CALIBRATION OF A SONOTRODE FROM A STAND COMPONENT FOR TEST CAVITATION EROSION THROUGH DIRECT METHOD

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ABSTRACT

This paper presents research done for the calibration of a sonotrode, a sonotrode which is used to test the cavitational erosion of specimens by the direct method, detailed in the standard method.

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

1. INTRODUCTION

The Eftimie Murgu University of Resita, through the „Centre for Research in Hydraulic, Automation and Thermal Processes" (CCHAPT) [1], has a stand for ~~to~~ cavitational erosion research of materials used to manufacture components for hydraulic turbines. This paper presents research done for the calibration of a sonotrode, a sonotrode which is used to test the cavitational erosion of specimens by the direct method, detailed in the standard method [2].

Through the direct cavitation, the specimen is attached to the top of sonotrode through a threaded assembly. The calibration aims at achieving a frequency of 20000 Hz of the sonotrode that is assembled with the specimen, frequency required by the standard [2]. Starting from a required geometry, calibration will be achieved by shortening the length of the sonotrode. Verification of the frequency will be done by direct measuring, in relation to the one calculated through modal analysis performed by the SolidWorks program. Deviation of the frequency of 20000 Hz can be within the ± 500 Hz.

2. STAND DESCRIPTION

The stand consists the following components, like in figure 1:

- an ultrasonic generator DG-2000-2 [3], used to test the cavitation erosion in the laboratory; 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 the amplitude in the sonotrode respectively in the specimen and to keep losses to a minimum focal point and to provide mechanical rigidity of the assembly;
- sonotrode itself;
- a test specimen, created from different materials of interest for the cavitational erosion study;
- a bowl of liquid with distilled water, in which a coil is included in a circuit network fed with cold water to maintain constant water temperature during the tests;
- a digital thermometer to measure and control temperature during the cavitation tests;
- a National Instruments measurement equipment that measure their frequency (hardware and software), the equipment is connected to the laptop through a USB 2.0 connection.

Experimental determination of their frequency is achieved through the excitation the sonotrode and specimen by a shock applied instantly and the specialized application, like in figure 2, which displays the measured frequency, frequency analysis, harmonic analysis and signal shape.

It can be set to display only frequencies within a specified range, setting than can be saved in a configuration file, together with other parameters. The „*Acquire Signal*" starts the continous acquisition process and the „*Trigger signal*" views only when the application requires shock. Fairness acquisition is continuously decreasing as indicated by the signal form.

Figure 1 Stand for cavitational erosion testing

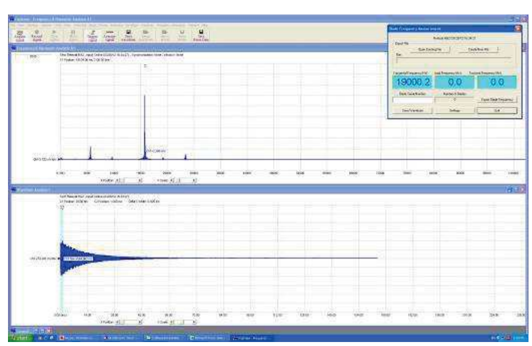


Figure 2 Application for measuring its frequency

3. DESCRIPTION OF THE 3D BOOSTER-SONOTRODE-SPECIMEN ASSEMBLY

The design of the 3D booster-sonotrode-specimen assembly was done in the SolidWorks application [4] and shown in figure 3 and the component elements in figure 4. The specimen is assembled with the sonotrode through an intermediate pin M12x1. The sonotrode is assembled with the booster through a pin by booster rod. The booster is provided with 6 screws. The sonotrode is generated by the revolution contour in figure 5 around the axis of symmetry.

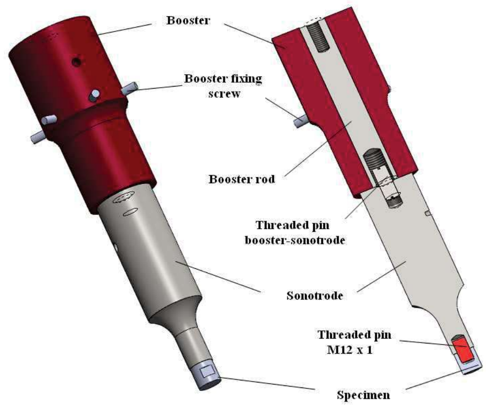


Figure 3 Booster-sonotrode-specimen assembly

To calculate its frequency the next stages must be followed:

a) Creation of the geometry parts: booster, sonotrode, specimen threaded pin M 12, threaded pin booster-sonotrode, booster rod, booster screw threading, specimen;

b) Creation of the 3D assembly: booster-sonotroda-specimen;

c) Activation of the *Simulation* module:
- click *Tools* → *Add-Ins*;
- select *Simulation* module;
- the simulation bar menu will be added to the main menu.

