Journal of the Korean Society of Marine Environment & Safety
Research Paper
Vol. 23, No. 4, pp. 393-399, June 30, 2017, ISSN 1229-3431(Print) / ISSN 2287-3341(Online) https://doi.org/10.7837/kosomes.2017.23.4.393

Transient Structural Analysis of Piston and Connecting Rods of Reciprocating Air Compressor Using FEM

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FEM을 이용한 왕복동 공기압축기의 피스톤 및 커넥팅로드의 구조해석

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Abstract : *In a reciprocating compressor, the piston and connecting rod are important parts. Excess mechanical stress on these parts may cause damage, and broken parts are expensive and difficult to replace. Therefore, it is necessary to analyze the mechanical stress affecting durability and longevity. The main purpose of this study was to identify locations of maximum stress on pistons and connecting rods. Based on dynamic calculation of the working process of a specific air compressor, an analysis of piston and connecting rod performance has been completed. A three-dimensional model for the air compressor's pistons and connecting rods was built separately, and FEM analysis of these components was carried out using a numerical method. The pistons were loaded by pressure which was changed according to crankshaft angle without thermal boundary conditions. The simulation results were used to predict and estimate stress concentration as well as the value of this stress on pistons and connecting rods. The maximum equivalent stress calculated are over 190 MPa on pistons and 123 MPa on connecting rods at crank angle 135° and 225° but these are under tensile yield strength. Besides, the calculated safety factors of connecting rods and pistons is higher than 1. Moreover, the results obtained can be used to provide manufacturers with references to optimize the design of pistons and connecting rods for reciprocating compressors.*

Key Words : *Piston, Connecting rod, Mechanical stresses, Crank shaft angle, Reciprocating compressors*

요 약 : 왕복동식 압축기에서 피스톤과 커넥팅로드는 중요한 부분이다. 이러한 주요부에 기계적 부하가 과도하게 가해지면 해당 기부속이 손상될 수 있으며, 교체하기도 쉽지 않고 비용도 많이 든다. 따라서 내구성과 수명에 영향을 미치는 요인을 분석할 필요가 있다. 본 연구의 주요 목적은 피스톤과 커넥팅로드의 최대 응력 집중 위치를 확인하는 것이다. 이를 위해 설계된 공기압축기의 작업 공정의 동적 계산을 기반으로 피스톤 및 커넥팅로드의 응력 분석을 수행하였다. 공기압축기의 피스톤과 커넥팅로드의 3 차원 모델을 따로 설계하고, 이러한 부품들의 유한요소 해석은 수치해석적인 근사해법을 사용하였다. 피스톤은 열 경계 조건 없이 크랭크 샤프트의 각도에 따라 압력 부하를 받는다. 시뮬레이션 결과는 피스톤과 커넥팅로드의 응력 집중 위치와 그 값을 예측하고 추정할 수 있다. 그 결과 크랭크 각도 135°와 225°에서 피스톤은 190MPa, 커넥팅로드는 123MPa 이상의 최대 등가응력이 나타났으며 이는 인장 항복강도 이하의 값이다. 또한, 커넥팅로드와 피스톤에 계산 된 안전 계수는 1보다 높게 나타났다. 더욱이, 이러한 결과는 왕복동 공기압축기 제작사에 피스톤 및 커넥팅로드를 설계함에 있어서 최적화를 위한 참고 자료로 활용 될 수 있다.

핵심용어 : 피스톤, 커넥팅로드, 기계적 부하, 크랭크 샤프트 각도, 왕복동 압축기

1. Introduction

Pistons and connecting rods are moving components of air compressors. Their function is reversed and force is transferred from the crankshaft for the purpose of compressing air in the cylinder Therefore, the load applied on piston and connecting rod is very complicated. The quality of piston and connecting rod directly are effects on the air compressor's performance as well as their durability and longevity.

In the past, traditional dynamics study of piston and connecting

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rod accurately unable to include variation of loading conditions and the calculation results and actual vary widely. Moreover, the cost in designing or producing for real pistons and connecting rods which serve for testing is high.

Nowadays, the development of computing technology and finite element methods supplied some software help for design and analysis structures becoming more convenient and more economical.

Therefore, the main objective of the presented work is to perform the Structural Analysis of pistons and connecting rods of specific air compressor model, so as to determine and evaluate the mechanical strength in pistons and connecting rods. Finally, the simulation results can be used to estimate the maker's design of pistons and connecting rods.

