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STATIC ANALYSIS OF THE INLET SPHERICAL VALVE FROM A FRANCIS TURBINE

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Abstract: *Spherical valves are used for blocking the water flow in the penstock of high-pressure hydraulic turbines. The spherical valves close in the following cases: turbine load rejection, safety shutdowns, shutdowns for inspections and repairs. Valve components are subject to mechanical stress in both the "closed" and "open" positions. At valves used for a long period of time in an operating mode with multiple starts/stops, fatigue may occur. In this paper are analyzed the stress and displacement distributions for an inlet spherical valve from a high head Francis turbine. The stress distributions are analyzed at the main components of the valve: impeller, casing and trunnions. The identification of the variation of stress values between the stress state corresponding to the "open" and "closed" positions allows to determine the stress cycles.*
Keywords: *spherical valve, stress, displacement, static analysis, Francis turbine.*

1. INTRODUCTION

Spherical valves are used in high pressure hydropower plants (up to 20 MPa) [1]. They are designed to shut-off the penstock in the following situations: at turbine shutdown after load rejection, at emergency shutdowns, at inspection and repair shutdowns [2, 3]. In the case of load rejection, the valve closure reduces the wear on the turbine wicket gate caused by clearance cavitation [4, 5].
Spherical valve opening is controlled by servomotors. Spherical valve closing is done without external actuation by counterweights. The water flow closing element of the valve is the rotor (shutter), fixed on two trunnions. The rotor occupies a spherical volume and has a cylindrical inner surface which allows water to pass through in the open position of the valve.
The components of the spherical valve are subject to mechanical stress in both the closed and open positions. The adjustment of electrical power generation grid at national level is very often done by hydropower plants, because the on/off times of hydro-turbines are short [6, 7]. The use of spherical valves for a large number of years, in an operating regime with many turbine starts and stops, can lead to the occurrence of fatigue. The fatigue occurs on the components with large variations of stress values from closed and open positions [8].
The goal of the paper was to determine the stress and displacement distributions in a spherical valve (Figure 1) of a high-head Francis turbine. The main components of the valve analyzed are: casing (upstream half casing and downstream half casing), rotor, trunnions, sealing elements, connecting pipes.

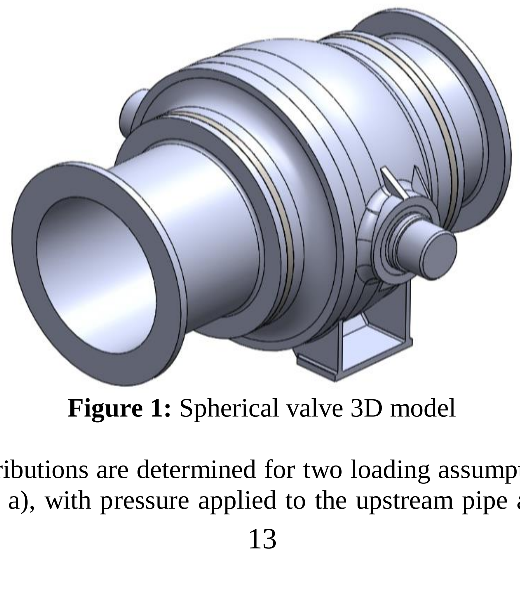
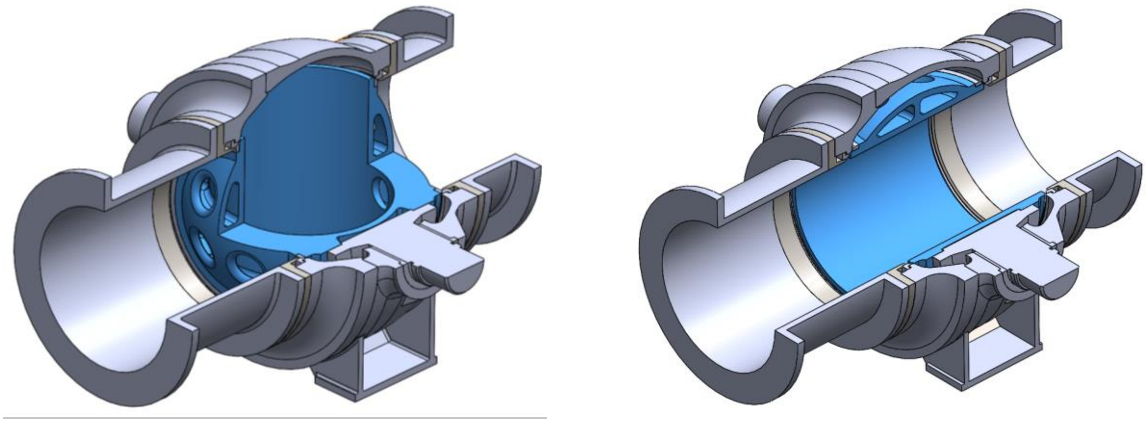


