Development of transport heating systems with cascade transformers of energy

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S u m m a r y . In article perspective schemes of heating and ventilating systems for the transport units, working at the principles of cascade and thermal compression are considered. Physical features of working process of the generator of cascade and thermal compression are revealed and analyzed, concepts of improvement of its properties are offered. Ways of increase of overall performance of heating and ventilating systems are opened and the various circuit solutions providing their maximum productivity under operating conditions are proposed.
K e y w o r d s : cascade-heating pressure, generator of gases, transports heating system, efficiency, rotor.

INTRODUCTION

In a total amount of consumption of energy by passenger train the considerable share is made by costs of providing a microclimate in cars and a cabin of the driver of the locomotive [2,3, 6, 9]. In the conditions of the increasing competition in the market of transport services the requirement for maintenance of comfortable sanitary and hygienic parameters in rooms of a rolling stock at simultaneous decrease in the energy consumed by systems of heating, airsupply and conditioning are of particular importance [8, 10, 31, 33].

The considerable reserve of increase of competitiveness of railway transport in passenger traffic is connected with increase of level of comfort in rooms of a rolling stock. Level of comfort of a trip on railway transport in many respects depends on a microclimate in salons of the rolling stock which parameters, and, first of all temperature, humidity, a dust content and a chemical composition of air, directly influence health of passengers and subjective perception of duration of journey [4, 11, 12, 22, 32].

Need of increase of efficiency of systems of heating and ventilation, search of the decisions possessing higher profitability, predetermines creation of new classes, schemes and the principles of action of heating systems. Significant progress in this direction can be made when using as a basic element of heating and ventilating systems of one of versions of cascade transformers of energy, namely – generators of cascade and thermal compression with an ejector step [7].

MATERIALS AND METHODS

The analysis of systems of heating and ventilation of cars shows that the best microclimatic conditions are provided by a multipoint supply of the warmed-up air in salons [21, 23, 24, 25]. However standard schemes of electro calorific heating have the extremely unsatisfactory power efficiency [5, 29].

Functionally the greatest ability to provide sanitary and hygienic requirements to a microclimate in rooms of a rolling stock air (calorific) heating system possesses [30]. Its advantages treats: simplicity of regulation of air temperature in car salon, reliability of a food of the heaters placed in one place, high level of safety for passengers, possibility of a combination of electric system about the steam, continuous inflow to salon of fresh air [26]. At the same time, air (electro calorific) heating is characterized by very small efficiency.

It is necessary to notice that power imperfection, as a whole, is typical for all systems of electric heating. The main reason consists in irrationality of the return transformation of the refined electric energy in the thermal. Really, warmly in essence is dissipative energy, and can serve as an indicator of imperfection or irreversibility of converting processes in transforming units and power machines.

Especially obvious inexpediency of use of the electric power as a source of warmth is shown in trains with diesel draft where on the one hand the electric power is a product of double transformation (with thermal in mechanical – in the diesel, and mechanical in the electric – in the generator), and on the other hand – branch of warmth in the power unit of a locomotive is a necessary condition of the organization of working process of a diesel cycle. Thus we will note that the warmth which is taken away in the cooling system of the diesel and with fulfilled gases, almost twice exceeds the warmth transformed to useful mechanical energy on a shaft of the engine [20, 26].

Lower value of efficiency of air systems of heating is caused by big costs of energy of heat transportation by an air stream. The compressed air is a product of the high-tech processing which receiving in the conditions of a rolling stock assumes use of the 3 or 4 units with the restrictions by efficiency of converting processes (cycles). For example, in case of diesel draft production of the compressed air is carried out according to the scheme:

• transformation of warmth of combustion of fuel to mechanical energy (diesel, η_e =0,32. 0,34),

• transformation of electric energy in electric (the generator η_g =0,84. 0,85),

• transformation of electric energy in mechanical the compressor drive (the electric motor η_{em} =0,8. 0,85),

• transformation of mechanical energy to located work of the compressed air (the compressor η_c =0,7. 0,72).