2. Methodology

2.1 Finite element method

The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It subdivides a large problem into smaller, simple parts. The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. The finite element method (FEM) applied in engineering is a computational tool for performing engineering analysis (Manjunatha et al., 2013). It includes the use of mesh generation techniques, as well as the use of software program coded with FEM algorithm. In software program, numerical methods for ordinary differential equations are methods used to find numerical approximations to the solutions of ordinary differential equations. Many differential equations cannot be solved using symbolic computation. For practical purposes, a numeric approximation to the solution is often sufficient. The algorithms studied can be used to compute such an approximation. An alternative method is to use techniques from calculus to obtain a series expansion of the solution. In addition, some methods in numerical partial differential equations convert the partial differential equations into an ordinary differential equation, which must then be solved.

2.2 Computational model and setup parameters

Firstly, the 3D model of air compressor are designed in Solidworks and the general parameters are showed in table 1 (Malhotra at al., 2014). The model of air compressor are then imported in ANSYS (Fig. 1). In ANSYS finite element model for the air compressor are built. By using mesh generation in ANSYS, geometry of air compressor is divided. The calculation model adopted hexa and tetra mesh style which consists of 1.1 million nodes (Fig. 2) (ANSYS, 2016).

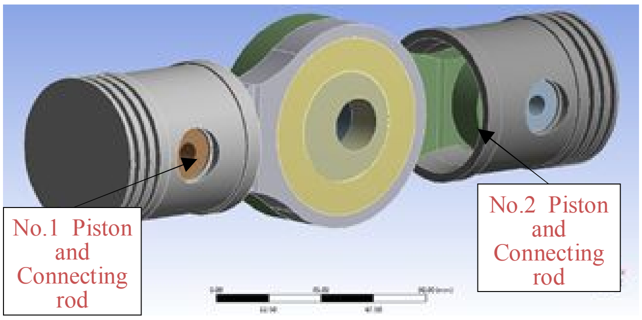


Fig. 1. Model of air compressor for transient structural analysis.

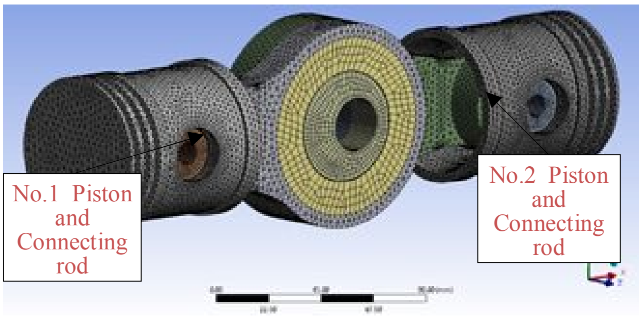


Fig. 2. Meshing Geometry of air compressor for transient structural analysis.

Table 1. General parameter of air compressor

General parameter of air compressor	
Number of stage	1
Number of Cylinder	2
Inside cylinder diameter	0.07 m
Outside cylinder diameter	0.08 m
Connecting rod length	0.1 m
Clearance Volume	2.15^{-6} m^3
Crank Radius	0.0058 m
Revolution	1,750 rpm

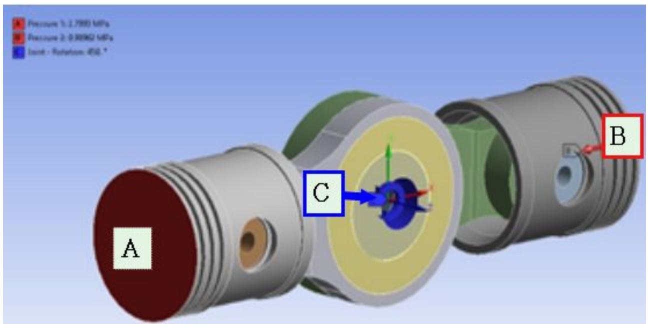
After meshing for air compressor geometry, setup mechanical properties of the different main parts of air compressor is shown in table 2 (Shenoy and Fatemi, 2006).

Before performing full transient dynamic analysis, the loads are applied for the air compressor. The first load is joint load rotation applied for connecting rod cam and the load value is 1,750 rpm. The second load which is pressure on piston No. 1, piston No. 2. The loads are illustrated in Fig. 3 and Fig. 4 (Hanlon, 2001;

Lingaiah and Narayana Iyengar, 2006). The initial loads are corresponding with crank angle 0°.

