VARIANTS OF SONOTRODE FOR A VIBRATORY APPARATUS FOR TEST CAVITATION EROSION BY THE INDIRECT METHOD

[1]NEDELONI MARIAN-DUMITRU, [2]NEDELCU DORIAN

[1,2]*„Eftimie Murgu" University of Resita, Romania*

ABSTRACT

The purpose of this work is to present the research done for the calibration of a sonotrode for the cavitation erosion testing of specimens through the indirect method.

Keywords: *Sonotrode, cavitation erosion, indirect method.*

1. INTRODUCTION

The vibratory apparatus used to test the cavitation erosion of materials within the Centre for research in Automation, Hydraulic and Thermal Processes (CCHAPT), works on the following parameters:

- vibration Frequency: 20000 + 500 Hz;
- amplitude of vibration (peak to peak): 50 μm;
- the test temperature: 25 ± 2°C.

The first condition is essential for the functioning of the device. The failure of this conditions leads to the non-functioning of the device, because of the activation of internal protection.

The purpose of this work is to present the research done for the calibration of a sonotrode for the cavitation erosion testing of specimens through the indirect method. In this case of indirect cavitation, the specimen is fixed and the sonotrode vibrates over the specimen at a controlled distance, both of which are dipped in water. It aims to achieve through calibration a frequency of 20000 + 500 Hz for sonotrode [1].

From an initial geometry, the calibration will be achieved by shortening the length of the sonotrode. Verification of the frequency will be achieved by direct measurement, compared to that calculated by modal analysis performed with SolidWorks.

2. STAND DESCRIPTION

The stand consists of the following parts, like in Figure 1:

- an ultrasonic generator DG-2000-2 [2], used in the laboratory to test the cavitation erosion; the generator protection locks operate if the frequency does not fall within the range specified above;
- a converter (piezoelectric acoustic transformer) supported and connected to the ultrasonic generator via a 6HF cable;
- an mechanical transformer (booster), which is intended to amplify the value of amplitude in the sonotrode;
- the sonotrode; in the case of cavitational erosion through the indirect method, the sonotrode has the same role as a vibrating Rod;
- the specimen from different materials is placed directly under the controlled sonotrode; cavitational bubbles that are induced in water through vibration collaps on the front top of the test specimen, where the attack will occur cavitational [3];
- a liquid container with distilled water, within which a wire is found in a circuit, circuit that is powered from the network with cold water to keep the water temperature constant throughout the test.
- a digital thermometer for measuring the temperature of cavitation during the tests;
- a National Instruments brand equipment that measure their frequency (hardware and software), the equipment is connected to the laptop via a USB 2.0 connection.

Experimental determination of their frequency is achieved through the excitation of the sonotrode and specimen by a shock applied instantly and the associated application displays the measured frequency, frequency analysis and harmonics analysis as well as the signal. Accuracy of the purchase is flagged by the continuously decreasing shape form of the signal.

3. DESCRIPTION OF THE 3D BOOSTER-SONOTRODE ASSEMBLY

The design of the 3D booster-sonotrode assembly was accomplished in the application SolidWorks [4] and is shown in Figure 2. The sonotrodes is assembled with the booster through a pin through the rod booster. The booster is fitted with 6 screws.

