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Assessment of efficiency of cascade power machines of locomotives

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Summary. Approach is given to determination of efficiency of power installations of cascade type for railway transport. The interrelation of the various efficiency used at determination of power efficiency of cascade power machines is presented. Efficiency of the transformer of energy of compressor type is estimated.
Key words: cascade power machines, pressure exchanger, mass exchange, recovery, efficiency.

INTRODUCTION

Search of ways of improvement of operational properties of power plants of railway transport isn't limited to improvement of indicators of working process of traditional designs of diesel diesels.

The perspective direction of improvement of fuel profitability of the power plant of the locomotive contacts use of heat reformative devices of cascade and thermal compression in systems of utilization of "waste" warmth of the fulfilled gases and cooling liquid [1, 2, 3].

Possibility of increase of efficiency [4-6] and simplification of a design of heat power cars contacts use of the principles of a cascade exchange by pressure for implementation of process of compression of gaseous environments in a running cycle of installation. The units realizing such compression – the cascade exchangers of pressure (CEP) – represent a new version of exchangers of pressure, in a particular approved in systems of pressurization of internal combustion engines [7-18]. Air compression in a cascade exchanger, as well as in wave exchangers of pressure of known system of pressurization of "Comprex" is carried out as a result of direct contact with squeezing gases, however with essential difference of the organization of working process.

OBJECTS AND PROBLEMS

The principle of action of a cascade exchanger is illustrated by fig. 1 where development of cells of a rotor of rather gas-distributing ports and pressure exchanging channels is schematized.

Arriving through a port of the gas of a high pressure (GHP) squeezing compress gas previously 1 air charge squeezed in a cell also forces out it through a port 8 of the air of a high pressure (AHP) to the consumer. Potential energy of the squeezing gas filling a cell after its dissociation with ports of a high pressure, it is useful it is spent for preliminary compression of a fresh charge in cells in the course of a cascade mass exchange via the pressure exchanging channels 3 which are periodically reporting adjacent cells of a rotor of sites of compression and expansion.

The purge of cells a fresh charge is carried out by compulsory aeration during their connection to ports of low pressure of 5 and 7 (ALP and GLP).

In a cascade exchanger of pressure, unlike wave, compression of air is carried out in energetically more rational quasi-stationary processes with insignificant amplitude of formed waves. In this case not only the dissipative phenomena of wave interaction of gas environments are leveled, but also sensitivity of working process the CEP to a picture of interaction of primary waves with forward edges of the gas-distributing ports, frequency of rotation of a rotor easily destroyed at a deviation or parameters of squeezing gas from calculated values considerably decreases.

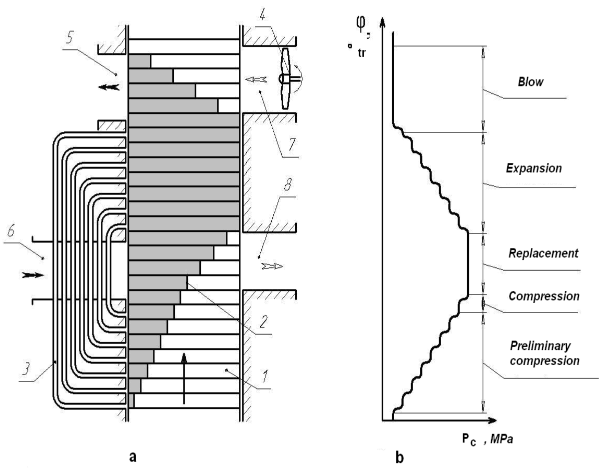

Fig. 1. Schematic diagram CEP:
a – rotor involute the CEP concerning ports and stator channels; b – the chart of change of pressure in cell on a rotor angle of rotation; 1 – rotor cells; 2 – conditional contact border of squeezing and squeezed environments; 3 – mass-exchanged channels of a stator; 4 – blowing-off fan; 5 – port of the gases of low pressure (GLP); 6 – port of the gases of a high pressure (GHP); 7 – port of the air of low pressure (ALP); 8 – port of the air of a high pressure (AHP)

Simplicity of production, absence of discretely operated locking bodies and displacement elements belong to number of the main advantages of rotor units of cascade type of continuous action. Low costs of energy of the drive of a rotor are caused by that compression of a working body is carried out at the expense of processes of a cascade heat mass exchange between adjacent cells of a rotor, as a result of use of energy of expansion of a working body of some volume at its heating. The received thus, compressed air can be used for further expansion in the turbine (in this case a cascade power exchange it is considered as the gas generator) or as the ICE supercharging air [19-23].

