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Influence of the constructive parameters for long stroke piston unit on a stressed deformed cylinder state

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Influence of the constructive parameters for long stroke piston unit on a stressed deformed cylinder state

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Abstract. This article assesses the influence of the long stroke piston unit design parameters for the stress-strain state of the cylinder slow-speed stage. The stress-strain state estimation for the piston compressor cylinder slow-speed stage with a cylinder diameter equal to and more than 50 mm, show a significant increase in gaps and leaks in the cylinder-piston pair is observed, as well as an increase in equivalent stresses in the cylinder walls to the value of the yield strength of the wall cylinder material. The analysis allows for optimal engineering of the piston compressor cylinder slow-speed stage for the most promising designs.

1. Introduction

Slow-speed long-stroke piston units (piston stroke cycle time τ = 0.5 ... 5 s; frequency $f \leq 2$ Hz), in particular, compressors, have good prospects for use in the presence of specific requirements, for example: operation at low noise and vibration levels; the possibility of using piston-type compressors as oil-free, in those cases when low productivity is required (up to $5 \cdot 10^{-3}$ m^3/s) and the pressure of the working fluid is more than 3 MPa [1], [2], [3]. A design feature of long-stroke piston units is an increased cylinder length: the relative length indicator is $\psi = S/d_c$ = 5 ... 20 (S is the piston stroke, m; d_c is the cylinder diameter, m) [4].

In [5], [6], [7], [8] the influence of the working processes of compressor stages upon compression of various gases for the temperature of the working fluid, and, therefore, on the cylinder walls temperature, is shown. In [9], [10], [11] a significant effect of the cylinder walls temperature for a low-speed compressor on their stress-strain state was shown, primarily for the gaps size in the cylinder-piston pair [5], [6]. In [12], the analysis of the gaps in the cylinder-piston pair of low-speed long-stroke piston units depending of the parameter $\psi = S/d_c$ and their influence the delivery coefficient for the compressor and pump is presented.

Therefore, analysis of the influence of the piston units design parameters, namely, the stroke S and the piston diameter d_c of the low-speed stage for the cylinder walls stress-strain state is an urgent task to develop new variants of the low-speed stages piston units.

2. The problem formulation

This article discusses the influence of the long-stroke piston unit design parameters (piston stroke S, cylinder diameter d_c) for the cylinder walls stress-strain state of a low-speed stage piston unit depending of the working pressure in the discharge chamber and the cylinder wall temperature. The study was performed using the ANSYS Workbench Mechanical software package (ANSYS WM). The program allows you to take into account various types of loads (changes in internal pressure and temperature) along the length of the cylinder walls and the conditions of contact between the moving elements of the unit.

The level of the cylinder walls stress-strain state for the of the piston unit primarily depends of the operating pressure in the discharge chamber to ensure the required unit delivery coefficient (accepted, p_{dis} = 10 MPa) and wall temperatures, which are determined according the indicator diagram for specific values of the piston stroke S and cylinder diameter d_c for the piston unit. The values to be studied are the radial displacements in the region of the cylinder-piston pair ΔR, which determine the size of the gaps and, consequently, the leakage of the working gas, as well, this parameters influence the equivalent stresses σ_{eq} in the cylinder walls of the low-speed stages of the piston units (Table 1).

3. Theory

The calculation model of the long-stroke piston unit, as already noted, is based the ANSYS Workbench Mechanical software package (ANSYS WM). Features of constructing a finite element model in ANSYS WM software package for assessing the stress-strain state of the low-speed stage cylinder walls piston unit under internal pressure loading of the working medium in the discharge zone and taking into account the temperature distribution of its walls are given in [15], [16], [17], [18], [19], [20].

The model is simplified compared to the actual design of the unit. The main elements of the low-speed piston unit model are: thin-walled cylindrical shell, pinched in two supports, and piston with o-rings. In the calculation model, the rigidity of the supports was not taken into account, and their pinching was modeled by the «Fixed Support» team. The movable contact between the wall of the inner wall of the cylinder and the piston seal of the unit is set by the boundary condition «Frictional» (friction coefficient f = 0.2). Figure 1, as an illustration, shows the finite element mesh of the piston unit cylinder. The mesh of finite elements was generated in the Mesh Sizing procedure automatically using standard PC tools ANSYS WM according to user-defined parameters of the finite element: element type – 10-node tetrahedron; the edge size of the tetrahedron ranged from 0.5 mm to 2 mm.

