Original article
https://doi.org/10.21683/1729-2646-2020-20-3-15-20

Methodology of experimental determination of dependability indicators when performing static bending tests of ball valves

Konstantin V. Osintsev[1*], **Nikita A. Kuznetsov**[2]

[1]South Ural State University, Russian Federation, Chelyabinsk, [2]OOO ChelyabinskSpetsGrazhdanStroy, Russian Federation, Chelyabinsk
[*]osintsev2008@yandex.ru

Konstantin V. Osintsev

Nikita A. Kuznetsov

Abstract. *The quantitative indicators of the dependability characteristics of process equipment, machines and entities include the reliability, maintainability, durability, storability. The* **Aim** *of the research is to develop a methodological framework of experimental determination of dependability indicators when performing static bending tests of ball valves. The aim is to be achieved by solving individual scientific problems, namely the development of the method of static bending testing of ball valves, experimental determination of the destructive test coefficient, analytical calculation of the coefficients of failure, efficiency preservation and product quality. A test stand was developed for experimental determination of the destructive test coefficient. The employed scientific methods of static testing are suggested for the first time ever. The minimal bending test load is the defining value, therefore the experimental work requires a large sample. Additionally, for the ball valve with the lowest endured bending load out of the tested items of the same diameter, it is recommended to use a specially developed methodology to identify such valve as solid-state monolithic units. The conclusions of the conducted experimental and theoretic research are in compliance with the solved research and development objectives. By conducting the experimental research, the authors evaluated the "enhanced" capabilities of ball valves by various manufacturers through comparative analysis of the conducted static bending tests. It is recommended to consider a solid-state monolithic unit along with the operation as part of a pipeline made of a certain material. The destructive test coefficients for the examined ball valves were experimentally determined. Efficiency preservation coefficients were identified that are the basic coefficients of the dependability indicator, that, in turn, is one of the primary dependability characteristics of process equipment, machines and entities.*

Keywords: *ball valve, dependability, static testing.*

For citation: *Osintsev K.V., Kuznetsov N.A. Methodology of experimental determination of dependability indicators when performing static bending tests of ball valves. Dependability 2020; 3: p. 15-20. https://doi.org/10.21683/1729-2646-2020-20-3-15-20*

Received on: *04.04.2020* / **Revised on:** *18.05.2020* / **For printing:** *21.09.2020*

Introduction

Pipeline valves are used in a number of sectors of the economy, for instance, in the oil and gas, chemical, metal, machine-building and energy industries. This paper examines the matters of improving the dependability of valves of heat supply, heating, hot and cold water supply systems. The categories of pipeline valves [1] include isolation, non-return, pressure-relief, distribution and mixing, control, separating and shutoff. The main types of pipeline valves include sliding valves, throttles, tap valves and butterfly valves. This paper examines the ball valves that fall into the category of isolation pipeline valves. The manufacturing process of ball valves is to take into consideration the dependability indicators [2] that will have an effect on faultless operation of industrial pipelines. For instance, the Technical Regulations of the Customs Union introduces the concept of assigned operating life of equipment, upon reaching which the operation of such equipment shall be terminated regardless of its condition [3, 4]. However, the dependability indicators differ from industry to industry and depend on the standard operation model [2].

