Application of the Finite Element Method for the Design of Small Arm Barrels

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***Abstract*. The article presents an experimental investigation of the possibility for using the finite elements method (FEM) for definite the frequency of cross vibrations to the barrel of the small arm. To achieve the goals of the investigation a model of a real barrel with software product based on the method of the final elements is created. An experimental investigation with real shooting is done and statistics hypothesis checking is executed.**

Keywords: barrel vibrations, small arms, finite element method, grouping of hits.

I. INTRODUCTION

In the last decade other countries have made research about increasing effectiveness on the battle weapons, they have proved the big effect from the transversal vibrations on the barrel to the group and the accuracy on the target. The transversal vibrations are turned to be one of the main reasons for reducing the accuracy of the shooting, because of sagging the barrel in the horizontal and vertical level, and for reducing the grouping, because the bullets get out of the barrel in a different stage of the movement of the muzzle part.

In Republic of Bulgaria this kind of research haven't been made yet and that why in this document it is investigated the possibility of using the method of ending elements for determination the frequency of self-transversal vibrations on the barrel of the shooting weapons.

For determination the frequency of self-transversal vibrations, the barrel is accepting for a pole with complex section, stably attached on the one end and free from the other.

The existing similar models for determination the frequency of self-transversal vibrations on the barrel of the battle weapons have these following disadvantages:

- their formulas are applicable only for cylindrical or tapered barrels and they can't be used for barrels with complex form;
- the models don't offer formulas for determination the frequency of self-transversal vibrations on the barrel in presence of added mass lying on it;
- the target that is placed on that research is to verify convergence of results from frequency of self-transversal of barrel of small arms, the results from using the method of the final elements and the results from the experimental shootings.

II. RESEARCH

The main purpose of the present study is to verify whether the finite element method is applicable for determining the frequencies of the natural transverse oscillations of the small arms barrel.

The tasks of research are:

- creating a model of a real barrel with software product based on the method of the final elements and the frequency of self-transversal vibrations of the barrel;
- conduction of experimental shootings and the frequency of self-transversal vibrations of the barrel;
- processing the results and assess the adequacy of the model.

True the researching is imputed the following restriction: it is explored only the secondary frequency of self-transversal vibrations, influencing the grouping on semi-fire.

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The creating of three-dimensional model on the barrel is realized with the program SOLD EDGE ST3, for base is used a real existing ballistic barrel, designed for rounds 7,62x54 model 908/30 year.

On the program NX 7.5 NASRAN is committed the separation of the three-dimensional model of the barrel in elements. For barrel, designed round model 908/30 year, are used 10-point elements with length cathetus 8 mm. The total number of the elements is 7233, and for the points are 13715. For the add weights are used 10 points elements with length cathetus 2 mm, there for the number of elements and the points are as it follows: for weight with mass 0,027 kg - 3612 elements and 7356 points: for weight with mass 0,054 kg - 6476 elements and 11462 points, for weight with mass 0,081 kg - 9455 elements and 15796 points. For weight with mass 0,105 kg - 11398 elements and 18640 points. For weight with mass 0,204 kg - 20700 elements and 32112 points. For weight with mass 0,303 kg - 29752 elements and 45125 points. For weight with mass 0,406 kg -44758 elements and 66867 points. For weight with mass 0,506 kg - 51673 elements and 76738 points.

For the analysis of the barrel is used steel mark 50 Pa with the following characteristics: flexural modulus - 2,16.105 MPa; density of the material - 7840 kg/m3; yield strength - 748 MPa; ultimate tensile strength - 980 MPa.

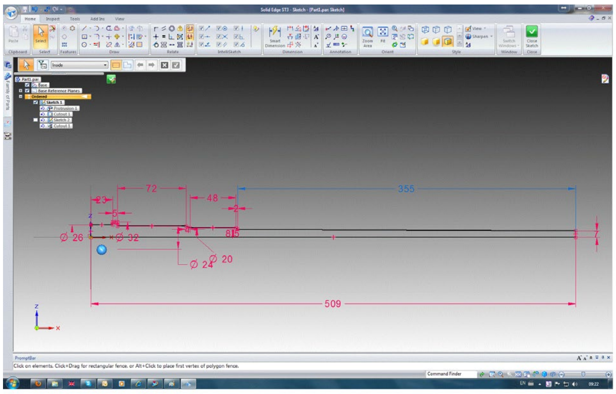

Fig. 1. Barrel draft.

