Design and Analysis of Industrial Ball Valve using Computational Fluid Dynamics

P. Ebenezer Sathish Paul, G. Uthaya Kumar, S. Durairaj, D. Sundarrajan

Abstract: Computational Fluid Dynamic analysis is carried out to establish a robust affiliation between the design variables of material design domain and product design domain. The CFD analyses performed for both ball valve and gate valve is necessitated with input parameters that outfits the application such as pressure, density, viscosity and temperature. The maximum pressure acting over diverse regions of the valve system that crop up due to fluid flow was examined by the extension of pressure concentration for different fluids viz. water, lubricant and diesel. The analysis is presumed to be conversant with material selection strategies that satisfy the criterions for the new product development and therefore well defined inputs inclusive of virtual solid model, boundary conditions are promoted with higher grade mesh resolutions. In these cases, approximate selections are exercised and numerical scheme of properties has been adhered to embrace perfection in simulation analysis. The CFD study exemplifies accurate regions wherein maximum pressure assaults the valve body and so the observations originate to ascend product development without the expense of physical testing. The verification studies put forth for the pressure distribution generated due to fluid flow through the valve system is in stripe with end results. Furthermore valve deformation and valve performance is obligatory for material and product design integration and hence customary predictions is done by coupling the CFD results with finite element analysis.

Keywords: CFD, Ball Valve, FEA

I. INTRODUCTION

Valves are components which controls the fluid flow and pressure of a system. Types of applications for valves differ on their own and are normally used on safety and flow control grounds. While these valves are used for flow control, it is obvious that the dynamics of the valve and its control loop has to match strictly with dynamics of the control system. In the course of study on these facets it is over and done with establishment of relationship between valve positions, pressure drop and flow which is commendable as highly non-linear. The able-bodied documentation of valves is not admirable for the reason; these facts features technical hitch to predict the properties down or up-sized. In any flow system the familiar flow restrictors are the valves and hence its design and performance analysis will be a significant task. The selection of the valve types, design and material plays a vital role in its performance and reliability. A number of researches have been experimented in valves for its shape, size, fluid types, operating parameters, discharge coefficient, and eroding characteristics for the improvement of valve technology.

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It is quite disturbing that detailed investigation was not done over the integration of material design and valve design to suit a specific functionality. This research work is focussed on establishment of relationships between the design variable of both material and product design domains. Computational fluid dynamics a powerful analysis tool is utilized to compute flow restrictions in the form of resistance co-efficient and flow volume co-efficient.

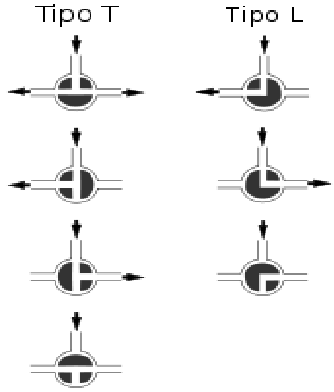

Fig. 1 WAY BALL VALVE L-SHAPED BALL RIGHT, T-SHAPED LEFT

In CFD analysis the pressure distribution across the required area is analyzed by gratifying the boundary condition applied. In order to perform the design, optimization and the analysis of the valve performance, for a particular application dynamic fluid analysis is performed on two types of valve viz. stem valve and ball valve. Valve body is chosen for generating relation between type of fluid flow, geometry and pressure loses using CFD, since they have a simple mechanical construction, utmost exposure during fluid flow, attains critical deformation, and more importantly, give a low head loss. CFD analysis is capable to reveal the complex flow structure and the sonic characteristics around the valve, which the experiments hardly ever provide. Even otherwise, experimentation needs to be supplemented with CFD analysis because of intricate geometry as well as complexities like turbulence during the sonic flow through a valve.

