International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

September 2024	Issue 60	Volume 16	Number 3	Pages 227-233

STUDY OF EQUIVALENT STRESS AND STRAIN IN IMPROVED VALVE CONSTURCTIONS HERMETIC ELEMENTS

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Abstract- To examine the impact of wear on the construction of the improved linear valve under diverse conditions, this paper specifically focuses on investigating the primary hermetic elements of the structure. The study altered a new calculation scheme for the proposed solution of the valve hermetic elements which afterwards transferred to MATLAB software by using the fuzzy logic method. The study takes into account multiple parameters to establish the pertinent pressure distribution across the components of the structure. Noteworthy studies employ finite element analysis, simulations, and fuzzy logic to enhance valve performance. Current article has been used the method of fuzzy logic to the variables over using the MATLAB software. Determination of equivalent stress in the hermetic elements of an improved valve has been researched and relevant calculation methods have been developed. The complexity of hermetic elements is reviewed, considering physical-mechanical and technological factors. The manuscript details a new calculation scheme for a trapezoidal cross-sectioned hermetic element, providing equations for stress and deformation which newly introduced at first time in given condition. The MATLAB program's utilization for variable analysis and optimization using the "bee colony" method is elucidated. Relevant obtained data depict the influence of system variables on angle variations, showcasing the program's capability to explore variable spaces comprehensively. The conclusion highlights the optimal pressure change angle for a trapezoidal spring in the improved valve design, determined through rigorous comparative analysis. This angle, identified as 62 degrees, serves as a critical reference point for further design enhancements and operational considerations, ensuring optimal valve performance. The article concludes with a broader perspective on the evolving trends in valve industry research, emphasizing a holistic approach to construction, durability, and performance optimization.

Keywords: Improved Linear Valve, Variables, Hermetic Elements, Corrosion, Erosion, Hermetic Elements, Workability.

1. INTRODUCTION

The contemporary oil and gas industry places significant emphasis on the reliability of equipment crucial for efficient operations. Valves, a widely utilized component in the industry, play a key role in controlling and directing the flow from wells to various processing equipment, and managing the shut-off process [1]. The advancement of the oil and gas sector now hinges on enhancing the reliability of closing units, especially those deployed underwater. Among the well-established closing devices, the ball valve emerges as a crucial element ensuring uninterrupted production operations. Its significance extends beyond the oil and gas industry, finding widespread application in chemistry, energy conversions, metallurgy, and other sectors [2, 3].

In aggressive environments within the oil and gas industry, ball valves prove to be the most suitable choice for on/off purposes. They demonstrate superior robustness compared to butterfly or gate valves under such challenging conditions [4]. Manufacturers have a wide array of materials at their disposal for crafting the distinct components of ball valves. Material selection depends on factors such as pressure, valve diameter, ball type, and temperature. In situations involving various wear and process streams, a careful compromise in material selection is sought to enhance the valve's longevity in aggressive environments [5].

The primary cause of failure in ball valve constructions often relates to the wear and tear of hermetic elements, crucial for preventing flow flooding and directing products between locations. Corrosion and erosion are frequently observed types of wear and tear in these valves, leading to operational failure and an increased risk of mechanical breakdowns [6]. In high-pressure applications where on/off operations are essential, high-pressure rated ball valves are commonly used, typically remaining in the closed position. However, this prolonged closure can lead to the formation of incrustations around the ball ring. It's important to note the occurrence of fretting wear, a common challenge for such constructions, as they must withstand high pressure throughout their operational lifespan [7].

Registered: 240304 Article Info: 1856 Accepted: 240815
Reserved: 240527 Available: 240930

2. LITERATURE REVIEW

The ongoing research centers on examining the pressure distribution within an upgraded valve structure. The primary difference between the existing and enhanced designs is found in one of its closing components, featuring an oval cross-sectional shape. This alteration guarantees a more uniform pressure distribution among the primary closing elements, ultimately improving the unit's overall performance [8-10]. Over the years, extensive research efforts have been dedicated to improving the reliability and functionality of valve constructions, subjecting them to comprehensive scrutiny.