Thus, the general efficiency of transformation of thermal energy in the potential of the compressed air on condition of nominal operating modes of all units makes:

$$\eta_{general} = \eta_e \eta_g \eta_{em} \eta_c = 0{,}15 \ldots 0{,}18. \quad (1)$$

In a type of high cost intensity of process of forcing of air power expediency of decrease in the general level of pressure in the highway of an air duct of heating system that can be reached by use of the individual fans placed in close proximity to is obvious snuffled supply of heated air in warmed zones. Such decision is interfaced to unjustified increase in quantity of heating elements and the motor fans, complicating the structure of heating system and reducing its reliability. Thus very it isn't simple to suppress the noise created by operation of fans.

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Costs of power of ensuring comfort make considerable part of power consumed by train. In Fig.1 average annual distribution of consumed energy standardized by intercity train Federal iron expensively to Switzerland (SBB) by weight 600t is shown at acceleration of 0,1 m / c^2 on lifting of 10%.

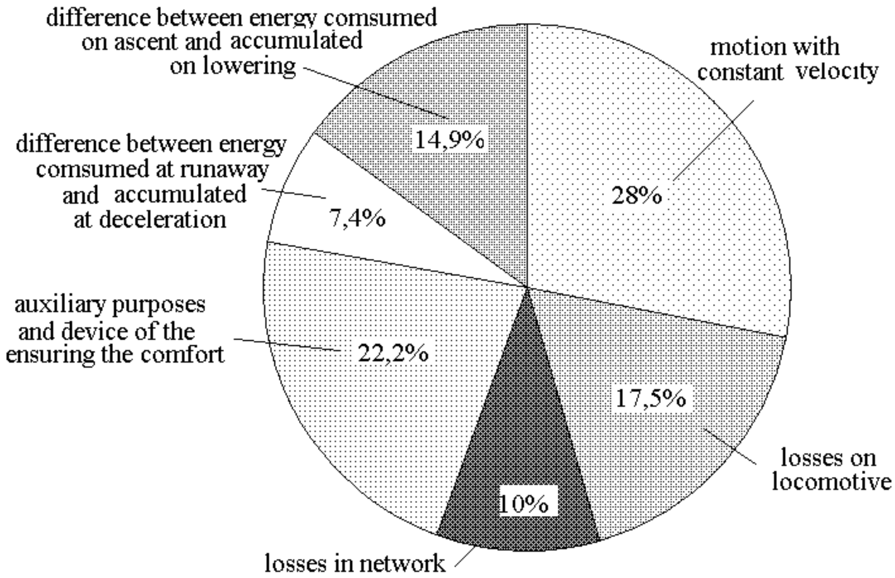

Fig. 1. Settlement distribution of annual power consumption for the standardized train

At train movement without acceleration on horizontal sites of the road, and also during stops specific costs of the auxiliary purposes and ensuring comfort increase.

ARTICLE PURPOSE

The purpose of article is identification of the major factors defining efficiency of application of the principles of cascade energy exchange in systems of heating of transport installations.

The main objectives of research was development of highly effective schemes of systems of heating on the basis of cascade transformers of energy.

RESULTS OF RESEARCH

The perspective direction of development of heating and ventilation is connected with creation of generators of the hot air based on use of effect of the cascade and thermal compression (CTC). Essence of a running cycle of CHP developed under the direction of professor Krajniuk A.I. consists in direct transformation of heat to energy of the compressed air. Thermodynamic cycle CHP can be based on a number of devices: CHP compressor [13, 20], generator of gas [20], cascade exchanger of pressure [1, 18], combustion chamber of gas-turbine installation [14, 15, 16], heater of cascade and thermal compression (HCT) [4, 7], various systems of pressurization of ICE [14, 17, 18], refrigeration machinesetc [19].

Besides simplicity and high reliability of a design, in a type of lack of mechanical displacers and mobile discretely operated gas-distributing bodies, CHP units are characterized by rather high efficiency even when using sources of warmth with rather low temperature potential that causes appeal of their application, including, as utilization systems as a part of traditional heat power plants. The principle of action and the description of the first CHP devices are opened in works [1, 26, 28].

Now on ICE chair and engineering science of the East Ukrainian University of V. Dahl efficient prototypes of the CHP unit which scheme is shown in Fig.2 are created.

