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APPLICATION OF ROTARY VANE EXPANDERS IN SYSTEMS UTILIZING THE WASTE HEAT

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ABSTRACT

Sources of waste heat have generally a very low heat output. Their utilization as positive heat sources in the C-R cycle with low-boiling refrigerants requires the application of expanders. Turbines are inefficient in this respect because of low steam flows. However, volumetric rotary machines can be successfully employed as expanders. In the present paper those properties of rotary vane machines are discussed which make them especially useful as expanders in the C-R cycles with the low-boiling refrigerant. A multistage vane expander and a thermodynamic cycle adjusted to it are also discussed. Authors' experience acquired in the designing of a system that utilizes the rotary vane expanders for waste heat recovering plants is also presented.

NOMENCLATURE

N - power
L - work
p - pressure
s - enthalpy
T - temperature

INTRODUCTION

Numerous waste heat sources, that are found in industry, are characterized by a low and unstable heat output. One way of their utilization [1] are steam power stations (Clausius-Rankine's cycle) with low-boiling substances employed as working agents. Such systems are usually small-size and, as a rule, do not allow turbines as expanding machines. Miniaturization of a steam power station implies the relative increase in investment costs and thus a prolonged period of investment repayment. Therefore, the employment of waste heat sources with small and unstable heat output is not economical. The amount of heat, however, that can be retrieved from sources having such characteristics, is enormous. In the Institute of Heat Engineering and Fluid Mechanics, Technical University of Wrocław, Poland, works are being carried out aimed at miniature steam power-station systems, which employ rotary vane machines as steam expanders and compressors\expanders of an auxiliary agent (air).

PROCESSES OF ENERGY AND SUBSTANCE FLOW IN A MICRO POWER-STATION EMPLOYING LOW-BOILING SUBSTANCES

The complete utilization of a waste heat source requires the employment of a multi-stage process of steam generation and expansion in various ranges of pressure and temperature [2]. Fig. 1 shows an example of a process, in which steam with varying output temperature and constant pressure is produced, while steam generation with both temperature and pressure varying is presented in Fig. 2.

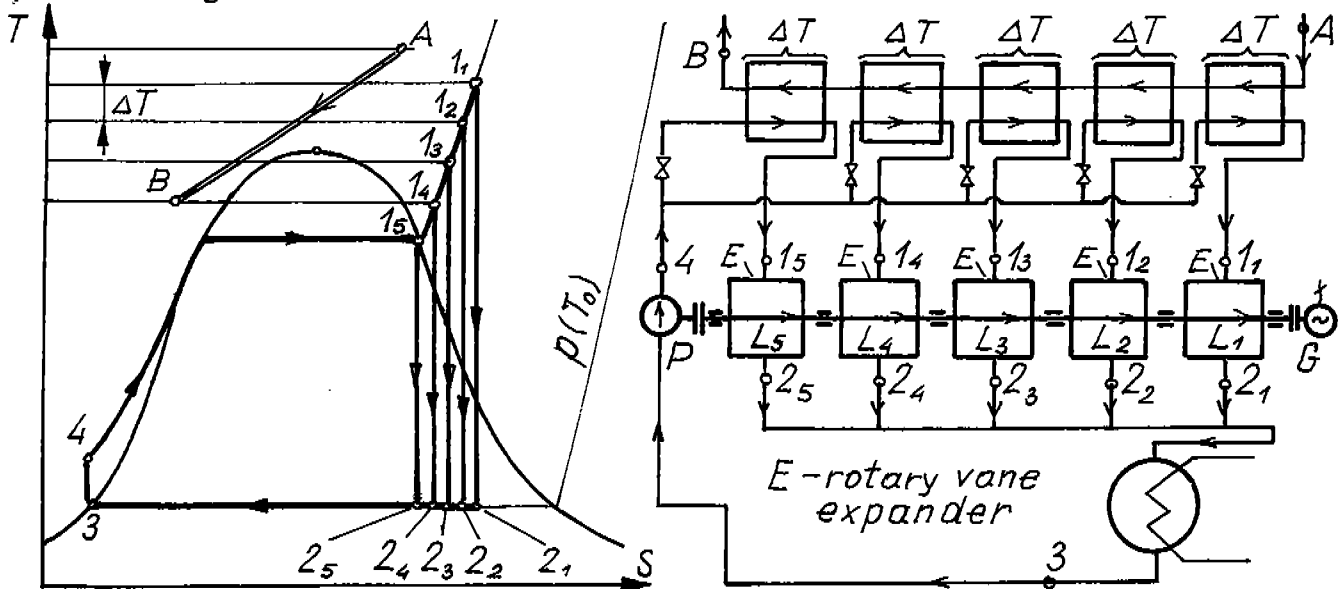


Fig. 1. An idea of micro power-station employing a set of rotary vane expanders for isobaric steam generation.