Relevance of the research topic

The standard operation model, for which dependability indicators are developed, is defined by the specified operating modes of equipment, levels of cooperating factors and loads for each mode, characteristics of the adopted service and repair system [2]. Currently, ball valve manufacturers use various structural materials [5, 6], which, subsequently, involves varied dependability requirements. For instance, each ball valve manufacturer may now designate its product as "reinforced" with no valid reasons, which inconveniences the consumer who is choosing and ordering a ball valve. Thus, it is required to develop a method of testing for classifying valves in terms of the degree of "reinforcement". The method may be based on the existing federal GOST [7], European [8, 9, 10] and Russian industrial [11, 12, 13] standards. The authors suggest developing an additional new standard for static strength testing of ball valves, that would include a classification table (rows) for the purpose of classifying "reinforced" ball valves as a category of its own. The rows are to be made depending on the conventional flow area (nominal dimension) that has no unit of measure and approximately equals the pipeline's diameter. Additionally, the category of "reinforced" ball valves is subdivided into subcategories depending on the range between the test load P_{test} and the maximum load allowed during experimental research $(P_{St})_{\max}$. In other words, it is supposed to distribute the subcategories of "reinforced" ball valves between P_{test} and $(P_{St})_{\max}$ as follows: subcategory "R1" corresponds to load $P_{test} + (0.8\text{-}1.0)\times[(P_{St})_{\max} - P_{test}]$, subcategory "R2" corresponds to $P_{test} + (0.6\text{-}0.8)\times[(P_{St})_{\max} - P_{test}]$, subcategory "R3" corresponds to $P_{test} + (0.4\text{-}0.6)\times[(P_{St})_{\max} - P_{test}]$, subcategory "R4" corresponds to $P_{test} + (0.4\text{-}0.2)\times[(P_{St})_{\max} - P_{test}]$, subcategory "R5" corresponds to $P_{test} + (0.0\text{-}0.2)\times[(P_{St})_{\max} - P_{test}]$. As regards the latter case it must be understood that value $0.0\times[(P_{St})_{\max} - P_{test}]$ means none other than the lack of additional reinforcement of a ball valve, and in this case its manufacturer may not claim it is "reinforced". The new standard must also provide basic definitions and take into consideration the effect of external factors on the condition of pipelines, their couplings and valves. The implementation of the new standard is to involve the issue of recommendations and modifications to other industrial standards in terms of dependability rates of pipeline valves.

Procedure and conditions of the research

The authors of the paper have developed an algorithm of static testing of ball valves and individual pipeline sections with valves connected to them. A test stand was created, on which items were tested. A ball valve that complies with the average experimental values and withstands the minimal static load is considered by the authors as a solid-state monolithic unit (SSMU). Upward deviations of this load for other manufacturers' products are used as correction factors. The average values of such coefficients are determined and will be taken as the destructive test coefficient. Out of reference data additional coefficients are selected that are responsible for an entity's dependability. Based on the results of the conducted experimental research, statistical data of ball valve testing is processed, destructive testing coefficients and correction factors (if required) are introduced. The test and reference coefficients form a pool of data that allows calculating the efficiency preservation coefficient C_{ef}.

Goals of the research and problem definition

The Aim of the tests consists in creating a methodological framework of destructive testing as part of static testing of ball valves.

In order to achieve the aim of the research, the following problems are to be solved: definition of the terminology for ball valve dependability indicators; analysis of experimental data based on the results of tests per the authors' method; definition of the most important coefficients and corrections for the standard, recommended as basic efficiency preservation coefficient C_{ef}.

Scientific novelty of the research

As of today, in pipeline valve engineering, there is no conceptual framework for identifying the efficiency preservation coefficient C_{ef} based on experimental data. The method developed by the authors can be extended first to large-diameter ball valves and throttles, and, should the result be satisfactory, be recommended as the foundation for a new dependability standard for pipeline valves. This standard will define the criteria for "reinforced" ball valves reduced to rows, as well as set forth experimental coefficients that make the efficiency preservation coefficient C_{ef}, such as the destructive test coefficient C_{ds}, etc.

Theoretical part. Dependability of the object of research

According to GOST [14] the primary criterion of dependability is the efficiency preservation coefficient C_{ef} that characterizes the effect of failures of an entity's element on the efficiency of its intended application. At the same time, standards [2, 14] define C_{ef} as recommended, while for each specific case it can be complemented or modified, which depends on the process equipment and industry of application.

The dependability of the object of research is primarily associated with the reliability of its operation. In turn, the reliability of a ball valve is defined by the concept of its "reinforced" capabilities. A well-known method of destructive testing as part of supervision hydraulic testing [9] used in the European Union provides recommendations regarding the test load on ball valves and the formula:

$$P_{test} = 1.5 \times P_{St}, \quad (1)$$

where 1.5 is the coefficient of overpressure relatively to the allowable pressure P_{St} at room temperature. Formula (1) is used for valves designated PN. In case of missing PN data, corrections are introduced.

