BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 68 (72), Numărul 2, 2022
Secţia
CONSTRUCŢII DE MAŞINI
DOI:10.2478/bipcm-2022-0014

DESIGN SOLUTIONS FOR LARGE SIZE BALL VALVES

BY

LAURENȚIU-IOAN IVANCU* and DANIELA POPESCU

“Gheorghe Asachi” Technical University of Iaşi,
Faculty of Machine Manufacturing and Industrial Management, Iaşi, Romania

Received: May 28, 2022
Accepted for publication: June 26, 2022

Abstract. Development of sustainable cities requires safe and efficient pipeline networks for the transportation of fluids. Ball valves are usually used to start/stop the flow of liquids or gases in pipelines, because they generate low hydraulic losses when the valve is in fully open position and no leakage in fully closed position. They are highly recommended, when quick operation is needed in emergency situations. European Union and United States of America have implemented stringent laws to regulate the standards of small and medium size pipeline components. Design parameters may require large size valves that are not in the focus of the present standards and in this case, individual solutions are needed.

In this work, a methodology to design ball valves that are not in the standardized series is step by step presented. The case study of a Trunnion ball valve with a 900 mm bore diameter is discussed. The standard API 6D/ ISO 14313 recommends design methods for valves with face-to-face dimension between flanges for diameters up to DN900, therefore the proposed methodology is original.

Keywords: pipeline networks, standards for valves, metal ball valves, design methodology, gas and petroleum industry.

*Corresponding author; *e-mail*: laurentiu.ioan96@gmail.com
© 2022 Laurențiu-Ioan Ivancu and Daniela Popescu
This is an open access article licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

1. Introduction

A valve is a device that is installed on a pipe to shut off, restore or adjust the circulation of the fluid. The most used valves in the industry are: the ball valve, the plug valve, the floating valve, the gate valve and the butterfly valve. Design solutions are specific to each type and details on procedures are explained in standards.

The present paper focuses on the design of ball valves, and more specific on the methodology of constructive design. This type is popular, because it generates low hydraulic losses when the valve is fully open and no leakage in fully closed position. The research domain is relevant and actual, because the valve industry market reached 58,547 $ million in 2020 (https://www.alliedmarketresearch.com/industrial-valves-market) and new and more and more efficient solutions are needed.

Studies on the design of ball valves were done by scientists interested in different topics. For example, Janusz Rogula analysed the phenomenon of fatigue that occurs in sealings and identifies the critical points where the valve has high risk of leakage (Rogula, 2011). Baoling Cui *et al*. studied (Cui, 2017) the evolution of flow characteristics for different positions of the ball.

This work focuses on the procedures to be used for the design of ball valves. Typically, methodologies described in standards for the natural gas and petroleum industry, valid also when the fluid is water are used. For instance, the difference between recommendations on designing a valve for gas/petroleum and one designed for transport and distribution of water consist in the different materials to be used for the ball; for the first category of fluids, the ball should be made of steel, and for the second type, the ball should be made of stainless steel, while the seats should be equipped with soft sealing.

In this paper, challenges that occur in the design of large ball valves implemented in long distance transportation gas pipelines are analysed. Recommendations regarding the design of valves that are out of the range of standards are provided. The steps for a design methodology are defined and the sizing of a ball valve nominal diameter DN 900 is presented.

2. Methodology

In Fig. 1, the most important components of a ball valve are presented: 1 – Ball zone; 2 – Seat zone; 3 – Main body; 4 – Second body; 5 – Acting stem zone; 6 – Connecting piece; 7 – Guiding plate; 8 – Acting Flange; 9 – Bolts.

Procedures for the design of valves are presented in standards API 6D (API, 2014), API STD 608 (API, 2020), SR EN 14313:2007 (ISO, 2007), ASME B16.10 (ASME, 2020), ASTM A370 (ASTM, 2021), ISO 5208 (ISO, 2015), ISO 5211 (ISO, 2017).

