

The influence of stiffening ribs on the natural frequencies of butterfly valve disks

C Ursoniu¹, D Pepa¹, M Tufoi² and G R Gillich²

¹UCM Resita, Department of Mechanical Engineering, Golului str., no.1, 320053, Resita, Romania

²“Eftimie Murgu” University of Resita, Department of Engineering and Management, Piata Traian Vuia str., no.1-4, 320085, Resita, Romania

E-mail: cursoniu@gmail.com

Abstract. In this paper a study regarding the influence of the ribs shape on the dynamic behavior of butterfly valves, in terms of natural frequency variation, is presented. This behavior is important because the valve disk vibrates due to fluid flow when it is fully or partially open. If the disk is “locked in”, which means that frequency of oscillation is equal to the frequency of vortex shedding, the negative effect of resonance occurs, and harming of the structure is expected. The phenomenon is undesired and can be avoided by designing the disk in order to have the natural frequencies higher as the shedding frequencies. The study is performed via the finite element method (FEM) and first concerns in finding the proper disk thickness for the valve’s geometrical input parameters by static analysis. Afterward, modal analysis on disks with stiffness ribs of various shapes and positions is made. As a result, guidelines for designing the disk’s stiffening elements are provided.

1. Introduction

Valves regulate either the pressure or the flow of the fluid in a circuit. This duty involves starting and stopping flow, controlling the flow rate or the fluid pressure, preventing back-flow, or diverting flow [1]. Various aspects, as the resistance and flow coefficients, corrosion and cavitation, noise and vibration produced by the flow through valves, are research topics of numerous authors [2-6].



Figure 1. Butterfly valve with ribbed disk



Butterfly valves have the closing mechanism element in the form of a disk. These valves are generally preferred because they have a lower price as other valve designs. Also, being lighter in weight, less support is required. The disc is positioned in the center of the pipe. A rod, passing through the disc is connected to an actuator on the outside of the valve, as depicted in Figure 1. Rotating the actuator turns the disc either parallel or perpendicular to the flow, the valve being in this way fully open or closed.

When the valve is fully open, the disc allows an almost unrestricted passage of the fluid. The valve may also be opened incrementally to throttle flow. In these cases, the disk is made to vibrate by the fluid flow; if one of its natural frequencies approach the shedding frequency resonance occurs.

The aim the research presented herein is to find the optimal disk shape topology, i.e. the disk thickness and the ribs geometry and position. The essential role of the valve is to totally restrict passage of the fluid. This desire is fulfilled if the maximum static deformation of the disk does not exceed a critical value. In addition, the lowest natural frequency should exceed the shedding frequency, in order to avoid significant vibration amplitudes, with negative consequences on the valve supports.

In prior researches we analyzed the influence of the mass and stiffness changes on the natural frequencies of beams and plates [7-10]. In this paper we present a study regarding the effect of stiffeners on the natural frequencies of circular plates fixed in two points, and conclusions regarding the optimum shape and position of these elements are traced.

2. The finite element analysis

The analysis is performed on a butterfly valve disk, as that presented in Figure 2. The disk, with a constant cross-section, has attached two ribs in the central position and two hubs located near the rim, placed in opposite position on the diameter.

