Baseplate Structural Stiffness Analysis of API BB5 Type Centrifugal Pump for FPSO Application

Pramod H. Kadam
PG Student,
Department of Mechanical Engineering,
PREC, Loni, Maharashtra, India

Sanjay B. Belkar
Associate Professor,
Department of Mechanical Engineering,
PREC, Loni, Maharashtra, India

***Abstract*–This dissertation work is the presentation of static structural stiffness analysis of API BB5 type centrifugal pump when used in FPSO application. Offshore oil exploitation now accounts around one third of the world oil production and its growing faster than onshore sector. Designing of the pump baseplate for FPSO application becomes critical task due to absence of cement grouting, foundation bolts and space limitations for piping supports which ultimately results in excessive piping reaction nozzle loads and premature failures. Since the non-grouted type baseplate for this pump model is to be supplied first time in FPSO applications, it is necessary to perform the static structural stiffness analysis of the baseplate. The API 610 makes it mandatory to assure the stiffness or rigidity of the pumps baseplate supplied in Petroleum, Petrochemical and Natural Gas Industries. The clause 6.3.5 of API 610 specifies details for conducting the structural stiffness testing of the pump baseplate when subjected to different nozzle load cases. This dissertation involves study of existing baseplate design guidelines and do necessary design changes to meet the non-grouted & twice the nozzle loads criteria. The theoretical study related to selection of baseplate structural members is carried out. Finite Element analysis by using ANSYS is completed to check the baseplate structural stiffness. During FEA some minor design modifications are carried out to have the best feasible design solution. Also the experimental analysis for validation of baseplate structural stiffness, under application of different load cases is completed. The results of these analyses will be in terms of shaft coupling end displacement. API 610 also defines the allowable limits for the shaft displacement. The results from both the analysis are further discussed and published.**

Keywords-Centrifugal Pump Baseplate, Structural Stiffness, API 610, Nozzle Load, FPSO, Non-grouted, Finite Element Analysis, ANSYS, Experimental analysis, Turnbuckle.

I. INTRODUCTION

Generally the pump baseplates are always designed as 'grouted type'. This cement grouting overcomes the effects of uneven foundation. The loads from pump pedestal are transferred to baseplate and finally to grout [5]. The grouting helps to reduce the vibration, deflection and noise of the whole pumping unit. Along with the concrete grouting, the foundation bolts secure the baseplate firmly to ensure vibration free pump performance [3]. When the pump needs to be installed on the FPSO, the baseplate needs to be designed as 'non-grouted type' [4]. Whenever pumps are supplied for petroleum, petrochemical and natural gas industries the compliance to API 610 standard is mandatory. Nozzle loads exerted on pump nozzles are the resultant forces and moments due to heavy, long piping, thermal expansions, loads due to less piping support etc. Generally when pump is installed in refineries, either hydrocarbons, condensate or gases are flowing through the pipes. The excessive nozzle loads results in high vibrations which can further leads to shaft misalignments, mechanical seal failures, bearing heating, wear rings galling etc. Such adverse effects will increase the maintenance works. In severe cases the pump failures may result in complete plant shutdowns. Considering the importance of these piping loads, the refinery engineers have worked out the maximum allowable forces and moments for each nozzle size and orientation, for which the pump & baseplate needs to be designed as a minimum. API 610 table 4 provides details of the allowable forces & moments [1]. The only option to minimize the piping load effects causing the misalignment between pump and motor shafts is to design the pump & its baseplate with sufficient structural stiffness, so that the pump shaft end displacement is well below the allowable values specified in the table 12 of API 610.

Presently very less research work is available related to design of pump baseplates in FPSO applications. Hence in this project the work is completed in following steps - 1) To study theoretical concepts related to baseplate structural stiffness, selection of baseplate structural members 2) Structural stiffness analysis of this complex Baseplate through Finite Element Analysis. Use of ANSYS to decide potential modifications & measure the shaft end displacement under application of different moment loads 3) Identify best feasible design solution and release the baseplate for fabrication 4) Experimental analysis of the fabricated baseplate, to measure the shaft end displacement under application of different loads cases 5) Review, compare and validate the results obtained through both FE analysis and experimental analysis.