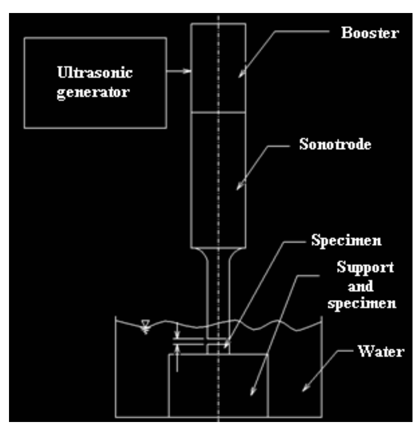

Figure 1 Stand for testing the cavitation erosion through the indirect method

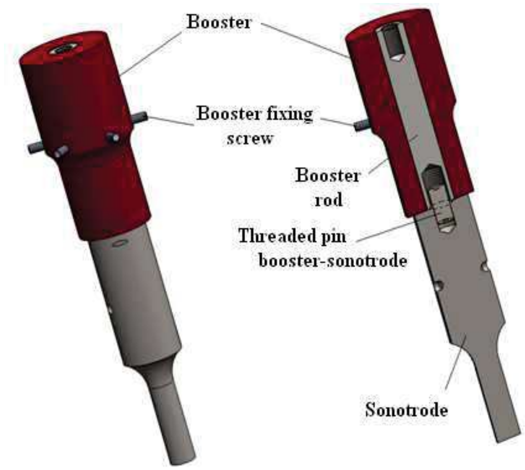

Figure 2 The 3D booster-sonotrode assembly

3. RESULTS OBTAINED WITH THE MODAL ANALYSIS

By reducing the length of the sonotrode, whose value is 160 mm and by restarting the calculation of the nature frequency one aims to close the frequency value of ~ 20000 ± 500 Hz, at the same time with the realization of the condition that the vibration mode must be axial (longitudinal).

Modal analysis was performed via SolidWorks, for the calculation of the nature frequency through the steps described in [5]. After the modal analysis, modes of axial vibration can be identified (oriented Y direction of the reference system) by turning on the *List Mass Participation* option, which displays tabular: sequence number of the method, calculated frequency and the mass participation factor on the standard directions X, Y, and Z; between the calculated modes of vibration only the axial one are of interest, those for which the coefficients on X and Z directions are semi or insignificant compared to the value of the coefficient in the Y directions.

Calculations were made for 4 lengths of the sonotrode: 160 mm, 155.5 mm, 150 mm and 145 mm. The mass participation coefficients for these lengths are presented in tables 1 and 2 for 25 modes of vibration. Graph of the variation rate that was calculated based on the number of vibration mode is shown in Figure 3, which shows that the value of 20000 Hz is around mode 19 of vibration.

Distribution of mass participation coefficient on the X, Y, and Z directions by number of vibrating mode for the 4 lengths of the sonotrode is shown in figures 4, 5, 6, 7. From these figures, one can see the axial modes, i.e. in which vertical bars are filled with red continues color, that have the numerical value of the coefficient marked. Other vertical bars are suitable for transverse vibration modes (on the X or Z direction) and are not of interest in the context of this analysis.

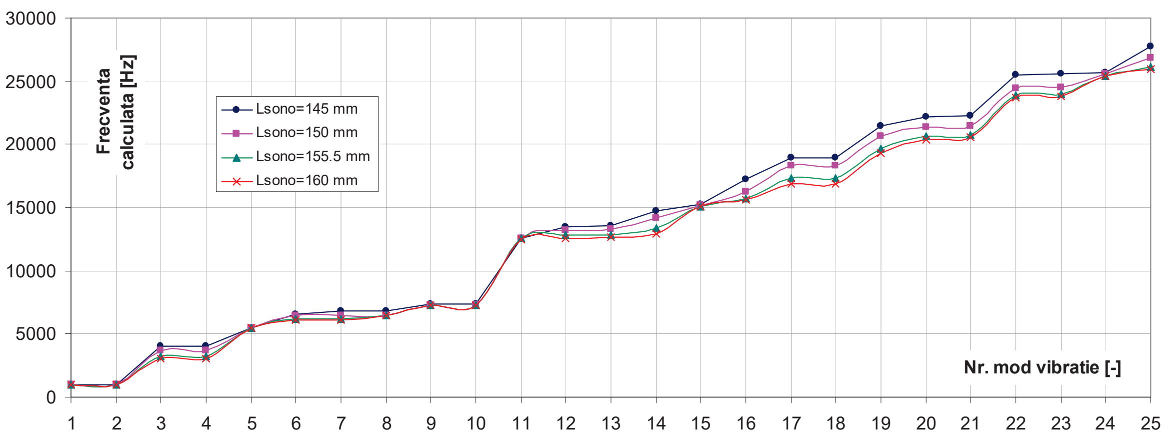

Figure 3 Variance of the calculated frequency by modal analysis by the number of vibration mode