In their study, Xue-Guan and Seung-Gyu [11] investigated the material properties employed in the production of valve bodies, with a specific focus on those that play a role in sealing functions. Their proposed model aimed to minimize corrosion by utilizing a Stainless-steel model CF8M. Structural reinforcement analysis, conducted through the finite element method and RSM optimization, revealed significant reductions in mass. In the year 2022, Aslanov and Mammadov [12] introduced an innovative approach to control pressure distribution across hermetic elements. Utilizing diverse calculations and SolidWorks simulations, the researchers introduced a fresh valve model designed for distinct positions (closed, semi-open, open). Their findings illustrated that modifying the structure of crucial valve components, including hermetic elements, effectively addressed pressure distribution concerns.

In 2019, Aslanov, et al. [13, 14] utilized fuzzy logic to predict the impact of alterations in valve construction involving diverse materials. Through comprehensive data collection and analysis using fuzzy equations, the researchers gained valuable insights into the potential degradation of valve performance. This approach facilitated the identification of worst-case scenarios under varying flow conditions.

A thorough review of the literature highlights those researchers are actively engaging in experiments and product redesigns with the goal of improving valve functionality. Various methodologies are being employed to enhance the durability of valve constructions. A focused analysis of the redesign and engineering of ball valve hermetic elements indicates a departure from traditional approaches toward embracing value engineering principles. This shift is characterized by a commitment to precision and is substantiated by the integration of advanced simulations. Scholars are increasingly emphasizing not only the empirical aspects of experimentation but also the strategic and innovative aspects of design modifications. This evolution in approach signifies a broader trend in the valve industry, where a holistic consideration of construction, durability, and performance is becoming pivotal, with an emphasis on incorporating cutting-edge engineering strategies for optimal results [15].

3. DETERMINATION OF THE EQUIVALENT STRESS IN THE HERMETIC ELEMENTS OF THE IMRPOVED VALVE

The operational efficiency and reliability of valves are intricately tied to the design and dimensions of their working parts. The primary selection of components and connections further contributes to their overall functionality. Specifically, linear valve constructions undergo evaluation based on a set of critical parameters. The shape and dimensions of these working parts play a pivotal role in determining how effectively valves perform their intended functions. The right selection of components and nodes within the valve structure is paramount to ensuring not only proper operation but also long-term reliability [16]. The following group of the parameters are considered for the linear valve constructions:

1) Dimensions of the structure in the disassembled state
2) Taking into account that the valve works in various environments during operation, including acid-alkaline environments and aggressive conditions, the stresses generated in the parts and nodes that make up the structure
3) Thermal processing of the parts that make up the basis of the valves, ways of strengthening its surface and placement of elements within the structure

The overall dimensions of the main working parts of the valves depend on the conditions and mode of its operation. The shape and size of the structural components of the valve should be optimally selected. In addition to performing their functions, these nodes must be able to overcome the impacting forces, distribute them evenly on the surface and ensure their functionality within the time period specified in their technical passport. "Metal-metal" and "metal-rubber" couplers are used to ensure tightness when the valve is closed. The part of the valve that is mostly subject to wear is its hermetic elements [17, 18].

Securing the hermetic elements within the valve structure is a multifaceted process influenced by various factors, primarily categorized into physical-mechanical and technological aspects. The physical-mechanical considerations pertain to the inherent characteristics of the chosen material. On the other hand, technological factors encompass a spectrum of variables contributing to the stress deformation state of the forming element, which includes sensitivity to altering pressures, displacement speeds, and related parameters.

The efficacy and dependability of the hermetic element hinge on the intricate interplay of these factors. Within the realm of physical-mechanical considerations, the material's properties assume a pivotal role. The selected material must possess attributes that align with the demanding requirements of the valve structure. Meanwhile, technological factors introduce a layer of complexity by incorporating variables such as the dynamic nature of pressures and displacement speeds. The relationship between these elements and their impact on the stress deformation state of the forming component plays a crucial role in determining the overall performance and reliability of the hermetic element [19].

