The ANALYSIS of the MECHANICAL PROPERTIES of REGIONAL PIPELINES

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ABSTRACT

Piston pumps and compressors are widely used for exploration and transportation of oil and gas. Piston machines are heavy-duty systems that are still failure prone due to high stresses and wear proses. Increasing the efficiency and durability of the piston compressors, pumps, internal combustion engines, etc. directly depends on the correct calculations and designing of these elements. Using ANSYS software, simulation and stress analysis are performed on the basis of the 405GP15/70 and ARIEL heavy-duty balanced opposed piston compressors used in the Caspian Sea-Black Sea Region. During working of the machines and equipment a number of the processes interconnected and causing each other are proceeds (dynamic processes, wear of the interfaced details, change of mechanical properties of materials, etc.). Improvement of modelling of technical condition of cars and mechanisms on a multicriteria basis is one of the actual directions of modern engineering science.

The improvement of methods of modelling of change of technical conditions of the piston mechanisms taking into account interrelation of dynamic characteristics, the wear interfaced details and the diagnosed mechanical parameters considered in this article.

By observing the analysis results, we can decide whether our designed pipelines are safe or not under applied load conditions. The durable and reliable work of compressor-pump stations used in the oil and gas industry has great importance for practice. Investigation of complex problems with respect to friction and wear (clearances), stresses, and thermodynamics phenomena in the piston machines, and oil and gas pipelines gives the opportunity to solve the problems of increasing the durability of these machines and pipelines. Confirmation that the new methodologies can be produced by the current supply chain improving manufacturing efficiency and reducing the environmental and social impact of the supply chain.

Keywords: Piston compressor, Pipelines, Thermodynamics, Structural analysis, ANSYS.

INTRODUCTION

Different heavy loaded machines and equipment (piston compressors and pumps) are used in the pipelines used for transportation the oil and gas resources. Compressor-pump stations used in the oil and gas industry have a strong impact on the environment. The environmental impact and the transport security of the oil and gas pipelines depend on durability and reliability of machines and equipment. Piston pumps and compressors are widely used for exploration and transportation of oil and gas.

The technical security and environmental situation on the oil and gas pipeline are depending on durability and reliability of machines and equipment used in oil industry. Specialized methods will be developed for the influence of impacts, vibrations, temperature, and film lubrication and unified in a system model. The research efforts will lead to more reliable and efficient design alternatives for reciprocating machines which are used for the transport of oil and gas and will thus contribute directly to the competitiveness of a key industry in the Caspian Sea - Black Sea Region, for example in Baku-Tbilisi-Ceyhan (BTC) Main Oil Pipeline, there are 8 pump-compressor stations (2 stations in Azerbaijan, 2 stations in Georgia and 4 stations in Turkey territory). Besides BTC today the region is functioning the Trans Adriatic Pipeline (TAP) which transported Caspian natural gas to Europe. Connecting with the Trans Anatolian Pipeline (TANAP) at the Greek-Turkish border, TAP will cross Northern Greece, Albania, and the Adriatic Sea before coming ashore in Southern Italy to connect to the Italian natural gas network (Fig.1).

The energy security of the Black Sea - Caspian Sea Region depends on the technical conditions -reliability and durability of the machines and equipment used in oil and gas pipelines in the Region. Increasing the reliability and durability of piston machines corresponds therefore to actual needs and political demands of reduced environmental impacts during exploitation and transportation of mineral resources - oil and gas.

Fig. 1. The Trans Adriatic Pipeline (TAP) and Trans Anatolian Pipeline (TANAP)

The main objectives are to investigate and analyze the thermal stress and mechanical stress distribution of pistons in real conditions during the working process of the piston machine. The work describes the stress distribution of the piston by using the finite element method to predict the higher stress and critical region on the component. By using ANSYS software the structural model of a piston will be developed.