When the design conditions are not usual, the sizing of each component must be done, one by one. Firstly, the ball and the seats will be sized and then the principal and second body, the guide plate, the connecting piece, the acting stem, the actuator flange, and finally the sealings (screws, bolts and pins).

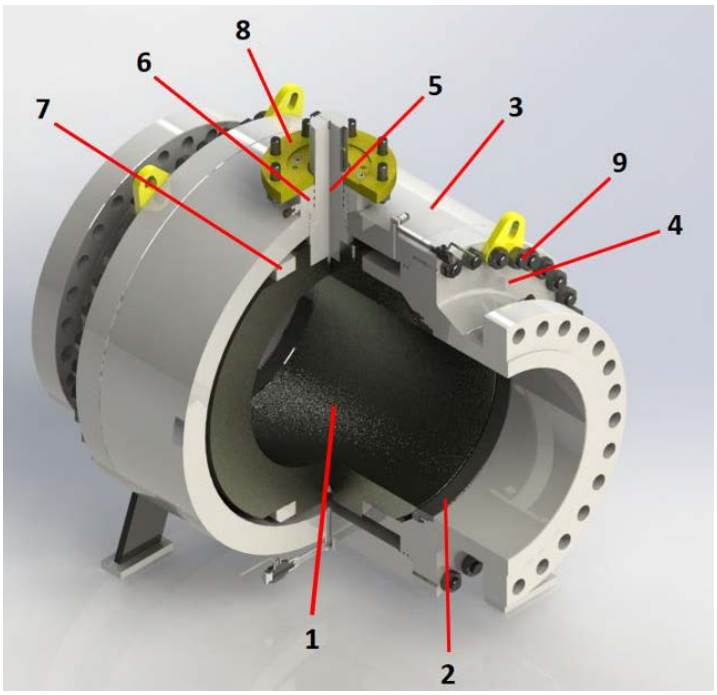


Fig. 1 – Ball Valve.

According to API 6D referring to specification for pipeline and piping valves (API, 2014) and ISO 14313 referring to petroleum and natural gas industries, pipeline transportation systems, pipeline valves (ISO, 2007), the minimum bore for full-opening valves is standardized in accordance with the operational pressure for the following size of valves:

- for the nominal pressure 20…100 bar up to DN1500 valves;
- for the nominal pressure 150 bar, up to DN1200 valves;
- for the nominal pressure of 250 bar, up to DN800 valves;
- for the nominal pressure of 420 bar, up to DN500 valves.

Outside the categories specified in standards, to overcome specific challenges of the operational environment, the design engineer has to decide which solution is best.

It is recommended to take into account the minimum bore size from standards. For instance, if the pressure domain is in the range Pn20…Pn100, the bore size in full opening position must be up to DN1500 (API, 2014).

In Fig. 2, a methodology to design ball valves is defined. The challenges to build a ball valve, with a diameter larger than the value from series described in standards, are summarized in the following and an example is presented in next section.