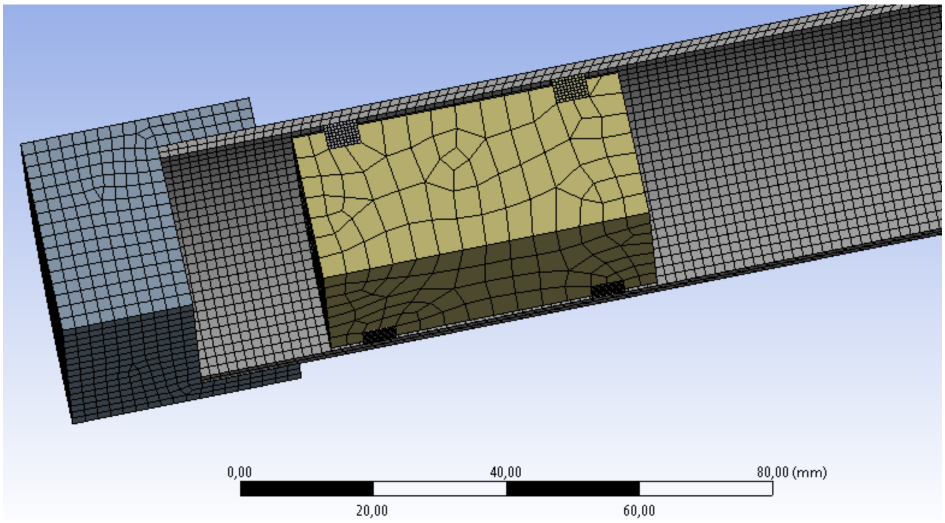


Figure 1. Finite element grid for modeling a piston unit in ANSYS WM PC

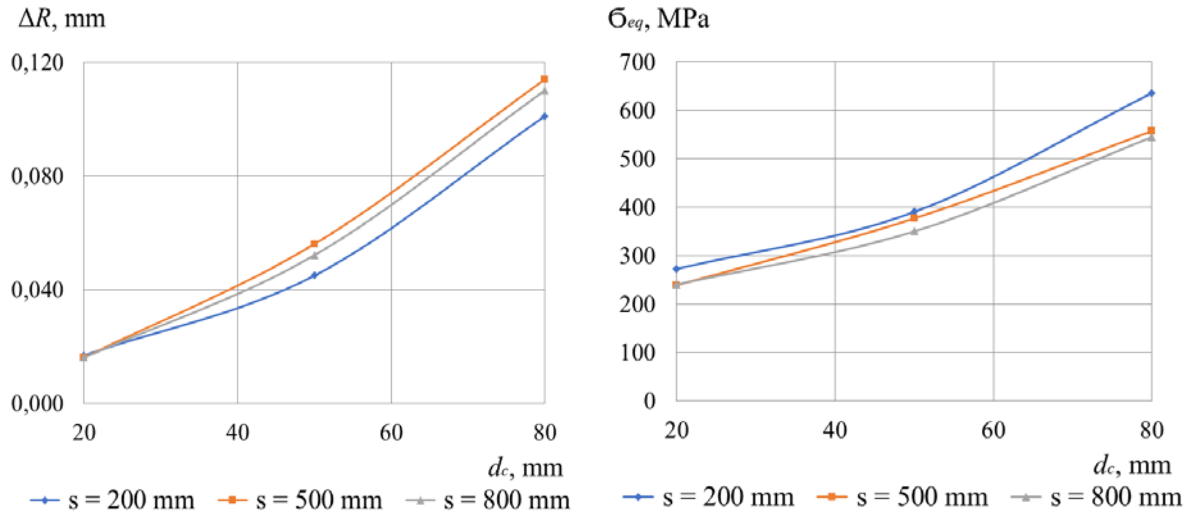
To take into account the influence of the temperature on the cylinder walls stress-strain state, the calculation model provides for a preliminary solution in the ANSYS WM PC package of the thermostatic task using the standard «Steady-State Thermal» module.

4. Results of calculation

Table 1 and Figure 2 show the results of calculations of radial displacements ΔR and equivalent stresses σ_{eq} in the cylinder walls for the studied ranges of design parameters of long-stroke piston units, namely: cylinder diameter d_c = 0.02 m, 0.05 m, 0.08 m; and, the piston stroke S = 0.2 m, 0.5 m, 0.8 m. The value of the cylinder wall temperature Tw was taken to be equal to the temperature of the working fluid depending on the discharge pressure p_{dis} = 10 MPa according to the working chart [21]. This assumption is caused by the high thermal conductivity of the cylinder walls material (in the calculations it was accepted – Steel 40X) and the condition that there is no cooling of the cylinder walls for the piston unit. Figures 3 and 4 show the results of calculating radial displacements ΔR (Figure 2) and equivalent stresses σ_{eq} (Figure 3) in the ANSYS WM PC for cylinder diameter d_c = 0.02 m, 0.05 m, 0.08 m and piston stroke S = 0.5 m.