d) Creation of the simulation study of frequency type and designation study, from the study of frequency type the *Properties* option is activated, where you set the number of calculated frequency in our case 25 modes;

e) Select the material from SolidWorks materials library; for sonotrode the Ti-6Al-4V material will be selected and the remaining parts Alloy Steel;

f) Apply restrictions; the assembly is fixed at the top of the 6 screws of booster by choice *Fixed Geometry*;

g) Create mesh - meshing in finite element;

h) Calculation analysis;

i) Viewing of the results; to identify the axial vibration modes (axial direction is oriented of the Y axis reference system) the *List Mass Participation* option will turn on, which will display tabular like in figure 6, the number of the vibration mode, the calculated frequency and the mass participation factor normalized by X, Y and Z directions; of the 25 calculated vibration modes interested only the axial, those for which the coefficients on the X and Z directions are zero or with insignificant values compared to the coefficient in the Y direction; the last line of the table will display the coefficients sum on the three directions;

j) Reduce the length of sonotrode, whose home value is 129.50 mm (see figure 5) and the resumption of its own frequency calculation; the goal is near 20000 ± 500 Hz value, while achieving the operating frequency, the condition which states that the mode of vibration must be axial must also be achieved.

a) threaded pin booster-sonotrode b) booster screw thread c) threaded pin M12 x 1

d) booster rod e) specimen

f) sonotrode g) booster

Figure 4 Component elements of the booster-sonotrode-specimen assembly

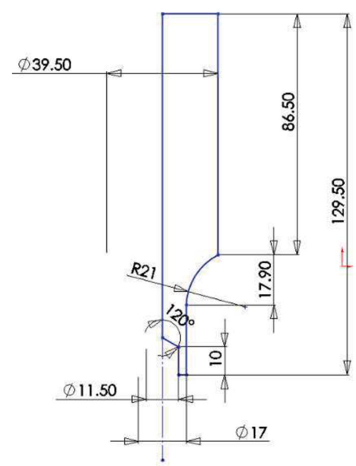
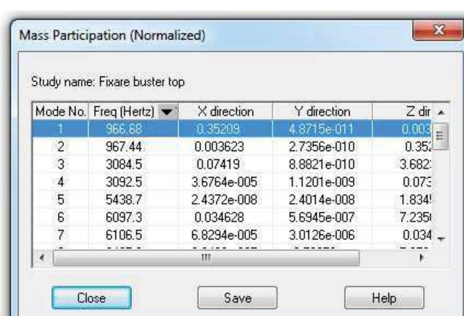


Figure 5 Geometry of the sonotrode



Mass Participation (Normalized)

Study name: Fixare buster top

Mode No.	Freq (Hertz)	X direction	Y direction	Z dir
1	966.68	0.35209	4.8715e-011	0.003
2	967.44	0.003623	2.7356e-010	0.35
3	3084.5	0.07419	8.8821e-010	3.682
4	3092.5	3.6764e-005	1.1201e-009	0.073
5	5438.7	2.4372e-008	2.4014e-008	1.834
6	6097.3	0.034628	5.6945e-007	7.235
7	6106.5	6.8294e-005	3.0126e-006	0.034

Close Save Help

Figure 6 Mass participation factor normalized by X, Y and Z directions

4. RESULTS

Due to limited printing space, only the results of six lengths of the sonotrode will be displayed from the 13 lengths that were measured and calculated.

For the sonotrode length of 129.50 mm, the results are presented in table 1 and figure 7; from table 1 can see that the axial vibration modes are achieved for modes 10, 15 and 19, the latter being closest to 20000 Hz and the calculated value is 19034 Hz; from figure 7 can see that the measured frequency of 19091.8. The percentage difference between the two values of frequency is 0.30%.

For the sonotrode length of 128.3 mm, the results are presented in table 1 and figure 8; from table 1 can see that the axial vibration modes are achieved for modes 10, 15 and 19, the latter being closest to 20000 Hz and the calculated value is 18713 Hz; from figure 8 can see the measured frequency of 18505.9. The percentage difference between the two values of frequency is -1.12%.