Table 2. Mechanical properties

Mechanical Properties			
	Connecting pin	Connecting rod, Piston	Connecting rod cam
Material	SCM440	A6061-T6	S45C
Density	7,700 kg/㎥	2,770 kg/㎥	7,850 kg/㎥
Tensile Yield Strength	415 MPa	276 MPa	343 MPa
Tensile Ultimate Strength	615 MPa	310 MPa	569 MPa
Poisson's Ratio	0.29	0.33	0.29



A : Pressure on the piston No.1
B : Pressure on the piston No.2
C : Rotation load applied for connecting rod cam

Fig. 3. The load applied on air compressor.

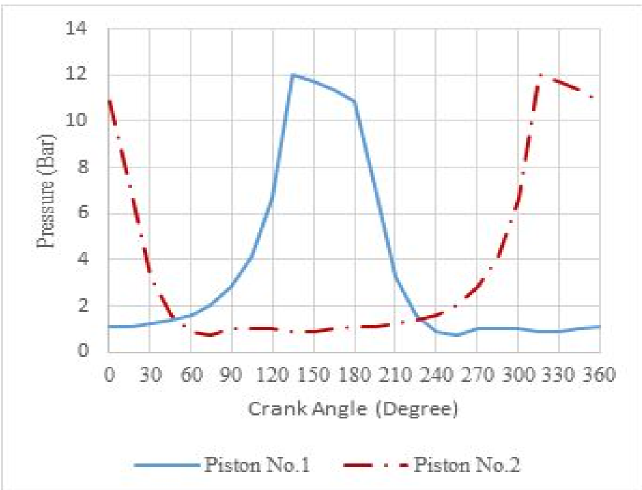


Fig. 4. Pressure on piston No.1 and No. 2 diagram.

3. Results and discussions

3.1. Equivalent stress on pistons and connecting rods

After solving in structural analysis, maximum equivalent stress on pistons and connecting rods are shown on Fig. 5 and Fig. 6. The X- axis is crank angle and Y- axis is maximum equivalent stress. actually, after solving, the minimum and maximum equivalent stress are identified at each point of crank angle but the minimum equivalent stress is dramatically lower than maximum equivalent stress. It is the cause that the minimum equivalent stress is not considered.

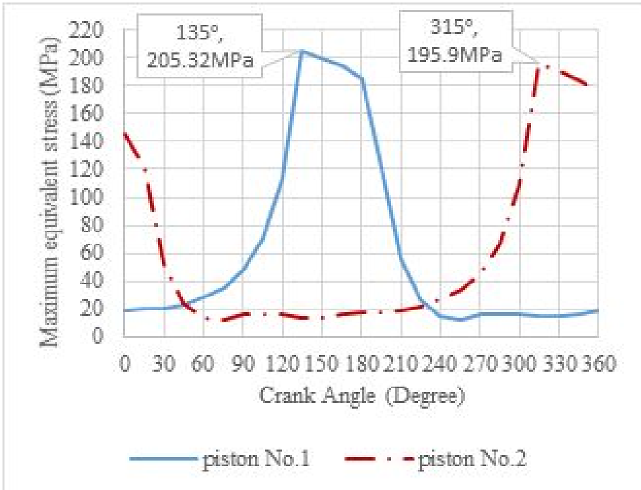


Fig. 5. Max. equivalent stress on pistons No. 1 and No. 2.

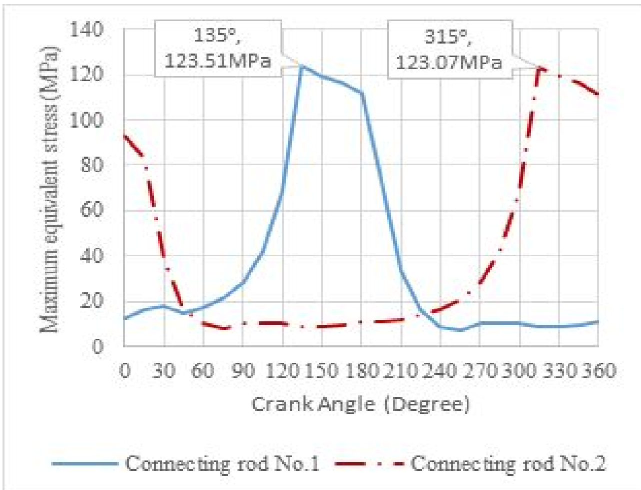


Fig. 6. Max. equivalent stress on con-rods No. 1 and No. 2.

