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# Modal Analysis of Barrels for Assault Rifles

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**Abstract.** This paper deals with modal analysis of barrels for assault rifles. The barrels are modeled as 3-D objects. Three different barrels for analysis were used. First barrel is fully cylindrical and served as comparison to another two barrels, the design of which is quite close to the real barrels for 5.56 mm and 7.62 mm calibers. The calculation of natural frequencies and corresponding mode shapes was performed using the Finite Elements Method, using the LS-DYNA software system. Modal analysis was solved using the iterative Lanczos method. All three barrels are compared from various viewpoints. In Tables 1-3 the natural frequencies for these barrels and their corresponding mode shapes with modification in gripping and also with application muzzle compensator for two real barrels are listed. Various sizes of natural frequencies versus corresponding modes with modification in gripping and applied muzzle compensator for these barrels are shown on Figures from 4-9.
**Keywords:** mechanics, modal analysis, barrel, assault rifle

## 1. INTRODUCTION

This paper deals with the problems of computation of modal analysis for three different barrels of assault rifles and a comparison of eigenfrequencies with solutions of dynamic analysis of the barrels during shooting. The finite element software LS-DYNA was used for finding of eigenfrequencies and eigenmodes of oscillation in the direction of the dynamic excitation.

Three components participate in the mechanical effect of the shot with regard to the barrel: powder gas, the bullet and the barrel itself. The reason for barrel vibration is the dynamic influence of loading pressure of the barrel from powder gas flow in axial direction, which is not the same in the individual places of the barrel. The barrel in front of the bullet is unloading and behind the bullet is loaded with the step function up to the value of the maximum pressure. From this place the barrel is not loaded with the step function. Deformational response of the barrel on the instant pressure loading is bigger than the static loading. We can say that the steeper the growth of pressure loading and smaller wall thickness of the barrel, so is the dynamic straining bigger. The thickness of the barrel wall decreases towards the barrel muzzle due to the lower pressure of the powder gas, but increase its pressure load, because the bullet reaches higher speeds [1].

## 2. MODEL ANALYSIS WITH LS-DYNA

The basic finite element formulation is described by equation [2]:

$$M\ddot{u} + Ku = f\,(t) \tag{1}$$

where: $M$ is the mass matrix; $K$ – stiffness matrix; $u$ – displacement vector; $f(t)$ – right side vector of forces acting on the system.

In order to perform a modal analysis, harmonic motion is assumed and displacements are described by harmonic function as follows:

$$u = \Phi sin\,(\omega t + \varphi) \tag{2}$$

where: $\Phi$ is amplitude of harmonic displacement; $\omega$ – circular frequency of motion; t – time; $\varphi$ – phase angle.

Substituting u from equation (2) into equation (1) the equation is transformed into an eigenvalue problem:

$$\omega^2 M\Phi = K\Phi \tag{3}$$

In LS-DYNA the focus is on eigenmodes, which have a more clear mechanical meaning than constraint and attachment modes. The general procedure is as follows. Firstly all parts that are going to be treated as rigid bodies with superimposed modes are identified. For them the eigenvalue problem:

$$[K - \omega^2 M]\Phi = 0 \tag{4}$$

is solved to get the $n$ desired eigenmodes.

## 3. BARREL ANALYSIS

Next analysis for three barrels was performed. The first barrel is only cylindrical and the second and third are quite close to the real barrels (i.e. a part around the chamber of the barrel is cylindrical and the next part from this point to the muzzle is conical). The first barrel has the inner and outer diameters 5.56 mm and 16.6 mm respectively, thickness of the barrel wall is 5.52 mm, length of the barrel is 488 mm. The second barrel has the inner and outer diameters 5.56 mm and 17 mm at the muzzle respectively – and the inner and outer diameters are 9.6 mm and 25 mm at the bottom of the chamber respectively, thickness of the barrel wall is 5.72 mm at the muzzle and 7.7 mm at the bottom of the chamber, length of the barrel is 488 mm. The chamber here was designed for a 5.56 mm model SS 109 cartridge (Fig. 1).