PURPOSE AND RESEARCH PROBLEMS

The purpose of the real research is definition of criteria of efficiency which provide an assessment of losses in structural to elements of cascade transformers of energy at various options of their use.

RESULTS OF RESEARCH

Essentially new organization of working process of such device predetermines need of use of specific criteria of efficiency of the power reformative processes to which consideration the real work is devoted.

Let's consider criteria of efficiency of units of a cascade power exchange of different function.

In case of use of the cascade transformer of energy as the generator of gases (used, for example, in broad cars for receiving mechanical work) the adiabatic efficiency is determined by a formula:

$$\eta_{gg}^{ad} = \frac{G_o \cdot \frac{k}{k-1} R \cdot T_{z\kappa} \cdot \left[1 - \left(\frac{P_{z\kappa}}{P_o} \right)^{\frac{1-k}{k}} \right]}{Q_{\text{int}}}, \quad (1)$$

where: G_o – a consumption of the gases which are taken away to the consumer; k – air adiabatic curve index; R – air gas constant; P_{zk} and T_{zk} – the cycle maximum pressure and temperature; P_0 – atmospheric pressure; Q_{int} – a thermal stream between a working body and walls of the utilization heat exchanger.

In case of use of the unit of the cascade transformer as the compressor (a source of the compressed air) expression of adiabatic efficiency looks like:

$$\eta^{ad} = \frac{G_o \frac{k}{k-1} R \cdot T_0 \cdot \left[\left(\frac{P_{z\kappa}}{P_o} \right)^{\frac{k-1}{k}} - 1 \right]}{Q_{\text{int}}}, \quad (2)$$

where: T_0 – ambient temperature.

Passing to real installation with cascade transformers of energy it is necessary to consider additional costs of energy of the drive of a rotor of the unit. Thus it must be kept in mind some ambiguity of determination of effective efficiency, in view of need of use of uncertain efficiency of the conditional broad car which capacity is equivalent to costs of the drive of a rotor of an exchanger.

Let's dwell upon a conclusion of expression of efficiency for two cases of use of the cascade compressor or the gas generator.

By consideration of physical essence of effective efficiency of the unit of the exchanger used as the compressor or the generator of gases the analogy to work of gas-turbine engine (GTE), according to intended for forcing of air or generating of hot gases, i.e. GTE in which the capacity of the turbine is spent only for the compressor drive is pertinent.

For convenience of carrying out parallel analogy further in the text we use braces; for designation of the GTE elements which are functionally corresponding to elements of the cascade transformer of energy [24-27].

a) Case of use of the cascade transformer of energy as the generator of gases.

All air which is taken away from an exchanger (GTE compressor) to the consumer of Go passes through a source of a supply of warmth (GTE combustion chamber) where heats up to the maximum temperature of T_{zk}.

At determination of effective efficiency as useful energy it is necessary to consider only "refined" part of a generated stream, after an exception of it the "expensive" part which is energetically equivalent to power of the drive of a rotor of an exchanger (GTE compressor) taking into account efficiency of transformation in the conditional broad car (BC) (turbine GTE).

The expense of a working body (gas) via the conditional broad machine of the drive makes:

$$G_{em} = \frac{N}{H_{z\kappa}\eta_{em}}, \quad (3)$$

where: N_{dr} – the power spent for the drive of a rotor of an exchanger (GTE compressor); η_{em} – efficiency of the conditional broad machine; H_{zk} – located heat difference of gases at a temperature T_{zk} determined by a formula:

$$H_{z\kappa} = \frac{k}{k-1} RT_{z\kappa}\left[1 - \left(\frac{P_{z\kappa}}{P_o}\right)^{\frac{1-k}{k}}\right].$$

The expense corresponding to a useful component of generated energy, is defined as G_g=$G_oG_{e\text{м}}$.

