Wedge gate valves selecting essentials in pipeline systems designing based on permissible operation parameters

M M Zakirnichnaya, I M Kulsharipov

Ufa State Petroleum Technological University, 1, Kosmonavtov St., Ufa, 450062, Russia

E-mail: kim102@mail.ru

Abstract. Wedge gate valves are widely used at the fuel and energy complex enterprises. The pipeline valves manufacturers indicate the safe operation resource according to the current regulatory and technical documentation. In this case, the resource value of the valve body strength calculation results is taken into consideration as the main structural part. However, it was determined that the wedge gate valves fail before the assigned resource due to the occurrence of conditions under which the wedge breaks in the hooks and, accordingly, the sealing integrity is not ensured. In this regard, it became necessary to assess the conditions under which the resource should be assigned not only to the valve body, but also to take into account the wedge durability. For this purpose, wedge resource calculations were made using the example of ZKL2 250-25 and ZKL2 300-25 valves using the ABAQUS software package FE-SAFE module under the technological parameters influence on the basis of their stress-strain state calculation results. Operating conditions, under which the wedge resource value is lower than the one set by the manufacturer, were determined. A technique for limiting the operating parameters for ensuring the wedge durability during the wedge gate valve assigned resource is proposed.

1. Introduction

Pipeline systems used at the fuel and energy complex enterprises include a large number of structural elements, including wedge gate valves. The variety of operating conditions for wedge gate valves makes it difficult to select it for specific working conditions. This process is complicated by the fact that the accompanying documentation indicates the resource assigned by the valve body calculation. In Russian publications research on the design, manufacture and operation of shut-off valves are widely presented. However, these studies are aimed at studying the causes of the wedge gate valves premature failure of the valve body. So, in the research by Syzrantshev VN, Tatarintsev VA, Borisenkova EA, the reasons for failures of the valves’ casings are considered taking into account operational factors [1-3]. The research by Vasilyev AS is devoted to improving the manufacturing quality of valve bodies [4]. Nevertheless, according to the valves periodic inspections results, operating companies are forced to resort to the premature recovery of most wedge valves due to seats plastic deformations and the wedge hooks destruction. In the studies of Beloborodov A.V., it is shown that it is necessary to assess the closure tightness taking into account the loads that arise during the operation at the design stage of new products [1]. In studies [5, 6], it was determined that the deviation of the wedge from the vertical in the process of the valve passage section closing and its non-entry into the seat, which contributes to the occurrence of plastic deformation, occurs with a certain combination of operating parameters. In
addition, there are a number of conditions under which the maximum equivalent stresses on the wedge exceed the permissible ones (Figure 1) [7]. As a result, the wedge gate valves fail before the established time, which can lead to an emergency situation, and consequently to large economic losses due to equipment downtime during unplanned repairs, negative environmental consequences and human casualties. [8]

Figure 1. Examples of stress distribution: a – the wedge hooks in the valve opening process; b – the wedge hooks destruction

In this connection there was a necessity of the adjustment method for calculating the wedge gate valves resource, taking into account the wedge stress-strain state.

As the objects of study ZKL2 250-25 (DN – 250 mm., PN – 2.5 MPa) and ZKL2 300-25 (DN – 300 mm., PN – 2.5 MPa), wedge gate valves were selected as the most common in refineries [9].

2. Hydrodynamic calculations

Hydrodynamics calculations were performed using the FLOWVISION software package (SP) to assess the process parameters impact on the wedge gate valve structural elements. The FLOWVISION SP is designed and suitable for liquid and gas flows three-dimensional modeling in the technical and natural objects, as well as the flow visualization of computer graphics methods [10].

Calculations of the fluid flow hydrodynamics through the wedge gate valve flow passage were carried out for the model of "incompressible fluid". Four main fractions obtained by refining: gasoline, kerosene, diesel, fuel oil were selected as the transported liquids. The liquid was set in view of changes in the physical properties (density and viscosity) with temperature. Temperature ranges were taken within the application temperature of fractions selected for the study. The liquid flow rate was taken in accordance with the recommended limits of change in velocity of the fluid process piping from 0.5 to 3 mps.

Calculations were made for a pressure in the range from 0.6 to 2.5 MPa according to the characteristics designated by the manufacturer for the test valve.