The CHP unit contains a rotor 1 covering a stator 2, containing the pressure exchanged channels 3 which are in pairs connecting adjacent cells of a rotor of 1 and opposite 4 supply of low pressure (SLP) located a window and a window 6 of the supply of a high pressure (SHP). The external surface of a rotor 1 is captured by a casing including a window 5 of the branch of low pressure (BLP) and a window 7 of the branch of a high pres-

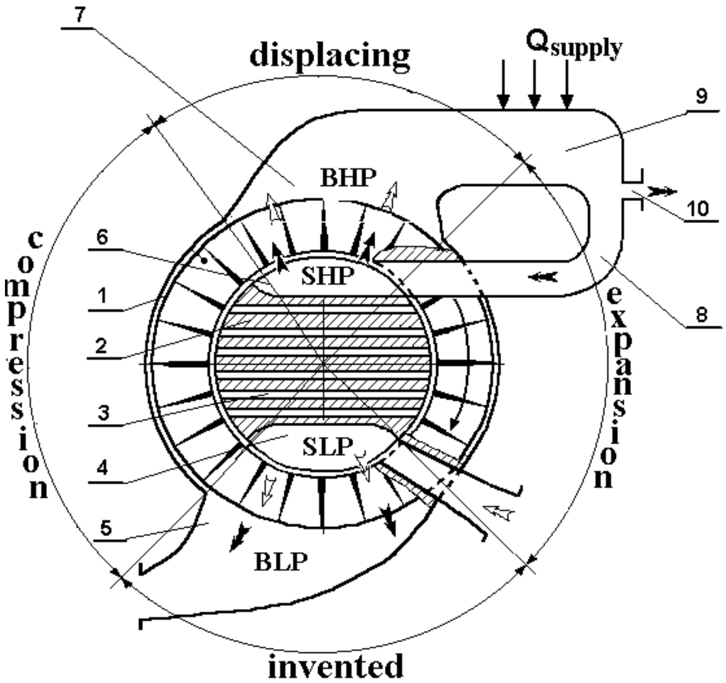

Fig. 2. Schematic diagram of the generator of cascade and thermal compression

sure (BHP), and the window 6 SHP and a window 7 are connected by a displacement path 8 to the heat exchanger 9 of a utilization contour. On a site of a displacement path 8 connecting the heat exchanger 9 and a window 7, the branch pipe of the 10 branch of the squeezed working body is located to the consumer.

In the course of rotation of a rotor 1 (clockwise) each of cells of a rotor 1 is consistently reported with pressure exchanged channels 3 stator 2 through which in it the working body from adjacent cells of a site of expansion arrives. As a result of cascade compression pressure in a cell gradually increases to the certain value depending on thermodynamic parameters of a working body at the beginning of process of expansion.

At the message of considered cells with windows of a high pressure (6 SHP and 7 BHP) displacement path under the influence of centrifugal forces or compulsory circulation replacement previously the air charge squeezed in a cell by the warmed-up source of warmth air or gases (in case of use of the camera of internal combustion) is carried out.

Thereof in a displacement path 8 and reported with it cells the maximum pressure of a cycle exceeding pressure of cascade compression is established. The part of the compressed air from a displacement path 8 is taken away to the consumer through a branch pipe 10 placed just before a source of warmth.

In the period of the subsequent message of cells with pressure exchanged channels 3 the part of a working body is taken away to adjacent cells of a site of compression that is accompanied by pressure drop in considered cells. Thus, work of expansion is spent for compression of an air charge in the course of a cascade mass exchange. Residual pressure at the end of expansion process as the indirect indicator of perfection of working process, depends on number of pressure exchanged channels, aspiring to atmospheric with increase in the last.

And, at last, the purge of cells the air charge, carried out during connection of cells to windows of low pressure of SLP and BLP, closes a running cycle of the CHP unit.

Despite uniqueness of the device, working process of the CHP unit doesn't contradict the classical principles of the organization of working process of heat power machines. Really, the running cycle in a cell of a rotor can be divided into the following processes conditionally:

- compression process at cell movement from the SLP window until its combination with the SHP window, being accompanied step increase of pressure in a cell, owing to a supply of part of a working body from adjacent cells of a rotor via stator channels,
- the process of the replacement including stages of increase of pressure in a cell with previously squeezed working body up to the maximum pressure of a cycle, during its connection to the windows SHP and BHP with simultaneous replacement from a cell and pushing through of a working body via the heat exchanger where its heating, and also branch from the displacement highway of part of the squeezed working body to the consumer with the maximum pressure of cycle CHP is carried out,
- expansion process, as a result of branch of part of a working body via stator channels in adjacent cells of a rotor,
- process of a purge of a cell by fresh air in the period of its message with the SLP and BLP blowing-off windows.

