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Free Vibration Analysis of a Motor Operated Gate Valve for Nuclear Application Using Finite Element Analysis

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Abstract

Motor operated gate valves are the important components responsible for maintaining hassle free operation for any process industries as well as power sectors by controlling flow of various fluids through it. The current study discuss about design and analysis of motor operated gate valves to be used for nuclear application. The design of various flow control valves including gate valves are governed by various standards and codes to name a few American Society for Mechanical Engineers (ASME) and American Petroleum Institute (API). These guidelines for valve design are adequate to develop a valve which is to be employed for standard flow control application. The same valve when used for nuclear application specially on reactor side where it is exposed to nuclear radiation as well as responsible to handle contaminated fluid from nuclear radioactive waste, the operability with high reliability to operate under the worst circumstances like event of natural hazard like earth quake becomes prime important. Therefore, Finite Element Analysis has been carried out for Motor Operated Gate Valve. The critical dimensions of the valve have been obtained for 3 inch class 600 valve based on ASME codes and API standards. 3D CAD model has been prepared and used as input for the FE analysis used for validating the design for nuclear application. Loading and boundary condition for the analysis is obtained from the Nuclear power corporation of india limited (NPCIL) guideline. This study aims at improvement in design of Motor Operated Gate Valve for nuclear application with an emphasis to increase the fundamental natural frequency.

Keywords: Motor operated gate valve, Free Viberation analysis, FE analysis.

1. Introduction

Valve is the component in a fluid flow or pressure system that regulates either the flow or the pressure of fluid in the system. This process may involve stopping and starting of flow, controlling pressure, or reliving pressure in the normal application. Varity of valves are available to control and regulate the flow like, Gate valve, Globe valve, Check valve, Plug valve, Needle valve, Butterfly valve. Power generation using nuclear fission process in nuclear power plant involves critical network of piping system which carries water and converted steam driving the turbine for power generation. The process equipment of nuclear power plant is categorized mainly in two groups which is Reactor side equipment and non reactor side. The valves used to control flow of steam or water for the nuclear application especially on reactor side, needed to be designed and analyzed critically as it falls under the components responsible for high risk factor in the period of emergency of natural disaster.

M.S. Kalsi and J.K.wang[1] have derived formulation to calculate motor thrust required for opening and closing motor operated gate valve. Robert Steele, Philip E Macdonald and James G Arendts[2] have showed the dynamic load effect on gate valve operability and also measured the effect of hydraulic load and dynamic load on gate valve during series of representative seismic events. They have performed experiments in seven different types of piping support system. Dae-Woong Kim, Sung-Geun Park, Sang-Guk-Lee, Shin-Cheul Kang[3] have analysed the effect of change in differential pressure on stem friction coefficient and determine the bounding value of stem friction coefficient. Dae-Woong Kim, Sung-Geun Park, Shin-Cheul Kang, Yang-Suk Kim[4] have analysed the rate of loading (ROL) phenomenon which occurs during the operation of motor operated valve under fluid pressure condition. During rate of loading the power transmitted from actuator to stem reduces. Shincheul Kang, Sungkeun Park, Dohwan Lee, Yangseok Kim, Daewoong Kim [5] has been given methodology to calculate stem friction coefficient of safety related motor operated gate valve and performed operation with different lubricant and different glob and gate valve. This paper work focus on analysis of motor operated Gate valve for nuclear application. Design of Gate valve will be carried out based on related standards for nuclear application. The design obtained through the standards has to be validated for the nuclear application as failure of the operability under the disasters like flood, earth quake, storm leads to danger to human being.

2. Design of Gate valve

3 inch class 600 valve has been selected for the present work. According to ASME B16.34 [7] the valves are classified according to its pressure and temperature limit for the specific material. Standard valves are design in accordance with API 600 [13]. This code give the critical dimension of gate valve. According to API 600 [13] minimum wall body thickness tm for 3 inch class 600 is 12.7 mm. In this design minimum wall body thickness tm assume as 13 mm. Gate valve is having raised face end, dimension for flange ends raised face is 7 mm. Face to face dimension of the gate valve in accordance with ASME B 16.10 [14] is 14 inch. From API 600 Table-4 [13] inside

minimum diameter of seat is 76 mm. From API 600 Table-6 [13] inside minimum stem is 25.4mm. Based on calculation as per standards, the 3D solid model has been prepared for various components and assembly for 3inch class 600 valves has been prepared as shown in figure 1.