Table 1 Mass participation factors

Vibration mode nr.	Mass participation factors for sonotrode length = 160 mm				Mass participation factors for sonotrode length = 155.5 mm			
	Freq (Hz)	X direction	Y direction	Z direction	Freq (Hz)	X direction	Y direction	Z direction
1	966.68	0.352090	0.000000	0.003633	978.67	0.358580	0.000000	0.000086
2	967.44	0.003623	0.000000	0.352440	979.66	0.000086	0.000000	0.359010
3	3084.5	0.074190	0.000000	0.000037	3251.1	0.074072	0.000000	0.000038
4	3092.5	0.000037	0.000000	0.073589	3259.6	0.000039	0.000000	0.073395
5	5438.7	0.000000	0.000000	0.000000	5443.5	0.000000	0.000000	0.000000
6	6097.3	0.034628	0.000001	0.000072	6197.5	0.028297	0.000001	0.000075
7	6106.5	0.000068	0.000003	0.034536	6207.5	0.000090	0.000008	0.028373

8	6437.6	0.000000	0.709790	0.000001	6457.5	0.000000	0.710460	0.000001
9	7269.6	0.274810	0.000000	0.046750	7276.5	0.276850	0.000000	0.049160
10	7274.6	0.046655	0.000000	0.276260	7283.1	0.049001	0.000000	0.278320
11	12529	0.000000	0.000000	0.000015	12558	0.000000	0.000000	0.000000
12	12602	0.068833	0.000000	0.000000	12805	0.072556	0.000000	0.000001
13	12679	0.000000	0.000000	0.068095	12883	0.000000	0.000000	0.071874
14	12943	0.000000	0.000000	0.000000	13368	0.000000	0.000000	0.000000
15	15050	0.000000	0.258610	0.000000	15104	0.000000	0.259830	0.000000
16	15627	0.000000	0.000000	0.000000	15734	0.000000	0.000000	0.000000
17	16857	0.005593	0.000001	0.046720	17359	0.000914	0.000000	0.053288
18	16863	0.046417	0.000000	0.005443	17369	0.053520	0.000000	0.000836
19	19283	0.000000	0.006671	0.000000	19710	0.000000	0.004669	0.000000
20	20415	0.056108	0.000000	0.002342	20659	0.049915	0.000000	0.002076
21	20529	0.002330	0.000000	0.055573	20766	0.002102	0.000000	0.049508
22	23688	0.001747	0.000000	0.000073	23865	0.001106	0.000000	0.000047
23	23816	0.000170	0.000000	0.001880	23980	0.000119	0.000000	0.001262
24	25418	0.000000	0.000000	0.000000	25462	0.000000	0.000000	0.000000
25	25960	0.000000	0.001471	0.000000	26182	0.000000	0.001574	0.000000
		Sum X = 0.96729	Sum Y = 0.97654	Sum Z = 0.96746		Sum X = 0.96725	Sum Y = 0.97654	Sum Z = 0.96735

Table 2 Mass participation factors

Vibration mode nr.	Mass participation factors for sonotrode length = 150 mm				Mass participation factors for sonotrode length = 145mm			
	Freq (Hz)	X direction	Y direction	Z direction	Freq (Hz)	X direction	Y direction	Z direction
1	1004	0.363960	0.000000	0.000161	1025.8	0.36792	1.047E-09	7.1179E-05
2	1005.3	0.000162	0.000000	0.364420	1027.3	0.000071	0.000000	0.368430
3	3650.3	0.076663	0.000000	0.000003	4036.1	0.082032	0.000000	0.000002
4	3662.6	0.000003	0.000000	0.075910	4053.4	0.000002	0.000000	0.081232
5	5451.1	0.000000	0.000000	0.000000	5456.9	0.000000	0.000000	0.000000
6	6477.8	0.010451	0.000003	0.000019	6534.7	0.000000	0.713420	0.000000
7	6488.5	0.000041	0.000351	0.010501	6823.1	0.002417	0.000000	0.000035
8	6499.2	0.000000	0.711630	0.000007	6831.2	0.000016	0.000001	0.002582
9	7298	0.315200	0.000000	0.022751	7363.2	0.335760	0.000000	0.002932
10	7306.2	0.022677	0.000000	0.316760	7370.6	0.002990	0.000000	0.337430
11	12568	0.000000	0.000000	0.000000	12576	0.000001	0.000000	0.000000
12	13179	0.078631	0.000000	0.000003	13474	0.081795	0.000000	0.000012
13	13257	0.000004	0.000000	0.077766	13544	0.000013	0.000000	0.080658
14	14230	0.000000	0.000000	0.000000	14710	0.000000	0.000001	0.000000
15	15185	0.000000	0.260860	0.000000	15235	0.000000	0.260590	0.000000
16	16228	0.000000	0.000000	0.000000	17257	0.000000	0.000000	0.000000
17	18362	0.026076	0.000000	0.040145	18977	0.050834	0.000000	0.025071
18	18368	0.040399	0.000000	0.025278	18990	0.024954	0.000000	0.049629
19	20649	0.000000	0.001943	0.000000	21452	0.000000	0.000737	0.000000
20	21400	0.030619	0.000000	0.002248	22176	0.016080	0.000000	0.002151
21	21500	0.002316	0.000000	0.031242	22279	0.002303	0.000000	0.017056
22	24458	0.000084	0.000000	0.000002	25524	0.000226	0.000000	0.000019
23	24552	0.000022	0.000000	0.000141	25591	0.000005	0.000000	0.000158
24	25564	0.000000	0.000000	0.000000	25659	0.000000	0.000000	0.000000
25	26840	0.000000	0.001823	0.000000	27710	0.000000	0.002069	0.000000
		Sum X = 0.96731	Sum Y = 0.97662	Sum Z = 0.96735		Sum X = 0.96742	Sum Y = 0.97682	Sum Z = 0.96748