Central to this intricate interdependence is the role of forces exerted on the hermetic element. These forces stand as the primary driving factor, essential for ensuring not only the efficiency but also the robust functioning of the valve structure. As such, a comprehensive understanding of the synergistic effects of physical-mechanical and technological factors is imperative for achieving optimal fastening and, consequently, the successful operation of the valve system [20].

The interrelation between stress and deformation in rubber ring fasteners, integral to the securement process facilitated by the molding effect of the hermetic element, is predominantly contingent upon the configuration and dimensions of the tightness. Consequently, the stress condition of the fastener in its initial state, followed by its subsequent deformation, warrants careful examination. The effectiveness and reliability of the tightening process are intricately tied to the inherent attributes of the tightening mechanism, which are defined by its unique shape and dimensions. The interconnection between the efficiency and dependability of the tightening process relies heavily on the specific geometric features and size specifications embedded within the tightening mechanism. This intricate relationship underscores the significance of precision in the design and dimensions of the tightening component, ensuring optimal functionality and reliability in securing the elements within the overall structure.

Ascertaining the stress state of the conditioner during its nascent stage, and subsequently analyzing its deformation, assumes paramount significance in elucidating the complex dynamics governing the securement and dependability of the hermetic element within rubber ring fasteners. The cross-sectional shapes of the hermetic element can be of different shapes. The cross-sectional area of the current one is assumed to be a trapezoid (Figure 1). Before applying the stress state, it is important to consider the forces acting on the beam in the Deckard coordinate system. The reporting scheme is given in Figure 1.

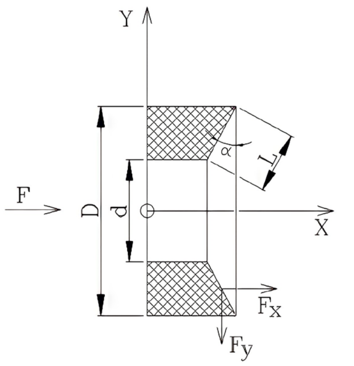

Figure 1. Scheme of the hermetic element that has been chosen as the trapezoid cross-sectioned

In order to obtain the acting equivalent stress, projections of F_x parallel to X and F_y parallel to Y axis were considered. The diameter of the hermetic element is D, and the transition diameter is denoted by d. If the main stress acting on the X axis denoted as σ_x, the main stress acting on the Y axis denoted as σ_y, and the tangential stress denoted as τ_{xy}, then the equivalent stress obtained according to the reporting scheme will be as follows:

$$\sigma = \sqrt{\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2} \quad (1)$$

where, σ_x, σ_y are main stresses over X and Y axis, τ_{xy} is shear stress. In the chosen scheme $\tau_{xy} = 0$. If the change in the cross-sectional area α from the pressure of the acting force is taken into account, then the main stresses can be written as following:

$$\sigma_x = \frac{F\cos\alpha}{S} \quad (2)$$

$$\sigma_y = \frac{F\sin\alpha}{S} \quad (3)$$

where, S is the cross-sectional area of the hermetic element and being calculated as per following:

$$S = \pi \times L \times (\frac{D}{2} + \frac{d}{2}) \quad (4)$$

$$L = \frac{D-d}{2\cos\alpha} \quad (5)$$

If statements (4) and (5) were substituted in statements (2) and (3),

$$\sigma_x = \frac{F\cos\alpha}{\pi(\frac{D-d}{2\cos\alpha}) \times (\frac{D}{2} + \frac{d}{2})} \quad (7)$$

$$\sigma_y = \frac{F\sin\alpha}{\pi(\frac{D-d}{2\cos\alpha}) \times (\frac{D}{2} + \frac{d}{2})} \quad (8)$$

It is possible to observe the dependence $f(\sigma) = f(F,\alpha)$ from the above equations. The in-depth exploration conducted in this study delves into the intricate world of linear valve constructions, with a specific emphasis on the crucial hermetic elements. It is imperative to underscore the engineering significance of these elements, as they play a pivotal role in the overall performance and reliability of valves in various operating conditions.