Figure 1: Spherical valve 3D model

Stresses and displacements distributions are determined for two loading assumptions: a) the valve with the rotor in the closed position (Figure 2 a), with pressure applied to the upstream pipe and rotor closing surface; b) the

valve with the rotor in the open position (Figure 2 b), with pressure applied to the water flow path, including the outer surfaces of the rotor and the inner surface of the upstream casing and downstream casing.
Intermediate positions between “closed” and “open” were not included in this analysis. In order to increase the quality of the mesh, geometrical details considered to be of low importance for the stress state (screw holes, fillets, chamfers with very small dimensions compared to the valve dimensions, etc.) were removed from the simulation.

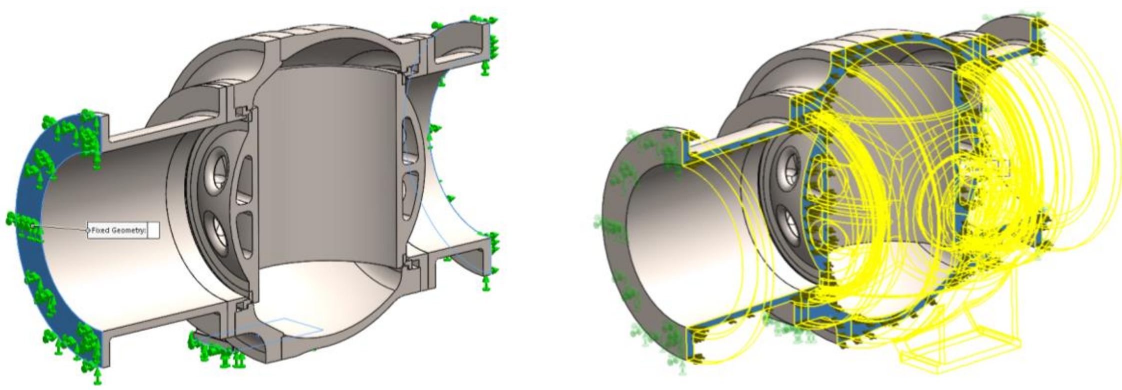


a) b)

Figure 2: Spherical valve 3D model (section): a) closed, b) open

2. ANALYSIS OF THE SPHERICAL VALVE IN THE "CLOSED" POSITION

The valve geometry was generated as a solid 3D model in SolidWorks. Stress and displacement analyzes were performed by using SolidWorks Simulation module. In order to increase computational accuracy [9] and reduce computation time, finite element analyses were performed on half of the valve, with symmetry condition applied relative to a vertical median plane. At the "closed" position of the valve, the water pressure was assumed to act on the rotor, the sealing elements and the upstream connecting pipe.
The constraints applied to the valve were: fixed geometry on the flanges of the connecting pipes, fixed geometry on the contact surface between the valve support and the foundation, fixed geometry on the contact surface between the trunnions and the flange of the servomotor (Figure 3.a). The two connecting pipes were included in the analysis in order to reproduce, close to in-situ conditions, the positioning and fixing of the valve in the hydropower plant. The symmetry constraint was applied to all the surfaces resulting from sectioning the geometry with a vertical median plane. This constraint assumes that the geometry, the fixings and the loads are symmetric relative to this plane (Figure 3b).



a) b)

Figure 3: Constraints applied - "closed" position: a) fixed geometry, b) symmetry

The water pressure used in the simulations (p = 5.7 MPa) corresponds to the head of the turbine. When the spherical valve is closed, this pressure acts on the upstream pipe, on the sealing elements and on the rotor. The rotor geometry is defined by an outer sphere and an inner cylinder. The cylinder represents the flow surface in the "open" position and the sphere represents the support surface in the closed position. To decrease the rotor mass, gaps are introduced between the spherical surface and the cylindrical surface. Thus, in the 'open' position, the water pressure acts on a spherical cap but also partly on the cylinder (figure 4.a).