II. BASEPLATE LONGITUDINAL AND CROSS MEMBER SELECTION

The longitudinal members are the main load carrying components of the baseplate. Here two nos of longitudinal members are required to fabricate the baseplate. Various sizes are available in the Indian Steel market & their specifications are governed as per the Industry Standard: IS 808. It is good practice to arrange the channel sections with the toes pointing outwards, to allow simpler cutting and welding. While the cross members are required both below the pump & driver pedestal. Cross members must be located so that they are aligned closely with the pump pedestal to transfer the nozzle loads.

These beams are selected based upon the maximum deflection, assuming as fixed beam subjected to uniformly distributed loads as shown in below figure.

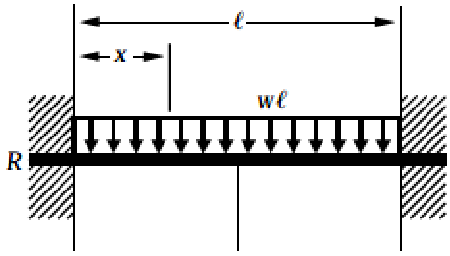

Fig. 1. Beam fixed at ends & subjected to uniformly distributed load

The maximum deflection is calculated by using equation,

δ max = (w * l^4) / (384 E x I) (1)

wherein δ max –Maximum deflection, w-load per unit length, l-Length of beam, E-Young's Modulus, I-Moment of inertia.

III. API 610 BASEPLATE DESIGN AND STIFFNESS TEST ACCEPTANCE CRITERIA

For the pumps to be supplied in petroleum or petrochemical industries, the API 610 standard provides details of the allowable forces and moments to be applied on pump nozzle based upon the nozzle opening size & orientation. The subject pump baseplate of interest is to be designed to suit twice the forces and moment values as specified in API 610 table 4. The standard also guides over the co-ordinate system to be followed to apply the nozzle loads for these BB5 type pumps. The baseplate structural stiffness is checked in terms of the pump shaft end displacement under different load cases and the test acceptance criteria shall be as per the below table [1].

Myc and Mzc equal the sum of allowable suction and discharge nozzle moments from API 610 [1]. These are calculated as below -

Myc=(My)suction+(My)discharge (2)

Mzc=(Mz)suction+(My)discharge (3)

TABLE I. NON-GROUTED BASEPLATE STIFFNESS TEST ACCEPTANCE CRITERIA AS PER API 610

Loading condition	Pump shaft allowable displacement µm (mm)	Direction of displacement
Myc	125 (0.125)	+Z
Mzc	50 (0.050)	-Y

From the co-ordinate system, API 610 considers only two loads cases, Myc and Mzc. Since under Mxc moment loading condition, there will not be any effect on shaft deflection, this loading condition is not considered [1]. In case of load cases wherein the moment will be applied about Y-axis (Myc), the deflection will be measured in Z-axis direction. Similarly the load cases wherein the moment will be applied about Z-axis (Mzc), the resulting deflection will be measured in Y-axis direction.

IV. FINITE ELEMENT ANALYSIS

The pump shaft end displacement measurement for checking the baseplate stiffness is performed by means of the finite element program ANSYS Workbench Environment Version 15.0.