Table 1. Radial displacements Δ*R* and equivalent stresses σ_{eq} of the piston unit cylinder walls

Cylinder diameter d_c, mm	Piston stroke *S* = 0.2 m			Piston stroke *S* = 0.5 m			Piston stroke *S* = 0.8 m		
	T_w, ^{0}K	σ_{eq}, MPa	Δ*R*, mm	T_w, ^{0}K	σ_{eq}, MPa	Δ*R*, mm	T_w, ^{0}K	σ_{eq}, MPa	Δ*R*, mm
20	380	272	0.017	370	239	0.016	430	240	0.016
50	405	390	0.045	400	377	0.056	430	350	0.052
80	430	636	0.101	430	557	0.114	420	545	0.110

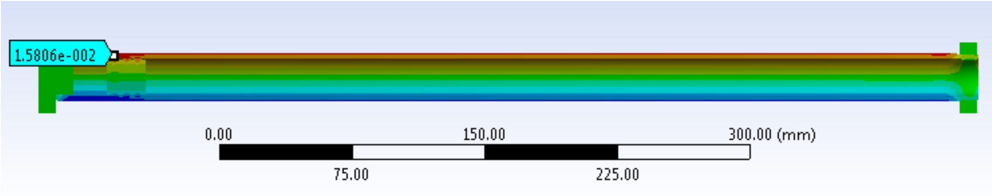


a) b)

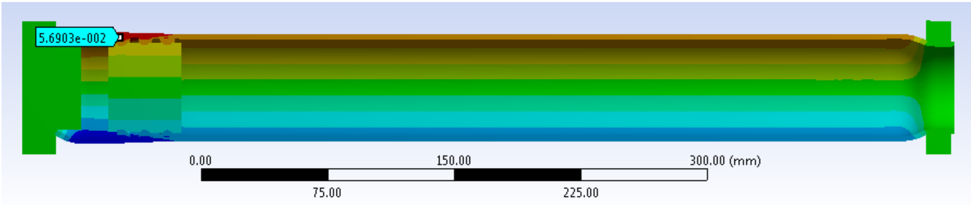
Figure 2. The results of the calculation in the PC ANSYS WM (discharge pressure p_{dis} = 10 MPa):
a) the radial displacement Δ*R* of the piston unit cylinder walls, mm;
b) equivalent stresses σ_{eq} in the piston unit cylinder walls, MPa

The calculation results (Figures 2 and 3 are the radial displacements Δ*R* of the piston unit cylinder walls; Figures 2 and 4 are the equivalent stresses σ_{eq} in the piston unit cylinder walls) are given for the most promising designs of long-stroke piston units. The considered options of design parameters (namely: piston cylinder diameter d_c = 0.02 m, 0.05 m, 0.08 m; piston stroke *S* = 0.2 m, 0.5 m, 0.8 m) of long-stroke piston assemblies are due to the fact that at a relatively low piston stroke speed (frequency the piston stroke $f \leq 2$ Hz) it is necessary to provide the flow rate of the working fluid for the piston unit. It is obvious that, in this case, units with higher values of the diameter of the cylinder and the stroke of the piston can be considered the most promising structural options for long-stroke piston units.

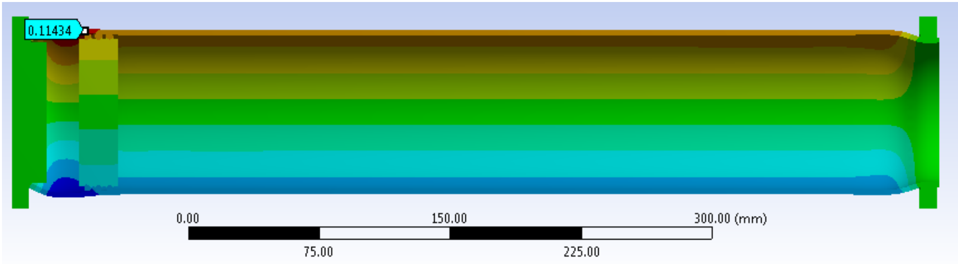
The results of calculations of the stress-strain state for the cylinder low-speed stage long-stroke compressor unit show a significant increase in the radial displacements of the cylinder walls Δ*R* to 60 ... 80 μm and the equivalent stresses in the cylinder walls of σ_{eq} up to 400 MPa for units with a cylinder diameter of more than 50 mm.



