

Experimental and Finite Element Analysis of Base Frame for Rigidity

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Abstract:

In this paper Experimental and Finite Element Analysis of Base Frame for Rigidity is presented. The assurance of rigidity as per API 610 is mandatory for pumps base frame supplied in petrochemical industry. A proven rigidity test procedure is used for testing the structural stiffness of base frame in line with API 610 clause 6.3.5. For typical base frame, the stiffness is measured by means of rigidity test (actual measurement) for different load cases. The test is carried out to check the conformance of the existing design to API 610 stiffness requirement. Since the existing design fails to meet this requirement, few potential design modifications are suggested. These modified cases are simulated using FEA techniques for stiffness qualification. ANSYS is used for simulation of these cases including that of existing design, for bench marking and comparison purpose. The results of FE analysis are presented in terms of deflection at coupling side shaft end (guideline form API 610), which is supported between bearings in pump bearing housing at static condition. Based on these results, best feasible design solution is proposed and validated experimentally.

Keywords: *API 610, Centrifugal Pump, FEM Analysis, nozzle load, Rigidity, Stiffness Test.*

1. Introduction

Pumps are widely used in various industries like petrochemical, textile, chemical, based on application. However, for petrochemical industry compliance of API 610 is mandatory. Generally, the piping systems carrying gases, liquids etc. is subjected to excessive piping reactions in pumps, thus causing higher vibrations, coupling failures, and pump shaft misalignments. In severe cases there are flanged joint leaks and the occasional occurrence of impeller rub or casing distortion. Excessive shaft misalignment in turn leads to premature seal and bearing failures. These difficulties are a costly maintenance item that can also result in plant shutdowns, and in severe cases, fires and extensive damage. Recognizing the critical importance of managing piping loads on rotating equipment, engineers have established standards for allowable forces and moments for rotating machinery. These standards become design criteria for the equipment manufacturer and establish allowable limits for the piping system designer. The American Petroleum Institute standard for centrifugal pumps provides a table for the maximum allowable forces and moments for various flange sizes. The standard stipulates that pressure casings are to be designed to twice the maximum allowable values, and limits the allowable coupling-end shaft displacement under specified test conditions as per API 610 standard (Table 12).

Presently for the established base frame of interest, there is no specific data available for rigidity measure. In principle, if pump base frame fails to meet rigidity criteria during stiffness testing, it will result in rework of base frame, longer lead-time and thus increased product cost. To investigate the root causes of failure and prevent the causes, current study is carried out. However, the scope of work is limited to pump base frame only, with the assumption of constant rigidity of all other parts, under static condition. Keeping this in view, the study has been carried out with the following objectives 1) To analyze the base frame for stiffness testing of existing design experimentally as per API 610 stiffness test requirement. 2) To investigate the root causes of failure for existing design of base frame by Finite Element Analysis. 3) To propose best possible base frame design to meet API 610 stiffness test requirement. 4) To manufacture and test the stiffness of the pump base frame for design

validation. This paper describes how the centrifugal pump base frame stiffness can be improved by using FEA technique.

2. API 610 Stiffness Test Acceptance Criteria

Table 1. Stiffness Test Acceptance Criteria

Base plate intended for grouting		
Loading condition	Pump shaft displacement μm (in)	Direction
M_{yc}	175 (0.007)	+Z
M_{zc}	75(0.003)	-Y
M_{yc} and M_{zc} equal the sum of the allowable suction and discharge nozzle moments from table 4.		
$M_{yc} = (M_y)_{\text{suction}} + (M_y)_{\text{discharge}}$; $M_{zc} = (M_z)_{\text{suction}} + (M_z)_{\text{discharge}}$		

The stiffness test acceptance criteria for rigidity testing are given in Table 1. API 610 Consider only two loads cases, M_{yc} and M_{zc} . In M_{yc} loading condition, loads are applied on suction or discharge nozzle, to create moment about Y axis and deflection of shaft is in Z direction. In M_{zc} loading condition loads are applied on suction or discharge nozzle, to create moment about Z axis and deflection of shaft is in Y direction. There is no effect of M_{xc} loading condition on shaft deflection; hence API 610 doesn't consider this loading effect. However, in present paper, the above equations are described in terms of subscript 's' for suction and subscript 'd' for discharge.

