OPTIMIZATION IN MECHANICAL SEAL DESIGN FOR API 682 CATEGORY 1 APPLICATIONS

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ABSTRACT

The paper covers development of mechanical seal design to optimize the adaptive part for API 682 category 1 applications. Under the guidelines of Forschungskuratorium Maschinenbau (FKM) the static strength is investigated using local stresses. Static structural load case is carried out on the adaptive parts with non-average element-nodal stresses. The new design performance is investigated using finite element analysis in terms of equivalent stress. Improved features in the design and their effects on manufacturing benefits, seal performance leading final product cost/weight optimization are discussed. Evaluation of centrifugally cast stainless steel raw material instead of forged wrought raw material is discussed.

Keyword : - *Finite Element Analysis, Localized Stress, Static Utilization, Mechanical Seals.*

1. INTRODUCTION

Mechanical seal is a commonly used device industry having application like pumps, compressor, agitators and mixers to prevent the fluid/gas leakage into the surrounding. Mechanical seal is located between the stationary housing and rotating shaft. [4] Centrifugal or positive displacement pumps used in industries having applications involving hydrocarbon media follow API 682 and ISO 20149 technical standards for mechanical seals. [11-15]. Seal faces are one of the basic mechanical seal components which get wearied and have to be regularly replaced. A cartridge unit of mechanical seal means an assembly consisting of seal faces, secondary sealing element, springs, shaft sleeve and adaptive parts. This complete unit can be directly assembled on the pumps. Adaptive parts in the mechanical seal have a long life as manufactured with stainless steel material with properties like corrosion resistance, aqueous usage, chemical resistivity, and elevated temperature environment. Adaptive parts are one of the costliest parts in the mechanical seal cartridge unit. Earlier literature revels that the mechanical seal operation is dependent on closing and opening force. [4] These forces depend on media pressure, spring forces and secondary sealing element positions. The major design constrains for adapter parts of mechanical seal are the min & max pressure, temperature condition, impeller speed and operating environment. Adaptive part design depends on load, complexity in shape, manufacturing processes and material selection. There are different arrangements for mechanical seal in the API 682, amongst which category 1 application with single seal arrangement 1 and dual seal with face to back arrangement 3 is considered for the analysis. [11-15] The single and double seal arrangement is shown in the Figs. 1 and 2 as below.

The adaptive parts for the single mechanical seal includes shaft sleeve and the cover, while for the dual seal arrangement an additional part Adapter is included in between the cover and pump housing. The stationary element for the single seal is the cover and rotating is the shaft sleeve, while for the dual seal the additional adapter is stationary. Manufacturing of adaptive parts using centrifugal casted raw material is considered under this study. API

682 tells pressure containing parts made from cast material has to pass the liquid penetration test as per ASME VIII, Division 1, and Appendix 7. [11-15]