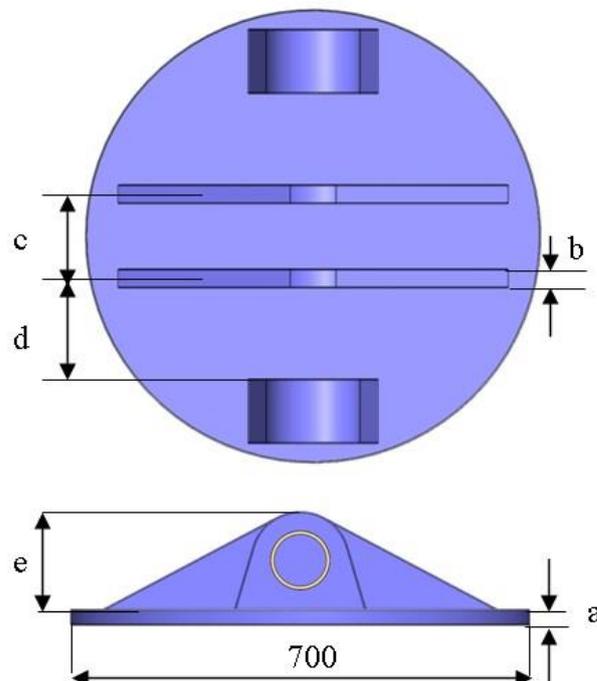


Figure 2. The butterfly valve disk with highlighted essential parameters

The finite element analysis is made using the *ANSYS* simulation software, in particular the static analysis respectively the modal analysis module. A circular plate with ribs, fixed on the two hubs, as

shown in Figure 3, is used for analysis. The plate has the radius $D = 700$ mm and a constant thickness a , with values set between 10 and 30 mm. Involved material is AISI 1045 structural steel, with the physical parameters presented in Table 1.

Table 1. The mechanical properties for AISI 1045 steel

Yield strength [N/mm ²]	Elastic modulus [N/mm ²]	Poisson's ratio [-]	Mass density [kg/m ³]
530	205	0.3	7,850

From the scheme presented in Figure 2, one can observe that there are four independent parameters proposed to be change in order to find the role of each of them on the total deflection and natural frequencies. This results due to the dependency between parameters c and d , which provides the constant sum $c + 2d = 410$ mm. Herein, the parameter a is altered during the static analysis and the optimal value is chosen. Then, for the identified thickness a , in the modal analysis the parameters b , c and e are changed. Table 2 shows the considered values of the geometrical parameters, with bold being marked the reference values.

Table 2. Values for the five geometrical parameters taken into consideration in the analysis

a [mm]	B [mm]	c [mm]	d [mm]	e [mm]
10	10	100	155	100
12	15	110	150	110
15	20	120	145	120
20	25	130	140	130
25	30	140	135	140
30	35	150	130	150
	40	160	125	160

In Figure 3 the boundary conditions and applied loads for the static analysis are presented. With green arrows the fixing condition in the hubs holes is marked, while the red arrows represent the applied pressure of 1 MPa. Under pressure the disk deforms; this deformation should be limited, in order to stop the water flow properly.

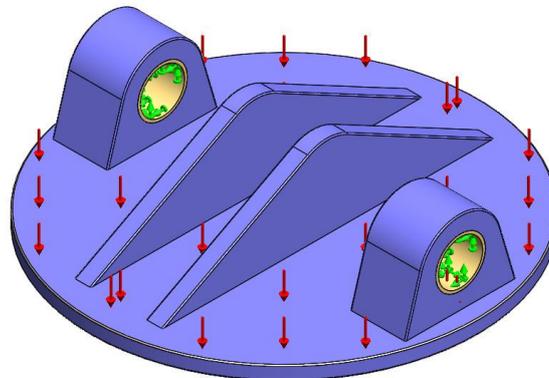


Figure 3. Fixing conditions and applied loads for the static analysis



Figure 4. Applied mesh for the butterfly disk assembly

To obtain reliable results *Standard Mechanical* elements with twenty characteristic points are used, the maximum edge dimension of one element being 3 mm. This mesh is applied both for static as well as for modal analysis. A number of around 4300000 nodes and 2300000 elements have resulted for all disk geometries; the fine element dimension ensures accurate results, especially necessary in the case of the modal analysis. Figure 4 present the applied mesh for the butterfly disk with ribs.

3. Results and discussion

Parametric studies were made for numerous disk configurations, defined by combinations of parameters *a-e*, which influence the rib geometry and position. The main findings are presented in next subsections.

3.1. Static analysis

First, a static analysis was performed in order to find the optimal disk thickness, which ensures a restricted deformation ($\delta < 1.5$ mm). For this reason the parameter representing the disk thickness *a* is iteratively increased from 10 mm to 30 mm, resulting a number of six analysis cases. For all for these cases the other parameters are indicated in the first row of Table 2. The simulation results are presented in Table 3.

