Modal-Based Design Improvement of a Butterfly Valve Disc

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The dynamic behaviour control of a butterfly valve is important because, when one of the valve disc natural frequency is close to the frequency of vortex shedding, which appears when the valve is fully open or partially closed, resonance may appear and vibration with significant amplitudes is generated. This paper presents an example by how the design of a butterfly valve disc can be improved by using a modal analysis performed by means of the finite element method. For this purpose, the research reveals the way in which the natural frequencies of the disc can be modified by applying stiffening ribs or changing the dimensions, respective the position of these ribs.

1. Introduction

Butterfly valves are control devices, typically used to regulate the flow of a fluid through the section of a pipe. They became very popular over the years, due to their short distance between the flanges and, consequently, being lighter in weight and ensuring smaller mounting dimensions, compared to other valve types. A literature review [1-7] indicates that various aspects, such as noise, vibration, corrosion, cavitation or flow coefficients are research topics related to the operation of butterfly valves.

As shown in Figure 1, the closing mechanism is a circular rotating disc or plate. In open position, the disc pivots 90° in the valve bore, being aligned with the fluid flow and creating nearly an unrestricted flow path. By rotating the disc with 90°, it ensures a very fast shutoff.

Both during normal operation regime of the valve, at variable fluid dynamics, and, especially during closing or opening maneuvers, undesired vibrations of the disc may occur. Therefore, in order to prevent the cases in which the resonance of the disc may occur, stiffening ribs are practiced on the disc surface.

Figure 1. Butterfly valve [8]

In this work, a modal analysis was performed for improving the design of a butterfly valve disc, respective to establish the ribs geometry and their position in order to achieve disc natural frequencies values above the shedding frequency of the valve.

2. Case study

The lenticular disc of the butterfly valve presented in Figure 2 was involved in the design improvement process by using modal analysis. The diameter of the disc is D= 1200 mm and it is manufactured from AISI 1045 (equivalent to C45, according to EN 10083-1: 2007) structural steel, having the mechanical properties presented in Table 1.
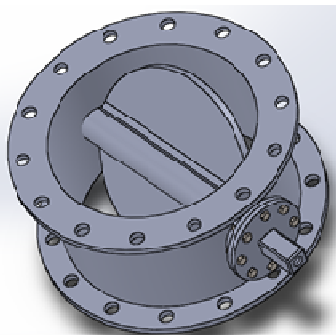

Figure 2. Butterfly valve- object of design improvement [9]

Table 1. Mechanical properties of the disc material

Yield strength [Mpa]	Elastic modulus [Mpa]	Poisson's ratio [-]	Mass density [kg/m^3]
530	205	0,3	7850

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For the design improvement of the disc, the following design elements were considered: disc thickness (t), number of stiffening ribs (n), ribs height (h), ribs thickness (b) and the distance between the ribs (d). Figure 3 shows the design elements considered in the design improvement of a disc with two stiffening ribs. Furthermore, Table 2 presents the five constructive variants which were assumed in the design improvement process.
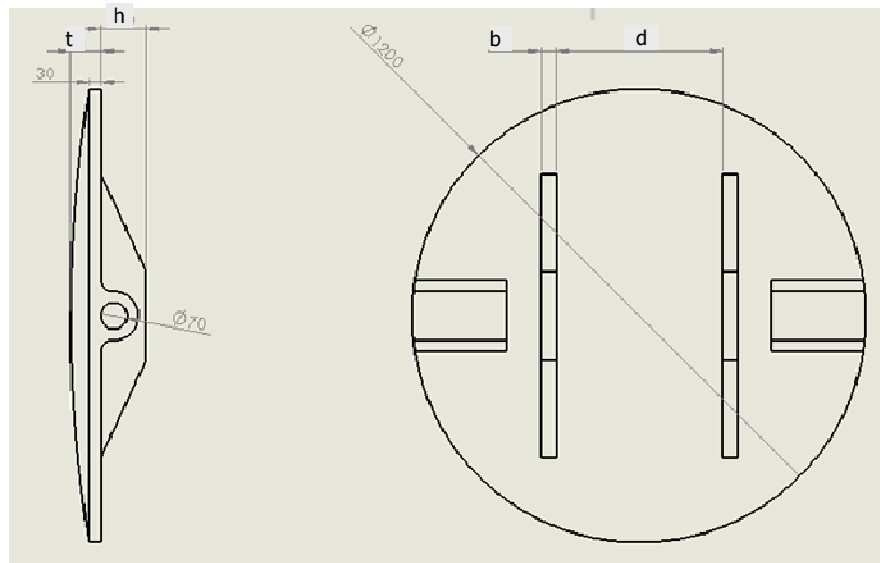