3. Experimental Setup

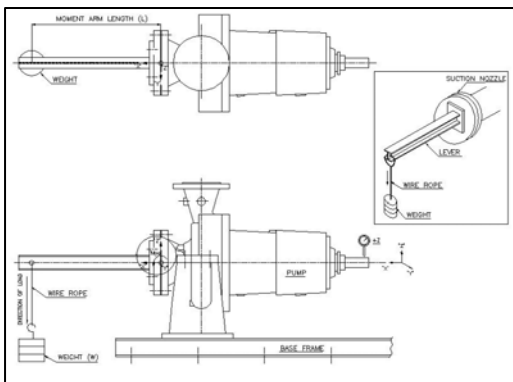


Fig. 1. M_{ys} Loading Condition.

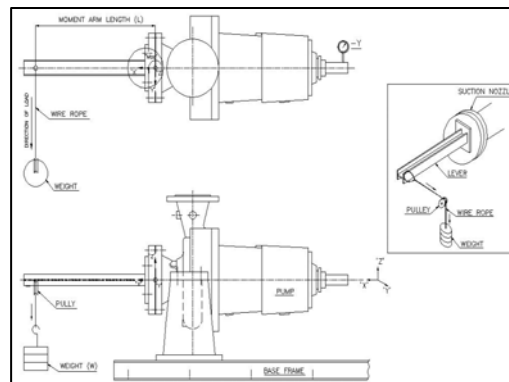


Fig. 2. M_{zs} Loading Condition.

Typical OH2 pump base frame of interest is considered for rigidity analysis. Centrifugal pump consists of the shaft which is supported by two bearings. One end of the shaft is connected to the coupling and the other end of the shaft is connected to the impeller which is in overhung position. Bearing housing consist of bearing through which shaft is fitted. This entire pump assembly is mounted on base frame pedestal. The pump assembly is fixed on base frame pedestal by using bolts, while the base frame is fixed on rails, through foundation bolts. A lever made out of an "I" beam is welded to the flange which is bolted to suction nozzle of pump. At the other end of lever, weights are attached by using wire ropes. To measure the coupling end shaft deflection of pump, a dial indicator is used which is mounted on an independent dial stand. In turn, the dial stand is fixed to the floor. The stiffness test is carried out at pump static condition. For stiffness test purpose four load cases considered are M_{ys} , M_{zs} , M_{yd} , M_{zd} , out of that only M_{ys} , M_{zs} load cases are illustrated in Fig. 1 and Fig. 2. Experimental set up of M_{yd} load case is similar to that of M_{ys} load case, except lever is attached to the delivery nozzle of pump. Experimental setup M_{zs} Loading Condition is shown in Fig. 2. A pulley is fixed on separate stand to hang the weights using wire ropes. Experimental set up of M_{zd} load case is similar to that of M_{zs} load case, except the lever is attached to the delivery nozzle of pump. In stiffness testing depending on pump suction and discharge nozzle diameters, nozzle load values have been taken from API 610 (Table 4). In Existing design the coupling end shaft deflections found to be not in conformance with API 610 stiffness requirement. For the purpose of comparison and validate the experimental results, it was thought to cross verify against FE technique using ANSYS software.

4. FEA of Base Frame

FE analysis of base frame is carried out in order to investigate low stiff area of pump base frame.

4.1 FE Model

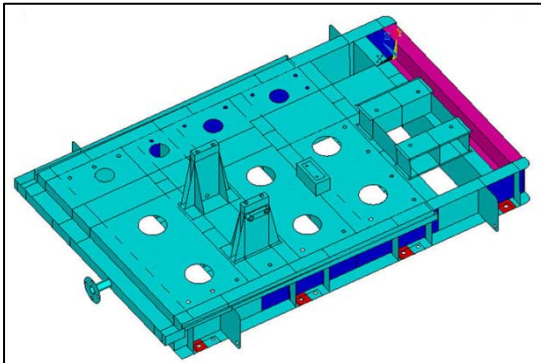


Fig. 3. ANSYS Model of Existing Base Frame Design.