Table 1 Mass participation factors

Vibration mode nr.	Mass participation factors for sonotrode length = 129.50 mm				Mass participation factors for sonotrode length = 128.93 mm			
	Freq (Hz)	X direction	Y direction	Z direction	Freq (Hz)	X direction	Y direction	Z direction
1	1193.3	0.249900	0.000000	0.000001	1221.3	0.244690	0.000000	0.001107
2	1196.4	0.000002	0.000000	0.250530	1224.4	0.001106	0.000000	0.245380
3	3603.1	0.073467	0.000000	0.000117	3512.3	0.070773	0.000000	0.000000
4	3610.9	0.000116	0.000000	0.072517	3518.3	0.000000	0.000000	0.069911
5	6059.4	0.000001	0.000000	0.000000	6148	0.000001	0.000000	0.000000
6	6454.4	0.006366	0.000000	0.000003	6442.5	0.007442	0.000001	0.000007
7	6475	0.000001	0.000001	0.005195	6462.4	0.000005	0.000001	0.006300
8	7343.5	0.387780	0.000021	0.024754	7345.1	0.291390	0.000002	0.127770
9	7345	0.024609	0.000001	0.389430	7347.4	0.126980	0.000000	0.292510
10	7421.5	0.000011	0.618790	0.000004	7510.6	0.000001	0.621830	0.000002
11	12483	0.000016	0.000000	0.000000	12479	0.000003	0.000000	0.000000
12	12780	0.091126	0.000000	0.000026	12907	0.091549	0.000000	0.000155
13	12811	0.000022	0.000001	0.089785	12938	0.000146	0.000001	0.090201
14	13376	0.000005	0.000000	0.000000	13214	0.000027	0.000000	0.000000
15	14532	0.000000	0.338460	0.000000	14553	0.000000	0.332610	0.000000
16	15023	0.000000	0.000001	0.000000	14868	0.000000	0.000000	0.000000
17	18125	0.069053	0.000000	0.012396	18155	0.036101	0.000004	0.044225
18	18135	0.011981	0.000001	0.071565	18161	0.042712	0.000003	0.037469
19	19034	0.000000	0.013287	0.000005	18713	0.000001	0.016013	0.000027
20	21099	0.000760	0.000000	0.042044	21067	0.000016	0.000000	0.043992
21	21125	0.043808	0.000000	0.000729	21099	0.045944	0.000000	0.000017
22	23884	0.000019	0.000000	0.001169	23921	0.000008	0.000000	0.001064
23	23968	0.001619	0.000000	0.000013	24001	0.001515	0.000000	0.000010
24	24385	0.000000	0.000618	0.000000	24214	0.000000	0.000539	0.000000
25	24721	0.000000	0.000000	0.000000	25092	2.20E-08	1.04E-08	4.16E-08

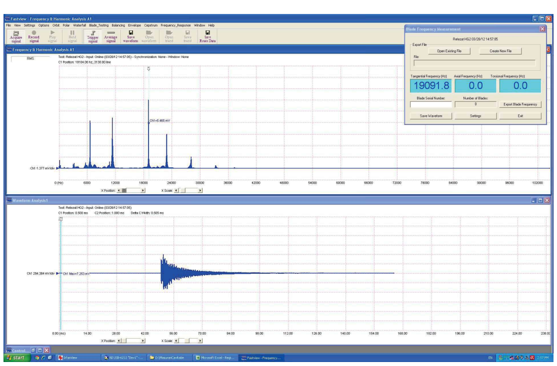


Figure 7 Natural measured frequency for sonotrode length = 129.50 mm

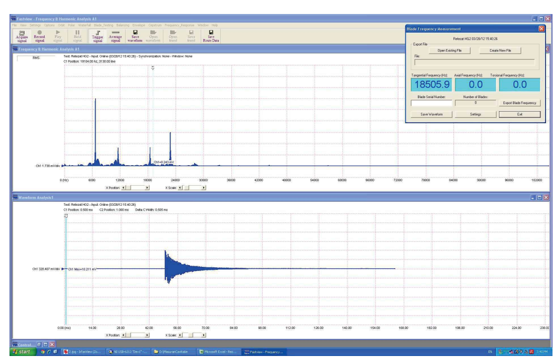


Figure 8 Natural measured frequency for sonotrode length = 128.93 mm

For the sonotrode length of 128.17 mm, the results are presented in table 1 and figure 9; from table 2 can see that the axial vibration modes are achieved for modes 10, 15 and 19, the latter being closest to 20000 Hz and the calculated value is 18887 Hz; from figure 9 can see that the measured frequency of 19091.8. The percentage difference between the two values of frequency is 1.07%.