According to Fig. 5 and Fig. 6, the maximum stresses on piston and connecting rod No.1 when the crank angle is 135° while in case of piston and connecting rod No.2, is 315°. corresponding with the pressure on piston No. 1 and piston No.2 are maximum. Moreover, the maximum stress on two pistons and connecting rods values are little different.

The maximum equivalent stress value on piston and connecting rod No. 1 shown on Fig. 7 and Fig. 8, obtained are 205.32 MPa and 123.51 MPa. The maximum equivalent stress value on piston and connecting rod No. 2 shown on Fig. 9 and Fig. 10, indicated are 195.9 MPa and 123.07 MPa. The figures also identify the location of maximum stress concentration. Obviously, the maximum stress on the pistons and connecting rods are lower than tensile yield strength of A6061-T6 material. It mean that the pistons and connecting rods deform elastically.

The stress concentration is distributed on different area are indicated by different colors. The maximum stress is viewed by red color.

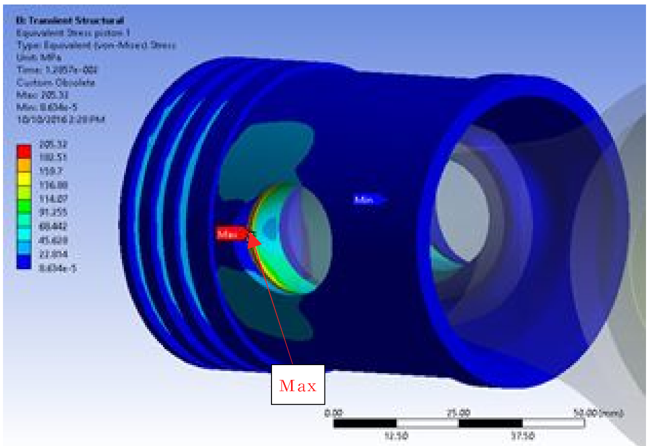


Fig. 7. Max. equivalent stress contour on piston No. 1.

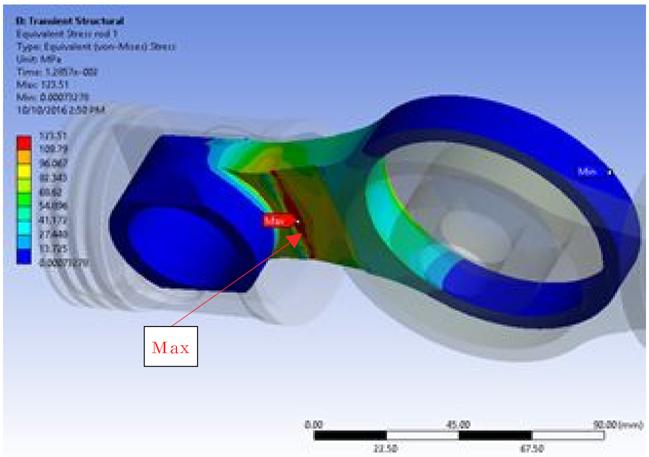


Fig. 8. Max. equivalent stress contour on con-rod No. 1.

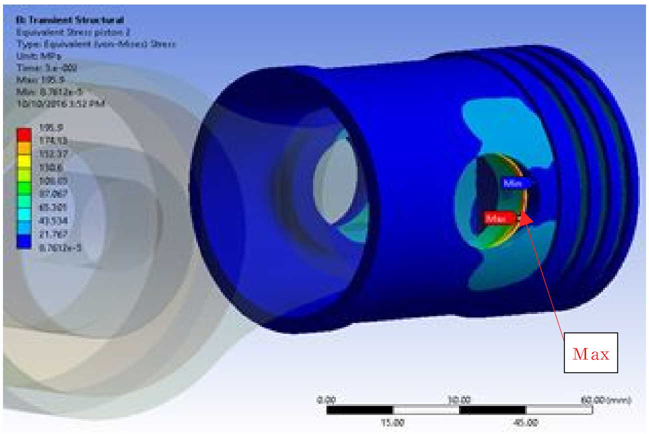


Fig. 9. Max. equivalent stress contour on piston No. 2.