The results of the modal analysis are centralised in table 3 for the vibration mode 19 one the basis of which the length calculated in Figure 8 was changed. This dependence has been linearly interpolated to find the value of the length sonotrode mm for 154.07 mm, that theoretically, is done for the frequency of 20000 Hz.

Table 3 The results of the modal analysis

Sonotrode length [mm]	Vibration mode nr.	Freq (Hz)	X Direc.	Y Direc.	Z Direc.
160	19	19283	0.000	0.0066	0.000
155.5	19	19710	0.000	0.0046	0.000
150	19	20649	0.000	0.0019	0.000
145	19	21452	0.000	0.0007	0.000

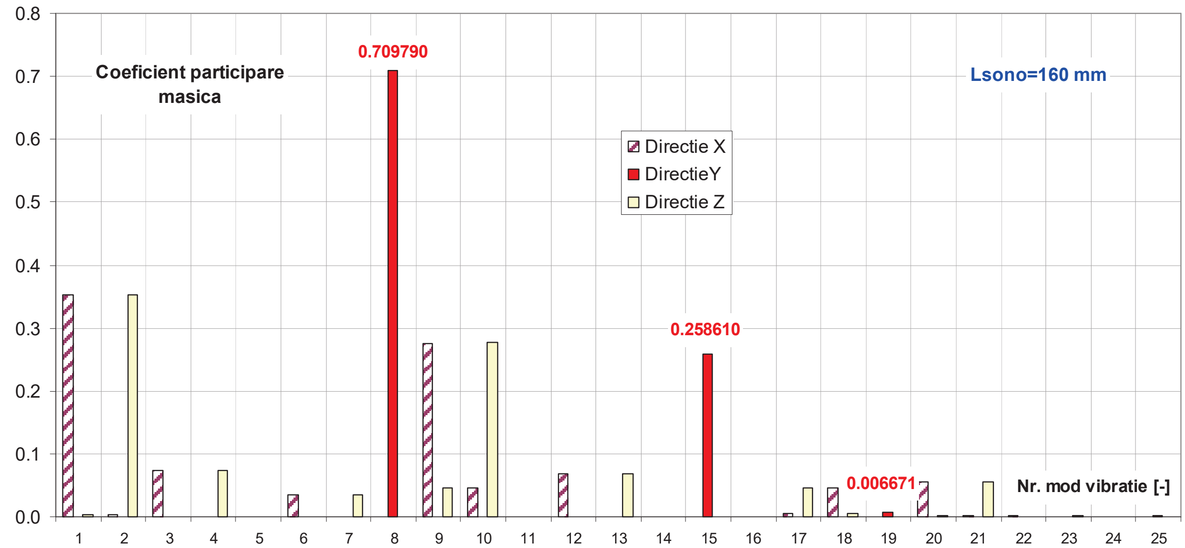

Figure 4 Distribution of mass participation factor based on vibration mode for sonotrode length of 160 mm

