SIMULATION STUDY WITH SOLIDWORKS SOFTWARE OF AN ULTRASONIC HORN OF DIFFERENT MATERIALS AND DIMENSIONS TO OBTAIN THE NATURAL FREQUENCY OF 20 kHz

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ABSTRACT: This paper present a study regarding especially the simulation results of an ultrasonic horn of different materials, especially Titanium (Ti). Such an ultrasonic horn can be used within a vibratory apparatus for experimental research regarding the cavitation erosion of materials. By simulating this ultrasonic horn using the SolidWorks software, there will be determined the natural frequencies according to the mode shapes for different materials as well as the various dimensions imposed on the Titanium ultrasonic horn. After the proper simulation of this ultrasonic horn, the final results, around the value of 20 kHz appear values at which the vibratory apparatus for cavitation erosion researches may correctly function.

KEY WORDS: Simulation, ultrasonic horn, materials, natural frequency.

1. INTRODUCTION

The ultrasonic horn or sonotrode that will be simulated is a part of a vibratory apparatus used for experimental research cavitation erosion of materials.

In this case, the vibratory apparatus, in addition to the ultrasonic horn further comprises a DG 2000 type ultrasonic generator, a piece-electric acoustic transducer and a mechanical transformer [1] - [4].

For an ultrasonic horn to operate properly in the composition of this vibratory apparatus, it is necessary that the natural frequency to be around 20 ±0.5 kHz.

Also, this vibratory apparatus has been equipped by the manufacturers [5], with two Titanium ultrasonic horns (Ti-6Al-4V) especially calibrated for Steel and Aluminum materials, for the direct cavitation method.

Currently, this vibratory apparatus is used in experimental research through the indirect cavitation method for different materials yields, with different results that were disseminated [6] - [9].

All the while an ultrasonic horn fails, requiring reaching others ultrasonic horns for further experimental research [10] - [12].

In this paper, through the SolidWorks software, the study that will be made is a Frequency type study.

For the 3D designed ultrasonic horn, its frequency will be determined according to the vibration modes in the area around 20 ± 0.5 kHz for different materials and different sizes for the Titanium material.

Based on results from other citations of authors [3], [13], [14], ultrasonic horns have been achieved in practical lengths between 154 ÷ 155 mm.

At these lengths, the ultrasonic horns functioned correctly for the vibratory apparatus. Such an ultrasonic horn is shown in Figure 1.

Figure 1. A practicably realized ultrasonic horn

For the proper simulation it will be chosen the 3D projection of the assembly: mechanic transformer (booster) – ultrasonic horn.

2. THE SIMULATION STUDY OF THE ULTRASONIC HORN

For going through the simulation with the SolidWorks on the Frequency type study several stages are covered [15] - [17], of which we remind:

- design the 3D geometries of the mechanic transformers (booster) and of the ultrasonic horn components (fig. 2);
- attributing the material from the SolidWorks library;
- meshing in finite elements;
- running the study;
- visualizing the results that include, in principle, the vibration mode shapes and the values of the natural frequencies, respectively the mass participation coefficients.

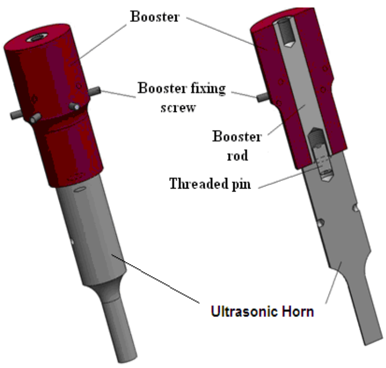
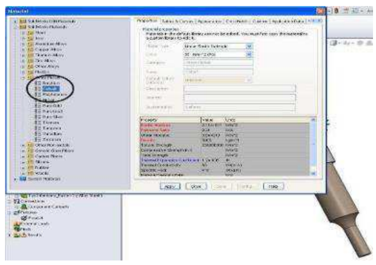


Figure 2. The 3D design assembly in SolidWorks: mechanic transformer – ultrasonic horn

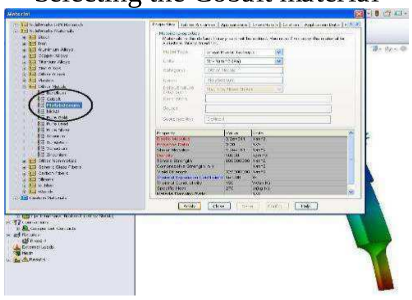
2.1. The simulating on different materials

This simulation that includes 20 vibration modes for the ultrasonic horn with the length of 154 mm, will be made on 8 materials with different mechanical properties chosen by the in SolidWorks, namely: Alloy Steel, Cobalt, Molybdenum, Nickel, pure Gold, pure Silver, Titanium and Vanadium.