For the sonotrode length of 126.3 mm, the results are presented in table 1 and figure 10; from table 2 can see that the axial vibration modes are achieved for modes 10, 15 and 19, the latter being closest to 20000 Hz and the calculated value is 19318 Hz; from figure 10 can see the measured frequency of 19793.7. The percentage difference between the two values of frequency is 2.40%.

Table 2 Mass participation factors

Vibration mode nr.	Mass participation factors for sonotrode length = 128.17 mm				Mass participation factors for sonotrode length = 126.3 mm			
	Freq (Hz)	X direction	Y direction	Z direction	Freq (Hz)	X direction	Y direction	Z direction
1	1225.8	0.246610	0.000000	0.000324	1236.4	0.248950	0.000000	0.000390
2	1228.9	0.000325	0.000000	0.247270	1239.6	0.000391	0.000000	0.249580
3	3575.7	0.070886	0.000000	0.000231	3737.3	0.072243	0.000000	0.000156
4	3583.2	0.000225	0.000000	0.069982	3746.3	0.000155	0.000000	0.071304
5	6149.4	0.000000	0.000000	0.000000	6154.6	0.000000	0.000000	0.000000
6	6481.8	0.005310	0.000000	0.000001	6591.2	0.000880	0.000000	0.000001
7	6502.3	0.000000	0.000000	0.004191	6609	0.000003	0.000001	0.000404
8	7349.8	0.001553	0.000017	0.420310	7372	0.421780	0.000000	0.000025
9	7351.5	0.418170	0.000000	0.001579	7375.6	0.000023	0.000001	0.423040
10	7515.5	0.000000	0.623040	0.000009	7530.7	0.000000	0.624520	0.000001
11	12482	0.000002	0.000001	0.000001	12498	0.000000	0.000000	0.000000
12	12945	0.092082	0.000000	0.000077	13050	0.092778	0.000000	0.000092
13	12980	0.000075	0.000000	0.090671	13087	0.000086	0.000000	0.091533
14	13323	0.000013	0.000000	0.000000	13556	0.000004	0.000000	0.000000
15	14571	0.000000	0.333290	0.000000	14629	0.000000	0.335330	0.000000
16	14965	0.000001	0.000000	0.000000	15264	0.000000	0.000000	0.000000
17	18257	0.012415	0.000006	0.071237	18481	0.000252	0.000002	0.089386
18	18264	0.068994	0.000004	0.012909	18488	0.086746	0.000000	0.000276
19	18887	0.000008	0.014133	0.000034	19318	0.000000	0.010505	0.000013
20	21192	0.000173	0.000000	0.040405	21506	0.000114	0.000000	0.033701
21	21216	0.042454	0.000000	0.000185	21537	0.035576	0.000000	0.000121
22	24005	0.000007	0.000000	0.000808	24283	0.000011	0.000002	0.000255
23	24086	0.001208	1.14E-07	4.78E-06	24316	0.000559	4.39E-07	9.55E-06
24	24312	5.78E-07	0.000595	2.39E-07	24605	2.81E-08	0.000757	4.27E-07
25	25112	3.64E-10	7.58E-08	4.53E-10	25118	2.23E-07	2.49E-07	2.27E-08

