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The forecasting of the single-row reciprocating expander temperature fields

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Abstract

The single-row reciprocating expander units and elements heat flows and temperature state forecasting results obtained on the basis of the programme KOMDET-M and calculation complex ANSYS are represented in the paper. The single-row expander temperature field dependence on the moving and fixed stage elements design features and materials properties, exhaust chamber and outlet parth geometry, external and internal thermal insulation availability and unit base elements cooling methods was examined in the course of numerical experiment. Isentropic efficiency η_s which maximum level corresponds to the gas final temperature minimum of the stage exhaust chamber T_f is accepted as the perfection criterion of the obtained engineering solutions. The application of the expander stage nonmetallic body having additional internal thermal insulation combined with defining and calculation explanation of optimal volume values, heat exchange surface area, exhaust chamber channels form and section as well as advanced valves and base elements cooling schemes at the design stage was shown to produce a positive effect in low and medium pressure low-consumption expanders at the shaft speed of $n \leq 50\ s^{-1}$.

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Keywords: expander; exhaust chamber; thermal insulation; processes; modelling; numerical experiment; temperature field; nonmetallic materials; efficiency, forecasting

1. Introduction

The characteristic tendency of the reciprocating expanders development at the present stage is the unification due to the bases with multiple-row high-speed compressors thus making it possible to predict the specific weight and dimensional parameters decrease, designed expanders high efficiency and reliability under expander stages

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providing with the conceptually new gas distribution system [1]. Alternatively, the expander efficiency depends on the heat flow rate to the working fluid from the unit base and expander stage elements having elevated temperature including "stage casing - cylinder liner" assembly with space between them forming the exhaust chamber, end valve plate and piston. Heat gains reduction is possible to be achieved by means of the stage elements construction changes, nonmetallic materials application, exhaust chamber form and dimensions changing, thermal insulation and cooling scheme improving, which is the core of the present study.

2. The study subject

The expander-compressor unit prototype vertical row ECU-3Sh 0.5-20-8/1S consisting of the direct-flow expander stage DS 0.5-20-8/1S with the single-acting piston which lower part functions as a crosshead was chosen as the study subject. In the standard version all the stage elements are made of metal. The feature of construction is the cylinder-piston group lubrication absence under the motion mechanism elements consistent grease. The stage is equipped with the self-acting normally open inlet valves having spherical shut-off devices. The exhaust ports are made on the bottom of the cylinder liner, and their quantity, form, dimensions and position relative to the top dead center (TDC) are provided by the complete gas expansion at the moment of piston enters the bottom dead center (BDC).

The study subject technical specification:

- base nominal force is $P_b = 0.5$ *m*
- working gas is actual air
- mass flow rate is $m_{nom} = 20$ (30) *kg/hr*
- cylinder diameter is $D_c = 50$ (≤ 60) *mm*
- piston stroke is $S_p = 45$ mm
- cylinder working volume is $V_h = 88.3125$ cm^3
- a number of intake valves is $z_v = 3$ (4)
- shaft speed is $n = 25$ s^{-1}
- initial pressure is $P_i = 0.80$ *MPa*
- discharge pressure is $P_d = 0.11$ *MPa*
- initial temperature is $T_i = 293$ (303) *K*

The relative piston stroke $C_i = (S/S_n)_i$ in the cycle fixed points for all the variants is accepted as a constant one: C2 = 0.310 … 0.312, C3 = C5 = 0.8667, C6 = 0.011.

The expanders efficiency improvement requires the following objectives achieving:

- the temperature field studying of the low pressure single-row direct-flow reciprocating expander without the cylinder lubrication, having combined gas distribution system and crosshead motion mechanism;
- the evaluation of the various factors influence on the heat gain reduction to gas of the cylinder and in the expander stage outlet chamber;
- the operation processes and expander stages constructions development recommendations justifying which contribute to the multiple-row high-speed expanders technical and economical performance improvement.

3. Methods

The numerical experiment including the expander stage current and integral parameters complex analysis as well as the velocities and temperatures level one of the single-row reciprocating expander RE 0.5-20-8/1S outlet path elements is the research methodology basis.

The study was conducted on the basis of the calculation complex ANSYS CFX [2, 3] and author's method based on the compressors and expanders stages operation processes mathematical modelling, supplemented by the complex of calculation and empirical dependences obtained when testing domestic and foreign full-scale compressors and expanders having various geometrical and operating parameters and working fluids properties. KOMDET-M programme is applied by the variety of domestic firms and higher educational institutions of the Russian Federation [4, 6].