In both design assumptions, bonded contacts between components were used. Consequently, the contact pressures in the bonded areas between two adjacent components were not analyzed.
Discretization of the valve was performed by using tetrahedral finite elements. The size of the finite elements was set smaller at the rotor, sealing elements, trunnions and casing (Figure 4b). The FEM simulations aimed to determine the stresses and displacements in particular for the rotor, casing and trunnions, considering that the sealing elements can be replaced if wear is detected during inspections.

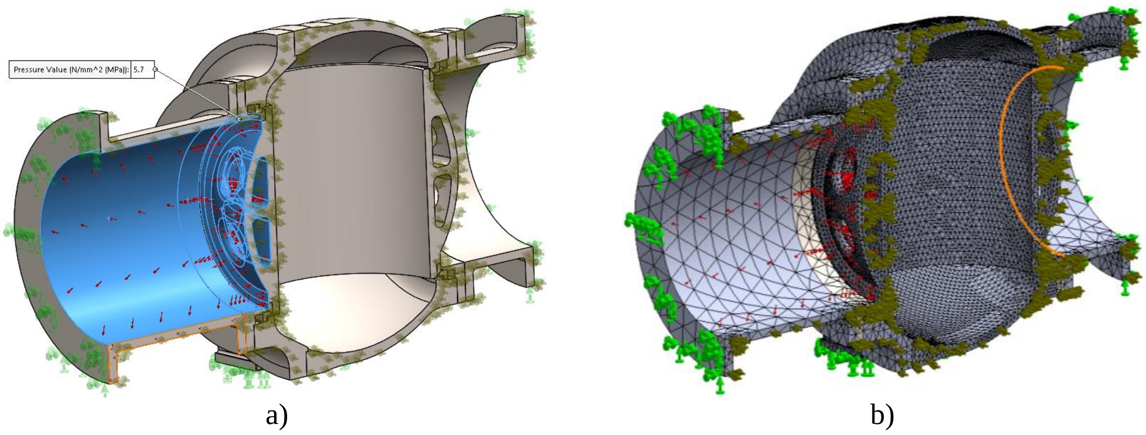


Figure 4: Pressure setting (a) and model discretization (b) - valve in "closed" position

For the upstream half casing, downstream half casing and rotor, the material used was a G20Mn5 alloy steel with yield strength 300 MPa and tensile strength 500 MPa. C35 steel with yield strength 210 MPa and tensile strength 380 MPa (minimum values) was used for the trunnions.
Figure 5 shows the distribution of the equivalent von Mises stress in the valve components for the "closed" position. It can be seen that the maximum stress is 211.1 MPa, this value occurring on a sealing element (Figure 5.a). On the casing the maximum von Mises equivalent stress value is 105.5 MPa (trunnion bearing area - figure 5.b). On the rotor the maximum stress value of 122 MPa occurs on the spherical calotte which takes over the water pressure (Figure 5c). For trunnions the maximum von Mises stress occurs in the area of the flange connection radius area and is 133.6 MPa (Figure 5 d).