In FEA optimum care must be taken in selection of proper element for analyzing the problem. For analysis SHELL63 element was used to model the base frame. BEAM4 element is used to model the lever. MASS21 element was used for Pump Casing. Pedestal mounting blocks are created by SLOSH190 element. The model is meshed using ANSYS 10.0 confirming that mesh is dense enough, so that results with required accuracy should be obtained and also it should be coarse enough such that the number of nodes and element should not be too large to solve for a computer used. The numbers of element generated are 119893 and the numbers of nodes are 119415. The meshed model along with loads and boundary condition are discussed section 4.3. Units of analysis were kg and μm .

4.2 Material Properties

Material grade used for pump base frame is **IS 2062 Gr.Fe 410B**. The Material properties are as listed in Table2

Table 2. Material Properties

Density	Young's Modulus	Poisson's Ratio	Ultimate Tensile Strength	Yield Strength
7850 kg/ mm ³	21000 kg/ mm ²	0.3	41.82 kg/ mm ²	25.50 kg/ mm ²

4.3 Boundary Conditions

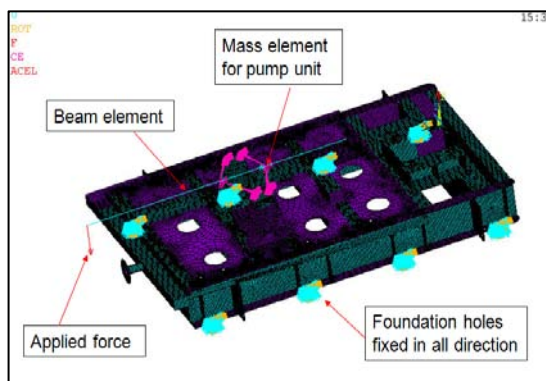


Fig. 4. Boundary Conditions for M_{ys} Load case.

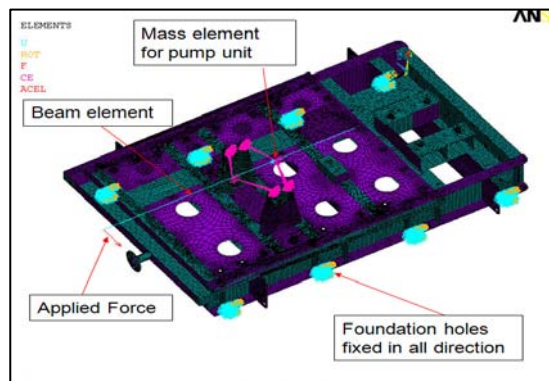


Fig. 5. Boundary Conditions for M_{zs} Load case.

Applying boundary conditions is the most important step in the Finite Element Analysis. Meshing and boundary condition for M_{ys} and M_{zs} load case is shown in Fig. 4 and Fig. 5. Eight foundation bolts are fixed in all direction (i.e. x, y, and z) as shown in Fig. 4 and Fig. 5. The beam element is used to transfer forces to mass

element. Mass element is connected to base frame pedestal using rigid elements. The resistance offered by structure is in terms of beam deflection.

5. Results and Discussions

5.1. Existing Design-Deflection Comparison

➤ Experimental Vs FEA

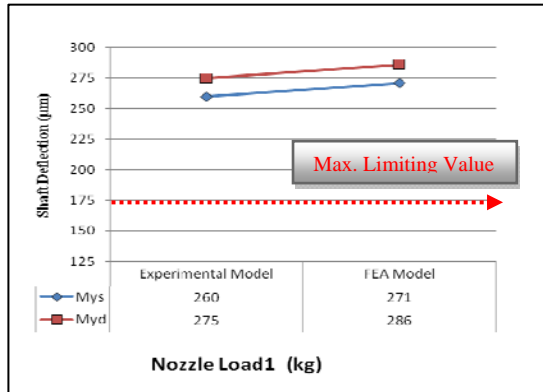


Fig. 6. Shaft Deflection for M_{ys} and M_{yd} Condition.

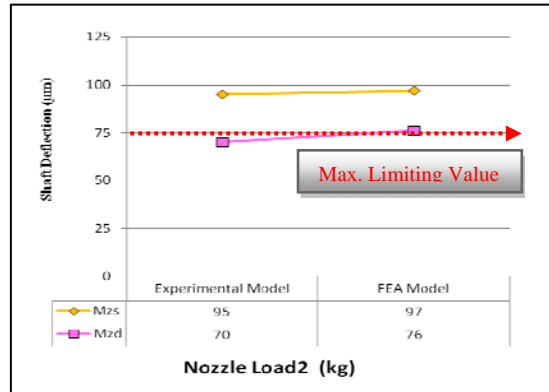


Fig. 7. Shaft Deflection for M_{zs} and M_{zd} Condition.