For the case of static tests, let us use formula (1), but, as the research, among other things, aims to identify the destructive test and correction coefficients, then:

$$P_{test} = K_{\text{THE}} \times (P_{St})_{\min}, \quad (2)$$

where $C_{\text{SSMU}} = 1.5$ is the coefficient of overpressure relatively to the allowable pressure at room temperature for an SSMU, while $(P_{St})_{\min}$ is the average value of the minimal withstood pressure for a ball valve by a manufacturer (SSMU) submitted to the test.

Experimental part

The authors have developed a test stand for the purpose of researching the effect of static bending loads on the strength of ball valves (Fig. 1, general view; Fig. 2, diagram of valve testing; Fig. 3, algorithm of the experiment).

Fig. 1. General view of the destructive testing stand

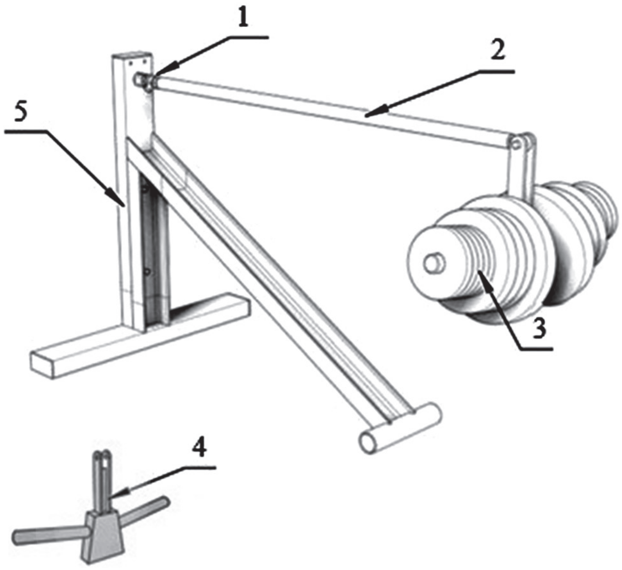

Fig. 2. Diagram of valve testing using the test stand
1 – tested valve; 2 – lever, 4 kg; 3 – weights;
4 – load no. 1, 6 kg; 5 – Stand

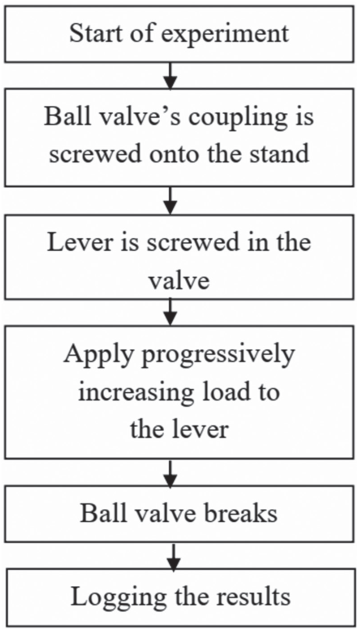

Fig. 3. Algorithm of the experiment.

Similarly, pipelines are tested on the stand.

The algorithms were developed accounting for [12], as well as individual articles and chapters of [13, 14].

The data obtained in the course of the experiment are shown in Table 1.

Let us plot the results summarized in Table 1 in a summary diagram that will also show the static load line.

Using formula (2) we will obtain, given that $(P_{test})_{\min} = 20.5$ kg:

$$P_{test} = C_{\text{SSMU}} \times (P_{test})_{\min} = 1.5 \times 20.5 = 30.75 \text{ kg}. \quad (3)$$

Table 1. Resulting experimental data

	Manufacturer, load, kg		
	1 (China, brass with powder additives)	2 (China, brass)	3 (Russia, brass)
1	19.5	28.5	34.5
2	20.5	28.5	30.0
3	21.5	25.0	33.5
Average	20.5	27.33	32.67