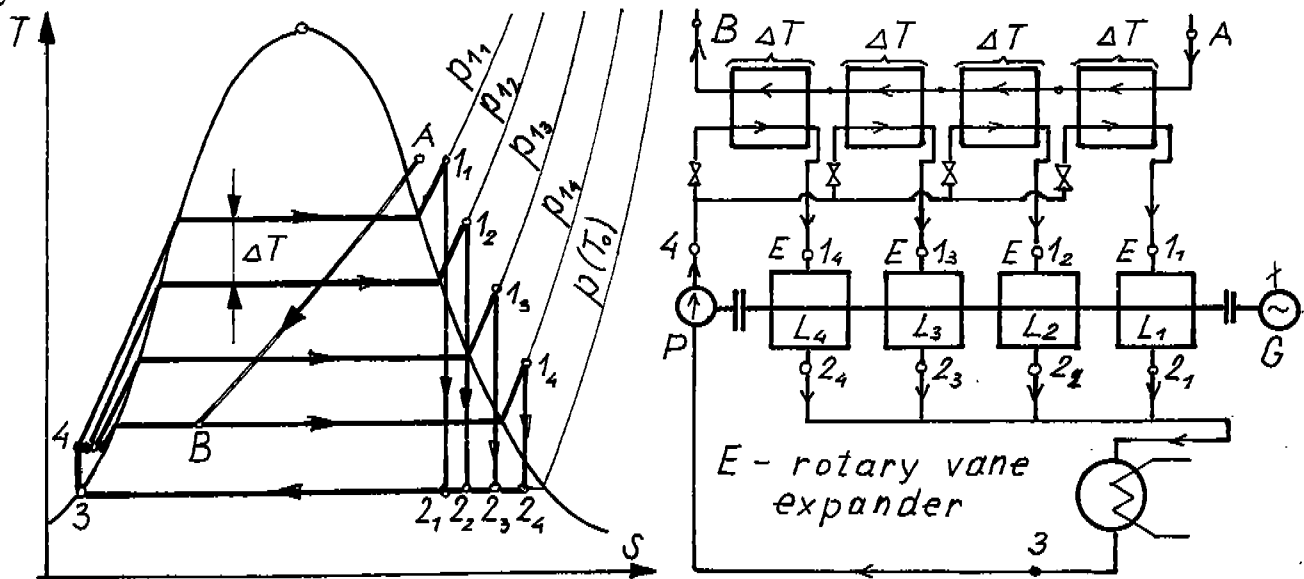


Fig. 2. An idea of micro power-station employing a set of rotary vane expanders for generation of temperature- and pressure-variable steam.

As can be concluded from the above diagrams, the expansion of variable-parameter steam requires a number of expanders with operating characteristics so selected as to enable the expansion between input and output pressures.

The power, which is produced in the system, can be employed for electric energy production and for driving the pump (see Fig. 2). Varying output of waste heat sources results in variable output of the generator and thus in variable power characteristics of expanders. In extreme cases, the power can be significantly higher/lower than this necessary to drive the pump and the electric generator. Therefore, the authors of the presented paper suggest that the micro steam power-station plant should be coupled with a pneumatic power-station, as presented in Fig. 3.