A. Baseplate FE Model Geometry and co-ordinate system

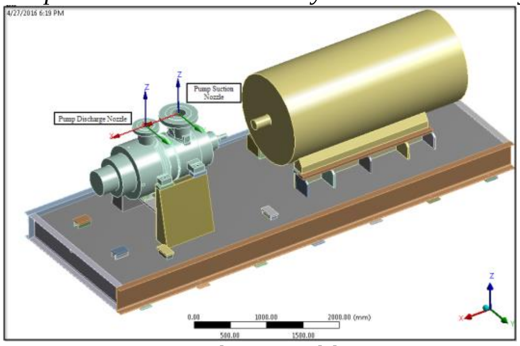

Fig. 2. Finite Element Model Geometry

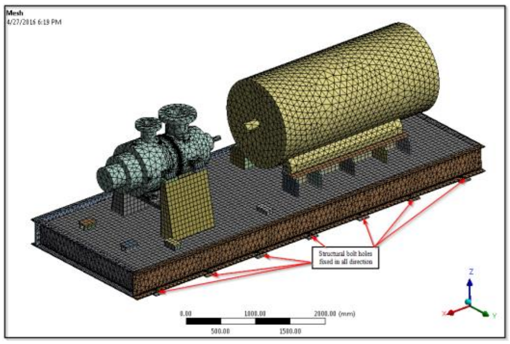

Fig. 3. Finite Element Meshed Model

The baseplate model is first prepared in AutoCAD and this external geometry is imported for static structural analysis by converting to file type Parasolid (*x_t). Unit of analysis are moment in N-m and displacement in mm.

B. Baseplate Material Properties

The material grade used for the fabrication of pump baseplate is 'IS 2062 Gr B'. The material properties are as listed in below table.

TABLE III. BASEPLATE MATERIAL PROPERTIES

Young's Modulus	Poisson's Ratio	Density
2.0 x 10^5 N/mm^2 (MPa)	0.3	7850 kg/m^3

C. Applicable nozzle loads

As per the project special requirement we need to apply the moments twice the values specified in the API 610 table 4. The details of the same are mentioned in the below table.

TABLE III. APPLICABLE NOZZLE LOADS

Description	Nozzle Size (mm)	Moment @ Y-axis (N-m)	Moment @ Z-axis (N-m)
Pump Suction Nozzle	250	4880	7600
Pump Discharge Nozzle	150	2360	3520

D. Different load cases

In total four different loading conditions are to be analyzed for shaft displacement as mentioned below.

1) Moment Myc applied to pump suction nozzle & discharge nozzle:

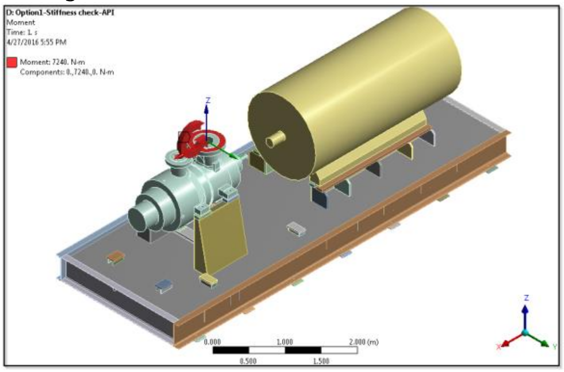

Fig.4. Moment Myc applied about Y-axis of the suction nozzle

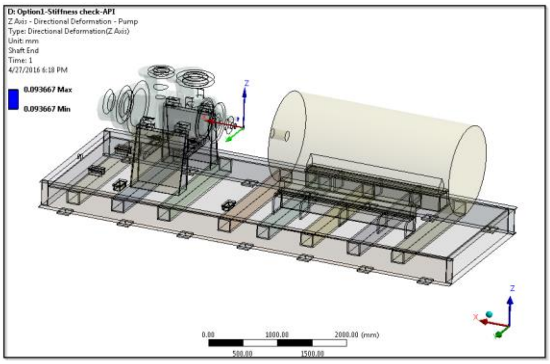

Fig.5. Shaft end displacement due to Moment Myc applied about Y-axis of the suction nozzle

The above figs 4 and 5, indicates the details of load case where Myc applied to suction nozzle. Similar arrangement will be used for application of Myc to discharge nozzle.