In relation to railway transport interest represents, for example, use of the generator of hot air in heating systems of a rolling stock. The obvious advantage of a heater of CHP, along with the low cost of service, autonomy in view of working capacity preservation is at a de-energization of the power supply network, also possibilities of operation on different types of fuel and from any source of warmth. Thanks to forcing of hot air directly heat carrier transportation in local zones of warmed object is carried out by the CHP unit without use of the driving compressor or the fan.

Other direction of development of devices of cascade compression is connected with creation of exchangers of pressure, for example, ICE used for pressurization.

In the cascade exchanger of pressure (CEP) air compression like the wave exchanger of pressure (WEP) is carried out as a result of direct contact with squeezing gas, however in process with significantly excellent distribution of power substances. The principle of action the CEP is opened in works [13, 27, 28].

Advantages of a running cycle the CEP concerning WEP are caused by the following. Wave character of an exchange of energy and forcing of the compressed air predetermines high sensitivity of working process of WEP to a picture of interaction of primary waves with forward edges of the gas-distributing windows, easily destroyed at a deviation of frequency of rotation of a rotor or parameters of squeezing gas from calculated values. However and on a settlement mode pulse compression of a charge is accompanied by the losses connected with dispersion of energy of formed waves as a result of their counter interaction and reflection in boundary sections of a cell.

Even more significant impact on the efficiency of the koeffitsien WED has the fullness of the displacement of compressed air through the window of high-pressure air. The increase in a share of the compressed air which has remained in a cell (after its dissociation with windows of a high pressure) causes almost proportional decrease in efficiency, to similarly negative influence of so-called "dead" volume in the piston compressor.

Given the presence of the mixing zone in the cell contraction and a compressed gas to carry out a complete replacement of the charge of compressed air, eliminating the cast of compressing gas in the windows low-pressure air is problematic. Especially much noted factors are shown at increase in a pressure of an exchanger with change of frequency of rotation of a rotor.

On a settlement operating mode the generator of cascade thermal compression forces hot air with high temperature and pressure depending on the maximum temperature of a cycle and the relative expense which is taken away to the consumer of air to components from 0,2 to 0,6 MPa. Noted thermodynamic parameters of generated air, allow to carry out transportation of heat to remote zones cars by means of an air duct with rather small section through passage with the subsequent dilution of hot air cold in the ejector cameras of mixture placed in branching of a communication network. Use of the ejector I snuffled, differing high reliability and simplicity, allows not only to reduce temperature of air arriving in salon to comfortable values, but also considerably to increase its expense.

Despite low efficiency of jet pumps their application as a part of heaters of CHP is justified as the dissipative component of an exchange of energy will be transformed to heat used directly in heating system.

The schematic diagram of the elementary system of heating with the CHP generator is shown in Fig.3.

1 hot air forced by the CHP generator is brought to an active nozzle of the ejector 2 which passive nozzle is reported with a blowing-off path 4. As a result of mixture in the ejector 5 camera, hot air is diluted with the blowing-off stream consisting of a mix of external blowing-off air and residual hot air, a rotor forced out from cells 6.

Here warmth of the residual air which is forced out from cells of a rotor remains in a contour of heating system. Thus connection of a blowing-off path 4 to the ejector 5 solves a problem of cleaning of cells 6 that promotes increase of overall performance of generatora CHP and simplification of its device.