Experimental and FEA results of Existing design are shown in Fig. 6 and Fig. 7. From above graphs, it can be observed that the existing design is not meeting the stiffness requirements of API 610 (Higher than Maximum Limiting Values). After Analyzing Structural behavior of base frame, it is observed that effective increase in stiffness can be achieved by base frame redesigning. It is clear that base frame stiffness needs to be increased in X-Z plane. However, from the stress plot shown in Fig. 11, it was observed that the induced stress is low for existing design and there is good scope for design optimization.

5.2 Modified Design - Cases

The rigidity of base frame can be improved by any or combination of the following points

- Increasing number of stiffeners below Pedestal.
- Increasing number of slant ribs
- Changing “C” section to box-section of cross channels below Pedestal.

Accordingly, the potential design cases have been explored to ensure the design in accordance with API requirement. As a part of design optimization, lower channel sizes are considered while exploring the modified design cases. The descriptions of modified design cases are listed in Table 3.

Table 3. Modified Design Cases

Modified Design Cases					
Case No	I	II	III	IV	V
Description	Stiffeners below pedestal, without slant ribs	Stiffeners below pedestal, with two equidistant small slant ribs	Stiffeners below pedestal with rib inside pedestal box, with two equidistant small slant ribs	Stiffeners below pedestal, with one big slant rib	Stiffeners below pedestal with rib inside pedestal box, with one big slant rib

For above cases FE analysis has been carried out. From comparison of FE results of above cases, it is observed that the deflections for all the cases are significantly reduced with the best, in the Cases-IV and V. Hence only these cases have been presented in Fig. 8. However, Case-V is not feasible from Pedestal cooling perspective, as the rib inside pedestal box restricts the water circulation. Henceforth, Modified Design Case-IV, which looks to be the best practical solution, has been considered for test validation.

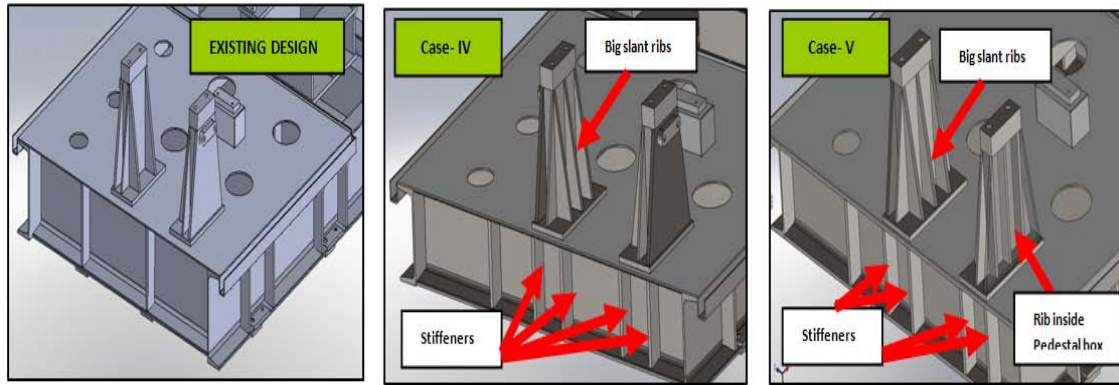


Fig. 8. Existing Design Vs Modified Design Cases.

5.3 Modified Design-Deflection Comparison

Following graphs show the deflection comparison between Experimental and FE results of modified design.

➤ Experimental Vs FEA

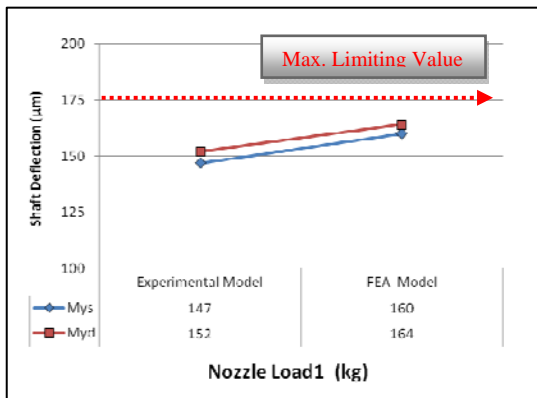


Fig. 9. Shaft Deflection for M_{ys} and M_{yd} Condition.