2) Moment Mzc applied to pump suction nozzle & discharge nozzle:

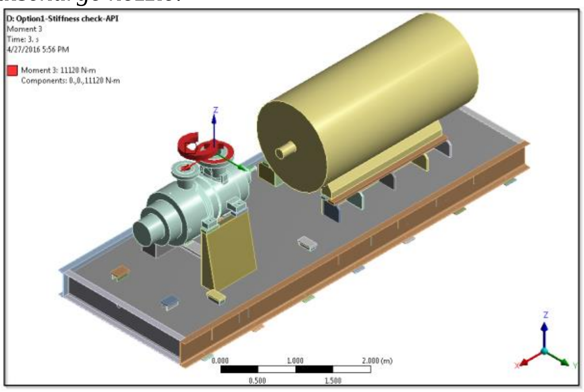

Fig.6. Moment Mzc applied about Z-axis of the suction nozzle

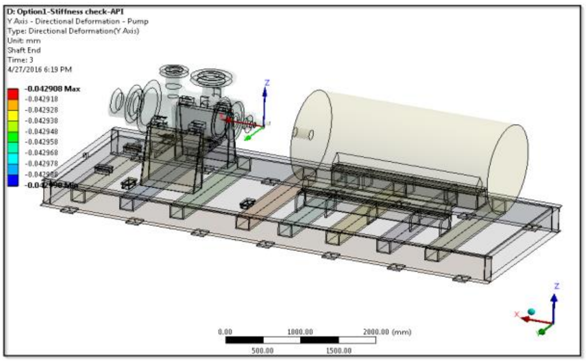

Fig.7. Shaft end displacement due to Moment Mzc applied about Z-axis of the suction nozzle

The above figs 6 and 7, indicates the details of load case where Mzc applied to suction nozzle. Similar arrangement will be used for application of Mzc to discharge nozzle.

The finite element analysis for all the four different load cases indicates the pump shaft end displacement within allowable limits.

V. EXPERIMENTAL ANALYSIS

After the theoretical & finite element analysis of the subject pump baseplate of interest, the experimental analysis is also carried out. The basic purpose of this exercise is to practically apply the nozzle loads under different load cases & then check whether the pump shaft displacement is within the acceptable limits or not. This will also have the validation of the theoretical & finite element analysis outputs.