a) piston diameter d_c = 20 mm

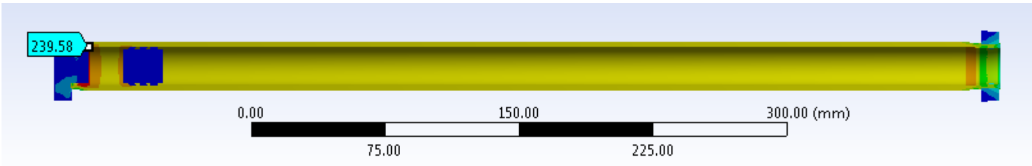


b) piston diameter d_c = 50 mm

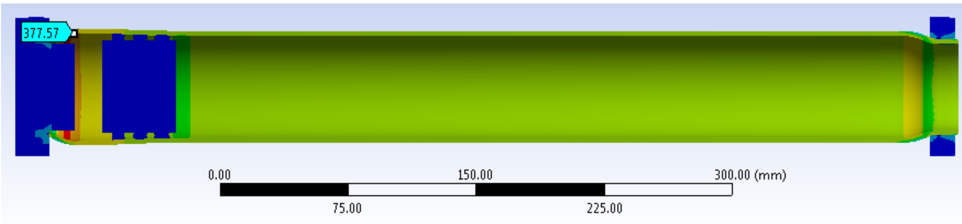


c) piston diameter d_c = 80 mm

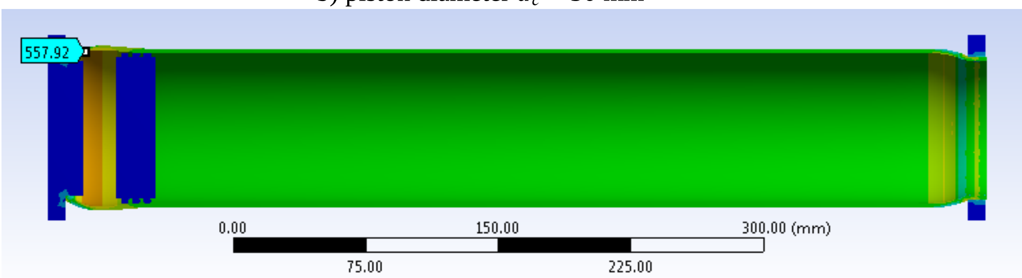
Figure 3. Radial displacement of the piston unit cylinder wall, mm
(piston stroke S = 500 mm; discharge pressure p_{dis} = 10 MPa)



a) piston diameter d_c = 20 mm



b) piston diameter d_c = 50 mm



c) piston diameter d_c = 80 mm

Figure 4. Equivalent stresses of the piston unit cylinder wall, MPa
(piston stroke S = 500 mm; discharge pressure p_{dis} = 10 MPa)

5. Conclusion

The results of the analysis of stress-strain state for the cylinder low-speed stage long-stroke compressor unit show:

– an increase in the cylinder walls radial displacements of the for units with a cylinder diameter equal to or more than 50 mm will lead to an increase in gaps and leaks in the piston-cylinder pair, which significantly affect the working processes of piston units [12]. Evaluation of the actual values gaps in the piston-cylinder pair is very important for clarifying the calculation methods of the piston units working processes. In addition, the use of various sealing options, in particular lip seals, can be a constructive solution to compensating for gaps.

– the growth of equivalent stresses in the cylinder walls reaches values up to 400 MPa for units with a cylinder diameter equal to and more than 50 mm, which corresponds to the level of wall material yield strength (stainless steel, in calculations, Steel 40X). Due to the fact that the increase in the cylinder walls stress level for the piston unit is primarily due to temperature influences from the working fluid side, it is recommended to use the cooling system for the low-speed stage cylinder walls of the piston unit.

6. References

[1] Almasi A 2009 Reciprocating Compressor Optimum Design and Manufacturing with respect to Performance, Reliability and Cost World Academy of Science *Engineering and Technology* vol 52 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.193.4024&rep=rep1&type=pdf.

[2] Almasi A 2009 Optimum selection and design of reciprocating compressor for petroleum services *Proceedings of the Institution of Mechanical Engineers. Part E. Journal of Process Mechanical Engineering* https://doi.org/10.1243/09544089JPME296.