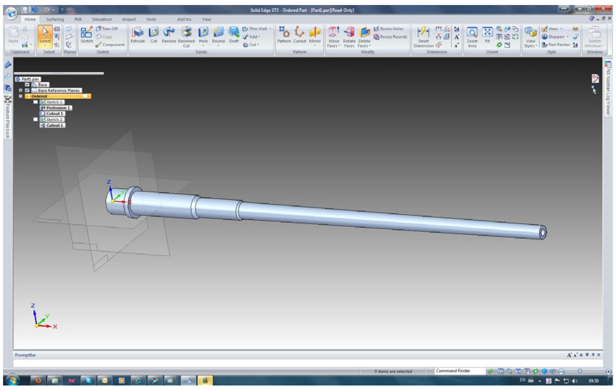

Fig. 2. Ballistic barrel three-dimensional model.

For the weights used steel 45 with the following characteristics: modulus of elasticity – 2,0694. 105 MPa; density of the material - 7829 kg / m3; yield strength - 129,5 MPa; ultimate tensile strength - 262 MPa. Data on the barrel: weight - 0,951kg; length to the point of attachment - 0,486 m; outside diameter at the point of attachment - 0,024 m; inner diameter of the channel - 0,00762 m. For maximum pressure in the barrel channel is accepted value Pmax. cp = 2900 kg/cm^2.

Place the maximum pressure is 448 mm from muzzle cut. The attachment of weight to barrel is carried out in four points, which corresponds to the actual attachment. Calculations were performed with real tables with weights placed sensor that: 0,027 kg, 0,054 kg, 0,081 kg, 0,105 kg, 0,204 kg, 0,303 kg, 0,406 kg, 0,506 kg.

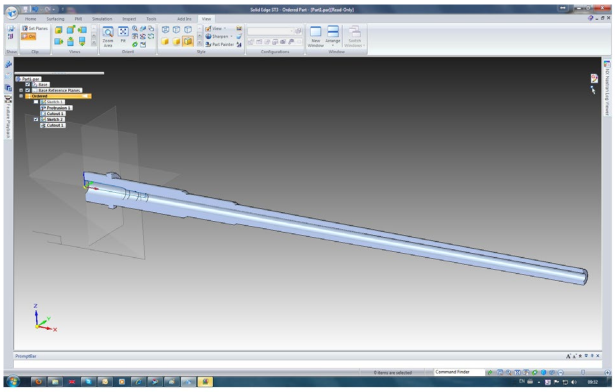

Fig. 3. Incision of ballistic barrel.

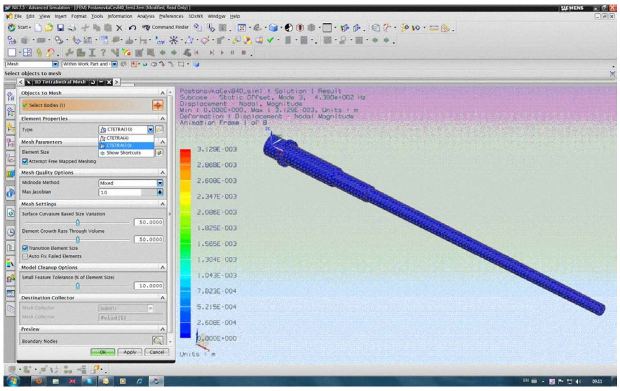

Fig. 4. Three-dimensional model of the barrel using 1908/30 cartridges, broken down into parts.

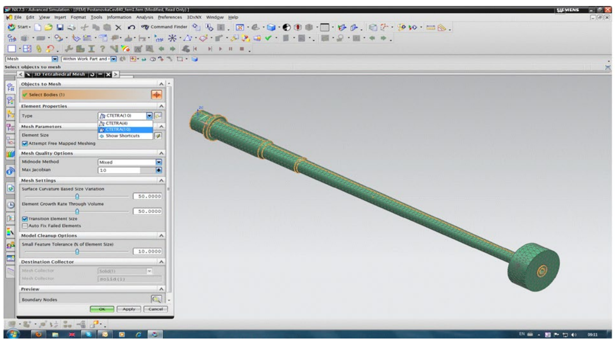

Fig. 5. Three-dimensional model of the barrel, using cartridges model 908/30, broken into elements, with a weight of mass 0.406 kg placed on its end.

The experimental study was performed in an indoor shooting tunnel in the workshop "Small and anti-aircraft weapons" in Central artillery technical testing ground (military unit 26940 - Stara Zagora). FIG. 6 is a schematic of the deployment of the equipment used to conduct the experimental shooting.