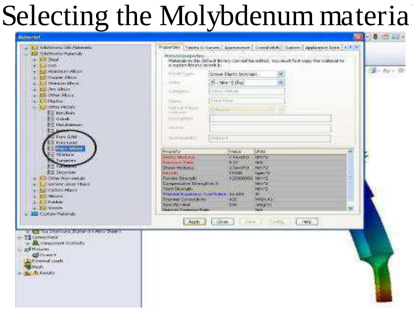
The selection of some of the 8 materials described above is shown in Figure 3.



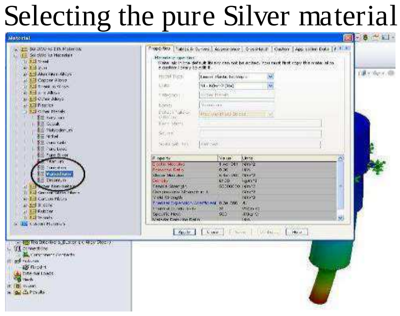
Selecting the Cobalt material



Selecting the Molybdenum material



Selecting the pure Silver material



Selecting the Vanadium material

Figure 3. Selecting and choosing of some materials from the SolidWorks software

These materials are different for the ultrasonic horn, while the mechanical transformer was awarded only the Alloy Steel material.

The obtained results for these materials, we were interested in only their frequencies around 20 kHz. These values are the only mode of vibration corresponding to the mode number 19, as shown in Table 1, wherein the density of each material is shown.

Table 1. Natural frequencies - mode 19 and the density for each material

No. Crt.	Name of material	Natural frequencies [kHz]	Density [kg/m^3]
1	Alloy steel	20,507	7700
2	Cobalt	19,615	8900
3	Molybdenum	21,595	10000
4	Nickel	19,896	8500
5	Pure Gold	12,444	19000
6	Pure Silver	14,345	11000
7	Titanium	20,041	4600
8	Vanadium	19,649	6100

Among these materials, the lower frequencies were recorded in pure Gold and pure Silver, materials which in reality are very expensive and which do not achieve the level at which an ultrasonic horn pays off.

The results are closest to the value of 20 kHz for the materials: Alloy Steel, Nickel, Titanium and Vanadium. Figure 3 presents these results in graphic form for all 20 of the mode shapes.

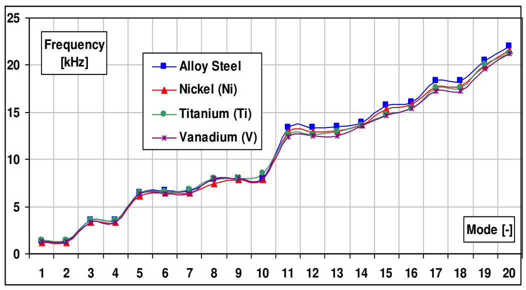
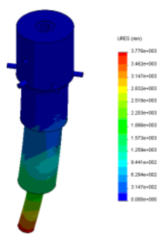


Figure 3. The graphic of the values close to 20 kHz

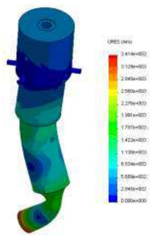
The amount of approximately 20 kHz for the Titanium material, which in Table 2 are intended to show the 20 mode shapes of mass participation coefficients, and in Figure 4, several vibration modes.

Table 2. Natural frequencies and the mass participation coefficients for the Ti material

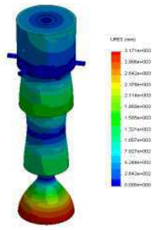
Mode	Frequency [kHz]	Mass participation coefficients		
		X direction	Y direction	Z direction
1	1,3985	0.16798	0.0000185	0.6233800
2	1,4041	0.6241400	0.0000022	0.16868
3	3,5073	0.056183	0.0000699	0.0090681
4	3,5093	0.0092024	0.0000114	0.055624
5	6,4969	0.032453	0.0001436	0.1834800
6	6,5244	0.1168700	0.0006552	0.031177
7	6,7909	0.0001462	0.0001686	0.0001212
8	7,953	0.021427	0.0012750	0.41268
9	7,9554	0.41101	0.0013526	0.02143
10	8,5358	0.0021665	0.49567	0.0045818
11	12,594	0.08347	0.0001203	0.00066715
12	12,598	0.00068585	0.0006022	0.082096
13	12,888	0.0013761	0.0002206	0.0000667
14	13,602	0.0004599	0.0001296	0.0000100
15	14,797	0.0000010	0.0420910	0.0000010
16	15,370	1.59e-008	0.44979	0.0000586
17	17,571	0.051019	0.0037638	0.00022043
18	17,606	0.00020626	0.0000003	0.052381
19	20,041	0.0002698	0.022648	0.0104810
20	21,258	0.00011087	0.0000888	0.10728
-	-	Sum X = 0.83382	Sum Y = 0.96812	Sum Z = 0.94138