In the realm of valve engineering, the careful selection of materials and the optimization of structural components are paramount. The study incorporates a novel calculation scheme, introducing the concept of a trapezoidal cross-sectioned hermetic element. This innovative approach not only expands the repertoire of available design options but also addresses the challenges associated with pressure distribution and wear in valve constructions.

4. DETERMINATION OF DEFORMATION IN HERMETIC ELEMENTS OF IMRPOVED VALVE

As it is known, according to the generalized Hooke's law, forces acting in three directions; The relationship between the main stresses $\sigma_x, \sigma_y, \sigma_z$ and the relative strain is as follows:

$$E_x = \frac{1}{E}\left[\sigma_x - \mu(\sigma_y + \sigma_z)\right] \quad (9)$$

$$E_y = \frac{1}{E}\left[\sigma_y - \mu(\sigma_x + \sigma_Z)\right] \quad (10)$$

$$E_z = \frac{1}{E}\left[\sigma_z - \mu(\sigma_x + \sigma_y)\right] \quad (11)$$

where, in plane problems, the above Equations (9)-(11) are simplified. So, since $\sigma_z = 0$, the determination of deformations will be as follows.

$$E_x = \frac{1}{E}\left(\sigma_x - \mu\sigma_y\right) \tag{12}$$

$$E_y = \frac{1}{E}\left(\sigma_y - \mu\sigma_x\right) \tag{13}$$

$$\gamma_{xy} = \frac{\tau_{xy}}{G} = \frac{2(1+\mu)}{E}\tau_{xy} \tag{14}$$

when, $\sigma_z \neq 0; E_z = 0$, the main stress over the Z axis is acting as per following:

$$\sigma_z = \mu\left(\sigma_x + \sigma_y\right) \tag{15}$$

Upon solving the equilibrium equations that account for the relationship between displacement and stress, the resulting equations are as follows:

$$E_x = \frac{1+\mu}{E}\left[(1-\mu)\sigma_X - \mu\sigma_y\right] \tag{16}$$

$$E_y = \frac{1+\mu}{E}\left[(1-\mu)\sigma_X - \mu\sigma_x\right] \tag{17}$$

$$\gamma_{xy} = \frac{\tau_{xy}}{G} = \frac{2(1+\mu)}{E}\tau_{xy} \tag{18}$$

Considering that the displacement occurs along the X-axis at a specific angle, calculations to be performed based on Equation (16) to determine the expression for Ex. Pressure of the valve construction are considered to be 70MPa and outer and inner diameters to be 9mm and 6mm respectively. The angle between the hermetic elements' tightness can vary between 0 degree to 90 degree. Considering the given data, it becomes possible to ascertain the optimal displacement angle by examining the displacement state across a range of angles from 0 to 90 degrees. Consequently, the values of the displacement equation exhibit variability based on the angle.

In the realm of valves operating under high pressures, a distinctive characteristic is their robust resistance to wear induced by friction. The fulfillment of this condition provides compelling evidence to assert that the longevity of the construction has been significantly increased. This enhanced durability is crucial for the effective and sustained operation of valves in demanding conditions. It underscores the importance of friction-resistant features in high-pressure valve design, contributing to prolonged reliability and performance. In summary, the consideration of various displacement angles and the emphasis on friction resistance contribute to the overall optimization and longevity of constructions, particularly in high-pressure valve applications.

Utilizing MATLAB program facilitates the representation of the interplay among multivariable expressions through a generalized graph. By disregarding angle variations, eliminating constants from calculation results based on the referenced equations described in above section, as well as focusing on changes within the 0 to 90-degree range, a simplified table of variables could be determined. The results of the variables capture scenarios where variations in obtained values are negligible.

Subsequently, leveraging the "bee colony" method in the MATLAB program allows us to load these variable values and discern their interactions in a 3D format. This methodology streamlines the assessment of variable relationships, providing insights into their dynamics within the specified angle range.

5. RESULTS

Through the "bee colony" method, the program efficiently explores variable spaces, facilitating a comprehensive understanding of their interdependencies and enabling the visualization of complex relationships in a three-dimensional context.