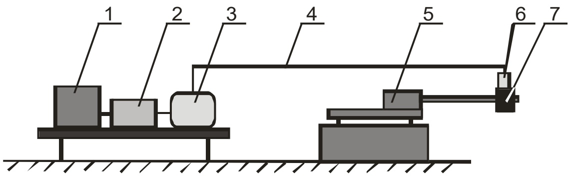

Fig. 6. Scheme of experimental investigation devices disposal. 1- computer (program "Lab View 8.5"); 2- DAQ - measurements plate NI USB-6211 – National Instruments; 3- measurements amplifier Type 2635 – Brüel & Kjær; 4- cable; 5- base for ballistic barrel; 6- censor for vibrations measurement.

Fig. 7. Base for ballistic barrel.

Fig. 8. Masses that were mounted on barrel edge with values 0,025; 0,05; 0,075; 0,100; 0,125, 0,150; 0,175; 0,200; 0,225; 0,250; 0,275; 0,300 kg.

Results from a theoretical study, done using a computer model and experimental study are presented in Table 1 and FIG. 9.

TABLE 1 RESULTS OBTAINED FROM THE COMPUTER MODEL AND THE EXPERIMENTAL STUDY OF THE SECOND FREQUENCY OSCILLATIONS OWN CROSS BALLISTIC BARREL, DESIGNED FOR CARTRIDGES 7,62x54 MODEL 908/30.

Distance from end of barrel to the mass [m]	***Results of the experiment***	***Results of the computer model***		***Results of the experiment examination***	***Results of the computer model***	
	Second frequency [Hz]	***Second frequency [Hz]***	***Relatively mistake [%]***	***Second frequency [Hz]***	***Second frequency [Hz]***	***Relatively mistake [%]***
Mass of added weight on barrel – 0,00 [kg]						
0	428	449	-4.906			
Mass of added weight on barrel 0,027 [kg]				**Mass of added weight on barrel 0,054 [kg]**		
0	388	401	-3.351	376	391	-3.99
0,01	392	415	-5.873	382	400	-4.71
0,02	396	421	-6.313	388	409	-5.41
0,03	400	426	-6.5	392	417	-6.38
0,04	404	430	-6.436	398	423	-6.28
0,05	405	433	-6.914	402	429	-6.72
0,06	406	436	-7.389	404	433	-7.18
0,07	407	438	-7.617	406	436	-7.39
0,08	408	439	-7.598	407	437	-7.37
0,09	408	439	-7.598	408	438	-7.35
0,10	408	438	-7.353	408	437	-7.11
0,11	407	437	-7.371	407	434	-6.63
0,12	406	435	-7.143	406	431	-6.16
Mass of added weight on barrel 0,081 [kg]				Mass of added weight on barrel 0,105 [kg]		
0	368	379	-2.989	364	371	-1.92
0,01	374	390	-4.278	370	383	-3.51
0,02	382	400	-4.712	378	394	-4.23
0,03	388	410	-5.670	386	405	-4.92
0,04	392	418	-6.633	392	414	-5.61
0,05	396	426	-7.576	396	423	-6.82
0,06	402	432	-7.463	400	429	-7.25
0,07	402	436	-8.458	401	434	-8.23
0,08	406	437	-7.636	402	437	-8.71
0,09	407	437	-7.371	404	437	-8.17
0,10	407	436	-7.125	406	435	-7.14
0,11	406	435	-7.143	405	439	-8.40
0,12	405	428	-5.679	404	429	-6.19
Mass of added weight on barrel 0,204 [kg]				**Mass of added weight on barrel 0,303 [kg]**		
0	350	352	-0.571	344	341	0.872
0,01	360	365	-1.389	352	355	-0.85
0,02	366	378	-3.279	360	369	-2.50
0,03	376	391	-3.989	374	382	-2.14
0,04	380	403	-6.053	378	395	-4.50
0,05	388	414	-6.70	390	406	-4.10
0,06	396	423	-6.818	400	416	-4.00
0,07	400	429	-7.25	404	423	-4.70
0,08	404	432	-6.93	408	428	-4.90
0,09	408	433	-6.127	406	428	-5.42
0,10	407	430	-5.651	403	424	-5.21
0,11	406	423	-4.187	402	417	-3.73
0,12	404	417	-3.218	400	406	-1.50
Mass of added weight on barrel 0,406 [kg]				**Mass of added weight on barrel 0,506 [kg]**		
0	338	334	1.183	332	327	1.51
0,01	344	347	-0.872	340	340	0.000
0,02	354	361	-1.977	348	350	-0.58
0,03	362	374	-3.315	358	357	0.28
0,04	372	387	-4.032	366	364	0.547
0,05	382	399	-4.450	378	371	1.852
0,06	386	402	-4.145	388	379	2.32
0,07	392	417	-6.378	402	387	3.73
0,08	396	421	-6.313	406	396	2.463
0,09	396	421	-6.313	408	405	0.735
0,10	398	418	-5.025	406	409	-0.74
0,11	395	418	-5.823	406	402	0.985
0,12	394	398	-1.02	404	390	3.465

The results presented in Table 1 and the graphs of FIG. 8 show that the nature of the ongoing processes in the pattern and experimental research is the same. Average relative mistake between experimental data and data generated by the computer model is 3.319%.