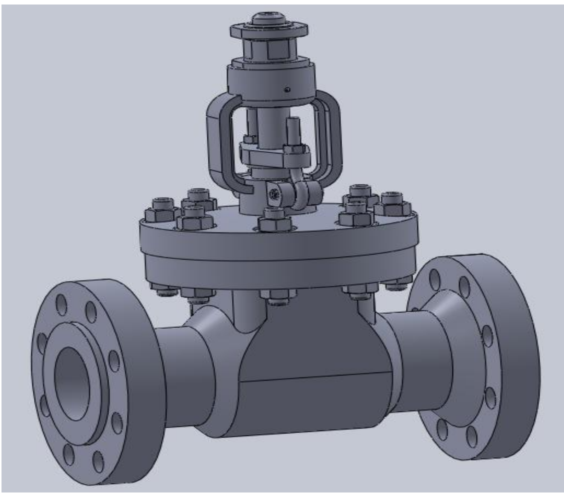

Fig. 1: Design of gate valve

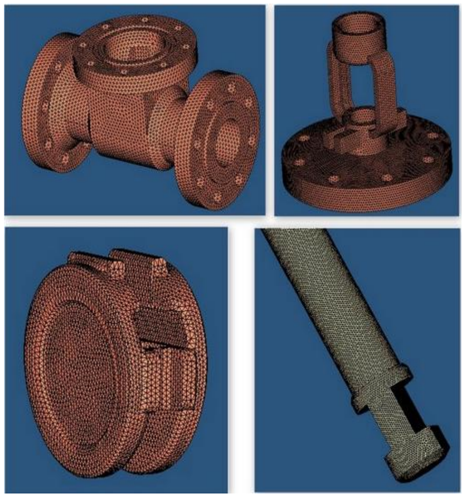

Fig. 2: Meshed components of motor operated gate valves

As the valve is operated using electrical actuator, it is required to calculate the torque required to operate the valve and select the suitable actuator for the same. In order to calculate the torque, following parameter are considered. For these parameters the total torque requirement is 101.15 N-m.

Bore diameter = 3 inch

Differential Pressure = 1480.83 psi

Stem diameter = 1 inch

3. FE Analysis of Valve Assembly

All major components of valve assembly i.e. body, bonnet, stem, and gate has been meshed with 3D tetrahedron element is shown in figure 2

The suitable connection has been created within the meshed component. In order to simulate the model precisely, the valve actuator consisting of actuator motor and gear box has been simulated as a lumped mass of 49 Kg and located at suitable co-ordinates representing the approximate center of gravity of actuator assembly. The lumped mass of actuator is connected rigidly with the top flange of the bonnet in order to obtain the effect of the normally mounted actuator on the fundamental frequency of the valve assembly. The position of gate for the analysis is kept in closed condition. Figure 3 shows the final assembly of meshed component.

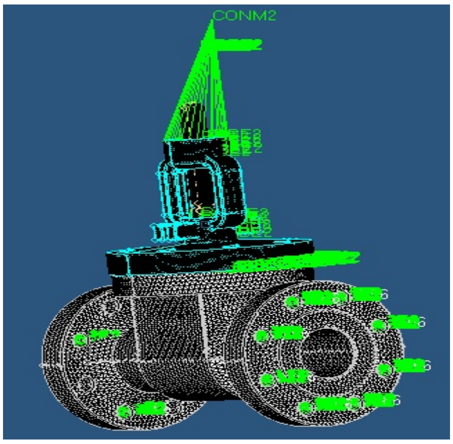

Fig. 3: Boundary conditions for analysis.

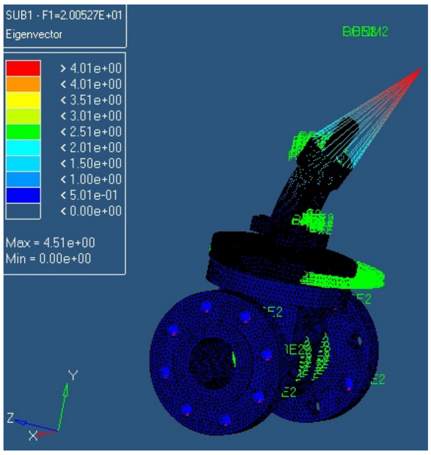

Fig. 4: Fundamental natural frequency.