II. LITERATURE SURVEY

Industrial ball valve is designed by integral formulations, differential formulations and also computer simulation is needed for validating every result computational fluid dynamic has been used as research and design tool in the modeling of ball valve. A search on the different simulation models from literature are given as follows:

Ying Sun et al [1] have predicted that the fundamental equations of thermodynamics, a new method proposed in this paper gives comprehensive consideration of the various factors, such as heat transfer, leakage, gas pulsation and valve motion, that influence the working process of the compressor and establish all the mathematical simulation equations. By using numerical computation, the thermodynamic parameters which govern the working process of the compressor and the macroscopic thermodynamic performances, such as capacity, power and specific power in the compressor can be found. The results of the computation are in good agreement with practical measurements and the correctness and applicability of the proposed method are demonstrated.

A.S.Tabrizi et al [2] have predicted that the ball valve performance is numerically simulated using an unstructured CFD (Computational Fluid Dynamics) code based on the finite volume method. Navier-Stokes equations in addition to a transport equation for the vapor volume fraction were coupled in the RANS solver. Separation is modeled very well with a modification of turbulent viscosity. The results of CFD calculations of flow through a ball valve, based on the concept of experimental data, are described and analyzed. Comparison of the flow pattern at several opening angles is investigated. Pressure drop behind the ball valve and formation of the vortex flow downstream the valve section are also discussed. As the opening of the valve decreases, the vortices grow and cause higher pressure drop. In other words, more energy is lost due to these growing vortices. In general, the valve opening plays very important roles in the performance of a ball valve.

Zhi-gang Su et al [3] have predicted that to achieve improvements in the production capacity and energy efficiency of an industrial tubular ball mill, a novel method, monitoring an unmeasured parameter (level of coal powder) and diagnosis of the operating modes of the mill, was proposed. Two accelerometers were installed on bearing housing to pick up the vibration transferred from the mill shaft. A system was designed to record the vibration signals and transfer them into energy amplitudes, by using a wavelet packet approach, based on the KINGVIEW program, as well as Visual C++ environment. Based on these, a series of experiments was conducted in a 250 MW power plant to investigate the vibration characteristics corresponding to the effects of different levels without air particle removal, milling times, and varying levels in practical working conditions.

The experimental results show that the operating modes of the mill, such as mill over-load, stable case, etc., can be diagnosed by proper interpretation of these vibration characteristics; and also the unmeasured parameters, i.e., level of coal powder filling the mill, can be monitored on line. Finally, methods for diagnosing operating modes and a model for on line monitoring of varying level by using a non-linear partial least square (NPLS) algorithm were presented. Combining the method and the model, we believe that the performance of ball mill can be improved.

Meng Shen et al [4] have fabricated and characterized a reciprocating polymethylmetacrylate (PMMA) ball-valve micropump actuated with a miniaturized cylindrical electromagnetic circuit. By finite element calculations, we have optimized the structure of the electromagnet that actuates a rare-earth permanent magnet embedded in a poly (dimethylsiloxane) (PDMS) pumping membrane. Powder blasting and conventional micromachining techniques are used for micropatterning the PMMA layers forming the microfluidic circuit. The self-priming ball-valve micropump exhibits a backpressure up to 35 kPa; water is pumped at a flow rate as high as 6.0 mL/min for a 2 W electromagnetic actuation power at the resonant frequency of 20 Hz. The actuation frequency-dependent flow rate is in excellent agreement with a damped oscillator model.

S. Bagherifard et al [5] have predicted that the failure of a sub-sea ball valve, used in an oil-piping line, is analysed. The valve was of the same type and material already used for the construction of valves that were worked in service without any problem. The valve failed in the first pressure cycles during the preliminary laboratory tests, although the applied pressure was less than the design value. Metallographic and microstructural analysis of the fracture surfaces performed by means of optical and scanning electron microscope (SEM), residual stress and hardness measurement, tensile, toughness and Charpy tests, were executed in order to identify the causes of the failure. The results allowed assessing that the failure was due to two concomitant factors: a severe notch effect and an incorrect thermal treatment.