Table 3. Deflection vs. disk thickness

<i>A</i> [mm]	δ [mm]
10	10.011
12	3.489
15	1.739
20	1.675
25	1.050
30	0.711

Having a look in Table 3 one can observe that a reasonable disk deflection is attained for the thickness of 25 mm. The deflection occurs at the disk central position, as depicted in Figure 5. The stress distribution for this case is presented in Figure 6. One can observe that the regions subjected to highest stress are around the hub. This happens because, for this analysis, a sudden cross-section change is present.

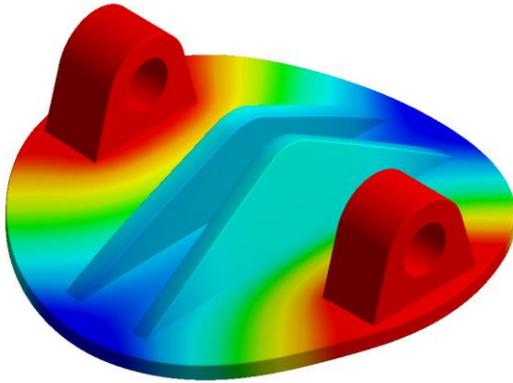


Figure 5. Disk displacement field for the applied pressure of 1 MPa

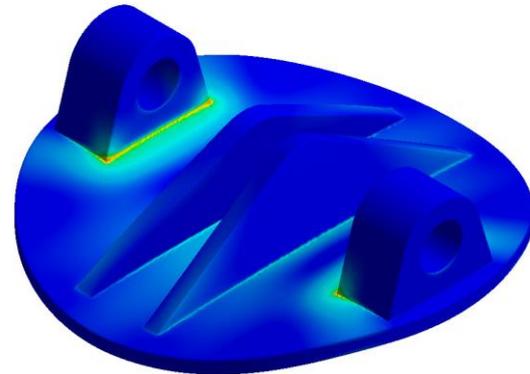


Figure 6. Stress distribution for the applied pressure of 1 MPa

The graphical representation of the deflection dependency on the disk thickness is represented in Figure 7. Note that all other parameters are these marked with bold in Table 2.

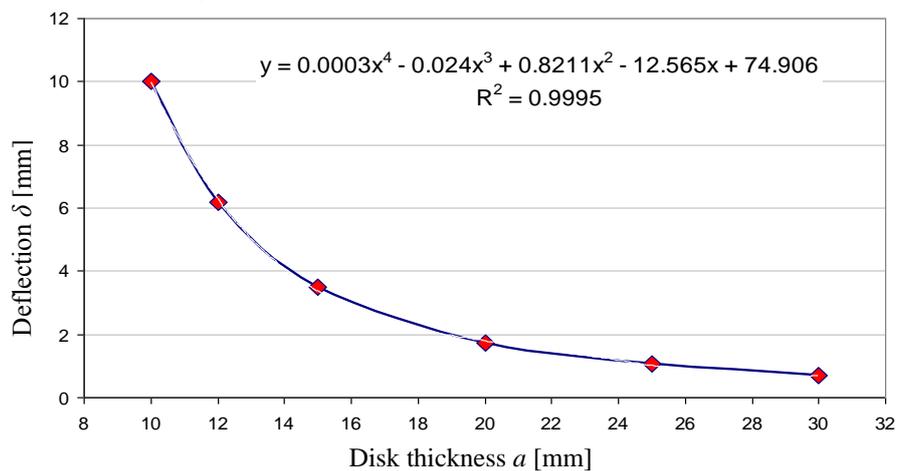


Figure 7. Graphical representation of deflection dependency of the disk thickness

Summarizing, the thickness of 25 mm will be used in the modal analysis, even if changing the rib's position and geometry the maximum achieved deflection of around 1 mm is easily altered.

3.2. Effect of rib thickness on the natural frequencies

To understand and quantify the effect of the rib thickness, parametric modal analysis was performed on the valve disk for several values of c , indicated in Table 2. The results for the first three vibration modes are presented in Table 4 and the frequency evolution is depicted in Figure 8.