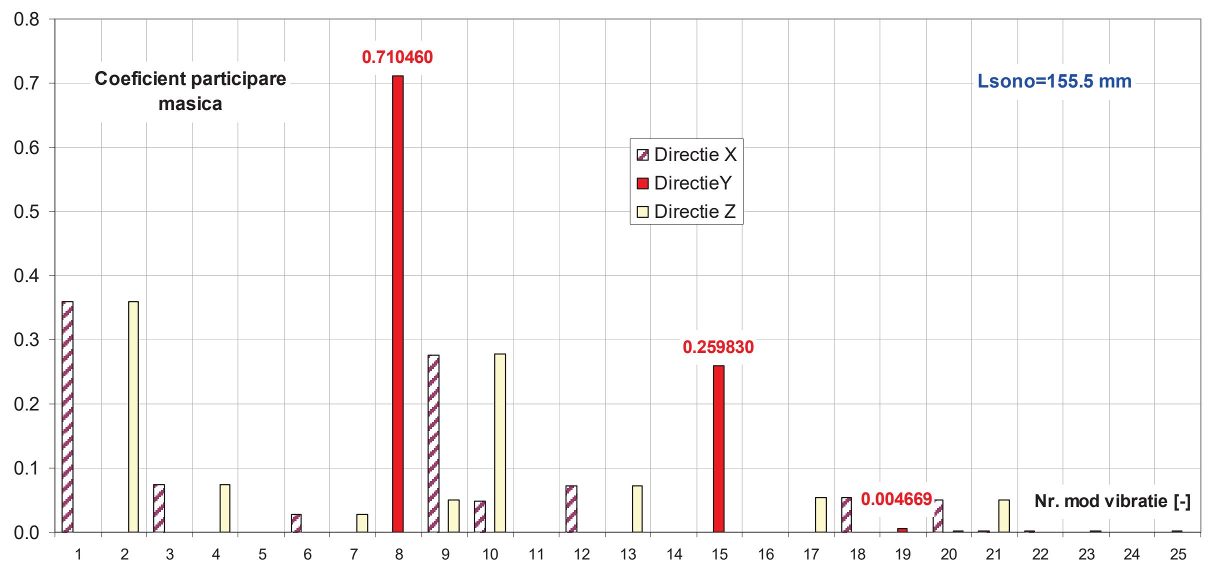

Figure 5 Distribution of mass participation factor based on vibration mode for sonotrode length of 155.5 mm

4. RESULTS OBTAINED BY DIRECT MEASUREMENT OF THE OWN FREQUENCY

From its theoretical length that can be seen in the preceding subparagraph of 154.07 mm, length required for the execution of a theoretical frequency of 20000 Hz and safely admiting a length of 157.4 mm. there occurred a switch to the centralized measurement frequency according to the data in table 4. The initial length of 157.4 mm declined gradually, after each shortening its own frequency was measured up to the permissible domain of 20000 ± 500 Hz.