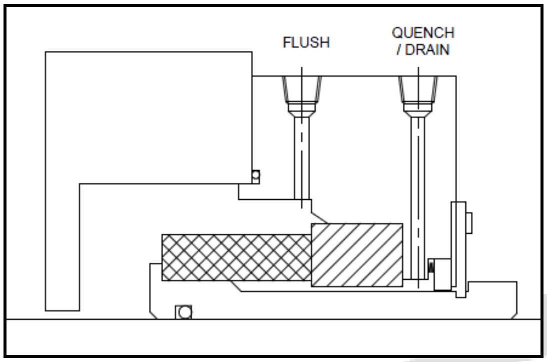


Fig -1: Arrangement 1 type mechanical seal

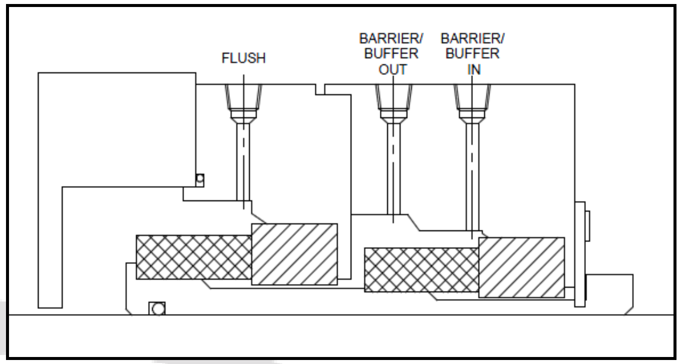


Fig -2: Arrangement 1 type mechanical seal

2. DESIGN CONSIDERATION FOR ADAPTIVE PARTS

The improvised adaptive components design consideration includes operating conditions, material selection, and pressure distribution over the sealing elements and forces imposed. The present study considers pressure value of 20 bar on the seal faces and Temperature range from 20°C to 176°C. The basic components of the mechanical seal are depicted in the Fig. 3 as below. The material detail composition consideration of individual components of mechanical seal is shown in the Table I.

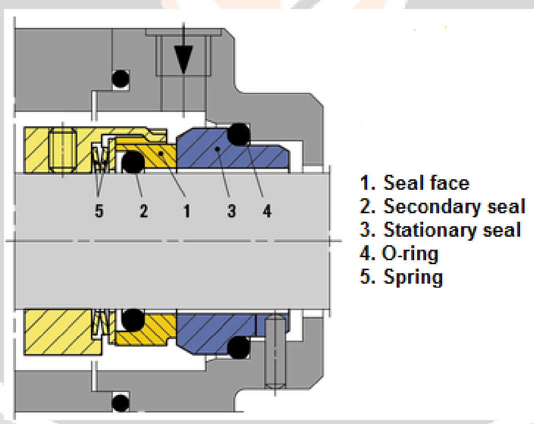


Fig - 3: Mechanical Seal Basic components

Table - 1: Material composition for Seal Components

Components	Material
Seal Faces	Carbon graphite antimony impregnated, Silicon carbide, Sintered Pressure-less
Stationary Seal	Silicon carbide, Sintered Pressure-less
O-rings	Fluorocarbon rubber, Per-fluoro-carbon rubber
Springs	Nickel-Chromium-Molybdenum Alloy, Hastelloy C-4 & C-276
Adaptive Parts	Chromium-Nickel-Molybdenum Steel (SS 316L / 1.4404) & Chromium-Nickel-Molybdenum Cast Steel (1.4409)

Pressure distribution on the adaptive parts is the important parameter in addition to temperature and material properties. Pressure distribution on the mechanical seal completely depends on the position and location of the secondary sealing element based on the consideration that the seal is balanced. The hydro static forces due to the fluid and spring force distributed on the new improvised adaptive part designs is shown in the Fig. 4. The worse pressure condition of fluid is considered and the forces are calculated. The relative forces based on the pressure combination are shown in the Table II.

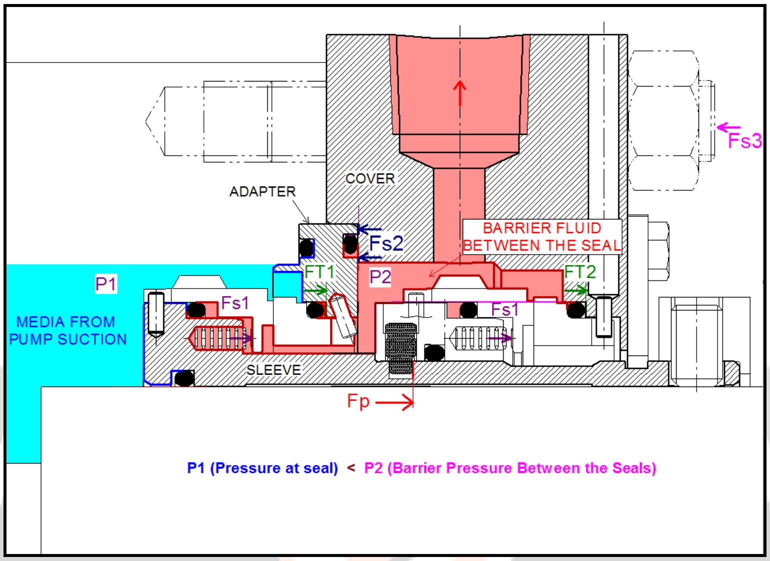


Fig - 4: Pressure and Force Distribution Diagram

P1 : Pressure between the seals
P2 : Barrier Fluid Pressure between the seals
Fp : Force directed to the sleeve through the pin
Fs1Total : Total Spring Force imposed on seal faces
FT1 : Force acting on adapter due to sleeve (Media Pressure) and springs
FT2 : Force acting on cover due to sleeve (Barrier Fluid Pressure) and springs
Fs2 : Force due to the seal mounting screws acting on adapter though cover
Fs3 : Force due to the seal mounting screws
N : Rotation of impeller shaft