G. Gokilakrishnan et al [6] have forecast the ball valve is a one way valve with a spherical disc, which controls the flow through it. Torque is the main factor for operating ball valves. Most of the ball valves require high operating torque for its operation, some external devices are required to overcome this torque. Hence more research is necessary to reduce the operating torque; thereby one can reduce manual effort. This paper deals with basics, advantages and disadvantages of ball valve, torque and its importance in ball valves, torque measuring and applying instruments used for ball valves.

Mahesh Kamkar A et al [7] have predicted that the valve is a mechanical device which regulates either the flow or pressure of the fluid. Among the different types of valves, high pressure ball valve finds use in certain application like industrial hydraulics and marine hydraulics. The present study involves designing the high pressure valve of nominal diameter 25mm (DN 25 and PN 350). When the flow line exceeds 150bar, the valves are known as high pressure valves. With the increasing the pressure, the design of various components of the valve become critical. The designing of high pressure ball valve components depends on pressure, temperature ratings and also other factors. The design calculation is done for sealing cup, ball, connection adaptor, valve housing and operating lever. The maximum stress and deflection is calculated for different sealing cup materials under high pressure. The torque required to operate the valve, which includes breaking torque, running torque and ending torque are calculated and compared with technical information from research case study.

Dong-Soo KIM et al [8] have predicted that the natural gas is being hailed as alternative energy sources for a petroleum, because it is almost no emissions of pollutants in the environment. Use of equipment for liquefied natural gas, along with increased demand for natural gas is also growing. Cryogenic ball valve is used to control the liquified natural gas which temperature is - 196^{0}C, supplied pressure is 168kg/cm^2. To acquire the safety along with durability of cryogenic ball valve, we should consider the structural mechanics such as stress, deformation and dynamic vibration characteristics and identify those important aspects in the stage of preliminary design engineering. For the cryogenic ball valve, the assurance of structural integrity and operability are essential to meet not only normal, abnormal loading conditions but also functionality during a seismic event. In this study, analytical approach and results using finite element analysis and computational method are herein presented to evaluate the aspects of structural integrity along with operability of cryogenic ball valve. Janusz Rogula [9] has predicted that the ball valves are used in places of pipelines where turn on/off of steam flow is needed. The leakage has influence on the system efficiency. Paper presents the results of investigations of the ball valve tightness. The basic assumption needed to be verified was, whether the leakage through a seal after fatigue load will increase. The helium detector was used to determine the leakage volume in given time intervals. Very important assignment was to build a measuring facility which would enable leakage detection from the ball valve at helium overpressure range 0, 1 – 4, 5 MPa. Impact of the pressurized air on the closed ball was used as a fatigue factor. Impact could be used as a diagnostic procedure simulating exploitation conditions. Gas escaping around the ball was measured when element was new, then after 5,000 and finally after 10,000 pressure impacts. Experiment included also similar leakage measurement through a stuffing box.

III. MODELING OF A 4"600# BALL VALVE

For designing the ball valve in ANSA software, the following parts are needed. They are inlet extension, inlet pipe, ball portion, outlet extension, outlet pipe etc. Modeling these parts should be enough for to get good result. The parts are drawn by using ANSA. Starting from Vertex, Edge, Face and Volume should be created. If more than one volume is there, then it should be named as Group are shown in Fig.2 & 4 and the assembled view of ball valve is shown in Fig.5. Specification for the 4" 600# Ball valve is given below:

Ød = 101.6
ØD = 273.05
T = 38.1
F = 6.35
Øg = 157.23
Øc = 215.9
Øh = 25.4
L = 431.8
H = 209.8
W = 462.28
ØA = 127
B = 114.3
N = 8