[3] Yusha V L, Karagusov V I and Busarov S S 2015 Modeling the work processes of slow-speed, long-stroke piston compressors *Chemical and Petroleum Engineering* vol **51**(3) pp 177–182

[4] Yusha V L, Busarov S S, Gromov A Yu Assessment of the Prospects of Development of Medium-Pressure Single-Stage Piston Compressor Units *Chemical and Petroleum Engineering* vol **53** pp 7-8

[5] Yusha V L, Nedovenchany A V, Busarov S S 2018 Experimental evaluation of the efficiency of the working processes of low-speed long-stroke reciprocating compressor stages during compression of various gases *Chemical and oil and gas engineering* **8** pp 27 **-** 29

[6] Busarov S S, Goshlya R Yu, Gromov A Yu, Nedovenchany A V, Busarov I S, Titov D S 2016 Mathematical modeling of heat transfer processes in the working chamber of a low-speed piston compressor stage *Compressor technology and pneumatics* **6** pp 6–10

[7]. Yusha V L, Dengin V G, Busarov S S, Nedovenchanyi A V, Gromov A Yu 2015 The estimation of thermal conditions of highly-cooled long-stroke stages in reciprocating compressors *International Conference on Oil and Gas Engineering OGE-2015 Procedia Engineering: Elsevier BV* **113** pp 264–269

[8] Yusha V L, Busarov S S, Goshlya R Yu, Nedovenchanyi A V, Sazhin B S, Chizhikov M A, Busarov I S 2016 The experimental research of the thermal conditions in slow speed stage of air reciprocating compressor *International Conference on Oil and Gas Engineering OGE-2016 Procedia Engineering: Elsevier BV* vol **152** pp 297–302

[9] Yusha V L, Busarov S S, Aistov I P 2017 Influence of wall thickness and properties of structural materials on the discharge temperature and strength characteristics of slow-speed long-stroke stages *Oil and Gas Engineering (OGE-2017) AIP Conf. Proc.* 1876 – 020040-1–020040-8

[10] Aistov I P, Vansovich K A, Busarov S S 2018 Evaluation of Stress-Strain State of the Slow-Speed Compressor Cylinder *Oil and Gas Engineering (OGE-2018) AIP Conf. Proc.* **2007** 030064-1–030064-7

[11] Aistov I P, Vansovich K A, Busarov S S 2018 Estimation of the stress-strain state of a low-speed compressor cylinder *Compressor equipment and pneumatics* **4** pp 7-11
[12] Busarov S S, Titov D S, Dyomin I S, Nedovenchany A V 2019 Evaluation of the effect of leaks of cylinder-piston seals on the working process of low-speed long-stroke piston units *Omsk Scientific Bulletin* **1** (163) pp 5-10 DOI: 10.25206 / 1813-8225-2019-163-5-10.
[13] Vaishali R N, Khamankar S D 2015 Stress analysis of piston using pressure load and thermal load *International Journal of Mechanical Engineering* vol **3** pp 1-8
[14] Madenci E, Guven I The Finite Element Method and Applications in Engineering Using ANSYS DOI 10.1007/978-1-4899-7550-8
[15] Gudimetal P, Gopinath C V 2009 Finite element analysis of reverse engineered internal combustion engine piston *Asian International Journal of Science and Technology in Production and Manufacturing Engineering* vol **2**(4) pp 85-92
[16] Yongjun N 2010 Finite Element Modeling and Analysis for Key Parts of a New type Internal Combustion Engine *International Conferences on Computer Application and System Modeling* vol **8** pp 181-184
[17] An X W, Hui G 2010 Fatigue strength and analysis of diesel engine piston on finite element analysis *Advanced Material Research* vol **156** pp 1086-1089
[18] Lokesh S, Suneer S R, Taufeeque H 2015 Finite element analysis of piston in ANSYS *International Journal of Modern Trends in Engineering and Research* vol **2** pp 619-626
[19] Neha P, Jaanhavi N 2016 Designing and Stress Analysis of the Industrial Compressor Connecting Rod Depending Upon the Design Inputs Using ANSYS Workbench *International Journal of Innovative Research in Science, Engineering and Technology* vol **5** pp 9574-9583
[20] Aistov I P, Vansovich K A, Busarov S S, Titov D S, Nedovenchany A V 2019 Analysis of the loaded state of the cylinder stage of the low-speed piston unit during compression of liquids and gases *Bulletin of Irkutsk State Technical University*. 2019 vol **23** 2 pp 205–213 DOI: 10.21285 / 1814-3520-2019-2-205-213.
[21] Plastinin P I 2000 Piston compressors *Theory and calculation* vol **1** (Moscow: Kolos) p 456