Figure 3. Constructive elements of the disc considered in the design improvement

Table 2. Constructive variants assumed in the design improvement process

Constructive variant	1	2	3	4	5
Number of ribs n	without	2			
Disc thickness t [mm]	100	90	80		
Ribs height h [mm]	0	100			
Ribs thickness b [mm]	0	40			
Dist. between ribs d[mm]	0	300	200	300	440
Weight of the disc [kg]	604,7	589	550,1	550,1	550,1

3. Methods

For the five assumed constructive variants of the disc, a finite element analysis (FEA) was performed, using SolidWorks simulation software, in particular the frequency analysis module. In order to obtain reliable results, a Solid Mesh type

was applied, having elements with twenty-nine characteristic points and a maximum dimension of the element of 5mm. An image of the meshed disc is shown in Figure 4, while Figure 5 illustrates the boundary conditions applied for the modal analysis (with green arrows are marked the fixing conditions of the disc).
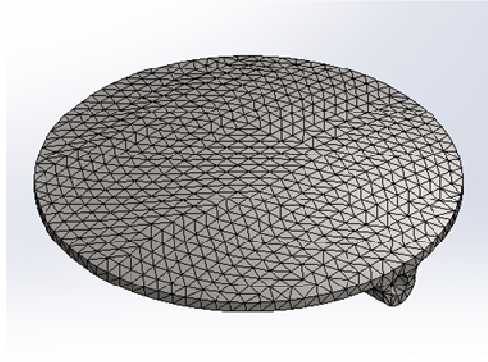

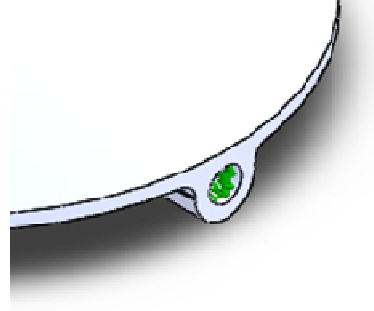**Figure 4.** Mesh applied to the disc [9]   **Figure 5.** Boundary conditions [9]

4. Results and discussion

The results of the modal analysis performed for the five investigated constructive variants, respective the first four natural frequencies of the disc are presented in Table 3.

Table 3. Natural frequencies of the valve disc for the five constructive variants

Constructive variant	Natural frequencies			
	f_1 [Hz]	f_2 [Hz]	f_3 [Hz]	f_4 [Hz]
1	159.9	293,3	427,9	482,8
2	172,7	300,3	465,0	526,8
3	179,4	305,2	496,6	538,3
4	162,4	299,4	426,5	507,4
5	168,8	304,9	428,1	553,3

For a better visual perspective about the phenomenon, Figure 6 presents the first four mode shapes for the constructive variant without stiffening ribs and the highest disc thickness (t= 100 mm- variant 1). In the upper mentioned figure, the lowest displacements are depicted in blue colour, while the highest values in red.

Figures 7 and 8 offer a graphical representation of the influence of the disc thickness, respective the influence of the distance between the ribs on the natural frequencies.
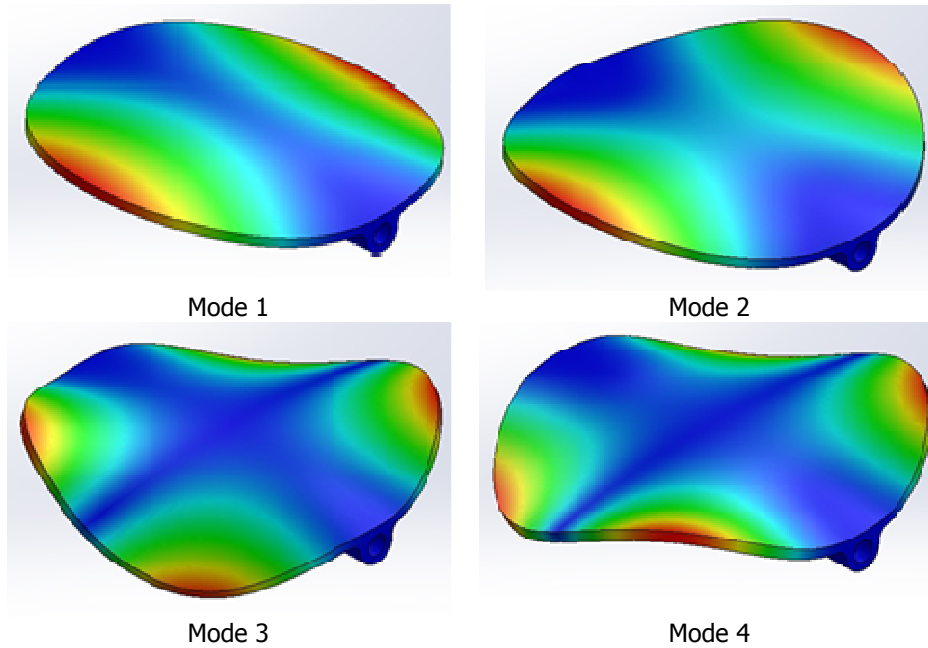
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Mode 1	Mode 2
Mode 3	Mode 4