Table - 2: Calculated force distribution at worse operating condition

Components	Sleeve	Adapter	Sleeve
N (rpm)	0	0	0
P1 (Mpa)	2.2	0	0
P2 (Mpa)	2.4	3.6	3.6
Fp (N)	827.5	-	-
Fs1 Total (N)		202	202
FT1 (N)		0	0
FT2 (N)		-	10495
Fs2 (N)		1746	-
Fs3 (N)		8810	8810

For the seal analysis boundary conditions are considered based on different combination of pressure at seal *P1* and intermediate pressure *P2* at two different operating speeds as shown in Table III. These are the optimum values to which mechanical seal would operate.

Table - 3: Operating condition/Boundary condition for seal analysis

Sr. No.	*N (rpm)*	*P1 (Mpa)*	*P2 (Mpa)*
Seal Faces	0	2.2	0.05
Stationary Seal	0	2.2	2.4
O-rings	0	0	3.6
Springs	3600	2.2	0
Adaptive Parts	3600	2.2	2.4

With the aid of pressure loaded area, the force acting on the adaptive parts is evaluated. In the present analysis the total spring force on the seal faces is calculated as 20N. The spring selected is compression type with 20.2N force over a length of 12.3 mm. The total of 10 such springs force along with the hydrostatic force creates a closing force over the seal faces. Thus a new mechanical seal is devised based on the above specification and respective parameters. Computer aided modeling is used to prepare the Adaptive part models. To avoid the complexities the details of each component dimensions are not provided. A pictorial comparison of new and old design is shown in Fig. 5. The new design features eliminates the critical manufacturing areas.

