Computational NX Fluid Structure Interaction (FSI) analysis on naval three way ball valve

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Abstract. This article represents the continuation of a study that was presented in another paper using the NX Siemens CAD program and FSI (fluid structure interaction analysis) for a complex valve encountered in the naval domain, a ball valve known as (three way ball valve - TWB). In designing of this valve presented in the previous work, some drawings (sketches) of the component parts presented in engineering guidelines were used, all dimensions being determined by the author. In the FSI analysis the same NX Siemens program was used to discretize the solid bodies of the valve coming into contact with the fluid, materials were chosen for these bodies, boundary conditions were set and the pressure field exerted by the fluid on the solid bodies was imported. Finally a series of conclusions were drawn about the speeds, pressures of the fluid and how they are distributed on the walls of the valve, determining the so-called structural analysis "fluid structure interaction".

1. Introduction
These TWB ball valves (figure 1) are among the least expensive, having a wide range of applications for all sizes, including very large sizes for oil pipelines and in the maritime industries. They are used for liquids in general (water, oil, liquid chemicals). These TWBs are used for a wide range of diameters, at full opening and their operation is simple and easy.

![Figure 1. The three way ball valve (TWB), 3D NX assembly and exploded viewing [1].](image)
The basic geometric element is a ball located in the body of the valve that has three flanges (three ways). The ball has a hole made along two axes arranged at an angle of 120° degrees. The complete operating motion is rotating the ball at 120° degrees. The ball can also be rotated at various angles so we can adjust the fluid flow.

The main parts of the TWB are [1]:
- the valve body;
- the body connectors;
- the ball;
- the threaded stem;
- the seats;

Full fluid flow is obtained when the hole inside the ball is aligned with the inlet and outlet flanges in the direction of flow by 120°. When the stem is rotated by 120° with the help of a lever or wrench, the flow is blocked in the third flange, and the locking washer may be incorporated to limit the movement of the lever, or continuous rotation may be possible. Larger ball valves can be actuated by means of reduction gearing or electric motor drives (actuators) [3].

In all cases, the opening/closing torque is low, because the frictional forces involved are only between the ball and the seats and the friction offered by the stem o-rings and lower-upper stem seals.

2. Computational Fluid Dynamic (CFD) analysis

In a previous paper [1] were presented CAD models made with NX Siemens of the component parts of TWB valve consulting engineering guidelines of some manufacturing companies [2], all dimensions of these models being original. All these models were assembled using geometric and dimensional constraints giving birth to the final assembly named “ans_valvulabila.prt” file.

Further, the volume of fluid was created which will interact with certain parts of the valve component. For this, enter the file named “ans_valvulabila.prt”, deselect the component parts that are not in direct contact with the fluid and then enter the “Part Navigator”; the geometry of the pieces that come into contact with the fluid is copied using the “Wave geometry linker” button and then they are merged into a final volume with “Unite”. By pressing the “Delete Face” button we will delete all the surfaces of the previously created parts except the surfaces that are wet with fluid if we activate the “Boss and Pocket Face” option. In this way the volume of fluid is created using specific tools listed in the NX program.

Two situations were considered for this flow study:
- First situation - when the valve is fully opened and the inlet flange is aligned with the outlet flange in the 120° flow direction and the third flange is blocked;
- Second situation - when the valve is partially opened and the liquid passes through two outlet flanges.

![Figure 2](image-url). Relative Press and Shear Resultants a.-first situation; b.-second situation.
2.1. Discretization of volume fluid and boundary condition

With the volume of fluid obtained previously opens the “Advanced Simulation” module of the NX Siemens program. For the discretization of the fluid volume, tetrahedral elements of the TET(4) type were used. It was considered water with a temperature of 80˚C with an inlet flow rate of 50 m³/h. At the exhaust flanges it is considered to be air at ambient temperature and pressure.