Compressor-pump stations are used on the oil and gas pipeline for the transport of this mineral resource. Current methods of reciprocating and centrifugal machinery design, see e.g. [1,2], are based on partial empirical relations and do not take into account many of the factors that are affecting the mechanical and thermodynamic processes in these machines. To date, no applied formulas are available for durability and reliability of the parts, for mechanical losses in the bearings, for energy losses in the kinematical couples of machines used in the oil industry, nor has there been basic research of the impact phenomena in these kinematic couples. On the other hand, very detailed models leading to computer-intensive simulations have recently been developed for piston ring dynamics in the context of blow-by estimation [3], for lubrication conditions of the ring/liner contact, for dynamically loaded bearings, and for stress and failure analysis of assembly parts. However, until now, the insight gained with these models has not found its way into more detailed models for reciprocating machines such as piston and centrifugal compressors. To this end, a modular system modeling approach as described below combined with model reduction is necessary in order to keep the computational efforts at reasonable magnitudes [4].

The research efforts will lead to more reliable and efficient design alternatives for reciprocating machines, since this type of equipment is used for the transport of oil and gas it will thus contribute directly to the competitively of a key industry in the Black Sea-Caspian Sea Region.

CONCEPT AND APPROACH. THE MECHANICAL ANALYSIS OF THE COMPRESSOR STATIONS

Mechanisms, couplings and devices used in oil industry (reciprocating compressors, pumps, internal combustion engines etc.) are heavy-duty systems. The bearings and joints of the crank-piston mechanisms of such systems undergo high stresses and wear, and their kinematical couplings are subject to fatigue and failure due to friction, seizure, oscillations and impact. Friction loss reduction and service life extension remain throughout the main problems of design and exploitation of reciprocating machinery. The central problems are optimal design of the crank-piston group and the piston-ring assembly, and choice of better materials for rubber coupling, leading to a balance between pulsation control and performance.

Compressor-pump stations applied in the oil and gas industry have a strong impact on the environment. These stations used on the oil and gas pipeline for transport of these mineral resource. Durable and reliable work of piston machines and their technical security has great importance for practice of estimation the level of environment in transportreducing the environmental impact of hydrocarbon transport and exploitation of oil and gas resources (Fig. 2).

The working process taking place in the cylinder in all piston compressors is the result of three main processes: the thermodynamic process in the cylinder, the heat exchange process between gas and walls of the cylinder, and the hydrodynamic process of gas flux through density in the distribution parts of the cylinder. Analyses of the complex problems depend on friction and wear processes in PM labyrinth sealings making it possible for the all-around solution of increasing its reliability and durability. Such a process as it is known can be determined by four equations of mathematical physics, describing the main laws of the forms of matter existence. They are the system of equations describing gas flux in the channel consisting of the equation of continuity, the equation of motion, the equation of energy (first law of thermodynamics), and the equation of state of gas flux [5-8].

Fig. 2 is presented the scheme of the crank-piston mechanism of the piston compressor with the double-acting cylinder with an indicator diagram. Where is demonstrated the diagram of gas pressure with respect to the volume of the cylinder, i.e. $p = f(V)$.

Processes of compressing and discharge in the cylinder accepted as polytrophic are subjected to the equation:

$$pV^m = \text{const} \tag{1}$$

where p is gas pressure in the cylinder, V is a volume of the cylinder, m is the polytrophic factor.

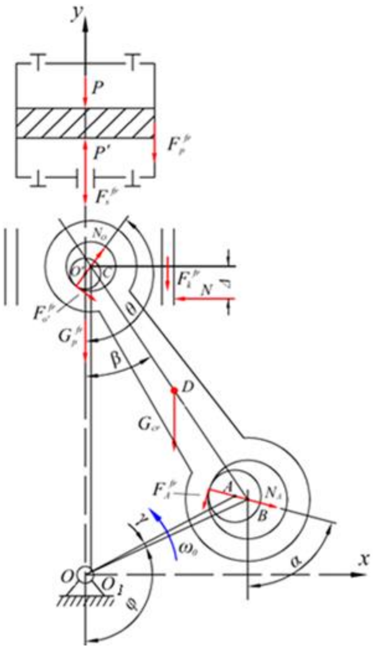

Fig. 2. Crank-piston mechanism of the reciprocating compressor

In accordance with the analyses mentioned above and on the basis of expression (1), the gas pressure compressing on the piston p and p', correspondingly from the upper and lower surfaces of the piston we presented the following expressions, taking into account the gaps in kinematic couples [3]:

$$p = \frac{f_p p_b V_0^{m1}}{\left[\begin{array}{c} V_{hr} + (S_p - R(1 - cos\varphi) + \frac{R^2}{2L} sin^2\varphi \\ - \frac{Re_1}{L} sin\alpha sin\varphi \\ - \frac{Re_2}{L} sin\Theta sin\varphi + e_1 cos\alpha + e_2 cos\Theta) f_p \end{array}\right]^{m1}}$$

$$p' = \frac{f_p p_h V_{hr}^{m2}}{\left[\begin{array}{c} V_{hr} + \\ \left(\begin{array}{c} R(1 - cos\varphi) - \frac{R^2}{2L} sin^2\varphi - \frac{Re_1}{L} sin\alpha sin\varphi \\ - \frac{Re_2}{L} sin\Theta sin\varphi + e_1 cos\alpha + e_2 cos\Theta \end{array}\right) f_p \end{array}\right]^{m2}} \qquad (2)$$

where p_b and p_h are the pressure of gas in the compressor inlet and outlet branch pipes; φ is a rotational angle of the crankshaft, m_1 and m_2 are factors of polytrophic processes of compressing and expanding gas in the cylinder; V_0 is the gas volume at the beginning of compressing process, S_p is the piston working displacement, f_p is an area of working surface of the piston, R - is the radius of the crankshaft, L is connecting rod length; V_{hr} is the harmful volume space of the cylinder, e_1 and e_2 are clearances in kinematic couples of connecting rod, α and Θ are angles which characterized the contact points in these clearances.

In accordance with the analyses mentioned above and on the basis of expression (2), the gas pressure compressing on the piston p and p', correspondingly from the upper and lower surfaces of the piston is obtained. For determining of main gas pressures p and p' in the cylinder influencing the piston group we divide the period of one working cycle into six identity phases in the limits of each one where the regularity of pressure from both sides of the piston remains unchangeable [9,10].

METHODS OF DEFINITION OF PARAMETERS OF MOVEMENT OF THE GAS STREAM IN THE PIPELINE

In the modern period, it is necessary to compensate for the needs of humanity and the potential and energy in great measure. In the last two hundred years the quick development and industrialization of the countries connected with the direct consumption of energy. Kind of the energy sources and the rationality of the user from them of the user of any country is the definition of the development level of the country. We will consider the movement of compressed gas in the pipeline, therefore we will define losses of the pressure of gas depending on the length of the pipeline at the isothermal process of a current of air accepted for ideal gas. In Fig. 3. the pipeline of diameter D and length L on which compressed gas moves is shown as length *x*. We will designate gas parameters in initial and final sections of the pipeline accordingly through P_0, T_0, and P_1, T_1, and gas parameters in sections, situated from the beginning of co-ordinates on distance *x*-through P, T. We noted that at the movement of compressed gas in a small initial site of the pipeline, its temperature will decrease in the course of heat exchange with walls of the pipeline cooled by an environment. Then the temperature field of a gas stream will be stabilized, owing to what the temperature of this stream practically remains a constant (Fig.3). Thus, gas and oil temperature at its movement on the pipeline specified above we will consider as a constant. Besides, a task in view we will solve at a pressure of gas to 10 MPa taking into account friction of a gas stream about pipeline walls at its isothermal current. Provided that, it is possible to use the equation of a condition of an ideal gas. The considered movement of a gas and oil stream, as is known, is defined by three equations: conditions, continuity, and energy. As on a condition of the decision of a task in view the temperature of gas *T* is constant, movement of a gas stream at its isothermal current is defined by thermidynamical equations.

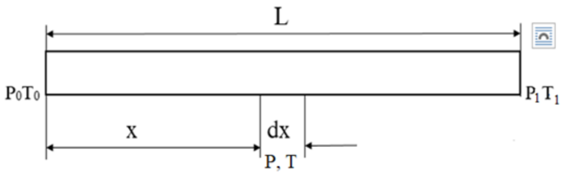

Fig. 3. The scheme of pipeline

We are investigate the thermodynamical parameters of oil and gas pipelines to define the pressure of the gas P in the given section of the pipeline. Setting various values of pressure of gas P, on the expression (2), it is possible to find corresponding lengths of sites of the pipeline at set parameters pressure P_0 and volume productivity G_0. Such calculation has been made at values of pressures P_0=5, 7 and 9 MPa, and volume productivity G_0=2, 3, 4 and 5 kg/s.