Table 4. Frequency evolution in respect to rib thickness

Thickness b	[mm]	10	15	20	25	30	35	40
Frequency f_1	[Hz]	264.26	262.06	259.89	257.96	256.22	254.59	252.95
Frequency f_2	[Hz]	360.31	357.82	350.1	341.85	333.96	326.74	320.32
Frequency f_3	[Hz]	439.71	606.6	658.05	664.66	675.2	680.19	671.07

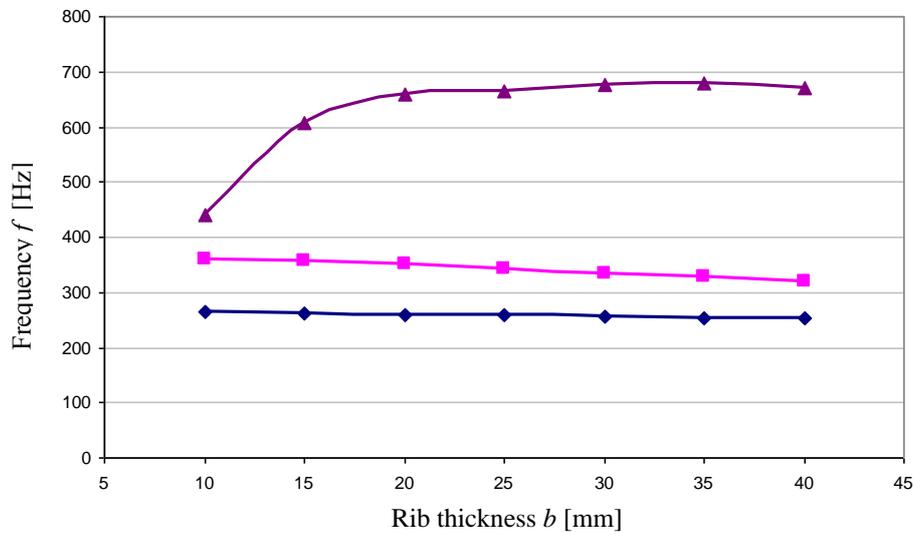


Figure 8. Graphical representation of deflection dependency of the rib thickness

One observes that the first two natural frequencies slowly decrease by rib thickness increase, while the superior modes increase dramatically for low values of b , and maintain approximately constant for higher rib thickness values.

3.2. Effect of inter-rib distance on the natural frequencies

To parametric modal analysis of the rib thickness influence on the valve disk frequencies was performed for the values of c , indicated in Table 2. The results for the first three vibration modes are presented in Table 5 and the frequency evolution is depicted in Figure 9.

Table 5. Frequency evolution in respect to inter-rib distance

Distance c [mm]	100	110	120	130	140	150	160
Frequency f_1 [Hz]	258.14	260.2	262.41	264.8	267.33	270.02	272.93
Frequency f_2 [Hz]	336.3	338.8	341.47	344.31	347.27	350.35	353.58
Frequency f_3 [Hz]	672.47	669.65	666.85	664.19	661.64	659.29	657.32

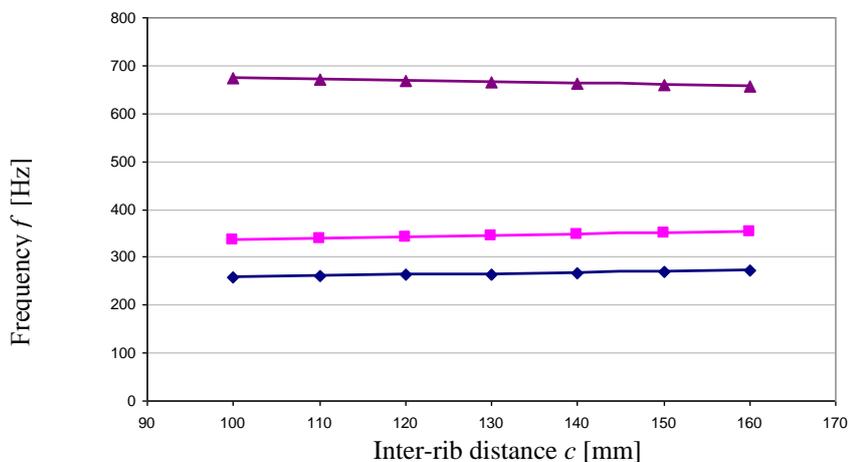


Figure 9. Graphical representation of deflection dependency of the inter-rib distance

One observes that the first two natural frequencies slowly increase by inter-rib distance increase, while the superior modes slowly decrease. This happens because the first two modes are weakly dependent of the transverse rigidity provided by the ribs, while the superior modes do not depend on parameter c . In this last case the mass increase defines the frequency change.