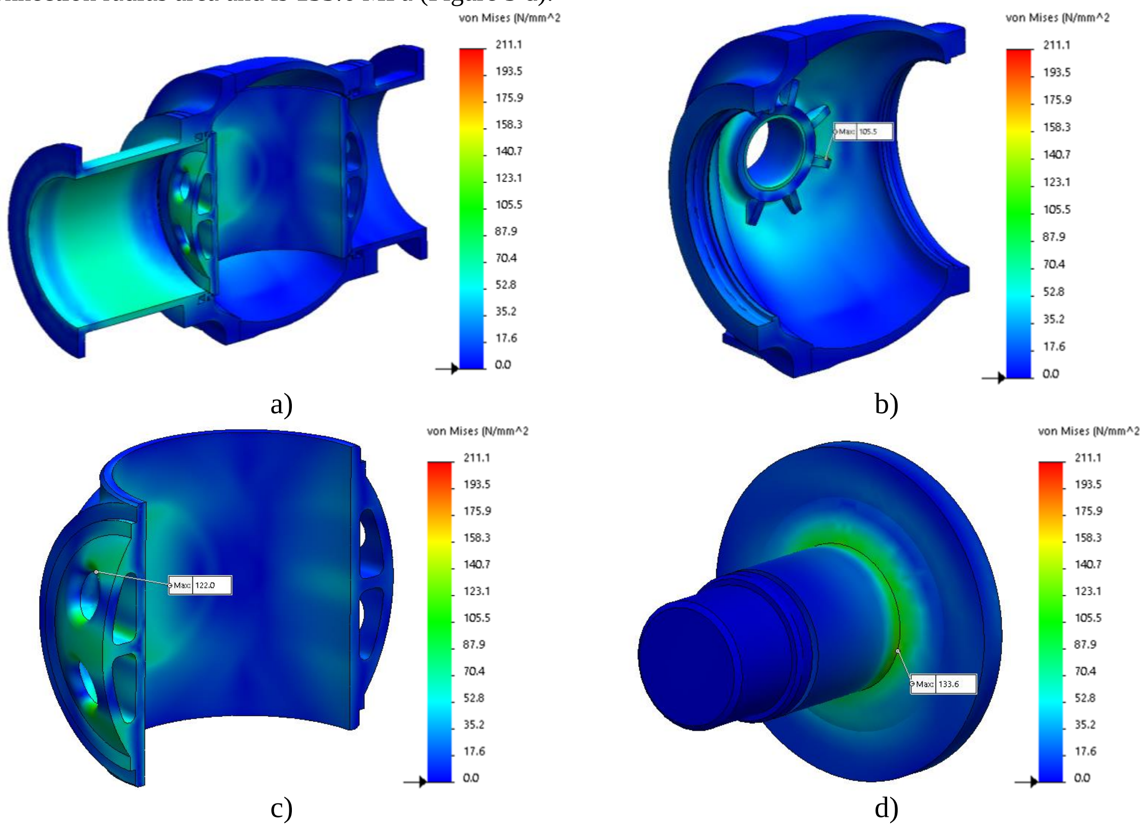
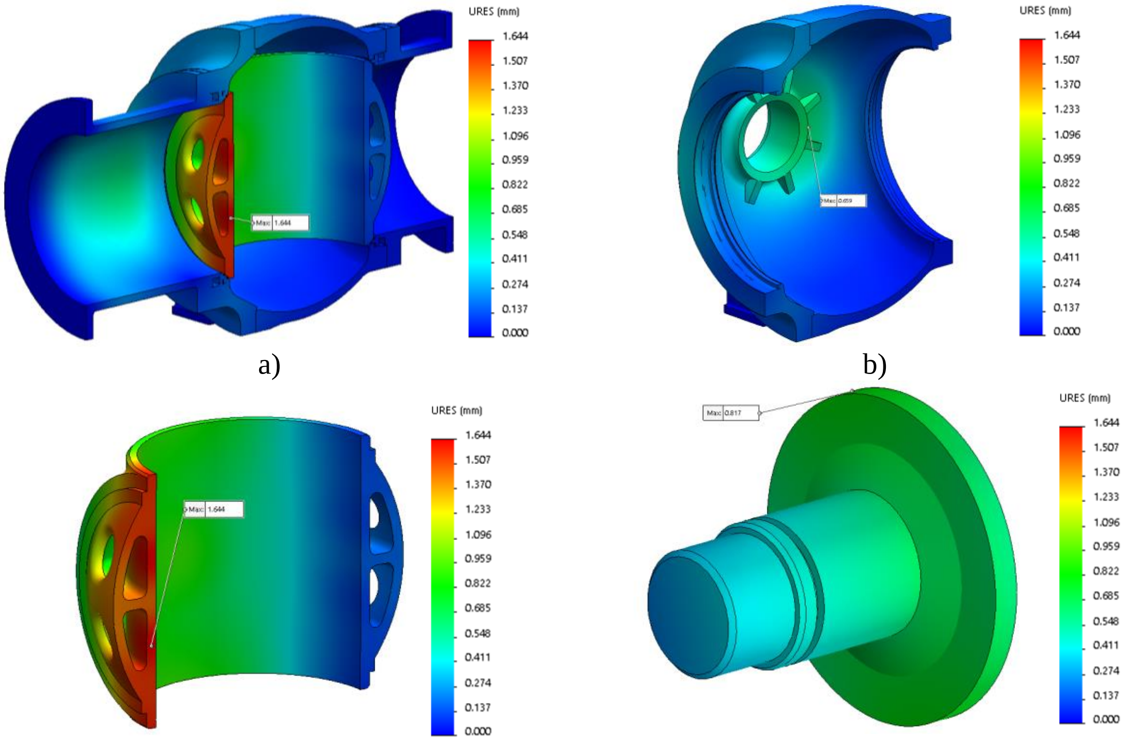