In the valve cross-sectional plane layer "Filling" of the variable “Pressure” was created to determine the difference between the maximum pressure on the wedge and the pressure in the system (Figure 2). It was found that the pressure on the wedge increases as the flow passage closing, and reaches its maximum value at 95% closure degree (Figure 3).
Calculations have shown that stationary vortices are formed behind the wedge further in the cross section when the flow passage is 50% of a closure degree or more. This situation is most clearly presents in the 95% closure embodiment. The increase in the valve flow passage diameter influences the nature and number of vortex shedding zones slightly. So, for the ZKL2 250-25 valve, the vortex formation zone starts at a distance of 1.25d axis of the wedge symmetry (d – flow passage diameter, mm), while for ZKL2 300-25 valve – of 0.88d distance (Figure 4). Vortex formation and fluid flow recycling that occur in the area of the flow passage, narrows because when passing through the obstacle in the form of a wedge, fluid flow changes direction and partially reverse flow occurs. Returning to the main flow, the fluid involved in the recirculation zone converts recirculation to vortex.

It was found that with temperature increasing, the pressure difference increases too, but the impact of temperature on the maximum differential pressure value on the wedge and the pressure in the system is negligible. For example, the difference in water pressure at a flow rate of 1.5 mps speed reaches 160.2 kilopascals at a temperature of 20 °C and 160.9 kilopascals at a temperature of 100 °C. The difference between the maximum (at plus 100 °C) and minimum (plus 20 °C) pressure differential is 0.43%.
Figure 4. The example of the flow rate vector field graphical representation in the ZKL2 300-25 gate valve symmetry plane when closing the flow section up to 95% (working medium – water, flow rate – 1.5 mps).

3. Stress-strain state assessment
The stress-strain state (SSS) calculation of valve structural elements, taking into account the wedge gate valve fluid flow hydrodynamics in the wedge closing process, was realized using FSI-technology in the Abaqus SP, which is widely used for the oil refining equipment elements of the stress-strain state assessment. The wedge moving process and its deformation was simulated in the Abaqus SP. The transported fluid movement was simulated in the FlowVision SP. Software packages interaction was executed using the MP-manager.

The valve movable part – wedge geometry was imported to the Abaqus SP. After importing the wedge geometry, physical and mechanical properties of the wedge material – steel 20L were assigned in the PROPERTY module. Boundary conditions (fixing conditions) in the wedge hooks field were assigned in the LOAD module. Interface surface required co-execution, which was assigned in the ASSEMBLY module. Finite elements meshing was performed in the MESH module.

Then the INP-file, containing the finite element coordinates mesh, representing the moving body, was generated.

The wedge gate valve flow passage 3D-model was imported to the FlowVision SP. The substance - oil, the physical model - incompressible fluid, boundary conditions - inlet, output, wall, imported moving body - wedge - on the basis of the INP-file received from the Abaqus SP were assigned. The finite-volume grid was created.

The appropriate lines were added to the Abaqus SP STEP module at the INP-file project to identify co-execution by the program.

Next, preparation of project files was executed by calculation using the MP-manager, which specifies the path to the settlement file, step exchange between the software systems was chosen. Calculation progress was tracked via the application "results show module" that allows one to visualize the calculation process in the wedge movement course (Figure 5). The pressure distribution nature on the wedge surfaces and fluid flow lines are consistent with the previous studies.

Figure 5. The fluid streamlines and pressure distribution on the wedge surface during the calculation during 30% closing of the flow passage

After the execution process completion, the Abaqus SP project ODB-file was obtained. It contains
data about the wedge SSS change for a single operation cycle (the moving process from the state of "Open" to the state of "Closed"). These values can be visualized in the VISUALIZATION module.

Based on the wedge maximum, equivalent stresses from the flow rate dependencies in the different working pressure values and different temperatures, the maximum values of the rates were obtained for which the wedge SSS does not exceed the permissible stresses at the appropriate temperature. Then, the surfaces limiting the operating limits of the valve wedge were simulated with the total working pressure, the flow rate and the medium temperature according to the allowable wedge metal stresses. These surfaces were confined to planes using which the operating parameters combination equations were obtained in accordance with the permissible stresses.

So, for example, for fuel oil, the operating parameters of the total effect equation on the wedge strength are as follows:

\[ \frac{T}{1460} + \frac{V}{8.44} + \frac{P}{3.36} \leq 1, \] (1)

where

- \( T \) – temperature of the working medium, °C;
- \( V \) – flow rate, mps;
- \( P \) – pressure in the system, MPa.