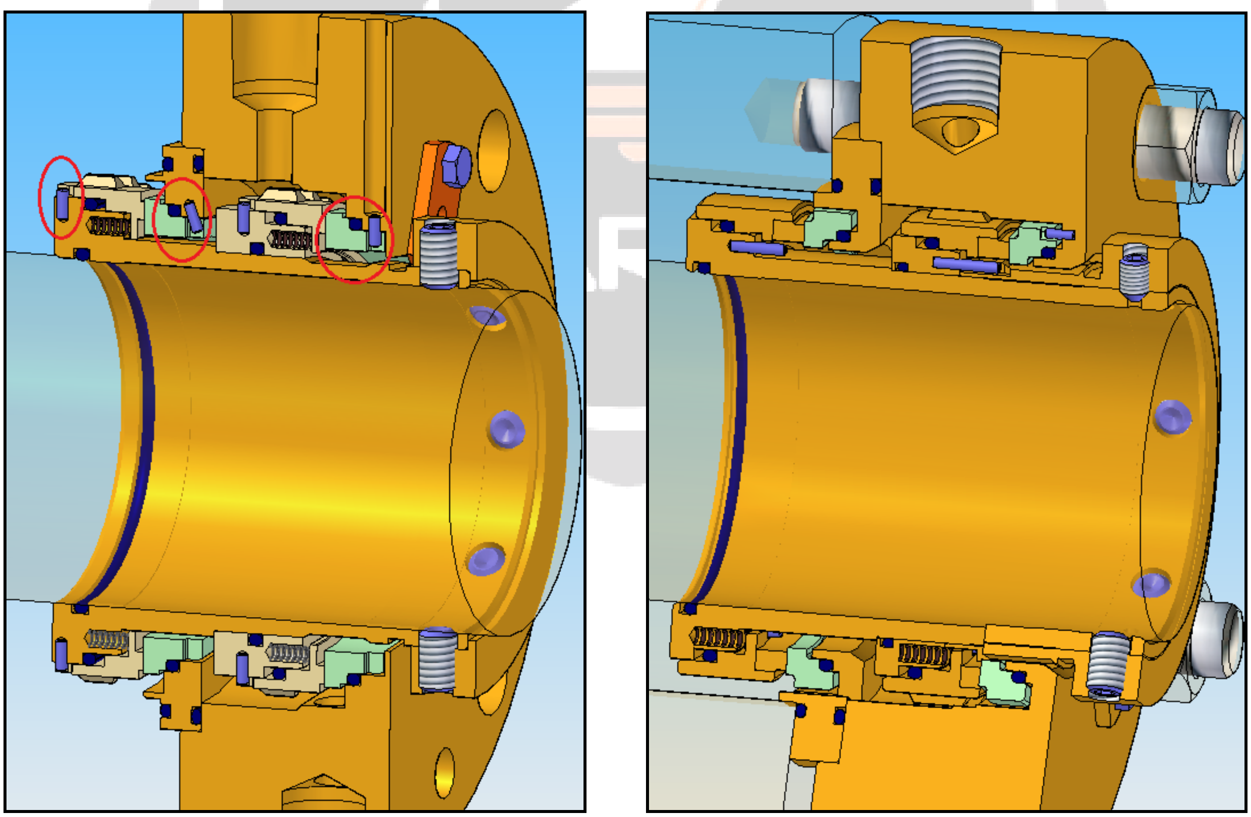
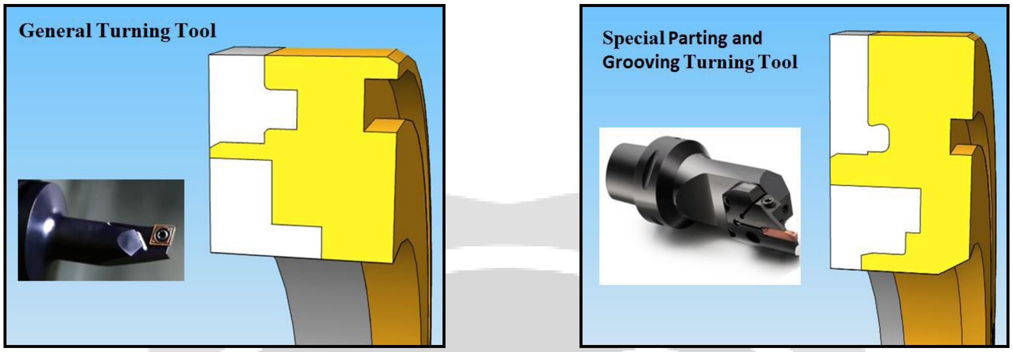


Fig - 5: Comparative pictures for new and old component designs

In the old design, for the turning operation a special Parting and Grooving Turning Tool had to be used in order to machine some critical areas as depicted in the Fig. 6. In the new design this is eliminated by using different type of seat and O-Ring grove. Thus the turning operation could be carried out with general turning tool. Horizontal pin in old design is replaced with vertical one, eliminated complexities that occurred due to the usage of long drills during manufacturing holes in the shaft sleeve.



a: Improved design **b**: Existing design

Fig - 6: Comparative pictures for new and old adapter design

3. STATIC STRENGTH ASSESSMENT

Analytically assessment of static strength is carried by evaluating the degree of utilization for equivalent stress. Degree of utilization is based on analytical relations involving static component stress, equivalent stress and total safety factor. The inter relationship between the parameter is given as in (1).

$$a_{SK} = \left| \frac{\sigma_V}{\sigma_{SK} / j_{ges}} \right| \tag{1}$$

a_{SK} : Degree of utilization for equivalent stress

σ_V : Equivalent Stress

σ_{SK} : Static component stress

j_{ges} : Total safety factor

Finite element analysis is used simulate adaptive parts. Dimensional details and geometrical criticalities of adaptive parts are considered while preparing the CAD model. These solid models are imported into analysis environment (ANSYS). To avoid possible errors these imported geometries are evaluated. Further solid tetrahedral element method is used for model meshing. A typical structure of ANSYS used for evaluation of can be seen in Fig. 7 below.