Figure 5: Von Mises stress distribution - "closed" position: a) spherical valve assembly, b) casing, c) rotor, d) trunnion

Figure 6 shows the distribution of the resultant displacement at the valve components for the "closed" position. On the casing the maximum value of the resultant displacement is 0.65 mm (spindle bearing area - figure 6.b). On the rotor the maximum value of the resultant displacement is 1.64 mm (Figure 6c) and on the spindle the maximum displacement is 0.81 mm (Figure 6d).



a) b)

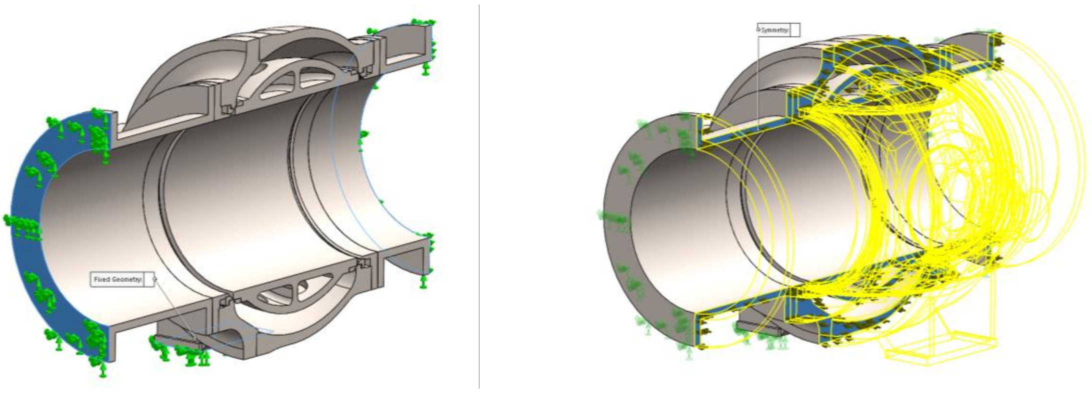
c) d)

Figure 6: Resultant displacement distribution - "closed" position: a) spherical valve assembly, b) casing, c) rotor, d) trunnion

3. ANALYSIS OF THE SPHERICAL VALVE IN THE "OPEN" POSITION

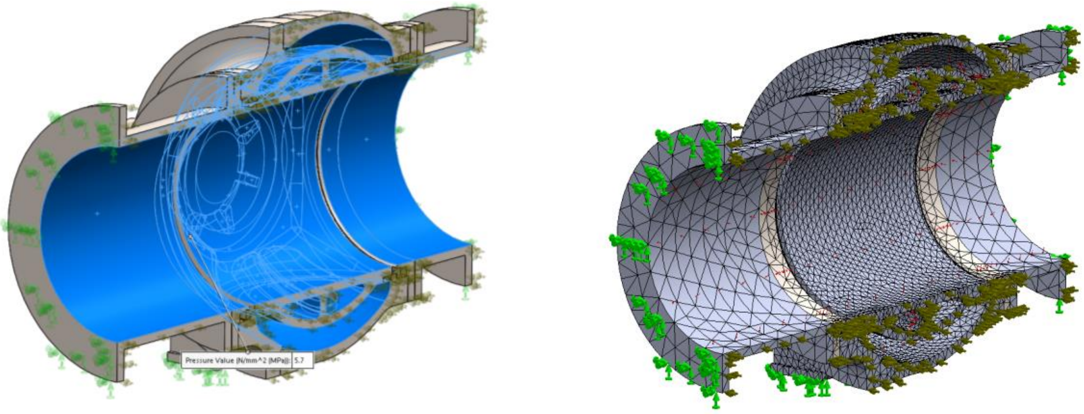
In the "open" position of the valve the working pressure acts on the water flow path. The inner cylindrical surface of the rotor aligns with the inner surfaces of the connecting pipes. The fixings applied for “open” position were similar to the fixing applied for the "closed" position - figure 7.