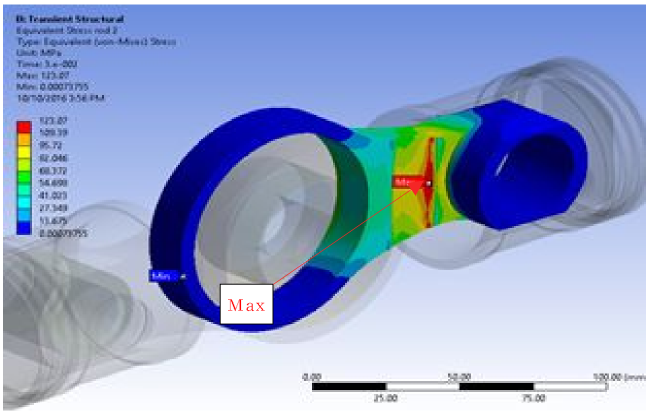


Fig. 10. Max. equivalent stress contour on con-rod No. 2.

3.2. Total deformation of pistons and connecting rods

The maximum total deformation value of pistons and connecting rods are illustrated on Fig. 11 and Fig. 12.

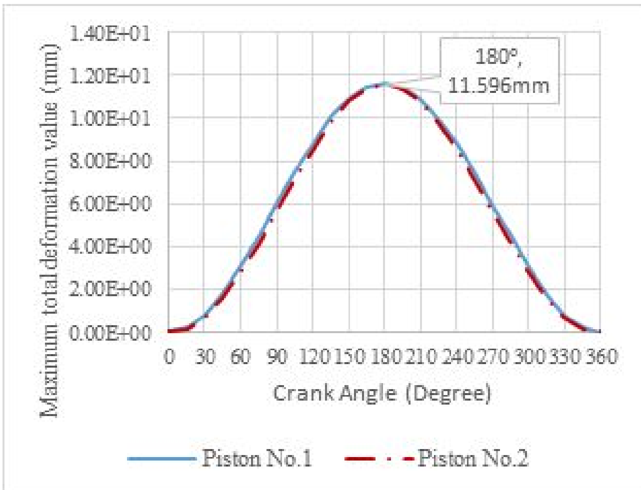


Fig. 11. Max. total deformation of pistons No. 1 and No. 2.

As Fig. 11 and Fig. 12 show, the maximum total deformation of pistons reach the top at crank angle 180° while the highest value of connecting rods are at crank angle 135° and 225°.

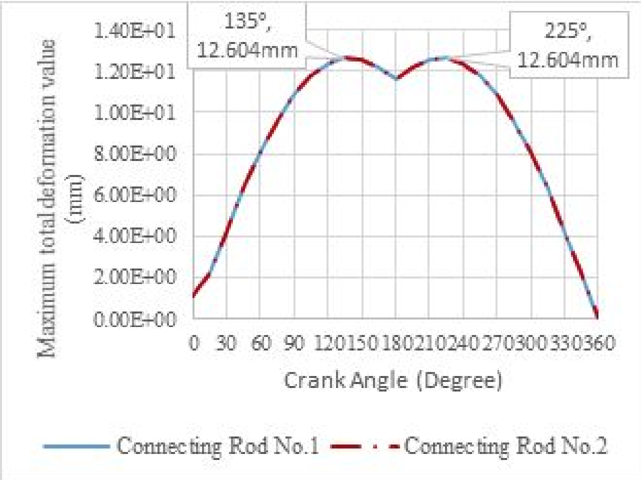


Fig. 12. Max. total deformation of con-rods No. 1 and No. 2.

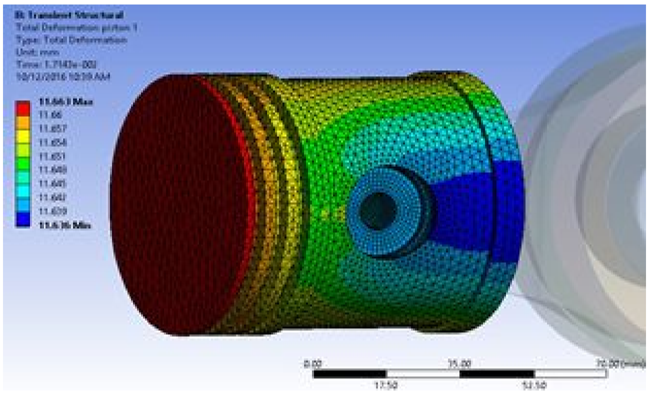


Fig. 13. Max. total deformation contour of piston No. 1.