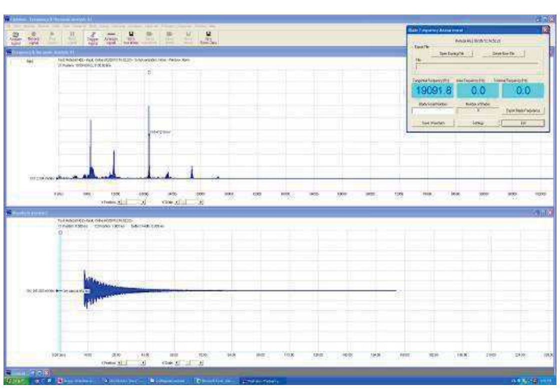


Figure 9 Natural measured frequency for sonotrode length = 128.17 mm

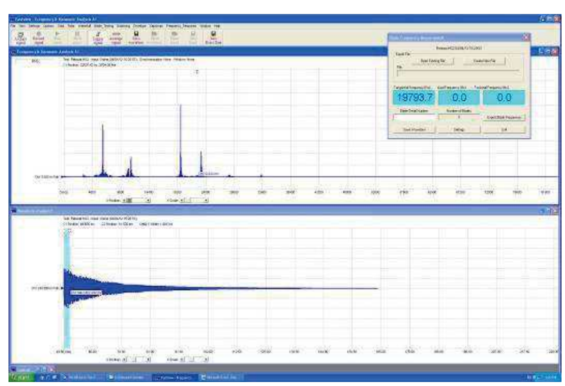


Figure 10 Natural measured frequency for sonotrode length = 126.3 mm

For the sonotrode length of 126.1 mm, the results are presented in table 3 and figure 11; from table 3 can see that the axial vibration modes are achieved for modes 10, 15 and 19, the latter being closest to 20000 Hz and the calculated value is 19375 Hz; from figure 11 can see that the measured frequency of 19769.3. The percentage difference between the two values of frequency is 1.99%.

For the sonotrode length of 125.7 mm, the results are presented in table 1 and figure 12; from table 3 can see that the axial vibration modes are achieved for modes 10, 15 and 19, the latter being closest to 20000 Hz and the calculated value is 19475 Hz; from figure 12 can see the measured frequency of 19738.8. The percentage difference between the two values of frequency is 1.34%.

Table 3 Mass participation factors

Vibration mode nr.	Mass participation factors for sonotrode length = 126.1 mm				Mass participation factors for sonotrode length = 125.7 mm			
	Freq (Hz)	X direction	Y direction	Z direction	Freq (Hz)	X direction	Y direction	Z direction
1	1237.50	0.248690	0.000000	0.000883	1239.8	0.249470	0.000000	0.000592
2	1240.70	0.000883	0.000000	0.249410	1242.8	0.000593	0.000000	0.250130
3	3754.90	0.072478	0.000000	0.000133	3790.8	0.072849	0.000000	0.000136
4	3764.50	0.000128	0.000000	0.071539	3800	0.000133	0.000000	0.071868
5	6155.60	0.000000	0.000000	0.000000	6156.5	0.000000	0.000000	0.000000
6	6603.10	0.000557	0.000000	0.000001	6630.3	0.000136	0.000000	0.000000
7	6622.30	0.000000	0.000000	0.000230	6645.6	0.000000	0.000001	0.000005
8	7374.30	0.421680	0.000015	0.000224	7380	0.421680	0.000001	0.000136
9	7378.20	0.000223	0.000014	0.422520	7383.1	0.000139	0.000003	0.422580
10	7532.80	0.000010	0.624810	0.000011	7535.4	0.000001	0.625230	0.000003
11	12498.00	0.000000	0.000000	0.000000	12500	0.000000	0.000000	0.000000
12	13062.00	0.092569	0.000000	0.000367	13086	0.092912	0.000000	0.000164
13	13099.00	0.000374	0.000001	0.091356	13123	0.000156	0.000002	0.091543
14	13577.00	0.000004	0.000000	0.000000	13620	0.000004	0.000000	0.000000
15	14635.00	0.000000	0.335440	0.000000	14647	0.000000	0.335660	0.000000
16	15302.00	0.000000	0.000000	0.000000	15388	0.000001	0.000001	0.000000
17	18498.00	0.003074	0.000001	0.087189	18541	0.000536	0.000002	0.090730
18	18512.00	0.084507	0.000000	0.003238	18560	0.088018	0.000000	0.000580
19	19375.00	0.000000	0.010080	0.000008	19475	0.000000	0.009400	0.000011
20	21542.00	0.000518	0.000000	0.032452	21610	0.000019	0.000000	0.031598
21	21570.00	0.034400	0.000000	0.000463	21647	0.033534	0.000000	0.000014
22	24282.00	0.000007	0.000001	0.000218	24343	0.000025	0.000001	0.000147
23	24349.00	0.000466	0.000000	0.000006	24406	0.000350	0.000001	0.000016
24	24655.00	0.000000	0.000783	0.000000	24735	0.000000	0.000825	0.000000
25	25132.00	0.000000	0.000000	0.000000	25138	0.000000	0.000000	0.000000