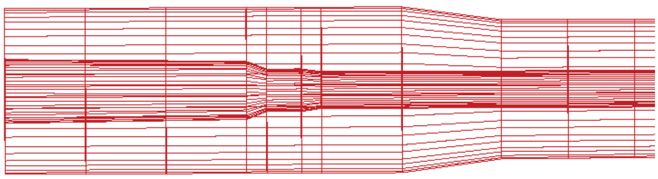

Fig. 1. Design of the barrel for caliber 5.56 mm near chamber for the second barrel

The third barrel has the inner and outer diameters equal to 7.62 mm and 13 mm at the muzzle respectively - and the inner and outer diameters 11.4 mm and 21 mm at the bottom of the chamber respectively, thickness of the barrel wall is 2.69 mm at the muzzle and 4.8 mm at the bottom of the chamber, length of the barrel is 390 mm. The chamber here was design for a 7.62 mm model 43 cartridge. The second and third barrels were equipped accordingly with the same muzzle compensator (MC) the outer diameter of which is 23 mm and its length is 75 mm (Fig. 2).

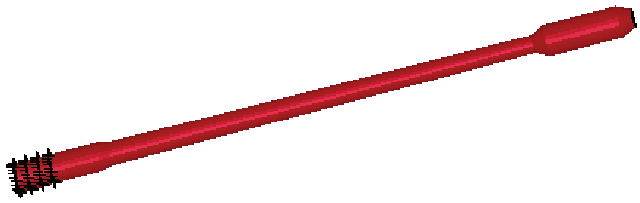

Fig. 2. Design of the 7.62 mm barrel with a muzzle compensator and fixed end around the chamber at the length of 26 mm

The geometry of the barrels was defined in the LS-DYNA mesh command and with the finite element models being generated [3]. The material chosen was elastic with material parameters for steel. Each of the barrels either 5.56 mm or 7.62 mm caliber was subjected to various gripping conditions (end of the left side – Fig. 2). That means, that the barrels were fixed around the chambers at three different lengths. For the basic gripping, the minimal allowable gripping length of the barrel was used. Next two gripping lengths are possible to use for mounting of the barrel to the cases of assault rifles. For example, for caliber 5.56 mm the length of gripping is 25 mm and for caliber 7.62 mm the length of gripping is 62 mm. The barrels were compared to a simple cylindrical barrel without change in both inner and outer diameters along the length.

Basic finite elements with 8 nodes in the corners of the brick were used with improved strain treatment across the volume of the element. In order to perform a modal analysis the implicit method has to be activated using CONTROL_IMPLICIT_GENERAL command. The imflag of the command has to be set to 1 and an arbitrary initial implicit time step has to be chosen as *DT0>0*. The eigenvalue analysis is activated by the CONTROL_IMPLICIT_EIGENVALUE command where the number of modes to be extracted has to be specified using the neigv flag. For all computations a double precision version of LS-DYNA has to be used and the results are written to the d3eigv file which can be thereafter opened using LS-PREPOST for visualization and further processing.

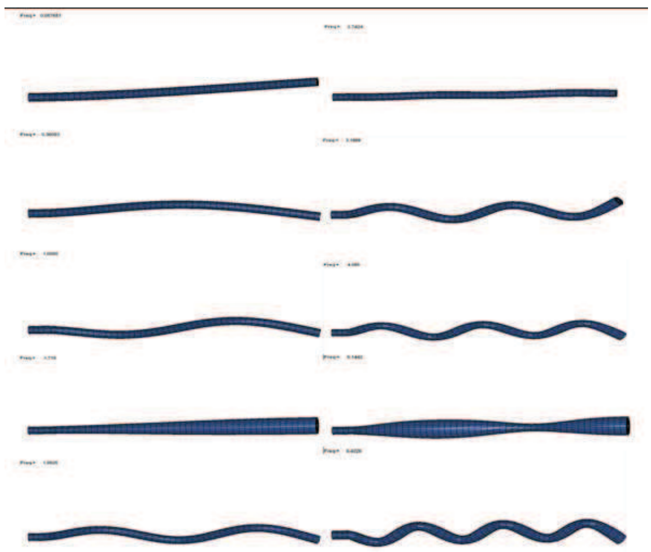

Fig. 3. Eigenmodes for cylindrical barrel
(from the left side to the right side is from 1 to 10 respectively)

Figure 3 depicts first ten mode shapes for the barrels. These mode shapes are identical for all barrels and only the corresponding eigenfrequency changes.

Tables 1-3 list natural frequencies of three different barrels and their corresponding mode shapes with variation in gripping. From these tables and also from Figures 4-6 visible is the dependence of natural frequencies from the length of gripping for each barrel separately. When the length of gripping of the barrels is greater the natural frequencies are also bigger.