Thus, the effective efficiency of the cascade generator of gas can be expressed as follows:

$$\eta_{gg}^{e} = \frac{G_n H_{z\kappa}}{Q_{\text{int}}} = \frac{G_o H_{z\kappa} - G_{em} H_{z\kappa}}{Q_{\text{int}}}.$$

Taking in account (3) we will receive:

$$\eta_{gg}^{e} = \frac{G_o H_{z\kappa} - \frac{N_{dr}}{\eta_{em}}}{Q_{\text{int}}} =$$

$$= \frac{G_o \frac{k}{k-1} RT_{z\kappa}\left[1 - \left(\frac{P_{z\kappa}}{P_o}\right)^{\frac{1-k}{k}}\right] - \frac{N_{dr}}{\eta_{em}}}{Q_{\text{int}}}.$$

b) Case of use of a cascade exchanger as the compressor.

The air compressed in exchanger, is brought to the consumer with a temperature of compression end T_{ck}, passing a source of a supply of warmth (GTE combustion chamber). However the conditional consumption of air which is energetically equivalent to expenses of power on the drive of a rotor (GTE compressor) has to be calculated taking into account its heating in a source of a supply of warmth (GTE combustion chamber) up to T_{zk} temperature. Thus located heat difference of the stream which is taken away to the conditional broad car (turbine GTE) increases in proportion to T_{zk}/T_{ck}.

The condition of power equivalence of a stream through EM to costs of power of the drive of a rotor can be written down in a look:

$$G_{em} H_{c\kappa} T_{z\kappa} / T_{c\kappa} \eta_{em} = N_{dr},$$

where: $H_{c\kappa} = \frac{k}{k-1} RT_{c\kappa}\left[1 - \left(\frac{P_{z\kappa}}{P_o}\right)^{\frac{1-k}{k}}\right]$ - located heat difference of the air which has been taken away to the conditional broad machine. From where:

$$G_{em} = \frac{N_{dr} T_{c\kappa}}{\eta_{em} H_{c\kappa} T_{z\kappa}}. \quad (4)$$

As in the cascade transformer of energy, unlike GTE, the drive of a rotor is carried out from an external source and warmly for heating of the stream which is taken away to EM in real process isn't spent, at definition of potential expenses of thermal energy (taking into account need of the drive of a rotor) it is necessary to consider additional heat on heating of a stream of Gem by means of composed in a denominator of a formula of effective efficiency:

$$\eta_e = \frac{(G_o - G_{em}) H_{\kappa}^{ad}}{Q_{\text{int}} + Q_{dr}} = \frac{G_o H_{\kappa}^{ad} - G_{em} H_{\kappa}^{ad}}{Q_{\text{int}} + Q_{dr}},$$

here $$H_k^{ad} = \frac{k}{k-1} R \cdot T_0 \cdot \left[\left(\frac{P_{z\kappa}}{P_o} \right)^{\frac{k-1}{k}} - 1 \right]$$ -

adiabatic heat difference in the compressor.

In view of $Q_{dr}=G_{em}C_p(T_{z\kappa}-T_{c\kappa})$ and taking in account (4) we will finally receive:

$$\eta_e = \frac{G_o \frac{kRT_0}{(k-1)} \left[\left(\frac{P_{z\kappa}}{P_o} \right)^{\frac{\kappa-1}{\kappa}} - 1 \right] - \frac{N_{dr} T_0 (\frac{P_{z\kappa}}{P_o})^{\frac{\kappa-1}{\kappa}}}{\eta_{em} T_{z\kappa}}}{Q_{int} + \frac{C_p N_{dr} (T_{z\kappa} - T_{c\kappa})}{\eta_{em} \frac{k}{(k-1)} RT_{z\kappa} \left[1 - \left(\frac{P_{z\kappa}}{P_o} \right)^{\frac{1-\kappa}{\kappa}} \right]}} . \quad (5)$$

Expediency of simultaneous consideration of adiabatic and effective efficiency at an assessment of a thermodynamic cycle is caused by possibility of identification of specific "contribution" of different types of the brought energy in production of unit of useful work. For example, direct comparison also allows to estimate components of expenses for the rotor drive.