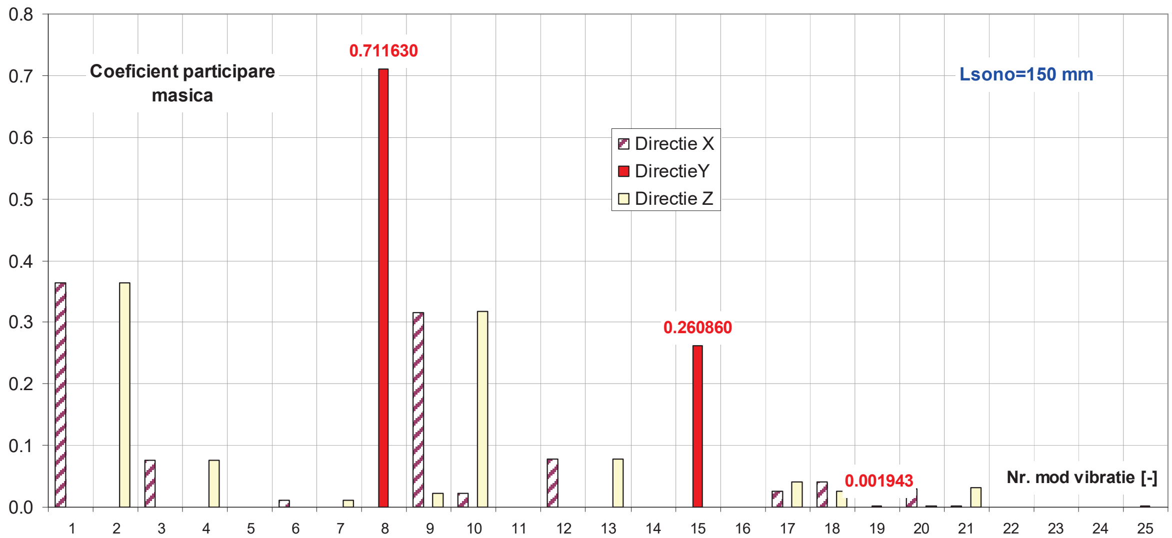

Figure 6 Distribution of mass participation factor based on vibration mode for sonotrode length of 150 mm

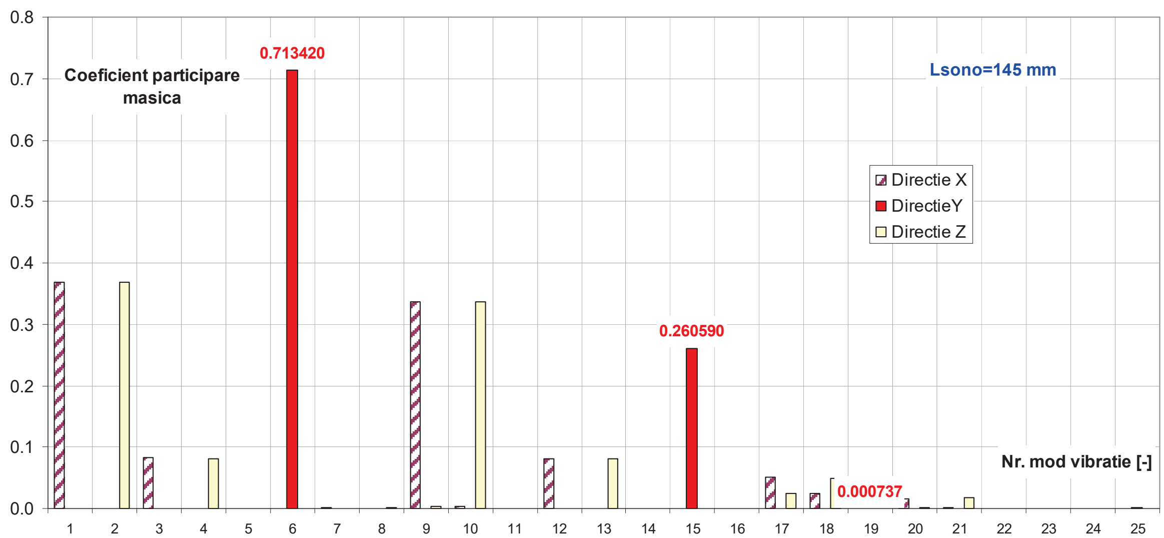

Figure 7 Distribution of mass participation factor based on vibration mode for sonotrode length of 145 mm

What sizes of table 4 is as follows:

- Sonotrode length – is the length of sonotrode;
- Frequency [Hz] – is the measured frequency;
- Δmm – is the shortened length of sonotrode in relation to the previous procedure;
- ΔHz – represents the difference in the measured frequency compared to the previous value.

Figure 9 shows the measured frequency variation (table 4) superimposed over the on that was calculated (table 3) based on the length of sonotrode.

The graph in Figure 9 shows the overlap of the calculated and measured curves, the measured values were lower than the calculated one. The graph shows the trend growth rate by reducing the length of sonotrode.