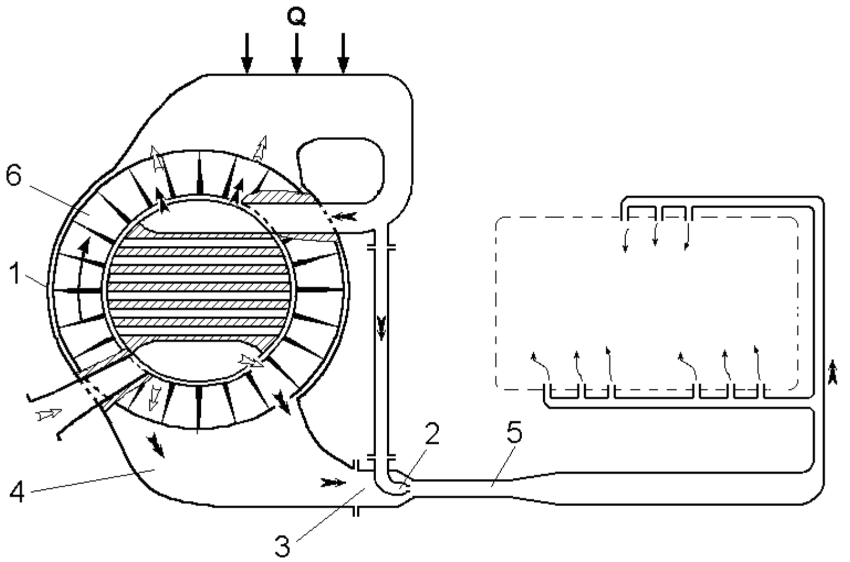

Fig. 3. Heating system with one-stage ejection of air

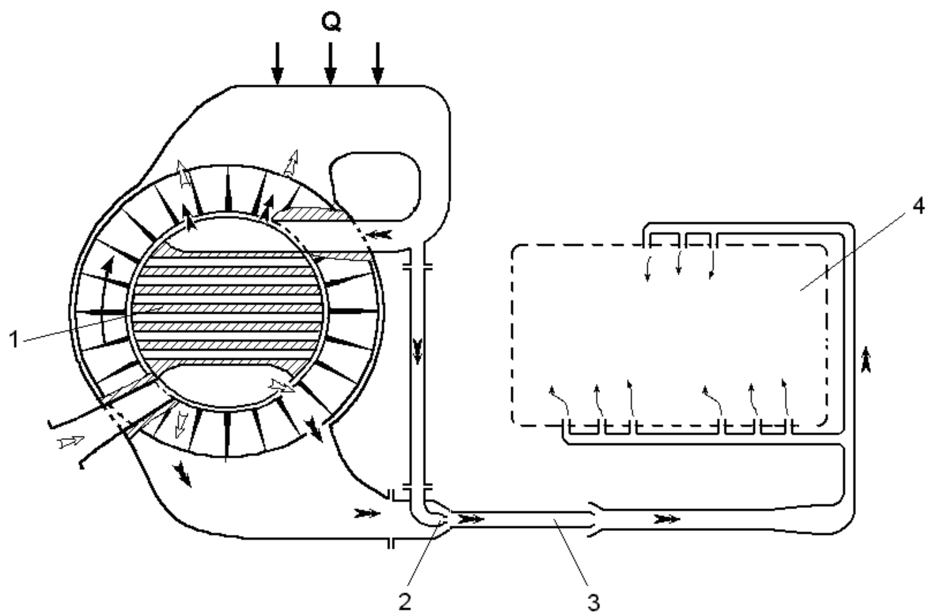

Fig. 4. Heating system with two-level ejection of air

Average temperature of a blowing-off stream in a passive nozzle 3 depends on coefficient of blowing-off air and in some cases, taking into account limited values of coefficient of ejection of one step, is high from the point of view of necessary comfortable cooling of warming air in output sections of a heating network. In case of the excessive temperature of warming air comfortable parameters of a microclimate in salon can be reached by additional dilution of calorific air in the second step of the ejector.

In the circuit shown in Fig.4 acceptable temperature of the incoming air in the interior is ensured by appropriate selection of the total ejection coefficient $n_{e_\Sigma} = (n_{e_I} + 1) \cdot (n_{eII} + 1) - 1$ two ejector stages.

At change of conditions of environment regulation of a temperature mode in salon of the car is carried out by change of power of a source of a supply of warmth in a displacement contour of generatora CHP. At the same time, for maintenance of necessary pressure in the pressure head highway of a calorific network the maximum pressure of Pz of a running cycle of generatora CHP on partial working hours of system on has to change considerably.

Noted condition is realized in adjustable systems of heating (Fig. 5) with the divided cameras of mixture of the first ejector step.

At temperature increase of environment and the corresponding reduction of a thermal stream in a displacement path of generatora CHP necessary level of the maximum pressure of Pz is provided thanks to reduction of an expense of the active environment which is taken away from a displacement contour of generatora CHP, a way of overlapping of one or several active snuffled the 1st ejector step gates 1 specially provided for this purpose.