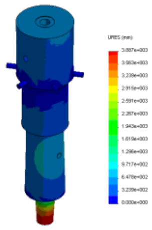
a) Mode 1



b) Mode 5



c) Mode 15



d) Mode 19

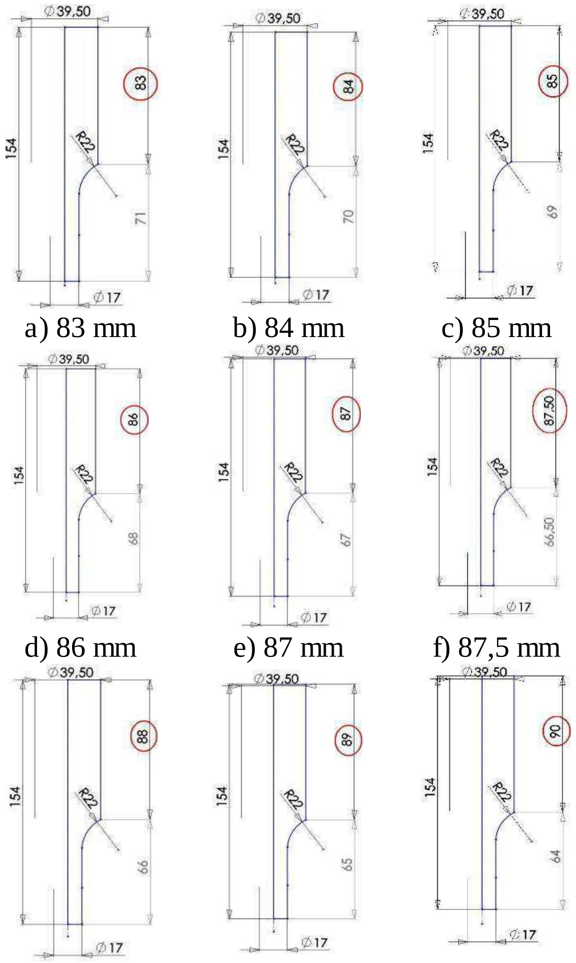
Figure 4. Some vibration mode shapes for the Titanium material

As there can be seen from Table 2, the mass participation coefficient in the Y direction is greater in value than those in the X and Z direction, respectively, as can be seen in Figure 4 d), where the ultrasonic horn at mode 19 has an axial displacement.

Because the nearest to 20 kHz is the 20.041 kHz value, it belongs to the Titanium material. Thus, a simulation will now be made only on the material for the ultrasonic horn of 154 mm length, but also for the different dimensions of the upper cylindrical part.

2.2. Simulating on the Titanium material for different dimensions

These dimensions of the upper cylindrical part of the ultrasonic horn with an overall length of 154 mm are given next in Figure 5.



a) 83 mm b) 84 mm c) 85 mm

d) 86 mm e) 87 mm f) 87,5 mm

g) 88 mm h) 89 mm i) 90 mm

Figure 5. The dimensions for the upper cylindrical part of the Titanium ultrasonic horn

For the 9 dimensions chosen for the acoustic concentrator, the results thus obtained were around 20 kHz for the same vibration mode of number 19 (Table 3).

Table 3. The natural frequencies of the Titanium material - mode 19

No. Crt.	Dimension of the upper cylindrical part	Natural frequencies [kHz]
1	83 mm	19,456
2	84 mm	19,574
3	85 mm	19,697
4	86 mm	19,820
5	87 mm	19,944
6	87,5 mm	20,006
7	88 mm	20,068
8	89 mm	20,190
9	90 mm	20,312

The value is close to 20 kHz for the dimension of 87.5 mm, which in Table 4 are shows the 20 mode shapes and the mass participation coefficients.

Table 4. The Natural frequencies and the mass participation coefficients for the dimension of 87,5 mm

Mode	Frequency [kHz]	Mass participation coefficients		
		X direction	Y direction	Z direction
1	1,4071	0.16213	0.0000124	0.00015267
2	1,4129	0.00015342	0.0000023	0.1628
3	3,5064	0.064018	0.0000146	0.00081624
4	3508	0.00082799	0.0000853	0.063356
5	6,4843	0.0329	0.0000153	0.2451800
6	6,5116	0.2179600	0.0012789	0.031513
7	6,7843	0.0000023	0.0000656	0.0002790
8	7954	0.035667	0.0227150	0.4017
9	7,9567	0.39984	0.0074461	0.035739
10	8,5773	0.0081513	0.48675	0.0039792
11	12,529	0.08372	0.0002621	0.00066875
12	12,533	0.00068106	0.0000042	0.082093
13	12,811	0.0000181	0.0000284	0.0000795
14	13,577	0.0000480	0.0005851	0.0000204
15	14,722	0.0000090	0.0000461	0.0000354
16	15,323	0.0010692	0.45785	0.0012627
17	17,507	0.049897	0.0008617	0.00064843
18	17,543	0.0006041	0.0010291	0.051207
19	20,006	0.0000834	0.02333	0.0070646