The FE result as shown in figure 4 shows that the first natural frequency of the designed valve assembly is 20 Hz, which as per NPCIL guidelines falls under the category of flexible assembly. However in order to have more robust and reliable valve assembly, it is recommended to have rigid valve design that requires natural frequency more than 33Hz which is needed for better performance compare to flexible one in case of worst seismic loading condition and hence modifications are done in valve assembly.

4. Design Iterations in Valve Assembly

The valve assembly is modified to achieve the fundamental frequency of the vibration above 33Hz. For that design iterations are carried out and after each modification in valve assembly FE analysis has been carried out for natural frequency to achieve the required natural frequency which will have the desired response under loading condition.

4.1 First Design Iteration

The result of the first fundamental frequency and associated mode shape shows that under resonance condition the valve will have a tendency to vibrate with respect to XY plane as shown in figure 4. Thus in order to reduce the compliance of the assembly the modification has been carried out in such a way that the bending resistance of the assembly with respect to XY plane should increase. Increase in thickness of the valve body will increase the cost of the component significantly. Thus it is advisable to focus the design modification to other part of the valve assembly. The mode shape result shows that the valve is more susceptible to deformation under the resonance condition at the fundamental frequency, thus if the section modulus of the bending of bonnet with respect to XY plane is increase, the valve will tend to behave as rigid component. The section modulus of bonnet side rib is increased compare to original design and again FE analysis has been carried out.The comparison between the original and proposed design is shown in figure 5.

The FE Analysis is carried out considering the same boundary condition as that of the previous case along with the same FE methodology (i.e. Lumped mass approximation of actuator assembly). The FE analysis results shown in figure 6 shows that the first fundamental frequency as 31.3 Hz. This indicates that further modification is required in valve assembly.

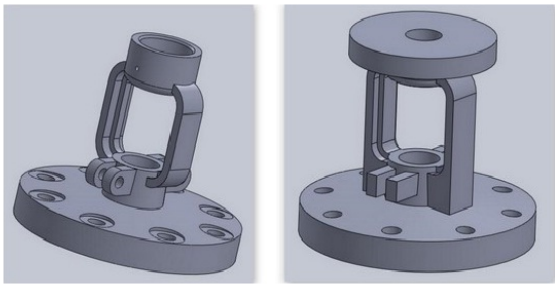

Fig. 5: Comparison of original and design I

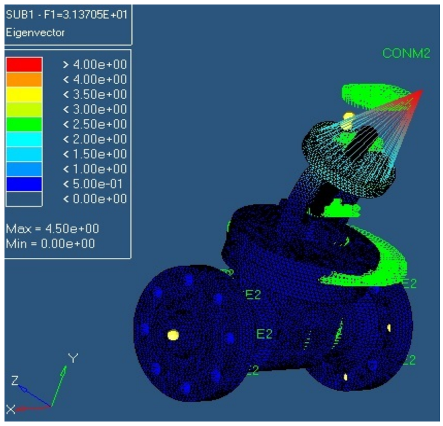

Fig. 6: Fundamental natural frequency.

4.2 Second Design Iteration

The upper rib of the bonnet is modified and the thickness along the radial direction has been increased. The modified design of the bonnet for the second design iteration in comparison to first design iteration is shown in figure. The FE result of first fundamental frequency is 33.5 HZ though the frequency is above 33.5 Hz but for the safety margin, it is desirable to achieve it higher compare to the current analysis result.