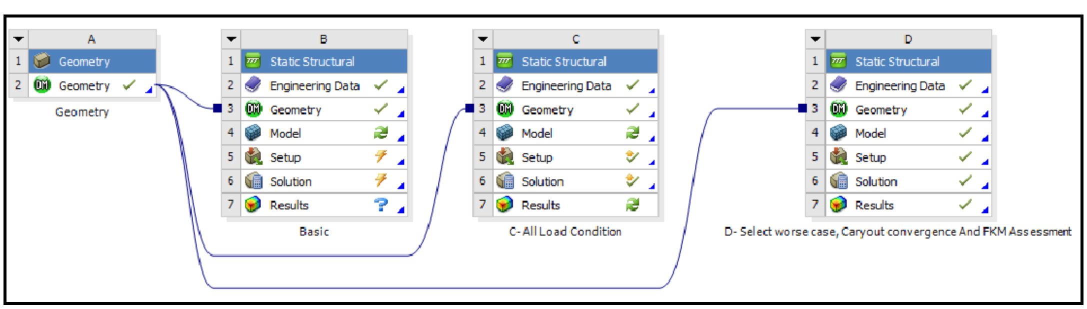


Fig - 7: ANSYS Structure for component evaluation

Using nodes the above mentioned boundary conditions are applied. In the case of sleeve the degree of freedom of inner circumference of the sleeve is arrested. The nodes at the guides provided for bolting on the cover are constrained with zero displacements. Forces and pressure are imposed on respective area as shown in Fig. 4. These areas are exposed to the same magnitude of pressure during practical condition. Static structural analysis is carried out on the adaptive parts. Based on the analysis the deformation and equivalent stress for the worse operating condition is identified. With the help of convergent command, mesh refinement is carried out to investigate the maximum stress region. Using this command more accurate equivalent stress evaluation is investigated. Convergent range is specified to be 2% in the present analysis. After the completion of convergence, the static stress assessment is carried out to evaluate degree of utilization using local stresses under FKM guidelines. [5]

Engineers dealing with design and calculation in mechanical engineering and related fields of industry use FKM assessment for analytical strength assessment. Static strength and fatigue strength is well described in the guidelines. FKM Guidelines is valid for components made from steel, cast steel, or cast iron materials with temperatures ranging from -40°C to 500 °C, as well as for components from aluminum alloys and cast aluminum alloys. It allows an assessment considering nominal stresses, local elastic stresses derived from finite element or boundary element analyses, from theoretical solutions using mechanics, or from any measurements. [5]

The FKM assessment is carried and stress plots for shaft sleeve, cover and adapter are given in Fig 8,9,10 respectively.