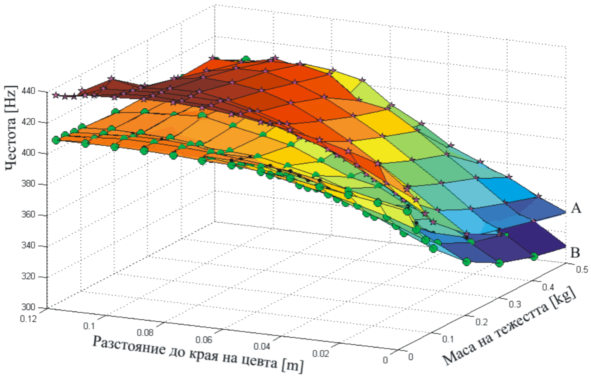

Fig. 9. Graphs of the value of the second frequency transverse vibrations resulting from the experimental shootings and computer models, depending on the distance of the mass to the muzzle cut.
A - schedule change frequency obtained from the computer model;
B - schedule change frequency derived from experimental firings.

III. Statistics Hypothesis Checking

The statistics hypothesis can be checked by comparing of the dispersions of the experimental and analytical results [5] [6] [7]. The zero hypothesis is that the dispersion of data, received from the analytical model is commensurable with the dispersion of the experimental data [8].

Formula (1) can be used to check the statistics hypothesis [1]:

$$\chi_0^2 = \frac{SS}{\sigma_0^2} \qquad (1)$$

where:

$SS = \sum_{i=1}^{n} \left(y_{Ei} - \bar{y}_E \right)^2$ - corrected sum of the squares of the experimental investigation data;

$\sigma_0^2 = \frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(y_i - \bar{y} \right)^2$ - dispersion of the analytical model data;

$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i$ - average analytical model data;

$\bar{y}_E = \frac{1}{n} \sum_{i=1}^{n} y_{Ei}$ - average experimental investigation data;

n - data number.

The zero hypothesis is rejected in cases, when $\chi_0^2 > \chi^2_{\alpha/2;n-1}$ or $\chi_0^2 < \chi^2_{1-\alpha/2;n-1}$ [1]. The values of $\chi^2_{\alpha/2;n-1}$ and $\chi^2_{1-\alpha/2;n-1}$ are tabu1lar [1].

The received results are presented in table 2.

Table 2 Results of zero hypothesis checking

№	*Mass of weight [kg]*	α	χ_0^2	χ^2 (0,025;9)	χ^2 (0,975;9)
1	0,027	0,05	4,452111	23,3366	4,40778
2	0,057	0,05	5,892019	23,3366	4,40778
3	0,081	0,05	5,494996	23,3366	4,40778
4	0,105	0,05	4,674365	23,3366	4,40778
5	0,204	0,05	6,387244	23,3366	4,40778
6	0,303	0,05	7,087494	23,3366	4,40778
7	0,406	0,05	6,249967	23,3366	4,40778
8	0,506	0,05	13,92859	23,3366	4,40778

The results presented in Table 2 indicate that the null hypothesis can be considered a true computer model, and the same can be used for practical determination of the second frequency of own oscillations of the developed cross tubes for arms.

IV. Conclusions

1. The study of the possibility of determining their lateral oscillations of the barrel FEM shows the applicability of the method to determine the same, regardless of the complexity of the shape of the barrel and the presence of added mass at various points along its length.

2. The main advantages of creating a model of the barrel using the software are:

- it is possible to create a model that corresponds to the actual shape and dimensions of the barrel, regardless of its complexity;
- it is possible to design a model of the barrel with the added weight, taking into account the actual form and the actual place where the weight is placed;
- it is possible to adjust the accuracy of the resulting solution.

3. The main shortcoming of the computer model of the barrel is the need to purchase and study of relevant software, with which to carry out modeling, leading to a significant appreciation of the study and a large expenditure of time.

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