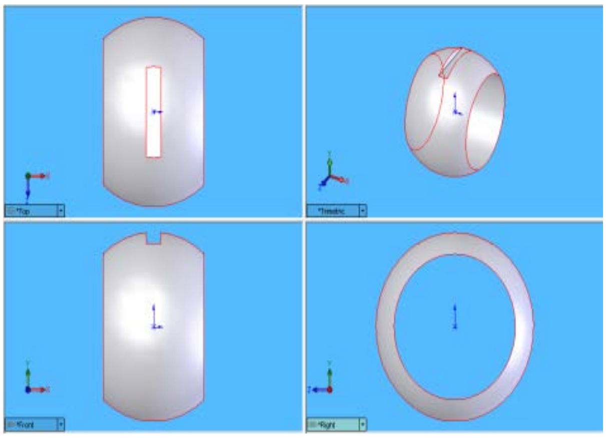

Fig.2 Four view of Ball

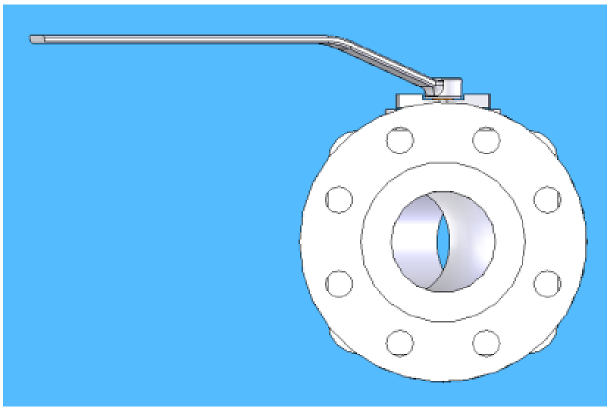

Fig. 3 50% Opened Valve

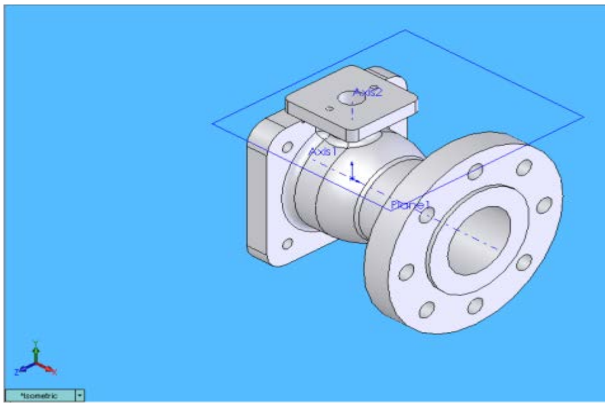

Fig.4 Body

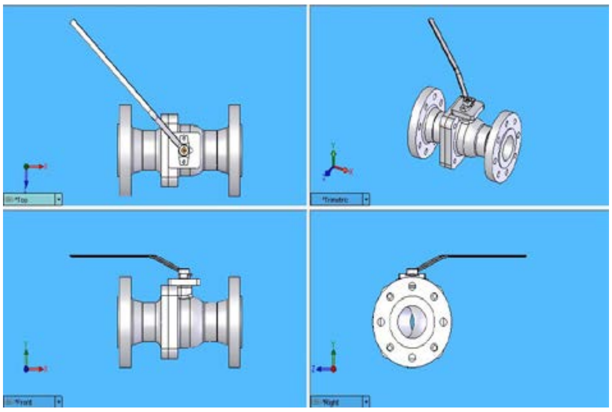

Fig.5 Top view, Front view, Right side view & Trimetric view of 4" 600# Ball Valve

TABLE 1 MATERIAL PROPERTIES OF 4"600# BALL VALVE

Name of Part	**Material**	**Density (Kg/m^3)**	**Young's Modulus (MPa)**	**Poisson's ratio**
Body	Cast iron (A216 WCB)	7850	2.06e5	0.28
Cap	Cast iron (A216 WCB)	7850	2.06e5	0.28
Stem	Stainless Steel (A275-316)	7850	2.1e5	0.3
Ball	Stainless Steel (A351 CF8M)	7850	2.16e5	0.3
Packing Ring	Poly tryfluoro tetra ethylene	1900	--	0.33
Handle	Cast Iron (A216 WCB)	7850	2.06e5	0.28
Gland	Cast Iron (A216 WCB)	7850	2.1e5	0.3
Gasket	Graphite	1900	--	0.33