The working pressure acts on the rotor on both the inner cylindrical surface and the outer spherical surface because in the "open" position water enter in the space between the rotor and the casing. The pressure applied in the FEM simulation was p=5.7 MPa (Figure 8 a). The mesh of the valve was similar to that defined in the analysis for the "closed" position (Figure 8 b).



a) b)

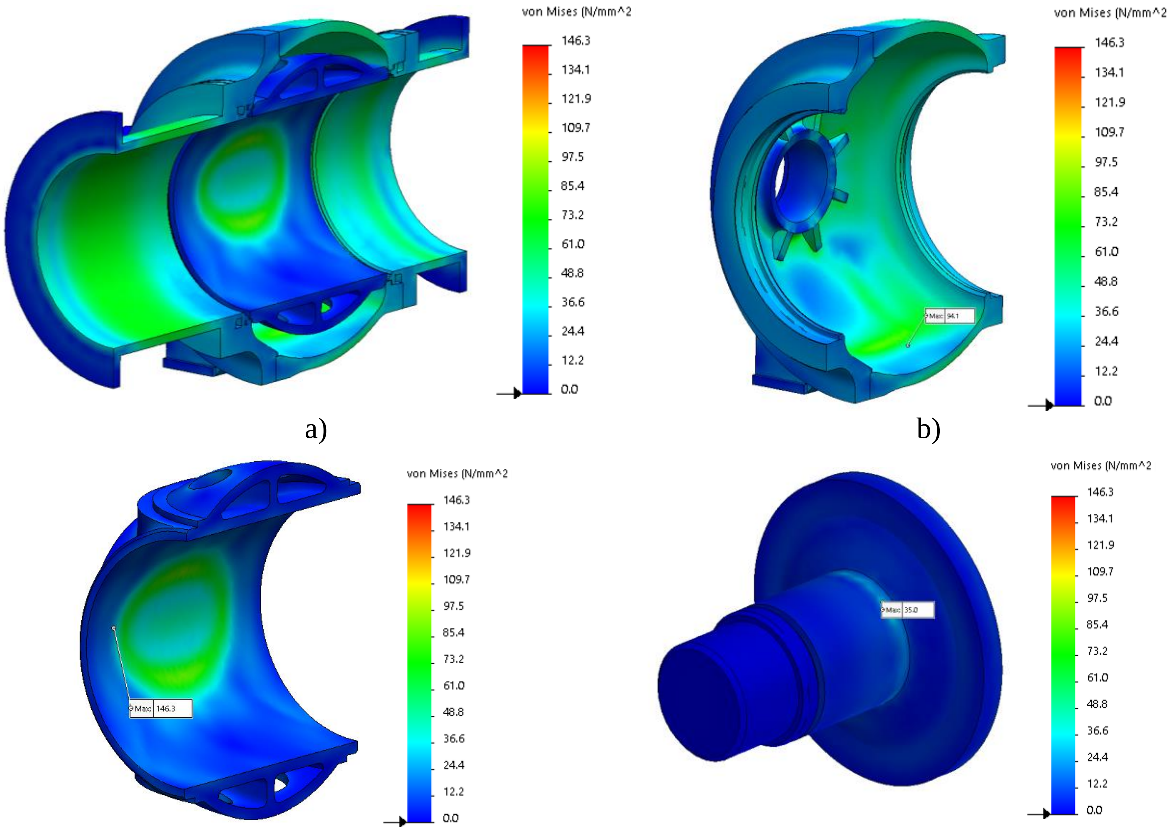
Figure 7: Applied constraints - "open" position: a) fixed geometry, b) symmetry



a) b)

Figure 8: Pressure setting (a) and model discretization (b) - valve in "open" position

Figure 9 shows the equivalent von Mises stress distribution at the valve components for the "open" position. It can be seen that the maximum stress is 146.3 MPa. This value occurs on the rotor (Figure 9.c). On the casing the maximum von Mises equivalent stress is 94.1 MPa (Figure 9.b) and on the trunnions the maximum von Mises equivalent stress occurs in the flange connection radius area and is 35 MPa (Figure 9.c).



a) b)

c) d)

Figure 9: Von Mises stress distribution - "open" position: a) spherical valve assembly, b) casing, c) rotor, d) trunnion

Figure 10 shows the distribution of the resultant displacement at the valve components for the "open" position. On the casing the maximum value of the resultant displacement is 0.71 mm (trunnion bearing area - figure 10.b). On the rotor the maximum value of the resultant displacement is 0.65 mm (Figure 10 c) and on the trunnion the maximum displacement is 0.20 mm (Figure 10 d).

