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Thermal stress state of the parts of quasi-isothermal long-stroke low flow stages in reciprocating compressors

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Abstract

For low flow long-stroke compressor aggregates with particular regime and structural parameters static analysis of thermal stresses state is carried out. Moreover, simultaneous influence of thermal and mechanical effect is taken into consideration. Boundary conditions for calculation are obtained while implementing the developed mathematical model. Thermal stress comparison of the stages with intense and soft cooling is given.

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Keywords: long-stroke reciprocating compressor; operating processes; mathematical modeling; durability; deformation; thermal stress

1. Introduction

One of the features of reciprocating compressor operation is periodical changing of the cylinder working gas pressure and temperature [10, 11, 12]. It is well-known that mechanical and thermal effects on the structural elements lead to the internal stresses, which intensify each other and can considerably influence materials strength characteristics, and, as a result, the service life and operation reliability of the whole compressor stage [1-5]. Processes, occurring during heating, are divided into two main stages: return and recrystallisation; both stages are accompanied by heat emission and free energy attenuation. Return takes place at lower temperatures, while recrystallisation – at higher ones [9]. Return is described as all changes of the fine structure and characteristics, which are not accompanied by the deformed metal microstructure change, which means that grains size and form do not change in the return process [8]. Recrystallisation is the process of forming and growth of new grains with less structural defects; as a result of recrystallisation new, in most cases equiaxed, crystals form [8]. Whereas return is divided into two stages: recovery and polygonization. Recovery, under the deformed metals heating, occurs in all cases, while polygonization takes place only under specific conditions. Recovery of the cold-worked metal is the stage of the return, when the quantity of the point defects, mostly vacancies, decreases; for some metals, such as aluminum and iron, recovery also includes dislocations rearrangement, which is accompanied by the interaction of different signs dislocations and results in their density decrease. Dislocations rearrangement is also accompanied by the internal stresses decrease. Recovery reduces specific electrical resistance and increases metal density.

Plastically deformed metals can recrystallise only after the deformation, which exceeds a critical value, known as critical deformation degree. If the deformation degree is smaller than a critical one, new grains do not form under heating.

There is also recrystallisation temperature; it is the lowest heating temperature, providing new grains growth. Recrystallisation temperature is lower than the metal melting point: Trecr. = 0.4Tmelt. For technical purity aluminum, copper and iron the lowest temperature of recrystallisation is equal, correspondently, to 100, 270 and 450° C [7].

New grains growth during recrystallisation occurs in the areas with the highest dislocations density, usually at the deformed grains boundaries. The higher the rate of the plastic deformation, the more recrystallisation centers occur. Such centers are

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submicroscopic areas with the minimum of point and line structural defects. These areas form during the rearrangement and partial elimination of dislocations; furthermore, between the recrystallisation centre and the deformed basis large-angle boundary form.

Taking into consideration that in the compressor working chamber during gases compression to medium and high pressure, together with thermal effect, as a result of gas compression, mechanical effect in the form of gas pressure also occurs, there is a task of defining thermal stress state depending on the two factors described above. It is necessary to note, that pressure increase is accompanied by the increase in gas temperature and maximum effect (maximum stress) occurs at the beginning of the discharge process.

2. Study subject

Under substantial increase in the ratio of stroke to cylinder diameter (up to 10…100), increase in cycle time (up to 0.1…3.0 s) and in ratio of discharge pressure to suction pressure (up to 50…100) together with intense external cooling, changing of working gas temperature in the cylinder and average discharge temperature can considerably differ from the known values [14, 27, 28], which influences working chamber parts thermal condition. Thus, this paper is aimed to analyze thermal stress state of the long-stroke low flow stage of reciprocating compressor under external cylinder cooling.

Design analysis of the long-stroke low flow stage was carried out under the following single-valued conditions: geometrical conditions: cylinder diameter is 0.02 m; piston stroke is 0.2 m; boundary conditions: cooling medium temperature is 293K, heat-transfer coefficient on the external surface of the working chamber is 2000 W/m2*K; physical conditions: compressible gas is air; initial conditions: initial gas temperature is 293 K, suction pressure is 0.1 MPa, discharge pressure is 7 – 15MPa.

3. Methods

Statistical thermal calculation is carried out by the "Solid Work" programme. Boundary conditions on the internal surface of the working chamber are obtained in the process of the mathematical model implementation.

Design model of the study subject is presented in Fig.1.

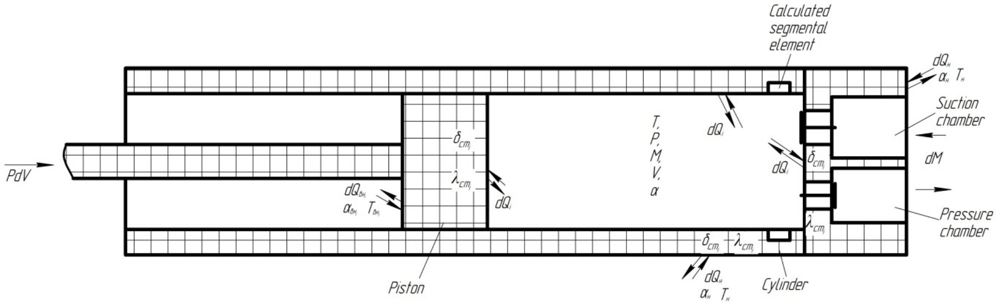

Fig. 1. Design model of the long-stroke low flow stage of the reciprocating compressor.

Basic assumptions for calculated analysis [15-23, 26]:

1. Gas environment is continuous and homogeneous.
2. Prototype processes are reversible, equilibrium and quasi-stable.
3. Parameters of the working gas state change simultaneously throughout the whole working chamber (cell).
4. Change of potential and kinetic gas energy is negligible.
5. Friction heat of the piston seals is not supplied to gas.
6. State characteristics in the discharge and suction spaces are constant.
7. Working gas flow through the gas-distributing units and structural clearance is assumed as adiabatic and quasi-stationary.
8. Heat exchange between gas and walls of working spaces is convective and can be described by the Newton-Richman equation.
9. Heat exchange on the external areas of the working chamber parts walls is defined at time-constant heat-transfer coefficient, chosen for the considered part of the heat exchange surface.
10. In the walls of the working chamber there are no internal heat sources.