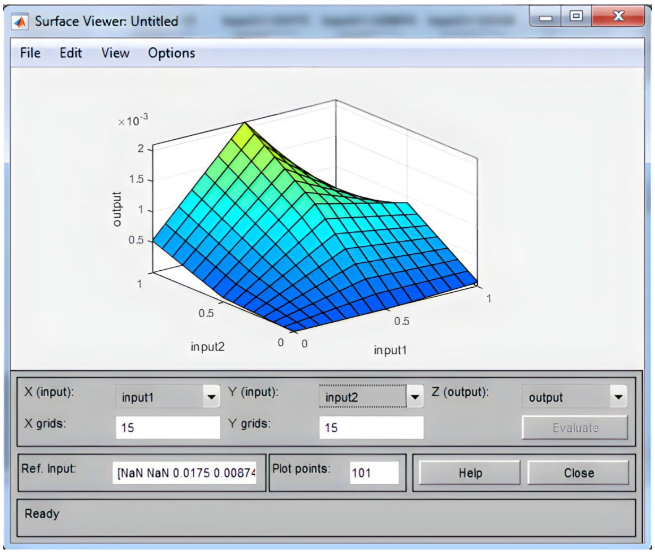

Figure 2. Analysis of "input 2-input 1" data with respect to variable angle

Figure 2 shows the change of angles under different variables which basically facilitate choosing of the optimal angle between the tightness of valve hermetic elements. It determines the movement of several angles depending on the inputs given to the elements onto each other, and the relevant graphs show the wear changes over the period dependance on force (*N*) applied and called "Input 2". Here, both materials are the same ST 20X - ST 20X.

As it can be noticed the wear increases at the beginning to a level and then starts to decrease over the period for the same steel materials while moving onto each other. Applied load varied during the time change and consequently the wearing factor changed accordingly depending on the level of the degree applied between 2 hermetic elements of the valve construction.

Figure 3 illustrates the change of angles under different variables formed via the changes of input 3- input 1 order. The shown variable is to facilitate choosing of the optimal angle between the tightness of valve hermetic elements. Through the utilization of the "input" command, the integration of the "and" operator serves to elucidate the mutual influence of the system variables. This reveals the system's impact on each other and effectively projects the angle variations onto the XYZ axis in an open format. The inherent capability of the software lies in its autonomous analysis of variable interactions for each degree, offering a comprehensive assessment of the system's behavior.

Figure 3 also determines the movement of 2 steel samples onto each other under different angles, and the relevant graphs show the wear changes over the period dependance on the force (N) applied and called "Input 3". Here, the materials chosen to differ from each other such as the one is ST 20X whereas another one is ST 40X. As it can be noticed the wear increases at the beginning to a higher level and almost reaches its maximum which is the time when two different metal surfaces contact with each other under the given maximum angles. After a while, the decrease of the wearing observed during the normalization of ST 40X movement onto ST 20X. The increase of the force lead to have the increment of wearing after certain time and it reaches a level of wearing again. Applied load is varied during the time and consequently the wearing factor changed accordingly deepening on the chosen angle over the period.

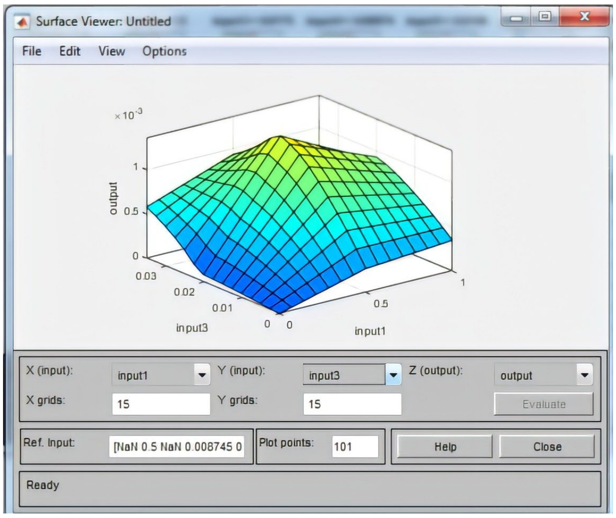

Figure 3. Analysis of "input 3-input 1" data with respect to the variable angle

6. COMPARATIVE ANALYSIS OF THE OBTAINED RESULTS

The given command exhibits a unique functionality by subjecting each "input" to the "bee colony" method at least twice. This strategic repetition enhances the robustness of the optimization process. Notably, when encountering substantial differences between variables, the system strategically excludes such instances from the optimization format. Instead, it intelligently introduces the "OR" command into the alternative selected column. This adaptive approach ensures a nuanced optimization procedure, effectively addressing variations in the system and enhancing the reliability of the analysis.