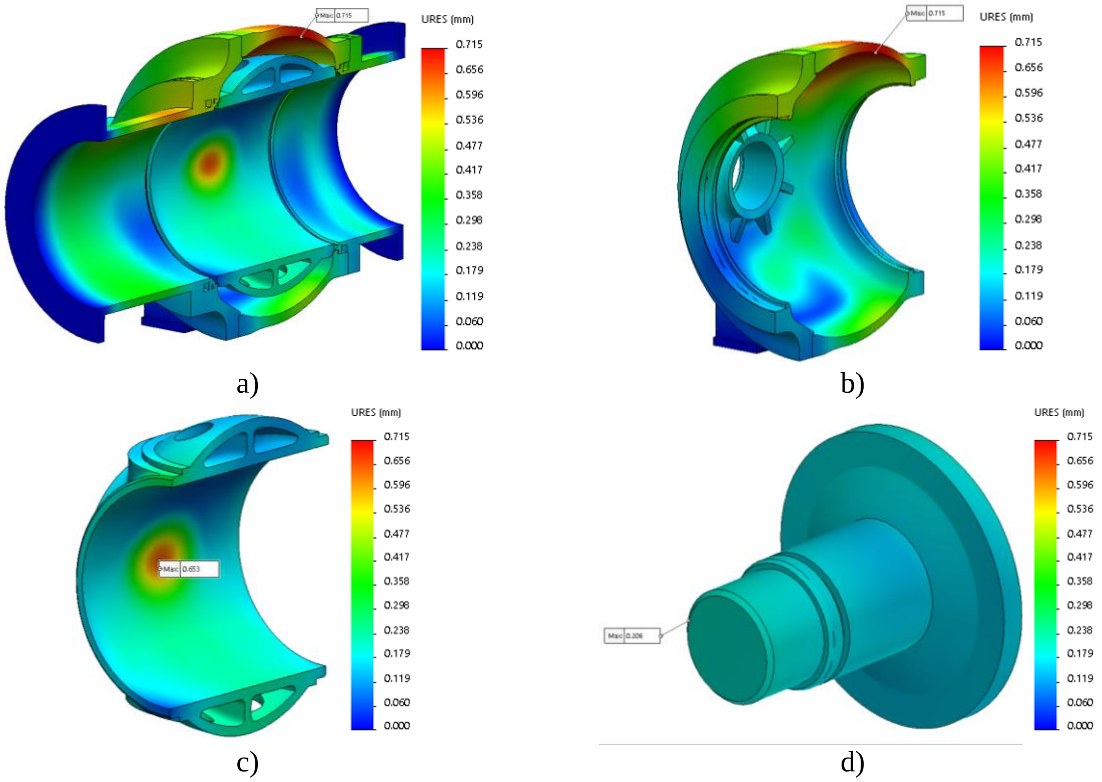


Figure 10: Resultant displacement distribution - "open" position: a) spherical valve assembly, b) casing, c) rotor, d) trunnion

4. CONCLUSION

Analysis of the distribution of stress and deformations of a spherical valve from a Francis turbine inlet was carried out for two operating positions: open valve and closed valve. The results showed that at the valve rotor the maximum value of the equivalent von Mises stress is 122 MPa at the closed position and 146.3 MPa at the open position. At the casing the maximum values are 105.5 MPa at the closed position and 94.1 MPa at the open position, while for the trunnions the maximum values are 133.6 MPa at closed position and 35.0 MPa at open position. The areas where these maximum stress values occur differ from the "open" to the "closed" position. Comparative analysis of the equivalent von Mises stress values for different zones of the valve components in the two calculation scenarios shows the occurrence of stress cycles.

In the next steps of the research, the variations of principal stresses, axial stresses and tangential stresses for several critical points from casing, rotor and trunnions will be analyzed, in order to determine the value of the asymmetry coefficient of cycles. These coefficients will be used in fatigue calculations and lifetime estimation.

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