The main differences of 5 options of adjustable systems of heating shown in fig. are connected with circuit performance of the 2nd ejector step.

When performing the second step of the ejector in the form of the ejector nozzles 2 placed directly in output sections of an air distributing network (see Fig. 5, b), secondary dilution of hot air by internal recirculation air promotes the fastest warming up of the heated room.

Shortcomings of such decision is limited removability of air in passenger salon inflow of external air. In option of execution of heating system with the antimony contours of the blowing-off and stitched highways containing consistently placed steps of the ejector (Fig.5, c) division of air streams with a various temperature is reached. Expediency of generating of air streams with a various temperature is caused by expansion of universality of heating system in cases of simultaneous heating of certain rooms, local surfaces and units of a rolling stock with various heatphysical characteristics.

When using as a source of warmth of a running cycle of generatora CHP of furnace cameras or the fulfilled gases of the diesel temperature of the gas stream leaving the heat exchanger of a displacement contour of generatora CHP, remains rather high as lower than temperature of a working body in rotor cells at the end of process of cascade compression doesn't fall.

Fuller use of thermal potential of a source of warmth possibly in the schemes (Fig.6) providing secondary utilization of a gas stream at the exit from the heat exchanger of 1 displacement contour for heating of external air in a passive nozzle of 2 first or second steps of the ejector.

Problem aspect of such way of utilization of "waste" warmth is need of dilution of a hot stream a significant amount external air that is difficult at limited number of steps of the ejector.

The most universal is the system of the mixed heating presented in Fig.7 in which residual heat of gases is taken away in a contour of water heating of the car.

Supplement heating ventilation CHP water circuit allows you to significantly increase the efficiency of the system, making best use of waste heat streams, and also solves the problem of reducing the temperature in the passenger compartment air to comfortable values by intermediate cooling flow after the first stage ejector.