The results of these calculations have resulted in Table 1. On the basis of the given tables schedules of dependence of loss of pressure $\Delta P = P_0 - P$ gas from the length of a site of pipeline *x*, при various values of the diameter of the pipeline are constructed. Apparently from drawings, with an increase in length of a site of the pipeline loss of pressure of gas and oil on this site increases at preset values of the diameter of pipeline D and parameters P_0 and G_0.

Table 1. The loss of pressure of gas with respect to diameter of pipeline.

P_0=4 MPa, T_0=300K, G_0=2kg/c

D / ΔP	0,100	0,125	0,150	0,175	0,200
4,9	$1,56\cdot10^3$	$4,57\cdot10^3$	$11,044\cdot10^3$	$23,26\cdot10^3$	$44,273\cdot10^3$
4,8	$3,09\cdot10^3$	9057,43	21865,85	46659,32	87653,23
4,7	4595,18	13447,47	32464,07	68383,96	130138,21
4,6	6063,75	17745,1	42839,18	90238,68	171728,93
4,5	7500,69	2195028	52991,16	111623,3	212425,5
4,4	8906,03	26063,01	62919,93	132537,9	252227,54
4,3	10279,78	383,32	72625,62	152982,6	291134,04
4,2	11621,92	34011,15	82108,12	172957,1	329146,79
4,1	12932,46	37846,54	37842,18	192467,4	366265,11
4,0	14211,33	41589,49	100403,8	211496,12	402488,96

We are observed the loss of pressure ΔP of gas moving in the pipeline with respect to the diameter *D* and length *x* of the pipe. The dependence to define the pressure of gas and oil P in the given sections of the pipeline is deduced.

The dynamic analysis of the parameters of gas depending on the constructive parameters of the pipeline is presented. In an attempt in this article, the pipeline is modeled by using computer software, and static analysis is done by using ANSYS Workbench software. There is evaluated the pressure and constructive parameters of the pipeline. The Workbench focuses on attaching existing geometry, setting up the finite element model, solving, and reviewing results.

The novelty of the article is characterized by new theoretical methods for the determination of parameters of gas pressure in pipelines and cylinders of reciprocating machines taking into account the real working processes and the clearances in kinematic couples of crank-piston mechanisms. The reliability of the received scientific results is provided by the correctness of the statement of tasks and decisions on the basis of laws of mechanics and thermodynamics. The results of the investigation are generalized for any piston machines and pipelines used in the oil and gas industry.

The dependence of loss of pressure of gas and oil ΔP from the length of the pipeline *x* can be practically replaced by a straight line. With the increase in diameter of pipeline D, the loss of pressure of gas and oil on its given site sharply decreases. From drawings, it is visible, that with the increase in pressure of air P_0 in the pipeline beginning, the pressure loss in the given site decreases at the set constant value of the expense of volume productivity G_0 proceeding on the pipeline. At an increase in the expense of gas and oil on pipeline G_0, the pressure loss ΔP on the given site increases at the set constant values of parameters of matter stream P_0, T_0, and diameter D of the pipeline. The important practical conclusion is that for reduction of loss of pressure of gas and oil, moving on the pipeline, it is necessary to increase the diameter of pipeline D at a preset value of the expense of matter G_0 from here follows. It in turn can lead to an increase in the expense of the metal necessary for the manufacturing of the gas and oil pipeline, that not always it can appear expedient.

CONCLUSIONS AND OUTCOMES

From the discussion of the results of the research presented above, some conclusions can be drawn:

1. The pressure of gas P in the given sections of the pipeline is determined.

2. Represented the curve of dependence of loss of pressure of gas and oil ΔP from the length of the pipeline x.

3. The important practical conclusion is that for reduction of loss of pressure of gas and oil, moving on the pipeline, it is necessary to increase the diameter of pipeline D at preset parameters of matter. It in turn can lead to an increase in the expense of the metal necessary for manufacturing the gas and oil pipeline, that not always it can appear expedient.

The results of the investigation can be useful for the design and exploitation of compressor stations and pipelines used in the oil and gas industry.

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