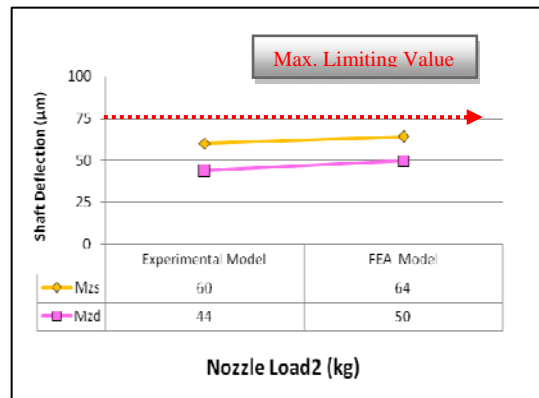


Fig. 10. Shaft Deflection for M_{zs} and M_{zd} Condition

Deflection results of Modified design are within acceptable limits of API 610 stiffness criteria. The stress plots for both the designs are presented in Fig. 11 and Fig. 12.

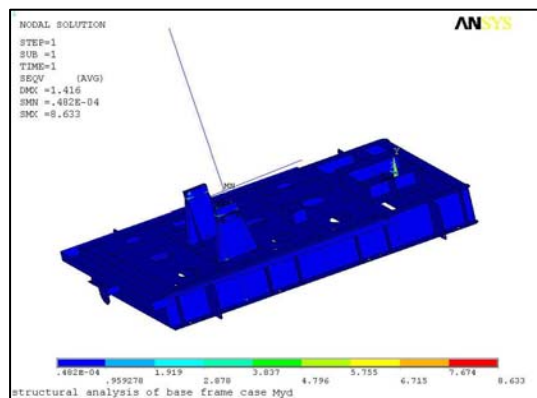


Fig. 11. Existing Design: $\sigma_{vm} = 8.63 \text{ kg/mm}^2$

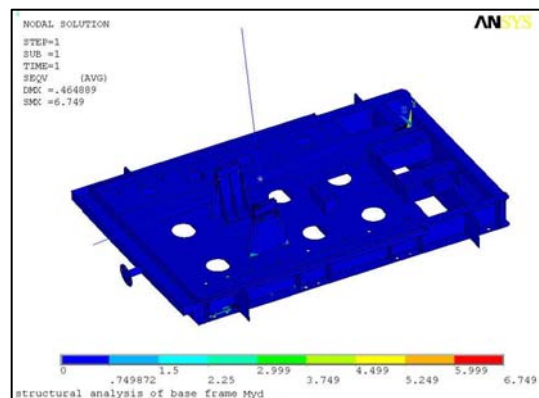


Fig. 12. Modified Design: $\sigma_{vm} = 6.75 \text{ kg/mm}^2$

The von misses stress (σ_{vm}) observed is maximum in existing design among all, for M_{yd} load case. It is 8.63 kg/mm^2 and shown in Fig. 11, where as for modified design it is 6.74 kg/mm^2 as shown in Fig. 12. In Modified design it is well below Yield point of Material; hence it is concluded that the design is safe and suitable for manufacturing.

6. Conclusions:

1) The Modified Design (Case-IV) is considered as the best design case which meets API 610 stiffness test criteria; it can be implemented for next fleet of pumps. 2) The smaller slant ribs have no significant effect on stiffness. 3) Since the bigger slant ribs have reasonably good effect on improving stiffness, the rigidity can be increased with more numbers of ribs. However, it has space implications. 4) In Modified Base Frame Design, the Von-mises Stress Levels are well below yield point, thus the design is safe with respect to load applied. 5) A weight reduction of 8.3 % of raw material cost is observed in present design improvement of base frame.

7. Acknowledgments

The authors like to express their thanks to the department of Mechanical Engineering of R.I.T. Sakharale, Maharashtra, India for their encouragement and support during this work.

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