Mode	Frequency [kHz]	Mass participation coefficients		
		X direction	Y direction	Z direction
20	21,199	0.0465520	0.0004372	0.10942
-	-	Sum X = 0.83046	Sum Y = 0.96794	Sum Z = 0.94013

Because the nearest 20 kHz size belongs to 87,5 mm, next a simulation will carried out around this size.

2.3. Simulating on the Titanium material for the upper cylindrical part around the dimension of 87, 5 mm

These dimensions around the 87,5 mm are shown numerically in Table 5 and also graphically in Figure 6.

Table 5. Natural frequencies for the dimension of 87,5 mm

Mode	Length of the upper cylindrical part around the dimension of 87,5 mm				
	87,4	87,45	87,46	87,47	87,48
1	1407.7	1407.4	1407.2	1407.2	1407.2
2	1413.5	1413.1	1413.1	1413.1	1413.1
3	3500.2	3503.5	3503.8	3504.6	3504.9
4	3502.1	3504.9	3505.4	3505.9	3506.8
5	6484.8	6485.8	6483.3	6484.3	6483.3
6	6512.6	6511.5	6511.4	6511.4	6511.8
7	6788.6	6785.9	6786.1	6786.2	6785.5
8	7954.7	7952.5	7954.1	7954.7	7952
9	7957.1	7955.8	7956.5	7956.9	7956.7
10	8580.5	8577.3	8577	8579	8577.4
11	12530	12527	12527	12528	12529
12	12534	12531	12532	12534	12534
13	12795	12806	12805	12806	12808
14	13572	13571	13576	13573	13570
15	14722	14722	14722	14722	14721
16	15323	15319	15318	15326	15319
17	17489	17497	17497	17496	17499
18	17526	17526	17531	17532	17535
19	19991	19998	19998	20003	20003
20	21199	21195	21192	21198	21191

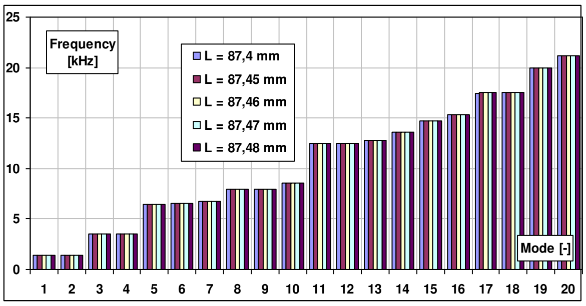


Figure 6. The natural frequencies for the 5 dimensions

From Table 5, it is noted in particular that the most appropriate value of 20 kHz for mode 19, is between the size of 87,46 and 87, 47 mm respectively.

Based on the results of the simulation as well as on other results from the previous research of authors [2] - [4] and [14], we can put in practice the realization of this ultrasonic horn. These dimensions will work correctly on the vibratory apparatus used through the indirect method for experimental research on cavitation erosion of materials.

3. CONCLUSION

The conclusions that can be drawn from this paper are:

- For the vibratory apparatus to work correctly, it is necessary that the used ultrasonic horn to be dimensioned and calibrated at the limits of 20 ± 0,5 kHz;

- The simulation study comprised 20 vibration modes regarding the ultrasonic horn with the total length of 154 mm, for 8 materials with different mechanic properties in the SolidWorks software, from which the simulation for the Titanium material continued up to the value of 20 kHz;

- From the simulation results for the chosen materials, the searched for natural frequencies came close to the value of 20 kHz only at the vibration mode number 19, where the Titanium material registered the value of 20,041 kHz;

- Each time for the vibration mode number 19, the mass participation coefficient on the Y direction has a greater value than the mass participation coefficients on the X respectively

Z direction, there taking place an axial displacement in that direction;

- For the simulated Titanium material at different dimensions, the value of 20,006 kHz has been obtained for the dimension of 87,5 mm of the upper cylindrical part, and around this value for the dimensions of 87,46 and 87,47 mm, there have been obtained even closer values to 20 kHz, namely: 19,998 respectively 20,003 kHz;

- For validating the simulation results, however one may try the ultrasonic horn on the vibratory apparatus practically, as well as with the aid of hardware and software equipment for measuring the natural frequency, so as to function correctly during the experimental researches regarding cavitation erosion of materials.

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