A. Experimental Setup

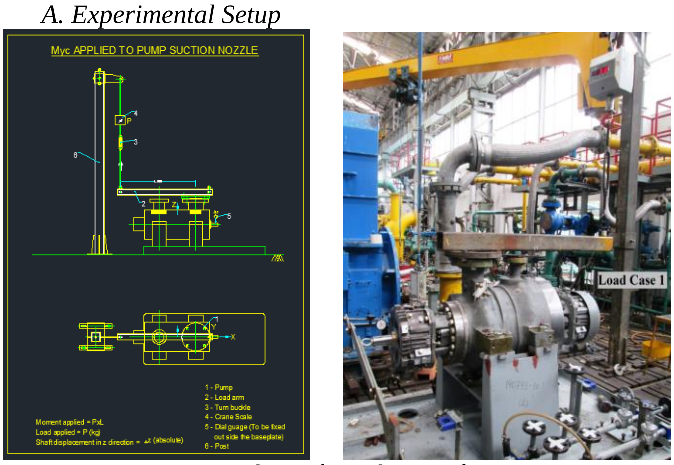

Fig.8. Experimental setup for application of moment Myc

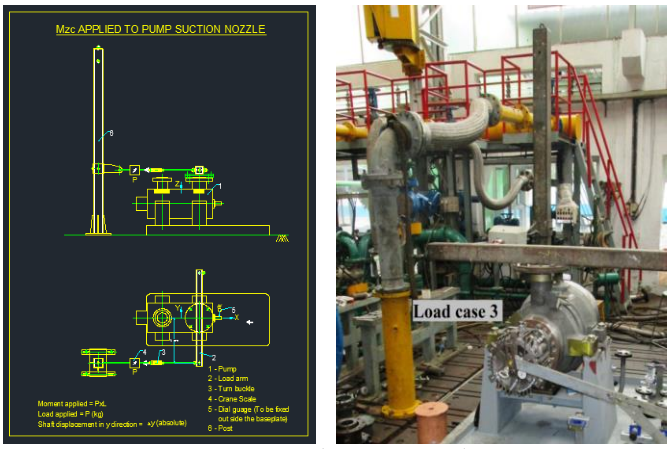

Fig.9. Experimental setup for application of moment Mzc

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 09, September-2016

The figs 8 and 9, indicates the experimental setup for applying moment at suction nozzle. Similar arrangement will be used for applying moment at discharge nozzle.

B. Experimental Procedure

The procedure is intended to apply the flange loadings on the pump nozzles fixed on the baseplate unit in line with the API 610 /10th edition guidelines. The pump is fixed on the baseplate pedestal by use of the mounting bolts. The baseplate securely anchored to test bed foundation by positioning fasteners near the holes provided in the longitudinal beam for the structural bolts. The special test flange is mounted on either of the pump flanges (suction or discharge) & bolted to torque arm. This torque arm will be further coupled with the Turnbuckle and Crane scale. This crane scale is further coupled either to the holding post (for Mzc load cases) or to overhead crane (for Myc load cases).

The moments Myc & Mzc are to be applied to either nozzle, but not the both, such that the corresponding shaft displacements can be measured & recorded [1]. Myc & Mzc shall not be applied simultaneously to either nozzle [7]. The torque arm length is known and to apply the required moment, the load / tension is adjusted by use of the turnbuckle and the crane scale. Dial indicator are to be located at the coupling end of the pump shaft and supported by separate mounting structure to get absolute displacement readings [1] [7]. The displacements are recorded for each load case & compiled data is then verified against the API 610 acceptable limits as well as with the outputs of the finite element analysis. Here also in total four different loading conditions are analyzed for shaft displacement similar to that of finite element analysis.

Myc applied to pump suction nozzle & discharge nozzle [1]

Mzc applied to pump suction nozzle & discharge nozzle [1]

The shaft end displacements observed via experimental analysis are slightly higher than through finite element analysis, however are within API allowable limits.

VI. RESULTS REVIEW AND DISCUSSIONS

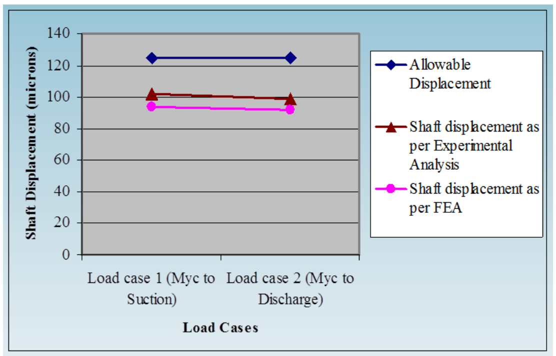

Fig.10. Shaft displacement due to moment Myc

In load case 1 and load case 2, the moment about Y-axis was applied on suction or discharge nozzle, to create the shaft displacement in Z-axis direction. The results of shaft displacement, both by finite element analysis and experimental analysis are represented in chart format in fig 10.

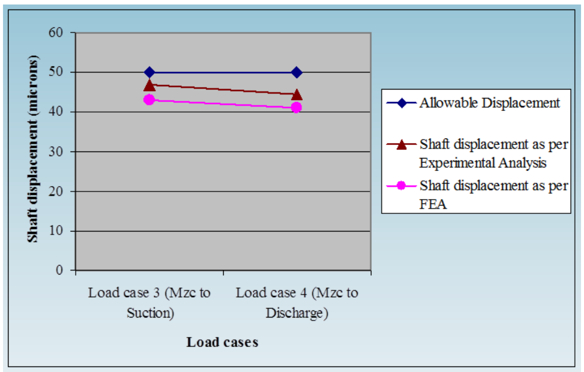

Fig.11. Shaft displacement due to moment Mzc

Similarly in load case 3 and load case 4, the moment about Z-axis was applied on suction or discharge nozzle, to create the shaft displacement in Y-axis direction. The results of shaft displacement, both by finite element analysis and experimental analysis are represented in chart format in fig 11.