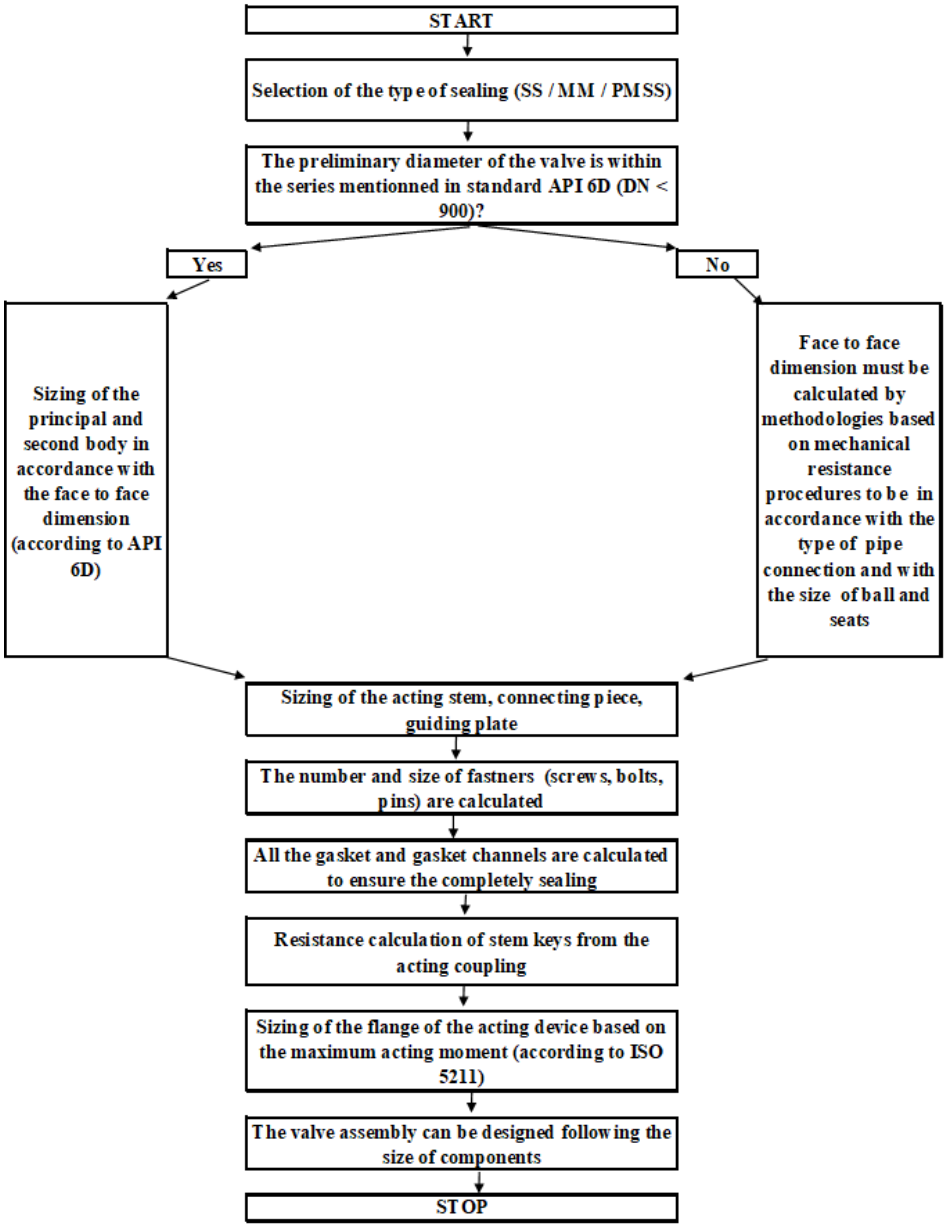


Fig. 2 – Design methodology for ball valves.

Particular design must be done in such a way to comply both with standards and results of mechanical resistance calculations. The solution must be in line with the devices available on the market, from specialized suppliers, because this component has to be bought.

Other design situation can be generated by the unusual face-to-face dimension, imposed when the valve must fit between two already installed flanges or when the available place is limited by other components of the pipeline network. Restriction generated by the facilities to install or remove the valve can also make the difference between design solutions, because the face-to-face dimension is different for a removable construction, comparing to a welded construction type. The welded construction type imposes larger end to end dimension, since a neck is necessary to be welded on the pipe. For the removable construction type, the connection on the pipe is made by using bolts.

Other step of the design methodology is the choice of end flanges, which are standardized in accordance with the nominal diameter and the nominal pressure. It is a wide offer in the domain therefore, the choice should be in accordance with the requirements of the beneficiary. Standards referring to flange connections, cover a larger field of diameters. For the example, SR EN 1092-1:2018 presents standardized flange until DN2000. If the flange is larger, the design engineer must use individual procedures to calculate the diameter, the number and size of bolts, the external diameter of the flange, the disposing diameter of the bolts, the thickness of the flange, etc. be using other standards such as ASME B16.10 (ASME, 2020), ASME B16.25 (ASME, 2017), ASME B16.47 (ASME, 2020).