3.3. Effect of rib height on the natural frequencies

The parameter e , i.e. the rib height, was also altered and modal analysis performed. The values, indicated in last column in Table 2, vary between 100 and 160 mm. Again, the other parameters are maintained constant and are indicated with bold in the same table. Achieved results are indicated in Table 6 and illustrated in graphical form in Figure 10.

Table 6. Frequency evolution in respect to rib height

Height e	[mm]	100	110	120	130	140	150	160
Frequency f_1	[Hz]	264.66	263.75	262.89	262.09	261.39	260.82	260.42
Frequency f_2	[Hz]	352.81	350.24	347.69	345.34	343.36	341.81	340.82
Frequency f_3	[Hz]	680.57	680.2	679.72	679.21	678.73	678.32	678.01

In this case all the natural frequencies slowly decrease by decreasing the rib height. This happens due to low contribution to the rigidity of the upper rib sector (in fact low stress values are observed), combined with the effect of frequency decrease due to reduced mass which is associated to rib height decrease.

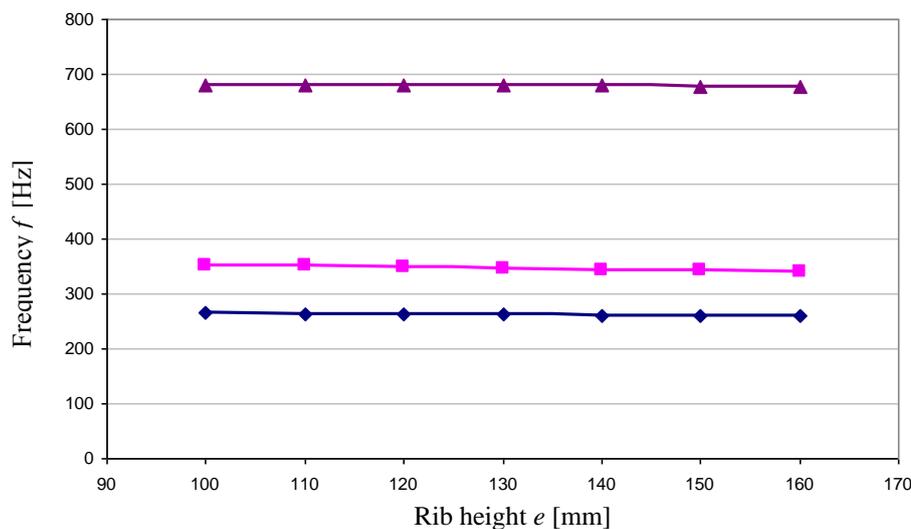


Figure 10. Graphical representation of deflection dependency of the rib height

To have a comprehensive image on the phenomenon, and clearly understand the effect of the geometrical parameters b - e upon the changes induced to the natural frequencies, the first six mode shapes are presented in Figure 11. Relevant are the displacements in each mode shape; lowest value being depicted in blue color, highest value in red color.