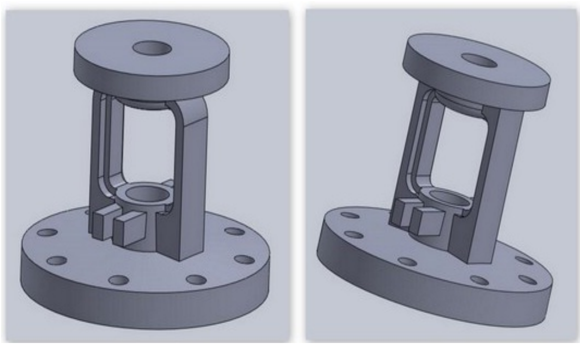

Fig. 7: Second design iteration

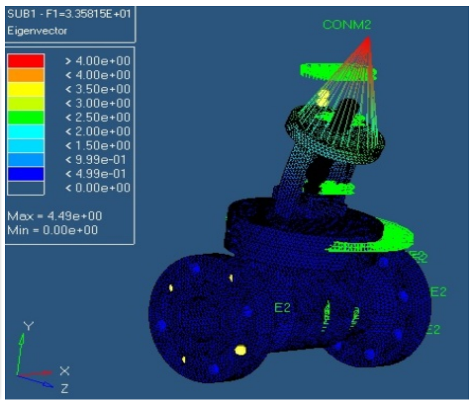

Fig. 8: Fundamental natural frequency

4.3 Third Design Iteration

The base of the rib of the bonnet is modified and the thickness along the radial direction has been increased. The modified design of the bonnet for the third design iteration in comparison to design iteration II is shown in figure 9. Here increase of thickness along redial direction at more height will not affect the frequency that much as shown in previous case, therefore the thickness at base has been increased. The FEA result of first fundamental frequency is 45.8 Hz as shown in figure 10. This frequency is higher than the limit as specified in the NPCIL guideline which is 33 Hz, thus this assembly is a rigid assembly. This result is for the valve in the close condition and analysis for the assembly in the gate open condition is also required. As the valve is operated, the stem along with the gate is moved in the vertical direction this will cause the mass distribution within the assembly. As the mass moving in the direction above the fixed portion of the valve assembly, it will tend to lower the natural frequency of system compared to the close position. The fundamental frequency of the valve assembly in open condition was also evaluated using FE software using same methodology.The FEA result shows that the first natural frequency is 40.1Hz in the open condition. Thus in the worst case the natural frequency of assembly is above 33 Hz.

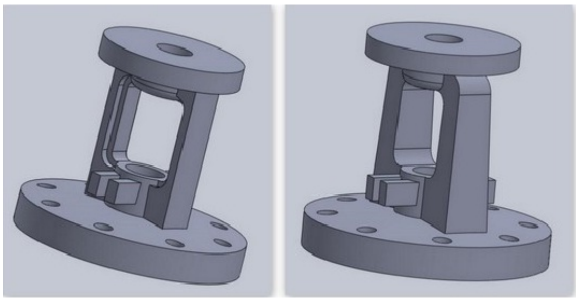

Fig. 9: Comparison of second and third design iteration

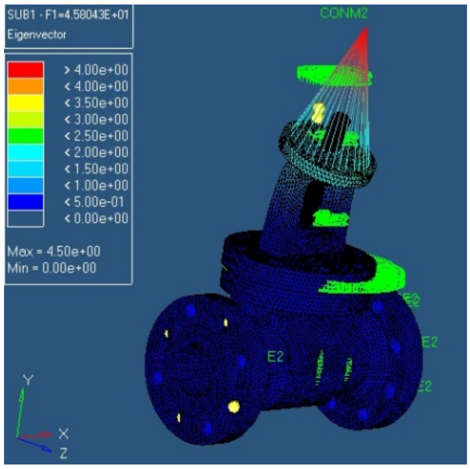

Fig. 10: Fundamental natural frequency.

5. Conclusions

Based on ASME B 16.41 the code for testing the valve for nuclear application, the finite element analysis has been carried out for natural frequency analysis using CAE tool such as it will have its fundamental frequency greater than 33 Hz. As per the analysis results, the valve body dimension has been modified considering the non violation of the ASME codes and API standards. The modified design has again been validated using finite element analysis, and the natural frequency under worst case condition is obtained as 40.8Hz which will qualify the valve assembly as rigid valve assembly. Weight of bonnet was increase up to 27.42 %.

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[6] Nuclear Power Corporation of India Limited, specification no.:pp.1819.

[7] ASME B 16.34

[8] QME-1, Qualification of active mechanical equipment used in power plant, 2007

[9] ASME B 16.41 functional qualification requirement for power operated a valve assemblies and nuclear power plant.

[10] ASME SECTION III NB CODE

[11] ASME SECTION II, PART-D

[12] ASME B 16.5

[13] API 600

[14] ASME B 16.10

[15] ASME B 16.20

[16] ASME B 18.2.2

[17] ASME B 16.25