IV. COMPUTATIONAL FLUID DYNAMICS

Computational fluid dynamics (CFD) is the science of determining a numerical solution to the governing equations of fluid flow whilst advancing the solution through space or time to obtain a numerical description of the complete flow field of interest. The various steps involved in solving a flow problem in CFD approach involve the following basic steps

- Defining the geometry of the problem (i.e. the physical boundary)
- Meshing the volume occupied by the fluid into discrete cells.
- Physical modeling of the problem (i.e. the governing equations)
- Defining the boundary conditions
- Solving the governing equations iteratively either as a steady state or as a unsteady state
- Post processing (i.e. analysis and visualization of the results)

V. SOFTWARE SIMULATION

Meshing is important for every parts, size interval is given as 0.05. If mesh size is minimized the accuracy is more. Ease of use was a major goal in Fluent's development of ANSA 2.2. It is a preprocessing software. Its role is to build the computer model, which is then processed by the solver portion of the software. The model structure, or geometry, is built. Then, a mesh of numerical coordinates is overlaid onto it, so that the analysis can take place.

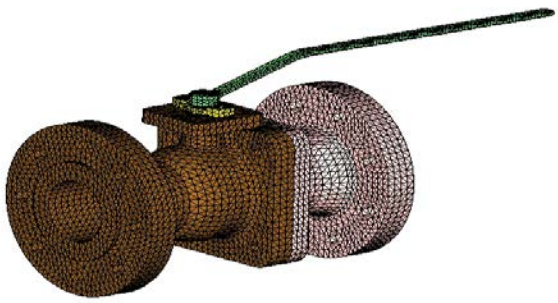

Fig.6 Meshing by HyperMesh

Finite element model was created with tetrahedron elements by using hypermesh software as shown in Fig.6. Both flanges are constrained in all degrees of freedom and the inlet pressure given in the domain as 15MPa as per API standards. The extraction of the domain with meshing is given in Fig.7 & its restrictions is given in Fig.8

Fig.7 Domain meshing by using TGRID

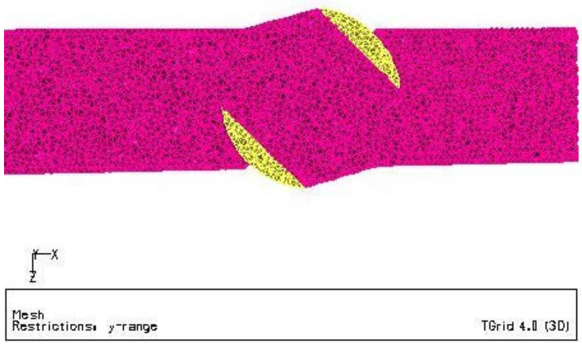

Fig.8 Volume mesh by using TGRID

TABLE 2 MATERIALS USED

Name	**WATER**
Material type	**FLUID**
Density	**1000 Kg/m^3**
Specific Heat	**4185.5 J/Kg-K**
Thermal Conductivity	**0.0014 W/m-K**
Viscosity	**1.79*10^{-05} Kg/m-s**

CFD has helped engineers improve a wide range of products involving fluid flow by allowing them to evaluate alternative designs on the computer without having to build costly prototypes. CFD involves the solution of the governing equations for fluid flow, heat transfer, and chemistry in tens or hundreds of thousands of computational cells in the defined flow domain. A CFD analysis yields values for pressure, velocity, temperature, and other flow variables throughout the solution domain. A key advantage of CFD is that it provides the flexibility to readily change design parameters and determine the impact of those changes on performance.