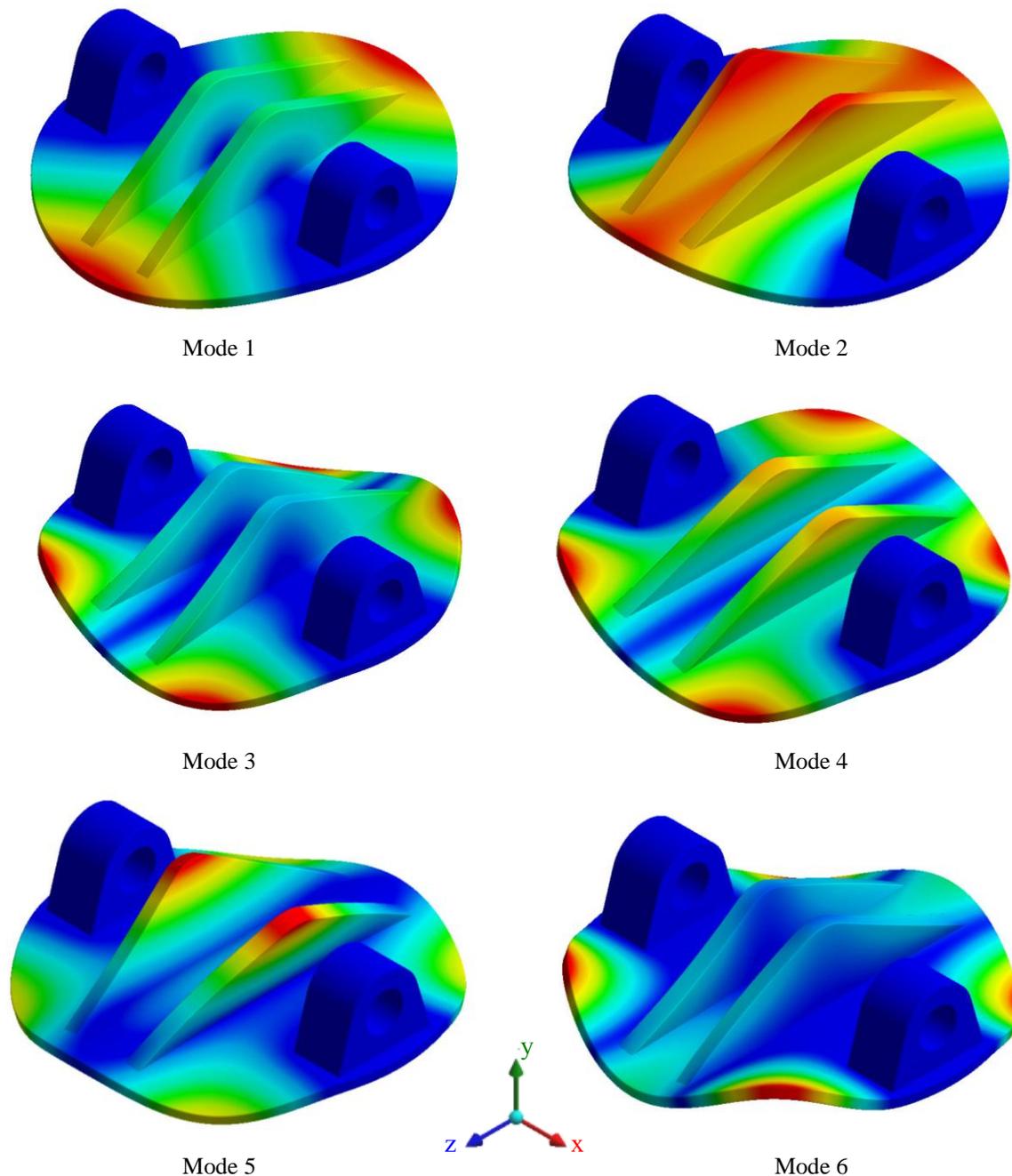


Figure 11. Graphical representation of deflection dependency of the rib height

4. Conclusion

In this paper the effect of rib geometry on the natural frequencies of a butterfly valve disk is analyzed. It was found that the natural frequencies can be controlled by the ribs shape, dimension and position. First, it was deduced that a higher mass ensures a frequency decrease, which is an obvious conclusion. It certifies the correctness of the study. Regarding the rib height, it controls the rigidity in the z direction, thus influencing the corresponding modes (e.g. vibration modes 1 and 2). Because shorter ribs are associated to lower mass, the effect of frequency increase due to stiffening is lightly reduced by the additional rib mass.

Regarding the rib position, it influences the disk rigidity in the x direction, which is orthogonal to the ribs, consequently controlling frequency of some particular modes as vibration mode 4 and 5. As a general conclusion, the natural frequencies of the valve disk can be moved to a desired domain by properly setting the rib geometrical parameters. This helps avoiding the shedding frequencies by increasing the natural frequency, so that the negative effect of resonance does not occur.

Acknowledgement

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