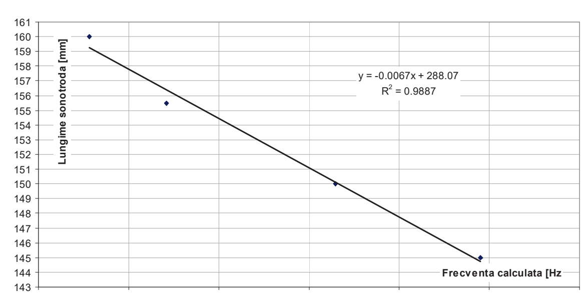

Figure 8 Sonotrode length variation based on how the calculated linear interpolation & addiction

Tabel 4 The length of sonotrode versus real frequency

Length of sonotrode	Frequency (Hz)	Δmm	ΔHz
157.4	19232.2	0	0
157.2	19274.9	-0.2	42.7
156.6	19372.6	-0.6	97.7
156.1	19476.3	-0.5	103.7
155.4	19567.9	-0.7	91.6
155	19635	-0.4	67.1
154.6	19708.3	-0.4	73.3
154.2	19775.4	-0.4	67.1

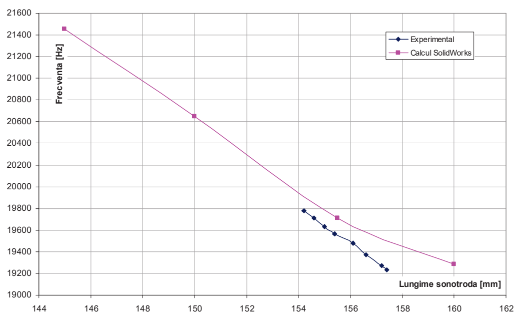

Figure 9 The change of the measured and calculated frequency according to the length of the sonotrode

5. SPECIMENS FOR CAVITATION EROSION

To check the stand, tests with specimens of steel were carried out, according to the data in table 5 and Figure 10.

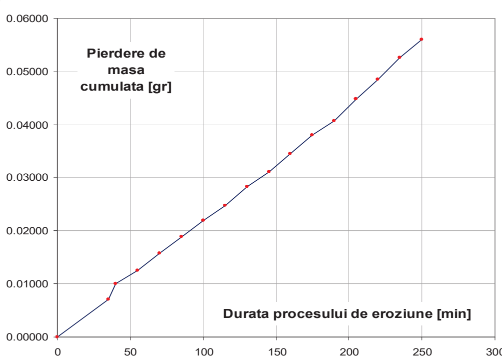

Figure 10 The variation of cumulative mass Σ Δm [gr] depending on the duration of the process of erosion

Tabel 5 Measurement results

Minute	Mass [gr]	Δm [gr]	Σ Δm [gr]
0	15.25309	0.00000	0.00000
35	15.24606	0.00703	0.00703
40	15.24310	0.00296	0.00999
55	15.24056	0.00254	0.01253
70	15.23728	0.00328	0.01581
85	15.23425	0.00303	0.01884
100	15.23106	0.00319	0.02203
115	15.22825	0.00281	0.02484
130	15.22473	0.00352	0.02836
145	15.22195	0.00278	0.03114
160	15.21863	0.00332	0.03446
175	15.21511	0.00352	0.03798
190	15.21235	0.00276	0.04074
205	15.20823	0.00412	0.04486
220	15.20455	0.00368	0.04854
235	15.20046	0.00409	0.05263
250	15.19703	0.00343	0.05606

6. CONCLUSIONS

The modal Analysis and the tests have allowed one to determine the sonotrode length for which the frequency of its work in the field is 20000±500 Hz. Final amount of sonotrode length 154.2 mm corresponds to its own frequency of 19775.4 Hz, which allows testing of the cavitational erosion.

7. ACKNOWLEDGMENTS

This work was partially supported by the strategic grant POSDRU /88/1.5/S/ 61178.

8. REFERENCES

[1] ASTM G32–10, *Standard Test Method for Cavitation Erosion Using Vibratory Apparatus*, Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States, 2010

[2] TELSONIC, *Operating Instructions Cavitations Test Equipment DG 2000*, www.telsonic.com

[3] Stanley G. Y., *Study of cavitation damage to high-purity metals and a nickel-base superalloy in water*, NASA TN D-6014, Septembrie, 1970

[4] Nedelcu, D., *Proiectare şi simulare numerică cu SOLIDWORKS*, Editura Eurostampa, Timişoara, 2011

[5] Nedeloni, M.D., Nedelcu, D., Ioan, I., Ciubotariu R., *Calibration of a sonotrode from a stand component for test cavitation erosion through direct method,* Constanta Maritime University Annals, Vol.17, Year XIII, 2012