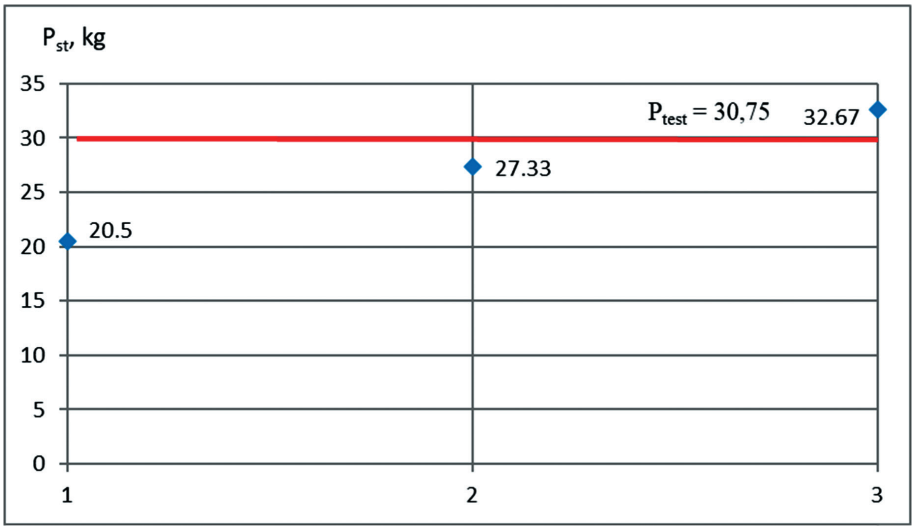

Fig. 4. Summary diagram for identifying the loads on “reinforced” ball valves

In Fig. 4, let us plot the static load line P_{test} = 30.75 kg, according to which we will deduce that ball valves by manufacturer 3 (Russia, brass) can be considered “reinforced” according to the test results.

Visualization of test results

As the result of the experimental activities using the test stand, ball valves by various manufacturers disintegrated under different loads. The test results are visualized in Fig. 5 and 6.

Fig. 5. The results of the conducted dependability tests 1 (China)

Fig. 6. The results of the conducted dependability tests 3 (Russia)

It should be noted that the ball valves get always ruptured in practically the same area.

Destructive testing coefficient

Let us identify the destructive test coefficient that will be used as the primary dependability coefficient:

$$C_{dt} = (P_{St})_i / [C_{SSMU} \times (P_{St})_{min}], \quad (4)$$

where C_{dt} is the destructive testing coefficient, while $(P_{St})_i$ is the average value of the withstood pressure for a ball valve by a manufacturer (*i*-th manufacturer) submitted to the test.

As the method of static bending tests under development is not standard, the formula of hydroproof testing can only be used as a reference. Given the recommendations regarding the processing of experimental data:

$$P_{test} = (P_{testA} + P_{testB})/2, \quad (5)$$

where P_{testA} is the average value of the test bending load of a ball valve, P_{testB} is the average value of the test bending value of a pipeline.

Thus, generally speaking, a "reinforced" small-diameter ball valve will be deemed as such if it complies with the experimental conditions:

$$P_{test} > C_{SSMU} \times (P_{test})_{min}. \quad (6)$$

Definition of experimental coefficients

According to formula (4), the authors deduced experimental coefficients and summarized them in Table 2.

Table 2. Coefficients obtained during the experiment

C_{dt}		
1 (China, brass with powder additives)	2 (China, brass)	3 (Russia, brass)
0.67	0.89	1.06

According to test data, manufacturer (1) has the lowest dependability coefficient that the authors defined as the destructive test coefficient.

Dependability coefficient according to reference data

According to [2], it is required to introduce correction coefficients for the end product depending on its characteristics:

1. A ball valve is taken as a non-restorable item of a heat supply system, therefore we adopt the failure coefficient $C_f = 0.96$ for all ball valves by various manufacturers.
2. The efficiency preservation coefficient depends on the type of valve. A ball valve for heat supply systems uses process water, therefore $C_{ep} = 0.97$.
3. The quality of manufacture and material will be estimated with the product quality factor C_{pq}. This coefficient will be preliminarily taken as $C_{pq} = 0.99$ for manufacturers (2) and (3) and $C_{pq} = 0.97$ for manufacturer (1).

Efficiency retention factor according to the developed methodology

As the result, using the formula developed by the authors, we will deduce the efficiency preservation coefficient.

$$C_{ef} = C_{dt} \times C_f \times C_{ep} \times C_{pq}, \quad (7)$$

We will obtain data for the efficiency preservation coefficient and summarize them in Table 3.

Table 3. Calculated efficiency retention coefficients

C_{ef}		
1 (China, brass with powder additives)	2 (China, brass)	3 (Russia, brass)
0.61	0.82	0.98

According to Table 3, all coefficients proved to be below 1. Therefore, the authors have correctly chosen the initial experimental conditions.