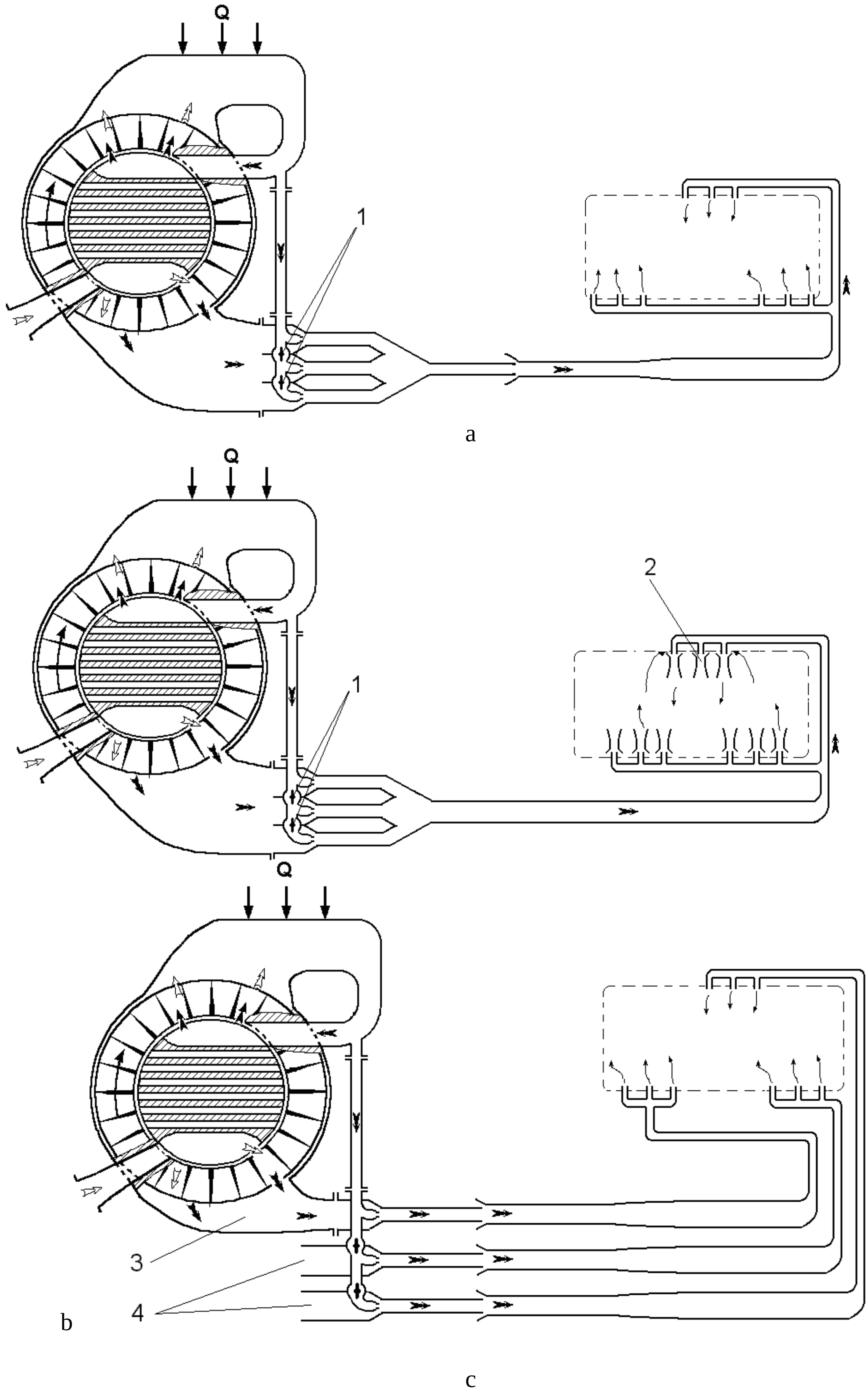

Fig. 5. Adjustable systems of heating

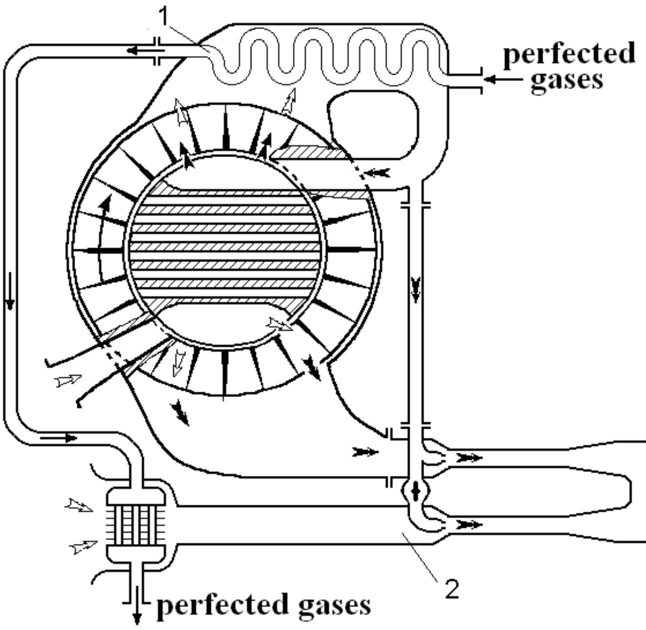

Fig. 6. Heating system with utilization of residual warmth of the gas stream leaving the heat exchanger of a displacement contour of generatora CHP