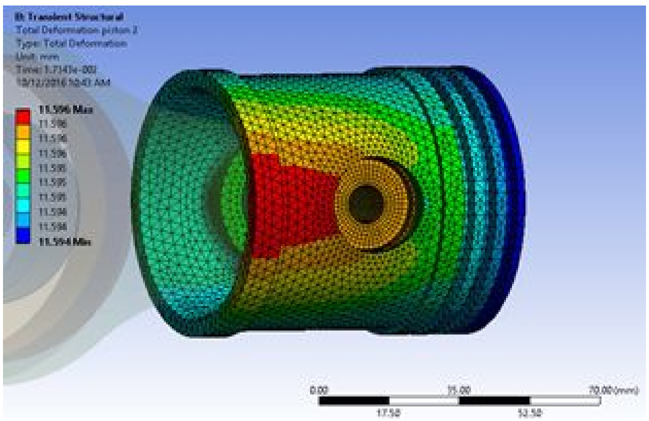


Fig. 14. Max. total deformation contour of piston No. 2.

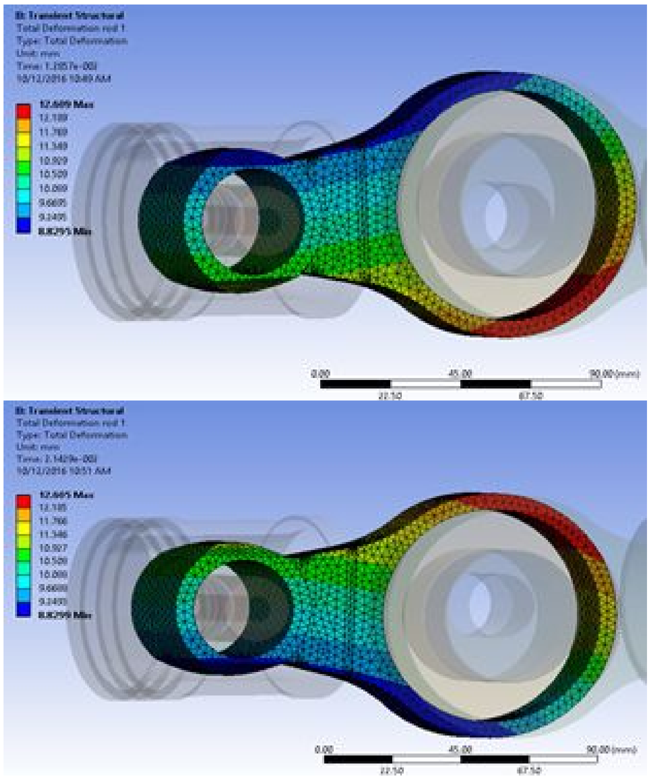


Fig. 15. Max. total deformation contour of con-rod No. 1.

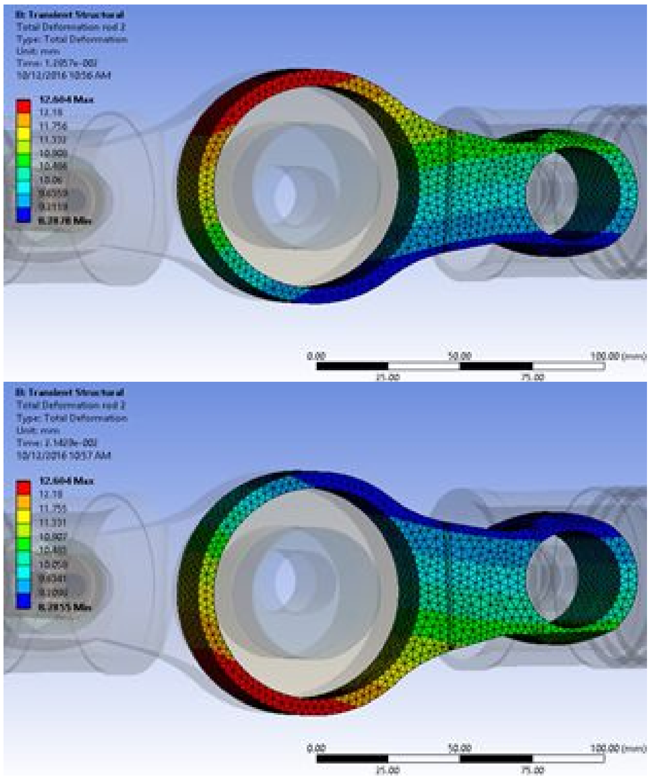


Fig. 16. Max. total deformation contour of con-rod No. 2.