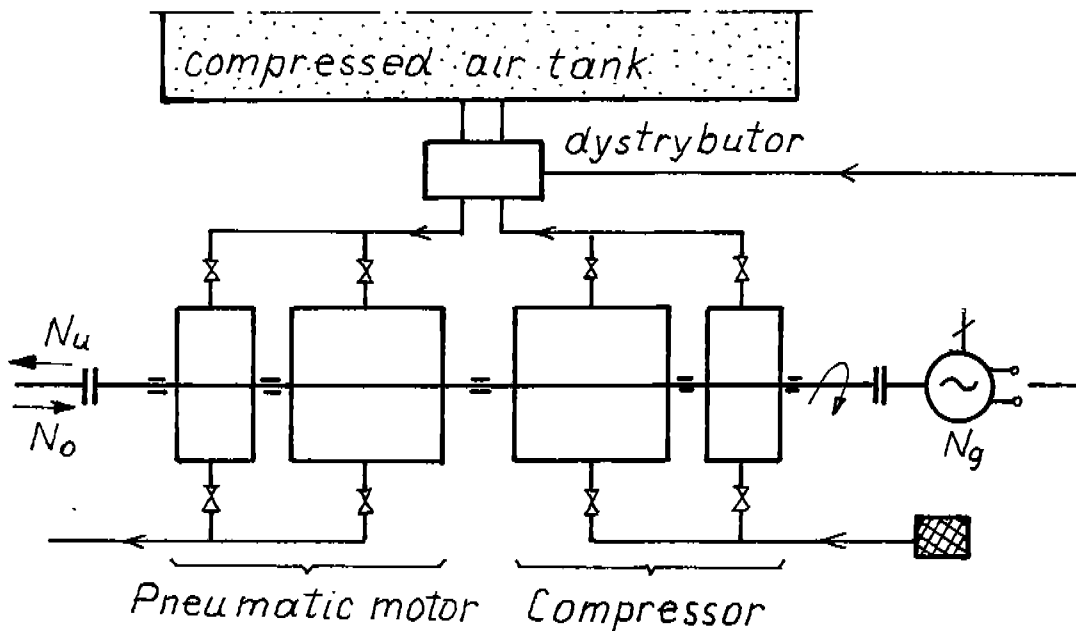


Fig. 3. Diagram of a pneumatic power station.

The system consists of a compressing unit, pneumatic motor, compressed air tank, and distributor. If a power excess condition exists in the steam micro power-station, i.e. when

$$N_o = N_{sp} - (N_g + N_{pf}) > 0 \quad (1)$$

where:

N_{sp} - power of the steam power station,

N_g - driving power of the generator,

N_{pf} - driving power of the pump and power dissipated through friction,

then the compressor is started, which compresses ambient air and directs it to the tank.

If the difference:

$$N_{ua} = N_{sp} - (N_g + N_{pf}) < 0 \quad (2)$$

then the compressor ceases operating and air from the tank flows to the pneumatic motor. Power developed by the motor feeds the micro power-station and allows the generator output to be kept at a constant level.

The compressing/expanding system consists of a number of units (thus facilitating the output control), set on a common shaft and linked through a clutch to the shaft of a micro power-station, operating according to the principle in Fig. 1 and/or Fig. 2.

ROTARY-VANE COMPRESSING/EXPANDING MACHINES IN A MICRO POWER-STATION EMPLOYING WASTE HEAT

The role of an expanding machine in a steam power-station, as well as that of a compressor and pneumatic motor in an air power-station, can be played by volumetric rotary machines, in particular rotary vane ones. Superiority of this machine type is justified by their advantages, of which most important are [3]:

- arbitrary pressure drops easily achieved in one or many stages,
- machine shaft directly coupled with the motor or power receiver,
- operation insured also for small agent flows through the machines in question,
- moderate rotational speeds,
- simple connection into multisegment systems.

The latter feature is especially important when discussing systems designed for waste heat retrieval. Fig. 4 shows schematically the layout of a multisegment vane compressor/expander that can be employed for the purposes discussed earlier.

Rotor 3, in which vanes 2 slide, is set eccentrically on shaft 4 in cylinder 1. Each rotor segment is separated from the adjoining one by means of a division 7. Length of the segment is proportional to the amount of steam or air that flows through it. Steam 8 or air 10 is delivered to each expanding segment and removed after performing a work through stub pipes 9 and 11 respectively. To the compressing unit, air is conducted via stub pipe 12 and removed via stub pipe 13. The shafts are supported on bearings 5. The steam segment is coupled with the air one by means of a clutch 6.

The presented machines are investigated in the Institute of Heat Engineering and Fluid Mechanics of the Wrocław Technical University. To this aim, a workstation was constructed that makes possible the simulation of a waste heat source and generation of steam with variable parameters. Besides, works are being carried out at the construction of the compressing/expanding system.