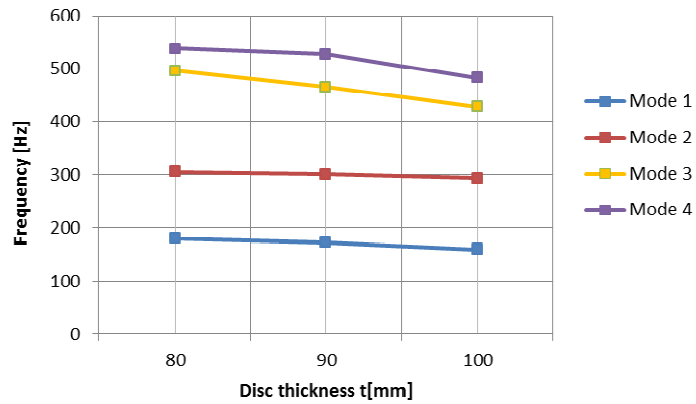**Figure 6.** First four mode shapes for the constructive variant 1 of the disc

Figure 7. Influence of the disc thickness on the natural frequencies

Looking on the Figures 7, 8 and on the values shown in table 3 respectively, one can observe some influences of the constructive variants on the natural frequencies of the disc.
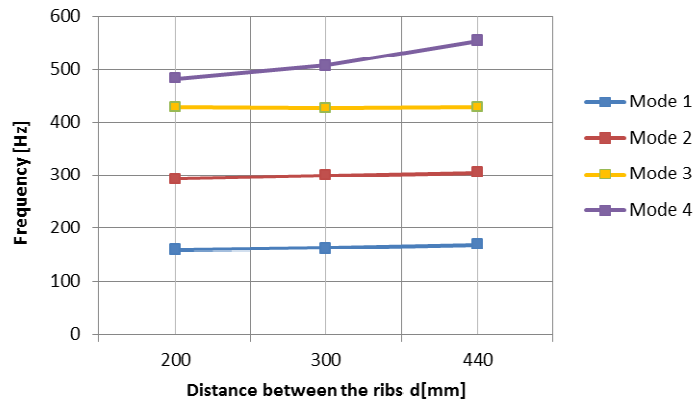
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Figure 8. Influence of the distance between the ribs on the natural frequencies

First, by increasing the disc thickness (t), the natural frequencies are decreasing. This can be explained by the effect of the higher mass on the frequency values.

Second, the position of the stiffening ribs doesn't significantly influence the natural frequency values. Thus, by increasing the distance between the ribs (d), the natural frequencies are increasing for the modes one, two and four, while a frequency decrease could be observed for mode three. This happens because the analysed vibration modes are not significantly influenced by the transverse rigidity ensured by the ribs.

5. Conclusions

This paper illustrates how to improve the design of a butterfly valve disc by involving the finite element analysis (FEA), using SolidWorks simulation software, in particular the frequency analysis module modal analysis. For this purpose, the research explains how the natural frequencies of the disc can be modified by applying stiffening ribs or changing their position and dimensions, respectively. This design improvement should ensure natural frequencies of the disc higher than the vortex shedding, in order to avoid resonance.

It was shown that the increase of disc thickness, which leads to an increased mass, contribute to the decrease of the natural frequency values. In addition, the modification of the distance between the ribs did not reveal very significant changes in the frequencies of the first four vibration modes. Thus, by increasing the distance between the ribs, it was possible to ascertain a small increase of the frequency values for the modes one, two and four, along with a narrow frequency decrease for mode three.

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