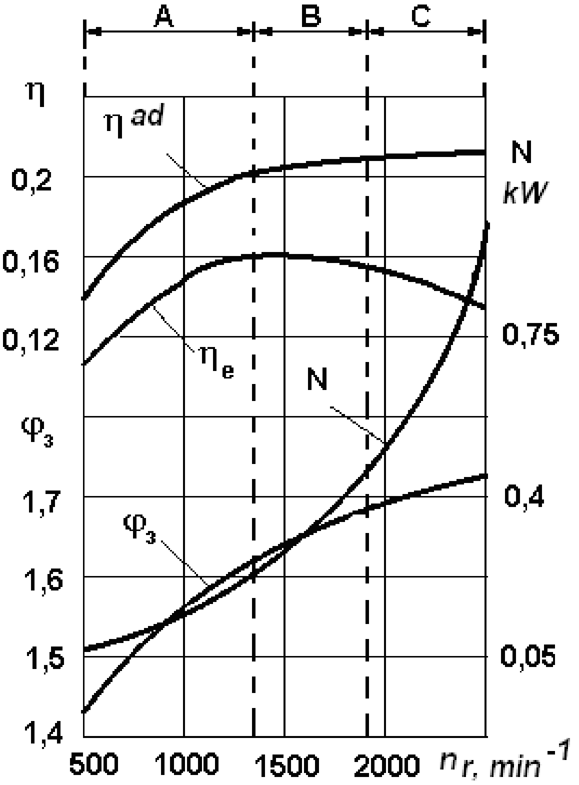

Fig. 2. Influence of rotor rotation frequency on thermal compressor indicators at temperature T_z = 650 K mode

Feature of working process of an exchanger is essential dependence of indicator transformation of thermal energy on quality of a purge of cells fresh air (fig. 2). The analysis of curves of change and depending on the frequency of rotation of a rotor, at an invariable maximum temperature of a cycle shows that in area “A” increase of n_r is unambiguously expedient as provides prevailing influence of coefficient of a purge on to what intensive growth testifies.

In area “C” the purge intensification (at the expense of increase in rotation frequency) doesn't provide noticeable influence on efficiency of indicator transformation, but is accompanied by essential increase in expenses of power at the drive of a rotor that causes decrease.

Expedient degree of an intensification of a purge in area “B” depends on the relative value of two types of energy in the conditions of the concrete power plant of the locomotive.

CONCLUSIONS

Thus, comparison of characteristics of the considered efficiency gives an idea of resource opportunities of increase of system effectiveness of cascade transformation of energy at the expense of various factors.

The presented efficiency estimation criteria of energy cascade transformers are approved on thermal compressor example, can be applied practically for any power machines of cascade type, applied on railway transport.

At creation of aggregates type-dimension row, based on direct co-operation of air-gas environments principles of cascade type it is expedient to use a mine-out criterion on the stages of losses prognostication in structural elements.

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ОЦЕНКА ЭФФЕКТИВНОСТИ КАСКАДНЫХ ЭНЕРГЕТИЧЕСКИХ УСТАНОВОК ЛОКОМОТИВОВ

Юрий Сторчеус, Олег Воронов, Александр Ковтун

Аннотация. Приведен подход к определению эффективности энергетических установок каскадного типа для железнодорожного транспорта. Представлена взаимосвязь различных коэффициентов полезного действия, используемых при определении энергетической эффективности каскадных энергоустановок. Оценена эффективность трансформатора энергии компрессорного типа.

Ключевые слова: каскадные энергетические установки, обменник давления, массообмен, рекуперация, коэффициент полезного действия.