To obtain secure sealing, following solutions are recommended. For the welded construction design solution, the Metal-Metal (MM) sealing of the ball and the seats is recommended, while the Soft Sealing (SS) is recommended for removable design solutions. When the working conditions are special, the valves can be equipped with PMSS sealing (Primary Metal Secondary Soft Sealing), meaning that the ball and the seats are coated with tungsten carbide and there is a soft sealing on the seats.

Whatever, the MM or PMSS solution is applied to the seats and to the ball, the design of the seat can be only done by the Simple Piston Effect (SPE) or by the Double Piston Effect (DPE) method. Design practise for a ball valve sized over DN150 recommends to use a type of seats with DPE (Double Piston Effect). The DPE method is recommended for large diameters, because it provides a highly efficient sealing due to the two O-Ring’s gaskets, situated at two stages to assures same sealing performance upstream and downstream. The SPE method provides efficient sealing only from the outside to the inside of the valve and risk of leakage occurs when the valve is closed and pressure is same upstream and downstream, therefore is recommended for small diameters (API 6D).

3. Case-study. Sizing of the principal body of a large ball valve

A case study, mechanical calculation of the body of a special valve with nominal diameter DN900 and nominal pressure of 100 bar is presented. The methodology is based on standards API 6D and SR EN 14313. For the cylindrical body of a large ball valve, the forged body solution is recommended. A high resistant steel, namely A350 LF2 is recommended in this case.

The main mechanical properties of the material are:

- Tensile strength: τe =485…655 MPa;
- Yield: >250 MPa;
- Elongation: >22 %;
- Hardness: <197 HB.

The design parameters are:

- Nominal diameter: DN900;
- External diameter: D_0=1690 mm;
- Nominal pressure: Pn=100 bar;
- Minimum thickness of the body: t_0=140 mm;
- Temperature of calculation: T_0=20°C;
- Fluid: natural gas
- Density of the fluid ρ=0.717 Kg/Nm^3.

The tolerance to negative deviation of the wall of the body can be calculated by the equation (ASME, 1980).

$$c_1=12.5\ t_0/100=17.5 \text{ mm}. \quad (1)$$

The corrosion addition is c_2=2.5 mm this case, in accordance with ASTM A350 – Table 6, a Standard specification for Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components (ASTM, 2021).

The effective thickness of the wall is (ASME, 1980)

$$te=t_0-c_1-c_2=120 \text{ mm}. \quad (2)$$

The effective internal inside radius is (ASME, 1980)

$$Ri=D_0/2-te=725 \text{ mm}. \quad (3)$$

The allowable stress for A350 LF2 is σ=118 N/mm^2;

The efficiency coefficient of the joint: $\varepsilon=1$;

The resistance pressure to be used in the testing process is calculated by the equation (ISO, 2015).

$$P_{th}=P_n \text{ x } 1.5=150 \text{ bar.} \quad (4)$$

The sealing test pressure is

$$P_{tp}=P_n \text{ x } 1.1=110 \text{ bar.} \quad (5)$$

According to the standard ASME Boiler and Pressure Vessel Code an American National Standard, Section VIII – Rules for Construction of Pressure Vessels, Division 1 (ASME, 1980), to validate the calculus, two requirements should be reached, the effective thickness of the wall must be smaller than half of the effective internal inside radius, the nominal pressure must be smaller than the allowable stress for A350 LF2.

$$t_e = 120 \text{ mm} < 0.5 \text{ x } Ri = 362.5 \text{ mm (verified);} \quad (6)$$

$$Pn = 100 \text{ N/mm}^2 < \sigma = 118 \text{ N/mm}^2 \text{ (verified).} \quad (7)$$

Both conditions are met, therefore the thickness of the cylindrical body it's enough to resist at the working pressure of 100 bar. Moreover, the valve will resist at the hydraulic test pressure of 150 bar, a mandatory condition for a prototype to comply with the standard API 6D.

The connection type is important in valve design. In general, for welded body type, the connection at the principal pipe must be welded. There are cases when connection is done by bolts, but they are rare. For welding end connections, the standard ASME B 16.25 is the recommended one, because it presents information about the welding end regarding valves from the category up to DN1200. For larger diameters, the designer must identify individual solutions.