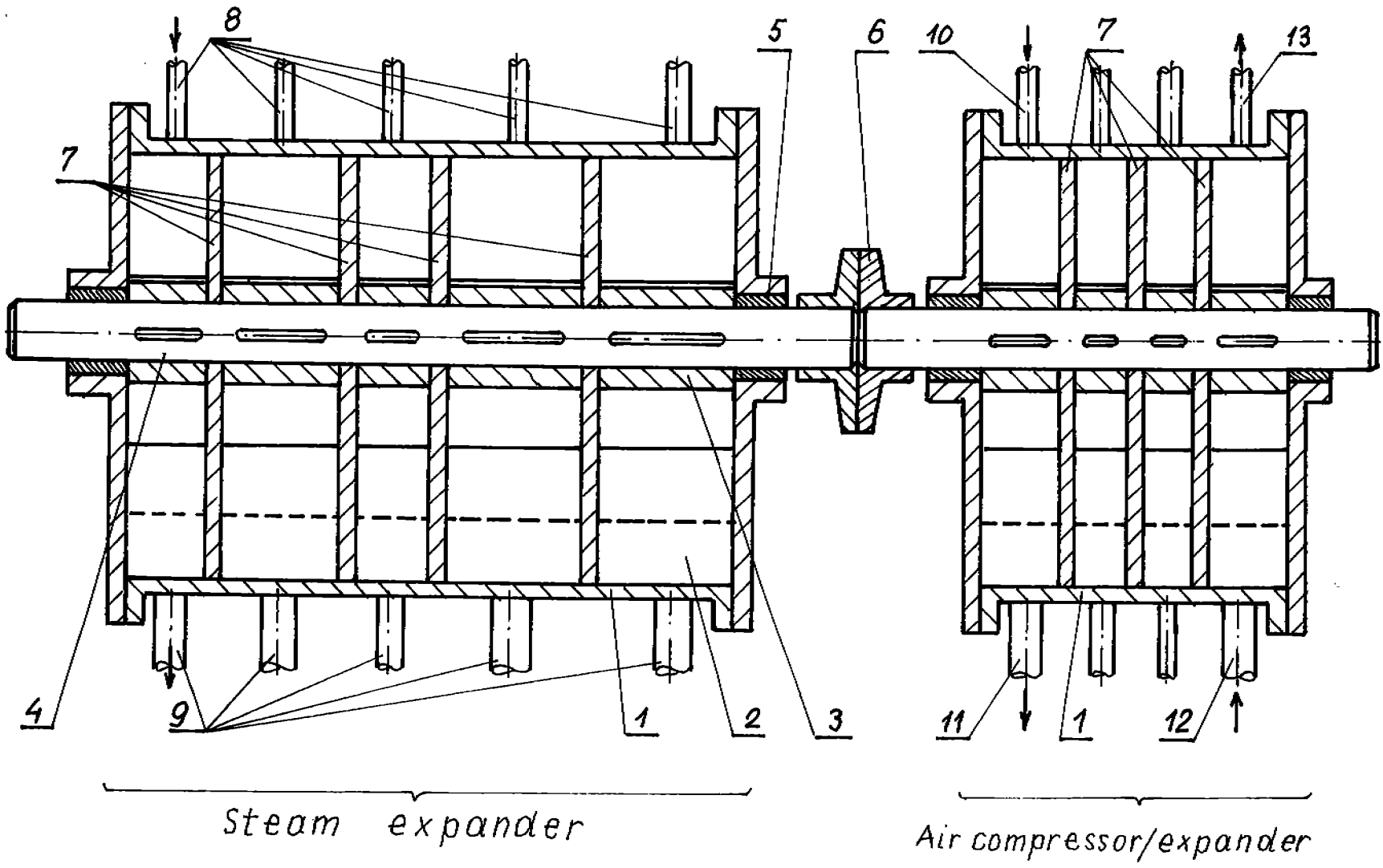


Fig. 4 Multisegment vane compressor/expander

CONCLUDING REMARKS

Utilization of low-output waste heat sources requires that machines should be developed, which - if manufactured serially - are expected to attain lower prices and therefore make the process of energy recuperation economically justified. Rotary-vane machines can be employed as compressing and expanding units, that are coupled into systems by setting them on a single shaft. A separate compression/expansion process can take place in each segment, enabling thus to retrieve in a considerable degree the energy of waste heat sources.

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