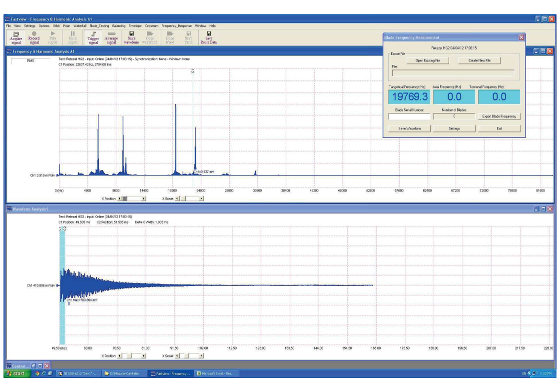


Figure 11 Natural measured frequency for sonotrode length = 126.1 mm

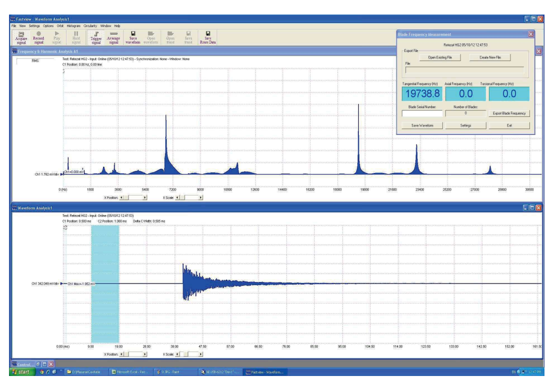


Figure 12 Natural measured frequency for sonotrode length = 125.7 mm

For the 13 measured and calculated lengths, the results are summarized in table 4 and figure 13, where:

- Current Issue - is the number of the experiment;
- Sonotrode length - is the length of sonotrode;
- Δl - is the shortened length of sonotrode in relation to the previous procedure;
- Measured frequency - is the measured frequency;
- Calculated frequency - is the calculated frequency through modal analysis from the SolidWorks software;
- Error – is the difference in Hz between the measured and calculated frequency;
- Err - is the percentage error between the measured and calculated frequency difference.

The graph from figure 9 presents the evolution of the calculated and measured nature frequency versus the sonotrode length in a comparative manner.

Table 4 Measured and calculated lengths

Current Issue	Sonotrode length	Δl	Measured frequency	Calculated frequency	Error	Err
	mm	mm	Hz	Hz	Hz	%
1	129.50	0	19091.8	19034	57.8	0.30
2	129.15	0.41	18841.6	18937	-95.4	-0.51
3	128.93	0.22	18505.9	18713	-207.1	-1.12
4	128.67	0.26	18920.9	18766	154.9	0.82
5	128.51	0.16	19000.2	18817	183.2	0.96
6	128.17	0.34	19091.8	18887	204.8	1.07
7	127.72	0.45	19274.9	18991	283.9	1.47
8	127	0.72	19348.1	19151	197.1	1.02
9	126.3	0.7	19793.7	19318	475.7	2.40
10	126.2	0.1	19696	19352	344	1.75
11	126.1	0.1	19769.3	19375	394.3	1.99
12	125.9	0.2	19860.8	19434	426.8	2.15
13	125.7	0.2	19738.8	19475	263.8	1.34
	Sum	3.8		Average	206.44	

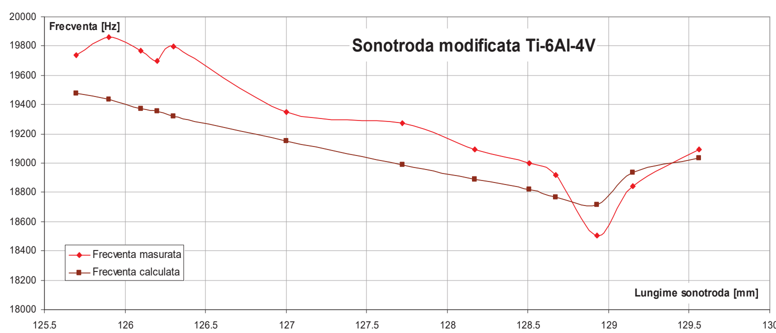


Figure 13 The nature frequency calculated and measured

5. CONCLUSIONS

The tests were continued until the sonotrode length was 125.7 mm, value for which the calculated frequency was 19475 Hz, the measured value was 19738.8 Hz and the ultrasonic generator protection has not blocked its operation.

Table 2 shows the errors between the measured and calculated values of frequency in the 0.30 ÷ 2.40%.

The graph in figure 9, shows similarity curves measured and calculated, the measured values are generally higher than those calculated, the average deviation is 206.44 Hz. From the graph one can see the trend of increasing frequency by reducing the sonotrode length.

6. ACKNOWLEDGMENTS

This work was partially supported by the strategic grant POSDRU /88/1.5/S/50783 and POSDRU /88/1.5/S/ 61178.

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