4. Conclusions

To design a ball valve that is not situated in the standardized dimension is a challenge that require individual solutions. The designer must identify the most appropriate methods and technologies to be used both for the components and for the valve assembly.

The originality of this work consists in the recommendations concerning the methods to apply for the design of valves with dimensions that are not standardized. The main steps to design an industrial valve are defined in this paper and summarized in a scheme. Issues are highlighted and discussed in

order to have a clear idea regarding how to design a safe and reliable equipment to be used in the metal pipelines valve industry. A case study is presented.

The future direction of research is to analyze the final valve assembly of a ball valve over DN900 and to propose new solutions for an efficient opening/closing procedure, able to reduce failure risks.

REFERENCES

Allied Market Research, *Industrial Valves Market*, Report, 2021, https://www.alliedmarketresearch.com/industrial-valves-market, accessed at 2.05.2022.

API, *API specification 6D. Specification for Pipeline and Piping Valves*, US, 2014.

API, *API STD 608. Metal Ball Valves—Flanged, Threaded, and Welding Ends*, US, 2020.

ASME, *B16.10-2020. Gray Iron Pipe Flanges and Flanged Fittings. Gray Iron Pipe Flanges and Flanged Fittings: Classes 25, 125, and 250*, US, 2020.

ASME, *B16.25-2017. Buttwelding Ends*, US, 2017.

ASME, *B16.47-2020. Large Diameter Steel Flanges: NPS 26 through NPS 60, Metric/Inch Standard*, US, 2020.

ASTM, *A350-21. Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, US, 2021.

ASME *Boiler and Pressure Vessel Code an American National Standard, Section VIII – Rules for Construction of Pressure Vessels, Division 1*, 1980.

Cui B., Lin Z., Zhu Z., Wang H., Ma G., *Influence of opening and closing process of ball valve on external performance and internal flow characteristics*, Experimental Thermal and Fluid Science, 80, 193-202 (2017).

ISO, *ISO 5208:2015. Industrial valves – Pressure testing of metallic valves*, 2015.

ISO, *ISO 5211:2017. Industrial valves – Part turn actuator attachments*, 2017.

ISO, *ISO 14313:2007. Petroleum and natural gas industries – Pipeline transportation systems – Pipeline valves*, 2007.

Rogula J., *The Influence of Seat Fatigue Test on the Leakage in Ball Valve*, Procedia Engineering, **39**, 91-97 (2011).

*** SR EN 1092-1:2018, *Flanges and their joints. Circular flanges for pipes, valves, fittings and accessories, PN designated Steel flanges*, 2018.

SOLUȚII DE PROIECTARE PENTRU ROBINETE CU SFERĂ DE DIMENSIUNI MARI

(Rezumat)

Dezvoltarea sustenabilă a orașelor implică siguranță și eficiență în rețele de conducte. Robinetele cu sferă sunt adeseori preferate, deoarece generează pierderi hidraulice foarte mici atunci când sunt în poziție complet deschis și asigură etanșarea completă (fără scurgeri) atunci când sunt în poziția închis. Sunt recomandate cu

precădere în conducte unde o acțiune rapidă (de închidere sau deschidere) este necesară, în caz de urgență. Uniunea Europeană și Statele Unite ale Americii au implementat normative stricte pentru a stabili standardizarea componentelor ce fac parte din sistemele de conducte de diametre mici şi medii. În cazul robinetelor de diametru mare, dimensiunile de proiectare nu sunt prezentate în standarde și sunt necesare soluții individuale, bazate pe calcul mecanic.

În această lucrare, sunt prezentate recomandări de proiectare a unui robinet cu sferă care nu este standardizat și se prezintă un exemplu de proiectare. Studiul de caz face referire la un robinet cu diametrul nominal de 900 mm. Standardul API6D și echivalentul acestuia, ISO 14313 conține recomandări privind distanța față la față numai pentru robinete din categoria celor cu diametrul sub DN900, așadar metoda de proiectare conține elemente de originalitate.