The wear behavior of two steel samples moving against each other depends significantly on the chosen materials, the angle of the hermetic elements, and the shape of the samples. The increase in wear is primarily influenced by the angle at which the moving parts contact the stationary seat. The samples compared are ST 20, ST 20X, ST 40, and ST 40X.

When ST 20X moves against ST 20X, wear increases initially before stabilizing and then decreases over time. Conversely, when ST 40X moves against ST 20X, wear sharply increases initially, reaching its maximum when the different metal surfaces contact each other. This is followed by a decline as the movement normalizes. Increased force leads to a subsequent rise in wear, which eventually stabilizes. In the case of ST 20X moving against ST 40X, wear is not significant at the beginning. However, it reaches a notable level once the metal surfaces contact and begin to move together, leading to continuous wear. Over time, wear decreases as the movement normalizes. Increased force initially causes a decrease in wear, eventually reaching a level of "normal wear" as the surfaces move smoothly at the optimum angle.

This pattern differs when ST 40X moves against ST 40X. Here, wear is initially low before the surfaces contact each other. Once contact is made and movement begins, wear increases and continues over time. Although there is a decline as the movement normalizes, the wear remains relatively high. Increased force results in further wear, which does not stabilize to a level of "normal wear" due to the hardness of the steel materials used.

At results, upon conducting a comparative analysis of the derived variables based on the figure 2 and figure 3, it is discerned that the optimal pressure change for the trapezoidal spring in the newly designed valve occurs at an angle of 62 degrees based on the chosen materials. This conclusion is drawn from a meticulous examination of the variables across different angles, emphasizing the pivotal role of the 62-degree mark in achieving optimal performance. The trapezoidal spring's pressure change at this specific angle showcases superior characteristics, signifying its effectiveness within the design framework judging by increase of wear over the angle chosen.

7. CONCLUSION

The current work is based on an in-depth exploration of the impact of wear on an enhanced linear valve under various operating conditions, with a specific focus on the primary hermetic elements of the structure. Introducing a novel calculation scheme for valve hermetic elements, the study seamlessly integrates fuzzy logic methodology, transferring the devised solution to MATLAB software for comprehensive analysis. Considering multiple parameters, the investigation establishes a nuanced understanding of pressure distribution across the structure's components. Leveraging finite element analysis, simulations, and fuzzy logic, the study significantly contributes to the improvement of valve performance.

The determination of equivalent stress in the enhanced valve's hermetic elements is a central aspect of the research, addressing the intricacies of these elements through a thorough consideration of physical-mechanical and technological factors. A pioneering calculation scheme for a trapezoidal cross-sectioned hermetic element is presented, unveiling equations for stress and deformation in a previously unexplored context.

The utilization of the MATLAB program, employing the "bee colony" method, reveals comprehensive insights into the influence of system variables on angle variations, underscoring the program's robust capability to explore variable spaces.

The conclusive findings highlight the optimal pressure change angle for a trapezoidal spring in the improved valve design, determined through rigorous comparative analysis at 62 degrees. This identified angle serves as a crucial benchmark for subsequent design refinements and operational considerations, ensuring optimal performance. The broader perspective emphasizes evolving trends in valve industry research, emphasizing a holistic approach to construction, durability, and performance optimization for future advancements.

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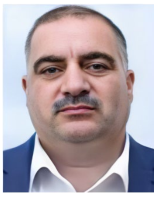
BIOGRAPHIES



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Scientific Publications: 9 Papers, 1 Patent, 3 Theses
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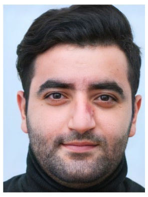

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