The maximum deformation is used to evaluate the shape deformation of pistons and connecting rods under stress effects. The maximum deformation of pistons at crank angle 180° is 11.6 mm for both pistons that are shown on the Fig. 13 and Fig. 14. The maximum deformation of connecting rods at crank angle 135° and 225° are 12.6 mm respectively that are shown on the Fig. 15 and Fig. 16. The maximum total deformation are not corresponding with the pressure on piston No. 1 and piston No.2 are maximum. Because, the pistons and connecting rods move on the plane and in the program, the total deformations is calculated from the intial position corresponding with crank angle is 0°.

3.3. Safety factor of pistons and connecting rods

Safety factor of pistons and connecting rods are shown on Fig. 17, 18, 19 and Fig. 20. Safety factor is a term describing the load carrying capacity of a system beyond the expected or actual loads. Essentially, the factor of safety is how much stronger the system is than it usually needs to be for an intended load.

The Fig. 17 and Fig. 18 described that the range of piston No.1st safety factor near with 1 is from 135° to 180° and these of piston No. 2 is from 315° to 360°. In this case, additional load will cause pistons to fail.

For case of connecting rods No. 1 and No. 2 as shown on Fig. 19 and Fig. 20, their safety factor always are higher than 2. The safety factor of No.1 and No.2 of connecting rods meet the safety requirement. And the connecting rods will fail at twice the pressure load.

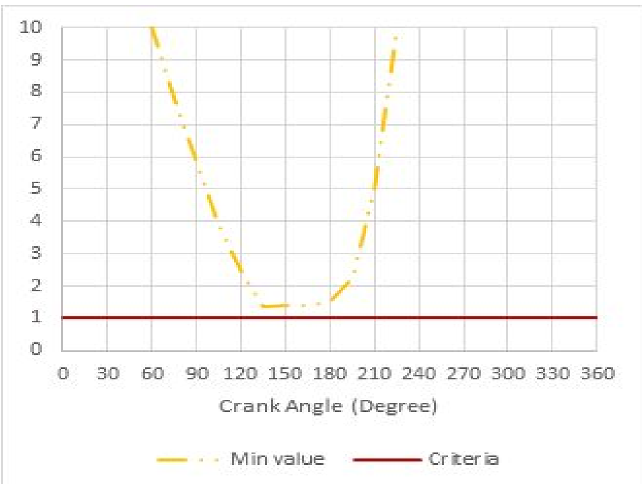


Fig. 17. Safety factor of piston No. 1.

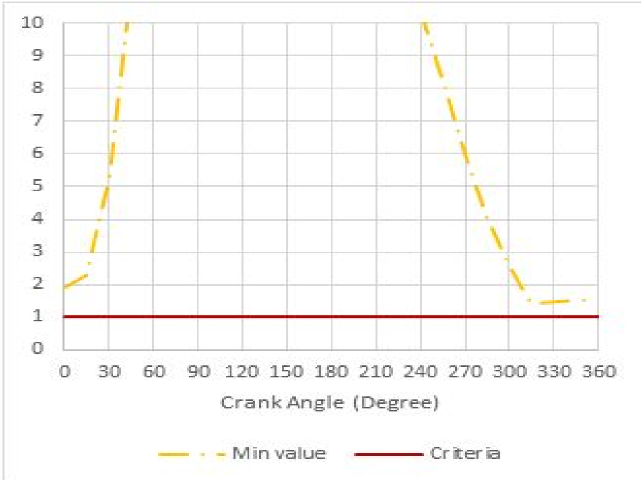


Fig. 18. Safety factor of piston No. 2.