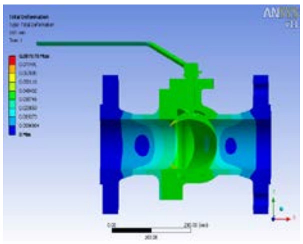

Fig.9 Deformation of the body

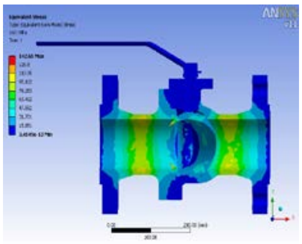

Fig.10 Stress induced in the body

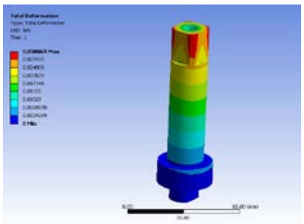

Fig.11 Deformation in stem

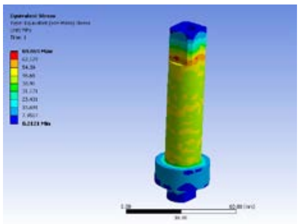

Fig.12 stress induced in the stem

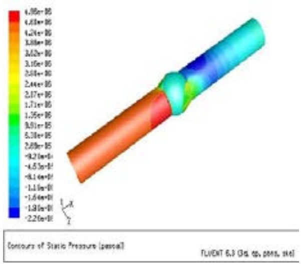

Fig.13 Static Pressure of Path Line

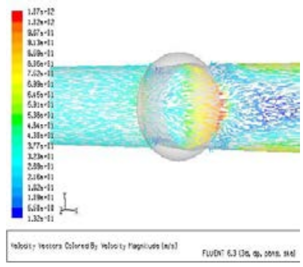

Fig.14 Velocity magnitude

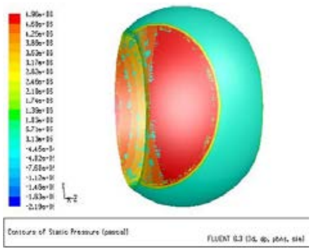

Fig.15 Static Pressure of the ball

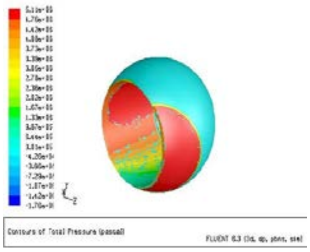

Fig.16 Total Pressure of the ball

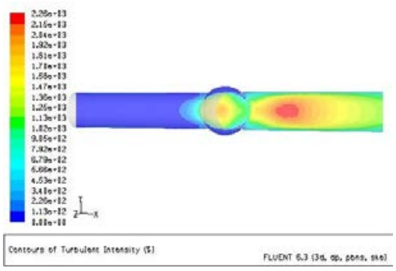

Fig.17 Turbulent intensity

VI. CONCLUSION

FEA has become a solution to the task of predicting failure due to unknown stresses by showing problem areas in a material and allowing designers to see all of the theoretical stresses within. This method of product design and testing is for superior to the manufacturing costs which would accrue if each sample was actually built and tested. From the above structural analysis on valve assembly at different Ball opening position the maximum stress found is 142.65 Mpa in the Ball at 50% opening condition and is below the yield stress 270 Mpa. So, the boundary condition applied in the ball valve is within the limit, the component is safe. The deformation of the body is around 0.087178mm. The stress developed in the stem is maximum at 50% opening position is 69.869 MPa. The deformation of the stem is around 0.030869 mm. The stress developed in Body and Cap is also maximum at 50% opening position is 108.3 MPa and 110.8 MPa respectively, and is below the yield or ultimate stress of the material 450 Mpa. From the analysis it is confirmed that the valve design is safe. The maximum stress developed in the shaft when a torque 50 N-m is applied is 69.8 Mpa and is below the yield stress of the material 270 Mpa and the component is safe.

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