Then I clicked Start→All Applications→Design Simulation which will open a toolbar with the “New Fem Simulation” window that created two renamed files: ans_valvulabila_fem3; ans_valvulabila_fem3_sim1. Added to these is the “Idealized Part” window that generated another ans_valvulabila_fem3_i.prt file. We have redefined the “Solution” window with the name “flow80t_50”, the solver chosen is “NX Thermal/Flow”, the type of analysis “Coupled Thermal Flow”, and the solution will be of the type “Thermal-Flow”. After pressing the “Solve” button and after completing the calculation operations in the directory structure, a series of data files about speeds, fluid pressures presented in figures 2 and 3 have appeared. The maximum speed values, pressures for the two study situations read from figures 2 and 3 are presented in table 1.

| Table 1. Velocities, Relative pressure and Shear Resultants, Total pressure. |
|---------------------------------------------------------------|
|                     | Velocities [m/s] | Relative Pressure and Shear Resultants [MPa] | Total Pressure [MPa] |
|---------------------|------------------|---------------------------------------------|---------------------|
| First situation     | 14.95            | 0.0915                                      | 0.108               |
| Second situation    | 15.38            | 0.129                                       | 0.143               |

![Figure 3. Total Pressure a.-first situation; b.-second situation.](image)

3. Fluid Structure Interaction (FSI) Analysis

FSI analysis considers how the fluid interacts with the material of the valve walls. There are two types of FSI analysis [4]:

- one way FSI type when the information obtained from the fluid flow simulation (CFD) is transferred to the valve wall material structure;
- two way FSI type when the data from CFD flow simulation are transmitted to the structure of the wall material but also the information from the structure level influences the fluid flow.

The analysis presented in this article is the one way FSI type. We will transfer the data obtained from the CFD simulation to the specific structural models made for this TWB valve. The structural models consist of the parts of the valve assembly that come into contact with the fluid. These are the
three body connectors with flanges, the seats fixed on them, the ball that is operated by the lever and the body valve. The ball is the structural element that is in contact with the three seats and when operated by the lever it is rubbed by the three seats. The selected materials are presented in table 2.

| Materials / Mechanical Properties | Yield Strength [MPa] | Ultimate Tensile Strength [MPa] |
|-----------------------------------|----------------------|---------------------------------|
| Nodular Cast Iron (the seats and the ball) | 250 | 400 |
| Steel Rolled (the body connectors and the body valve) | 235 | 340 |

The choice of cast iron for rubbing parts was dictated by the carbon in the cast iron structure nodularly arranged in a structure that plays the role of lubricant and thus exhibits a better wear resistance than a carbon steel. It is a cheaper material than bronzes and has a good corrosion resistance.
Figure 6. The deformations (strains) for a.-first situation; b.-second situation.

Figure 7. The Misses Stresses for a.-first situation; b.-second situation.

In mesh discretization it should be taken into account that the structural models are made up of several parts of the assembly. The first structural model consists of two body connectors with flanges, two seats and a ball (figure 4, first situation), to the second, a seat, a body connector with flange and the valve body (figure 4, second situation) are added. For discretization, tetrahedral elements CTETRA (10) with element size of 5 and 3 mm were used. The solver chosen is “NX Nastran” and the type of analysis is “Structural”.

The “NX Thermal / Flow” solver was chosen at the “New Solution” and the “Mapping” option for the type of analysis to be able to transfer from the CFD analysis the fluid pressure and force field (Relative Pressure and Shear Resultants - figure 2) oriented normally to the surface of the walls through which the fluid flows. Choose the file with the “.bun” extension that contains the result of the CFD analysis and refer to the “Optional Output” to create a “Mapping Nastran” solution.
At “Simulation Object” the surfaces of the parts (the ball, seats, flanged body connectors) in contact were highlighted by “Face Contact” and this fact is shown in figures 4 through those brown arrows.

Fixed constraints were also applied on the flange holes where the screws come with nuts and on the rectangular hole executed on the surface of the ball where the threaded stem that is rotated through the lever comes fixed. Fixed constraints are coloured in blue and there are presented in the figure 4.

The “Solve” button was pressed and the following results were obtained for the structural analysis in the figure 5 – the displacements, figure 6 – the deformations (strains) and figure 7 - the Misses stresses.

4. Conclusions
From the static structural analysis it is evident that the most significant distribution of stresses is at the level of the body flanged connectors (figure 7) and at the level of the ball and seats (figure 8).

Usually, these component parts are the most exposed to both friction by actuating the valve lever but also by the direct action of the fluid. All the results were obtained taking into account the influence of the temperature. Generally the biggest problems in operation are given by seats that have to be changed quite often due to wear and the stress cracking corrosion phenomenon. Problems also occur on the ball as well as on the body flanged connectors.

The aim is to use materials (metal alloys) with much better mechanical properties such as bronze and brass alloys. The periodic change of fixing and sealing gaskets is also considered. An important conclusion can be drawn from the structural analysis of stresses; it is indicated that this type of valve should work as far as possible in the fully open position, so that the inlet and outlet flanges are aligned in the flow direction by 120°. In this situation the loads of seats and the ball are much smaller.

5. References
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