left(\frac{P_\kappa}{B_0}\right)^{-\frac{\kappa-1}{\kappa}}\right)P_\kappa}{k_g\left(k \;\; - 1\right)\cdot\left(1 - \left(\frac{P_{g1}}{B_0}\right)^{-\frac{\kappa_g-1}{\kappa_g}}\right)P_{g1}}, \qquad (3)$$

where:
K, K_g- indicators of adiabat for air and gas; B_0- atmospheric pressure.

This expression shows independence of efficiency of the idealized cascade pressure exchange cycle from the temperature of compressing gas T_{g1}, different from wave pressure exchange cycle where increase T_{g1} is accompanied by some decrease of use effectiveness of heat difference of compressing gas.

Physical nature of the regularity is connected with the fact that in the working cycle cascade pressure exchange dominating role is given to exchange of potential energy in the processes of cascade mass exchange. Thus the increase of potential energy of compressing gas caused by its temperature is transformed to a great extent into increase of potential energy of the pressing gas pressure.

In the wave pressure exchange considerable part of energy exchange is carried out by transference of the quantity of front motion spreading along the wave cell. Quantity of motion transferred by wave disturbance to compressed air depends on the ratio of densities of interacting mediums. That is why the density decrease of comprising gas while increasing its temperature under other equal conditions is accompanied by wave pressure exchange productivity. Due to this wave pressure exchange is inferior to cascade as for effectiveness of use of heat component of the heat difference H_{g1}.

Thus from the point of view of recovery of heat release of heat power units and the ability of transformation of heat energy into mechanical working cycle cascade pressure exchange is more perfect.

Fig 4 shows that with ratio increase P_k/P_{g1} efficiency cascade pressure exchange steadily grows, aiming at unit at P_k/P_{g1}=0,9…0,85. Lower values of effective efficiency cascade pressure exchange, obtained on the basis of experimental data, reflect real leakage of working mediums through incompact of movable matings and also costs of mechanical energy for rotor drive. In addition to that obtained efficiency values and pressure indicators of samples of cascade pressure exchanges are the best samples of wave pressure exchange [4]. It should be noted that there are no fundamental limitations for ratio increase P_k/P_{g1} to the values close to the unit. The exception is increase of mass sizes of the exchanger because of decrease of average speed flows in the windows of light pressure.

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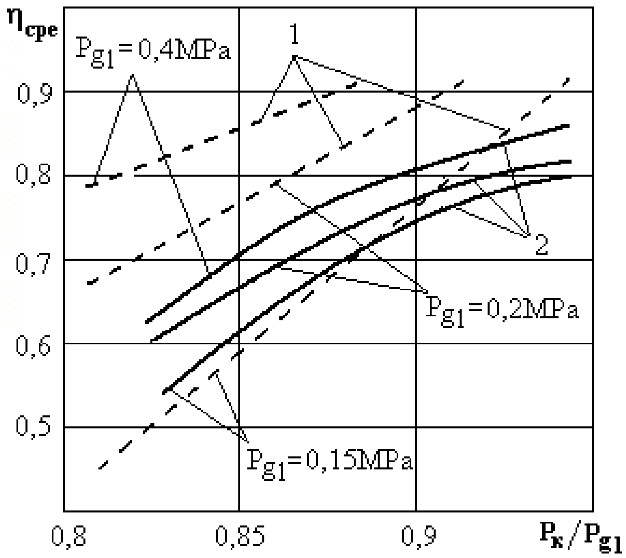

Fig.4. Efficiency dependency cascade pressure exchange on the ratio of pressure P_k/P_{g1}
1 – idealized cycle; 2 – test specimen allowing for the costs of power drive.

3. Directions of application the cascade compression units

Considerable compressed air discharge permits to use cascade pressure exchange as main unit of the system two-stage supercharging of internal combustion engine with insignificant increase of supercharging in the second stage necessary for realization blow of cylinders of piston part of internal combustion engine. To the opinions of the authors, the use of cascade pressure exchange as heat amplifier of the flow which performs the functions of a multiplier of air discharge is rather perspective

The possibility of cascade pressure exchange as the unit of air compression in gas-turbine units deserves definite attention (fig. 5).

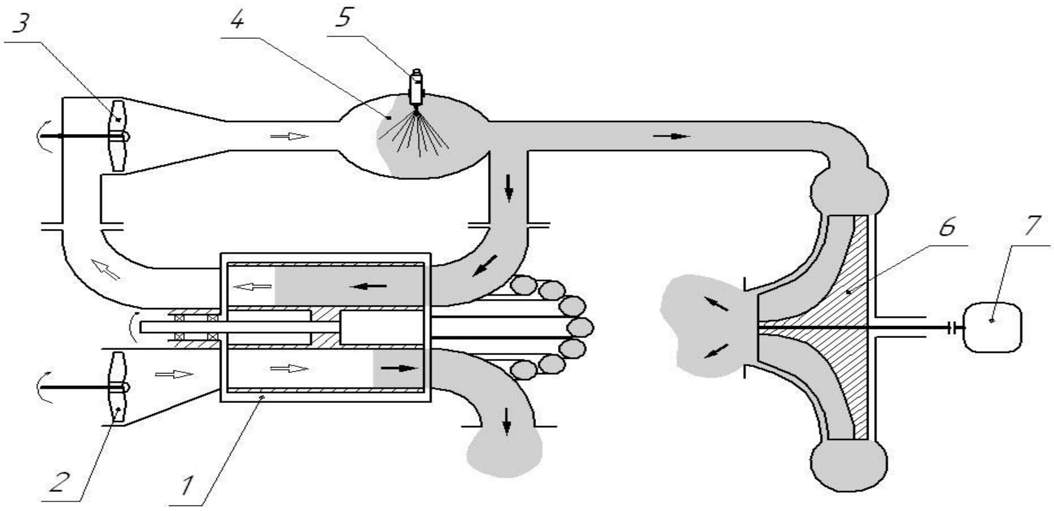

Fig.5. Diagram of gas- turbine unit with cascade pressure exchange
1- cascade pressure exchange; 2- scavenger fan; 3 - positive-displacement fan;
4 - combustion chamber; 5 - injector; 6 - power turbine; 7 - generator

High thermo-dynamical efficiency of gas- turbine units of cascade pressure exchange is based on higher efficiency of transformation given off in the combustion chamber, heat into the energy of compressed air relatively working process in classical system of gas- turbine units where air compression is carried out in the turbo- compressor which includes vane compressor and part of working steps of turbine.

In gas-turbine units about 50…60% power developed by a turbine for drive of vane compressor is spent. For rotor drive cascade pressure exchange insignificant power of external source is spent – the work of air compression is carried out due to internal energy redistribution of gas flows in running cascade pressure exchange elements. Only part of gas from the combustion chamber is directed into power turbine which has smaller sizes and power. All together at practically non-inertia work cascade pressure exchange the smallest inertia moment turbine stipulates higher quality of transition processes of gas-turbine units.

The above insensibility of the working cycle cascade pressure exchange to non-completeness of compressed air displacement from the rotor at frequency deviation of its rotation or thermo-dynamical parameters of working mediums stipulates satisfactory effective indicators with gas-turbine unit, with cascade pressure exchange.

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