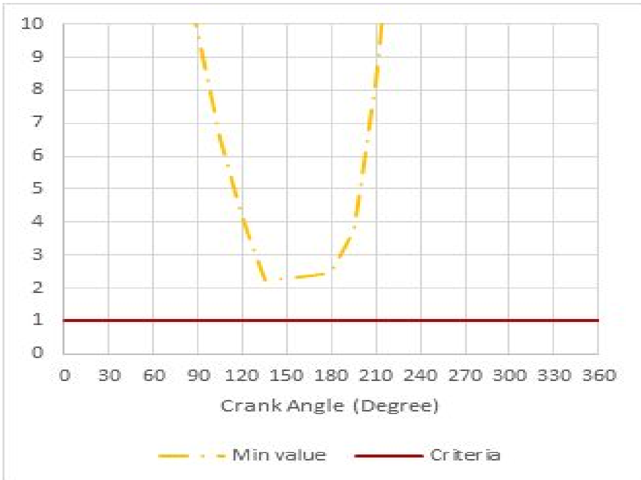


Fig. 19. Safety factor of con-rod No. 1.

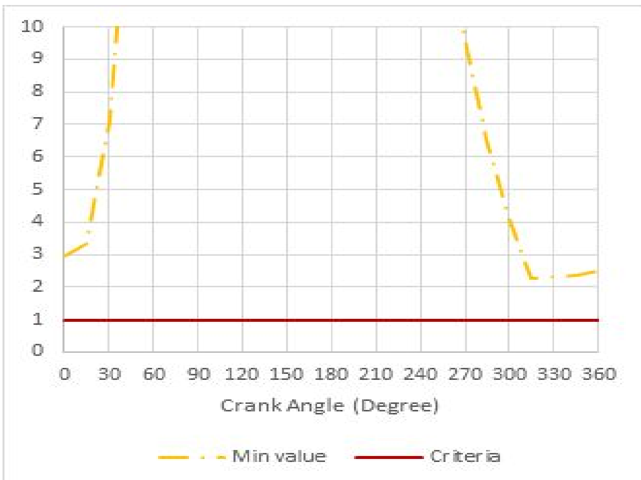


Fig. 20. Safety factor of con-rod No. 2.

4. Conclusion

This paper introduce part of author's work on long term study about the reciprocating compressor as well as the structural analysis. To summarize the work presented above, conclusions are made below

1) The maximum equivalent stress value on piston and connecting rod No. 1 are 205.32 MPa and 123.51 MPa. The maximum equivalent stress value on piston and connecting rod No. 2 are 195.9 MPa and 123.07 MPa. These highest value are found at joint of the pistons and piston pin. Because maximum stress on the pistons and connecting rods lower than tensile yield strength of design material, the pistons and connecting rods deform elastically.

2) The maximum total deformation of pistons reach the top at crank angle 180° while the highest value of connecting rods are at crank angle 135° and 225°. Beside, the maximum deformation on piston No. 1 is different from piston No. 2. However, the maximum total deformation are not corresponding with the pressure on piston No. 1 and piston No. 2 are maximum.

3) As Fig. 17 and Fig. 18 shown, the safety factor of piston No. 1 and No. 2 are near with 1, therefore it is necessary to consider about design of pistons. While, in case of the connecting rod No. 1 and No. 2 are higher than 2 as shown in Fig. 19 and Fig. 20, and meet the requirement of safety (Ilman and Barizy, 2015).

References

[1] ANSYS(2016), Inc.ANSYS Mechanical ADPL Structural Analysis Guide.
[2] Hanlon, P. C.(2001), Compressor Handbook.
[3] Ilman, M. N. and R. A. Barizy(2015), Failure analysis and fatigue performance evaluation of a failed connecting rod of reciprocating air compressor Engineering Failure Analysis, pp. 142-149.
[4] Lingaiah, K. and B. R. Narayana Iyengar(2006), Machine Design Data Handbook, Suma publishers.
[5] Malhotra, D., A. Bansal and S. Chaudhry(2014), Thermo Mechanical Analysis and Weight Reduction of Air Compressor Piston using CATIA and ANSYS, International Journal of Engineering Research and Technology, Vol. 3, Issue 10, pp. 1178-1181.
[6] Manjunatha, T. R., H. V. Byre Gowda and G. S. Prabhunandan(2013), Design and Static Structural Analysis of Cylinder and Piston of Two Stage Reciprocating Compressor Using ANSYS, International Journal of Innovative Research in Science Engineering and Technology, Vol. 2, Issue 12, pp. 7590-7596.
[7] Shenoy, P. S. and A. Fatemi(2006), Dynamic analysis of loads and stresses in connecting rods, IMechE, pp. 615-624.

Received : 2017. 03. 14.
Revised : 2017. 06. 14. (1st)
: 2017. 06. 21. (2nd)
Accepted : 2017. 06. 28.