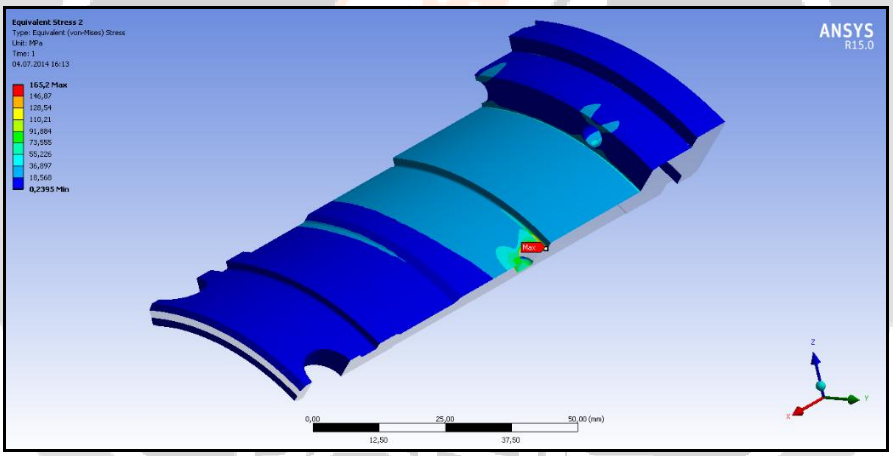


Fig - 8: Equivalent Stress plot for the sleeve

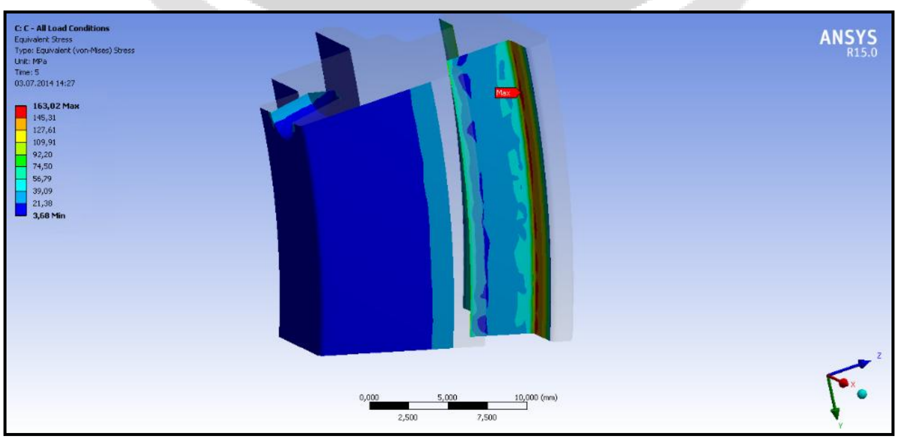


Fig - 9: Equivalent Stress plot for the adapter

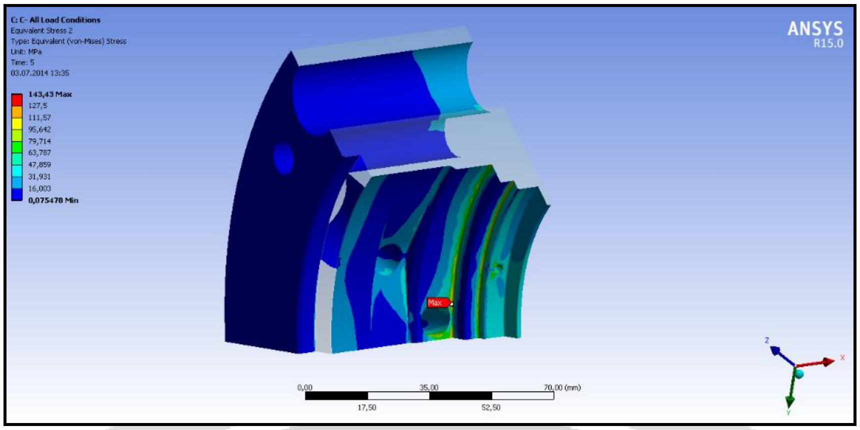


Fig - 10: Equivalent Stress plot for the cover

3.1 FKM report of Finite Element Analysis

The FKM results of the equivalent stress for static utilization percentage are tabulated in Table II as below. From the values of static stress we observe that for the cover and adapter the percentage of stress utilization is improved as compared to the old design. For sleeve the stress values are increased, but they fall under acceptable limits.

Table - 4: Percentage degree of Static Utilization for Adaptive Parts

Adaptive Parts	Static Utilization (New Design)	Static Utilization (Old Design)
Shaft Sleeve	97.50%	55.55%
Adapter	96.32%	223.91%
Cover	84.75%	141.23%

4. CONCLUSION

From the finite element analysis carried for shaft sleeve, adapter and cover following are the inferences drawn.

i. Stress utilization improvements for critical manufacturing area for all components were observed.
ii. Finite element analysis values of stress and deflection shows significant changes in stress patterns as compared with the old design.
iii. Manufacturing method i.e. casting instead of conventional forging is employed, affects in reduction cost of the final product.
iv. Close co-relation between the values of static stress utilization is observed at some locations for analytical and finite element analysis methods.
v. Static stress utilization for the components made by two material viz. wrought stainless steel and cast stainless steel shows better product with enhanced capability and reduced cost be developed by using centrifugal cast raw material.

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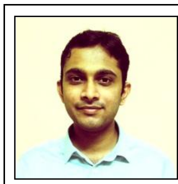
BIOGRAPHIES

	**Akshay S. Kunkolienkar** a Design Engineer at EagleBurgmann India Pvt. Ltd. Pune. He obtained his Bachelor’s degree in Mechanical Engineering from Goa University, India. He is perusing Master’s in Engineering Design from Department of Mechanical Engineering from Savitribai Phule Pune University, Pune, India.
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