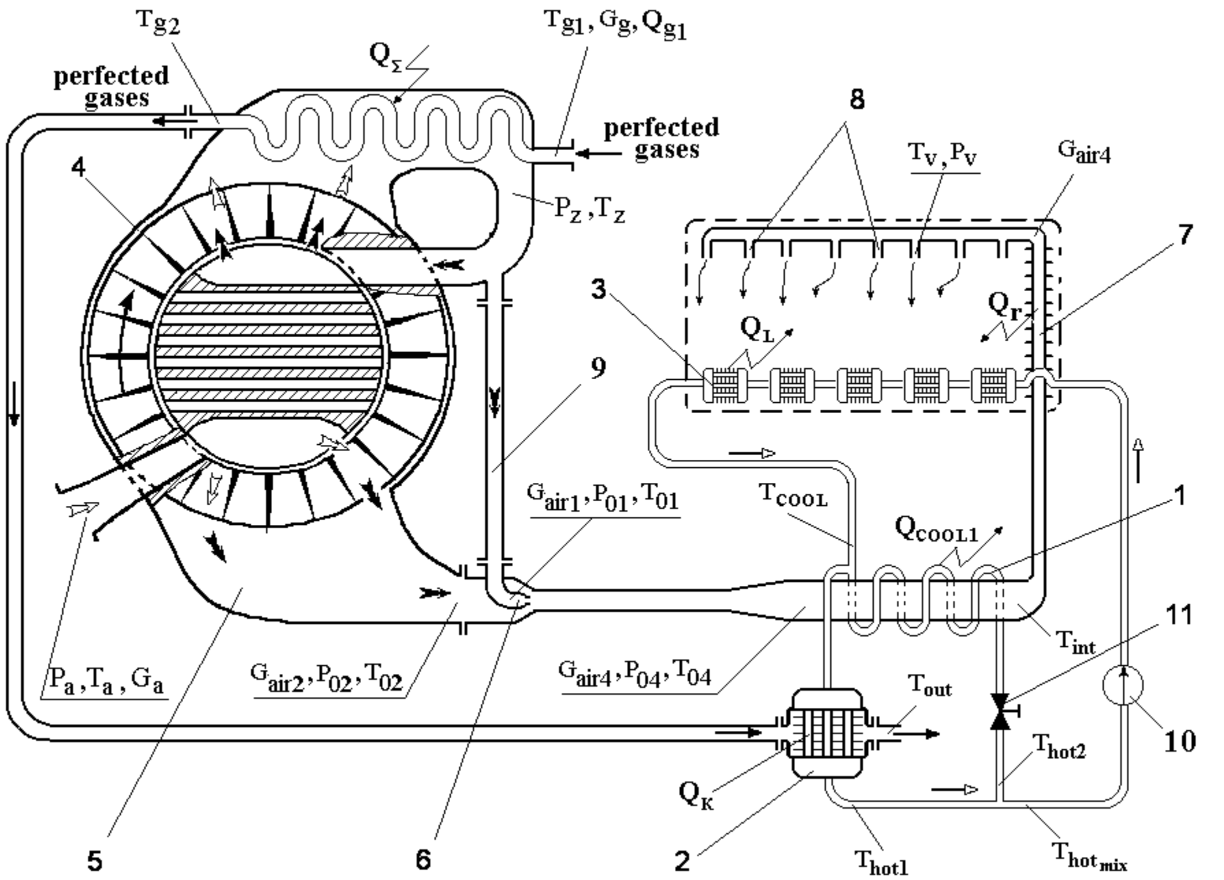

Fig. 7. System of the mixed heating with utilization of residual warmth of a gas stream in a water contour

The liquid of the water contour which is warmed up at the beginning in the heat exchanger of 1 ejector step and then in the heat exchanger of 2 utilization of "waste" warmth of fulfilled gases, are moved in the radiators 3 placed in warmed salon. Additional cooling of the air given to salon to comfortable values, is carried out on a site of the air route supplied with edges of cooling. Finned air line portion 7 is located directly in the heated compartment and thus serves as an additional convective heating radiator.

CONCLUSIONS

1. The running cycle, circuit decisions and design of essentially new structure of heating and ventilating system of the cascade and thermal compression, protected by patents of Ukraine and Russia are developed.

2. Expediency of use as a power source of heating and ventilating systems of generators cascade and thermal pressure, realizing direct transformation of warmth to energy of the compressed air in the devices which aren't containing volume displacers and discretely operated gas-distributing bodies is proved.

3. It is established that the fullest use of thermal potential of a source of warmth possibly in the schemes providing secondary utilization of a gas stream at the exit from the heat exchanger of a displacement contour for heating of external air in a passive nozzle of the ejector.

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РАЗВИТИЕ ТРАНСПОРТНЫХ ОТОПИТЕЛЬНЫХ СИСТЕМ С КАСКАДНЫМИ ТРАНСФОРМАТОРАМИ ЭНЕРГИИ

Юрий Сторчеус, Александр Данилейченко, Константин Лупиков

Аннотация. В статье рассмотрены перспективные схемы отопительно-вентиляционных систем для транспортных установок, работающие на принципах каскадно-теплового сжатия. Выявлены и проанализированы физические особенности рабочего процесса генератора каскадно-теплового сжатия, предложены концепции совершенствования его свойств. Раскрыты пути повышения эффективности работы отопительно-вентиляционных систем и предложены различные схемные решения, обеспечивающие их максимальную производительность в условиях эксплуатации.

Ключевые слова: каскадно-тепловое сжатие, генератор газов, транспортная отопительная система, эффективность, ротор.