Recommendations regarding further development of methodological framework

The authors of the paper stress that the developed methodological framework requires additional tests and experimental trials. Thus, the minimal bending test load $(P_{test})_{min}$ is the defining value, therefore the experimental work requires a large sample. Additionally, in this case the authors recommend defining the ball valve with the lowest endured bending load out of the tested items of the same diameter as the SSMU using the method under development.

Conclusions

1. As the result of experimental research the authors evaluated the "enhanced" capabilities of ball valves by various manufacturers through comparative analysis of the conducted static bending tests of the valves.
2. It is recommended to consider an SSMU along with the operation as part of a pipeline made of a certain material. The pipeline is also recommended to submit to static load tests.
3. As the result of conducted experimental research, the ball valve by manufacturer (1) was identified as the SSMU. Given the SSMU, the minimal test load was identified as $(P_{test})_{min} = 20.5$ kg.
4. The destructive test coefficients for the examined ball valves were experimentally determined.
5. Efficiency preservation coefficients were identified, that, according to [2], are the basic coefficients of the reliability indicator, that, in turn, is one of the primary dependability characteristics of process equipment, machines and entities.

References

[1] GOST 24856-2014. Pipeline valves. Terms and definitions. Moscow: Standartinform; 2015. (in Russ.)

[2] GOST 27.003-2016. Industrial product dependability. Contents and general rules for specifying dependability requirements. Moscow: Standartinform; 2018. (in Russ.)

[3] [Technical Regulations of the Customs Union On the safety of equipment operating under excess pressure (TRCU 032/2013) of November 18, 2013]. (in Russ.)

[4] [Technical Regulations of the Customs Union On the safety of machines and equipment (TRCU 010/2011) of October 18, 2011]. (in Russ.)

[5] Ball valves types, construction, applications and advantages. [accessed 01.04.2020]. Available at: http://www.pipingguide.net.

[6] [Ball valves]. [accessed 01.04.2020]. Available at: http://www.chsgs.ru. (in Russ.)

[7] GOST 16504-81. Product test and quality inspection. Moscow: Standartinform; 2011. (in Russ.)

[8] API Standard 598. Valve Inspection and testing; 2004.

[9] BS EN 12266-1: 2012. Industrial valves – Testing of metallic valves. Part 1: Pressure tests, test procedures and acceptance criteria – Mandatory requirements.

[10] BS EN 12266-2: 2002. Industrial valves – Testing of metallic valves. Part 2: Tests, test procedure and acceptance criteria – Supplementary requirements.

[11] [ST TsKBA 008-2014. Pipeline valves. Calculation and assessment of dependability and safety at the stage of design]. Saint Petersburg: Izdatelstvo ZAO NPF TsKBA. (in Russ.)

[12] [ST TsKBA 092-2014. Valves for long-distance pipelines. Design loads caused by pipeline. Methods of calculation and numerical values]. Saint Petersburg: Izdatelstvo ZAO NPF TsKBA. (in Russ.)

[13] [ST TsKBA 008-2014. Pipeline valves. Periodic testing. General requirements]. Saint Petersburg: Izdatelstvo ZAO NPF TsKBA. (in Russ.)

[14] GOST 27.002-2015. Dependability in technics. Terms and definitions. Moscow: Standartinform; 2016. (in Russ.)

About the authors

Konstantin V. Osintsev, Candidate of Engineering, Head of Department of Industrial Heat Power Engineering, South Ural State University, Russian Federation, 454080, Chelyabinsk, 76 Lenina Ave., e-mail: osintsev2008@yandex.ru.

Nikita A. Kuznetsov, Engineer, OOO ChelyabinskSpetsGrazhdanStroy, Russian Federation, 454010, Chelyabinsk, 47 Yeniseyskaya Str. e-mail: kna@chsgs.ru.

The author's contribution

K.V. Osintsev developed a methodological substantiation of experiments using destruction test stands, suggested using new dependability coefficients and rows of "reinforced" ball valves.N.A. Kuznetsov conducted a research using the destruction test stand, processed the experimental results.

Conflict of interests

The authors declare the absence of a conflict of interests.