Equation (1) allows us to obtain a operating parameters combination, in which the stresses on the wedge hooks do not match the tolerances. The medium temperature values are recommended to be selected according to the corresponding fractions application technological mode, the flow rate - according to the liquids speed change limits in industrial pipelines, the working pressure - is not higher than the nominal pressure of the valve.

4. Resource assessment

The Abaqus SP FE-SAFE module was selected to the technical resource assessment. It is used for analyzing fatigue life of metal components under the complex cyclic loading influence. The FE-SAFE combines the finite element analysis results for a different loading conditions from the Abaqus SP with a cyclic loading history and predicts the service life, using the resulting ODB-file.

After the ODB-file import, the data to calculate the wedge gate valves fatigue life analysis was selected in the SELECT DATASETS TO READ dialog box. In the AVAILABLE POSITIONS column the type of calculation by the finite element mesh – the ELEMENTAL was chosen. It makes a mark that will take into account the geometry of the valve three-dimensional model and the resulting interaction between the ring surface and wedge - DETECT SURFACE and GEOMETRY MODEL. The STRESSES was chosen as the QUICK SELECT parameter.

In the MODELS PROPERTIES dialog physical quantities measurement unit required during the calculation was assigned.

Assigned service life calculation in the FE-SAFE module was carried out within the framework of data multi-axis analysis concerning the different ways of load (pressure) applications on a wedge. In each case, the elastic stresses were used for calculating. Analysis Type was assigned after importing the loads (* .amc) file, which contains the accompanying cyclic loading amplitude.

The path to the file * .amc was specified in the LOADED DATA FILES dialog box.

The calculation for the WHOLE GROUP was selected in the SUBGROUP SELECTION dialog box.

The SURFACE FINISH DEFINITION module was used to select surface finish. The surface roughness (Ra) for the settlement was accepted of 0.4 mm. Valve metal physic-chemical properties were assigned using the MATERIALS DATABASES base.

The residual stress was assigned to be zero. As the output FE-SAFE displays the number of cycles to failure. The number of cycles to failure calculating visualization is possible in the Abaqus SP after importing the results file (Figure 6, b).
Figure 6. a – the wedge surface equivalent stresses distribution at a working pressure of 2.5 MPa; b – calculation results visualization example in the Abaqus SP VISUALIZATION module

The calculation results showed that the wedge safe operation resource is affected by such operating parameters as the pressure and flow rate in pipeline (Figure 7) while the temperature effect is negligible (Figure 8). If one changes the valve flow passage diameter, dependence of the number of cycles to failure of the fluid flow rate are similar in character (Figure 9). For example, Figure 10 shows the dependence of the wedge hooks number of cycles to failure of liquid flow rate for the ZKL2 300-25 valve for the different mediums. It is evident that the wedge safe operation resource below the values specified by the manufacturer (Table 1).

Figure 7. The number of cycles and failure dependence of the fluid flow rate for ZKL2 250-25 valve different working pressure values (operating environment - fuel oil, the medium temperature +100 ° C)
**Figure 8.** The number of cycles and failure dependence of the medium temperature at ZKL2 250-25 different working medium flow rates (operating environment - fuel oil, working pressure – 1.0 MPa)

**Figure 9.** The number of cycles and failure dependence of the fluid flow rate for different ZKL2 300-25 valve working pressure values (operating environment – fuel oil, the medium temperature +100 ° C)

**Figure 10.** Dependence of the number of cycles on failure of the fluid flow rate for different media ZKL2 300-25 (working pressure – 1.0 MPa)
Table 1. ZKL2 300-25 wedge gate valve assigned resource powered by the manufacturer catalogs

| Manufacturer                                      | ZKL2 300-25 valve assigned life, cycles* |
|---------------------------------------------------|----------------------------------------|
| Murom Industrial Valves Plant, JSC                | 2500                                   |
| Ural Pipeline Valves Plant, LLC                   | 2500                                   |
| Blagoveschensk Pipeline Valves Plant, JSC         | 2500                                   |
| “Palur” Regional Gas Company                       | 3000                                   |
| YarGasArmatura, LLC                               | 3000                                   |
| PenzTyazhArmatura, JSC                            | 3000                                   |

5. Conclusion
The researches have shown that in order to ensure the assigned resource of wedge gate valves, selected in the pipeline systems design, the premature failure of the wedge should be taken into account during operation due to the negative influence of operating factors. It is recommended to limit the permissible ranges of the operating conditions, or to take the valve resource in accordance with the wedge resource.

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