From both of the above charts it is clear that the shaft displacement observed in all four load cases is well below the API 610 allowable limits. Also it is observed that the shaft displacement values obtained during experimental analysis are higher than the values from finite element analysis. The final combined results are as per below table.

TABLE IV. FINAL RESULTS

Load Case	Shaft allowable displacement (mm) / Direction	Shaft displacement as per FE Analysis (mm)	Shaft displacement as per Experimental Analysis (mm)	Result Remarks
1.Myc to suction nozzle	0.125 +Z	0.09366	0.102	Passes API Criteria
2.Myc to discharge nozzle	0.125 +Z	0.09158	0.099	Passes API Criteria
3. Mzc to suction nozzle	0.050 -Y	0.04299	0.047	Passes API Criteria
4. Mzc to discharge nozzle	0.050 -Y	0.04108	0.044	Passes API Criteria

VII.CONCLUSION

1) Designing pump baseplates in FPSO applications is more critical due to absence of grouting and foundation bolts. 2) The excessive nozzle loads results in high vibrations which can further leads to shaft misalignments, mechanical seal failures, bearing heating, wear rings galling and other undesirable effects. Such adverse effects will increase the maintenance works. 3) To overcome these problems the pump baseplate needs to designed with sufficient structural stiffness. API 610 standard guides for this stiffness testing method and also specifies the allowable pump shaft coupling end displacement limits as a measure of baseplate stiffness. 4) The baseplate static structural stiffness analysis by using theoretical manual calculations has limitations due to the complex fabrication structure of the baseplate. 5) The finite element analysis by using ANSYS is useful for the structural stiffness

analysis of such complex baseplate. The method provides more accurate results. The shaft end displacements, under different piping load cases are observed within acceptable limits. 6) Experimental analysis completed to validate the results of finite element analysis. The resulting shaft end displacements through the experimental analysis are also within acceptable limits, however slightly higher than the finite element analysis displacements. The possible reasons shall be application of slightly higher moments, possible loosening of clamps -bolts used to fix baseplate on the test bed or cumulative fabrication tolerances in the complete experimental setup. 7) The shaft end displacement results of both finite element analysis and experimental analysis are within the allowable limits and pass the API 610 stiffness test criteria. Hence it is concluded that the subject baseplate of API BB5 centrifugal pump is designed with sufficient structural stiffness to get installed in 'FPSO' application.

ACKNOWLEDGEMENT

The author likes to express thanks to all concerns from department of Mechanical engineering, PREC-Loni, Maharashtra, India for their assistance, encouragement and honest support to complete this project.

REFERENCES

[1] API 610, "Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries" 10th edition, American Petroleum Institute, Washington, D.C, 2004

[2] Thomas F.Kaiser and Richard H.Osman, "Analysis Guide for Variable Frequency Drive Operated Centrifugal Pump", Twenty fourth international pump users symposium, TX, USA, 2008,

[3] Greg Towsley, "Foundations" White paper published in Grundfos Pumps journal, 2009

[4] David Sear and Suriyanty Pushpadewi, "Critical pumps on FPSO", Pump Engineer Magazine, 2004

[5] Todd R. Monroe & Kermit Palmer, "Prefilled Equipment Baseplates-How to get a superior Equipment Installation for Less Money ", Nineteenth international pump users symposium, 2002

[6] T.F.Kaiser, F.M.Hauck, "Nuclear Waste Cross Site Transfer Pump Operational Resonance Resolution", prepared for the U.S. Department of Energy, Fluor Daniel Hanford, 1999

[7] James E.Steiger, “API 610 Baseplate & Nozzle Loading Criteria", Third international pump symposium, 1998