Table 1. Natural frequencies and corresponding mode shapes

| Caliber: 5.56 mm<br>Length of cylindrical barrel: 488 mm | | | |
|---|---|---|---|
| Gripping | basic | 27.38 mm | 57.83 mm |
| Mode | Natural frequencies [Hz] | | |
| 1. | 51.556 | 57.651 | 67.56 |
| 2. | 324.59 | 360.93 | 420.89 |
| 3. | 906.61 | 1005.5 | 1167.7 |
| 4. | 1614 | 1715 | 1849.3 |
| 5. | 1762.2 | 1952.5 | 2258.8 |
| 6. | 2565.2 | 2742.4 | 3002.4 |
| 7. | 2876 | 3186.8 | 3673.9 |
| 8. | 4227.2 | 4685 | 5384.3 |
| 9. | 4846.5 | 5144.2 | 5545.3 |
| 10. | 5796.6 | 6422.6 | 7359.4 |

Table 2. Natural frequencies and corresponding mode shapes

| Caliber: 5.56 mm<br>Length of barrel: 488 mm (+ 75 mm MC) | | | | | |
|---|---|---|---|---|---|
| Gripping | basic | 24.33 mm | 24.33 mm with MC | 60 mm | 60 mm with MC |
| Mode | Natural frequencies [Hz] | | | | |
| 1. | 83.688 | 87.878 | 65.013 | 96.34 | 69.873 |
| 2. | 436.21 | 465.83 | 340.01 | 521.23 | 371.52 |
| 3. | 1128 | 1219 | 892.56 | 1383.6 | 986.67 |
| 4. | 2083.3 | 2133.6 | 1617.4 | 2220.8 | 1661.1 |
| 5. | 2112 | 2296.2 | 1696.6 | 2634.9 | 1894.6 |
| 6. | 3014.7 | 3110.6 | 2691.3 | 3330.9 | 2851.6 |
| 7. | 3373.7 | 3670.4 | 2743.9 | 4243.3 | 3092.8 |
| 8. | 4906.2 | 5316.1 | 4027 | 5758.7 | 4420 |
| 9. | 5300.7 | 5485.1 | 4247.3 | 6168.2 | 4571.7 |
| 10. | 6684.9 | 7217 | 5536.4 | 8367.6 | 6308.9 |

Table 3. Natural frequencies and corresponding mode shapes

| Caliber: 7.62 mm<br>Length of barrel: 390 mm (+ 75 mm MC) | | | | | |
|---|---|---|---|---|---|
| Gripping | basic | 26 mm | 26 mm with MC | 62 mm | 62 mm with MC |
| Mode | Natural frequencies [Hz] | | | | |
| 1. | 128.53 | 137.76 | 73.986 | 153.32 | 80.036 |
| 2. | 617.15 | 680.97 | 409.06 | 782.56 | 459.17 |
| 3. | 1537.4 | 1729 | 1088.7 | 2034.6 | 1244.9 |
| 4. | 2824.6 | 2944.5 | 1453.4 | 3083 | 1481.9 |
| 5. | 2855.3 | 3197.8 | 2071.7 | 3832.9 | 2411.7 |
| 6. | 4050.7 | 4250.8 | 3006.8 | 4609.6 | 3162.1 |
| 7. | 4505.2 | 5046.1 | 3384.8 | 6115.9 | 4004.3 |
| 8. | 6530.6 | 7185.1 | 4906.5 | 7649.5 | 5174.7 |
| 9. | 6807.8 | 7259.7 | 5018.5 | 8810.4 | 6020.31 |
| 10. | 8839.9 | 9785.1 | 6970.1 | 11844 | 8188.8 |

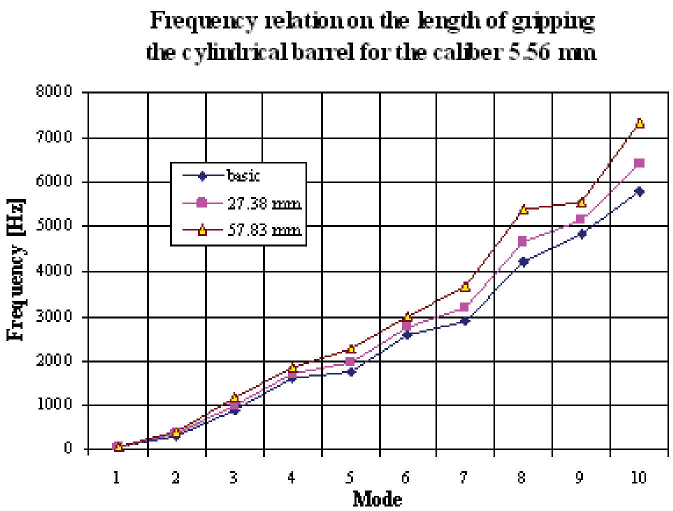


Fig. 4. Variation of natural frequencies vs. modes with modification in gripping

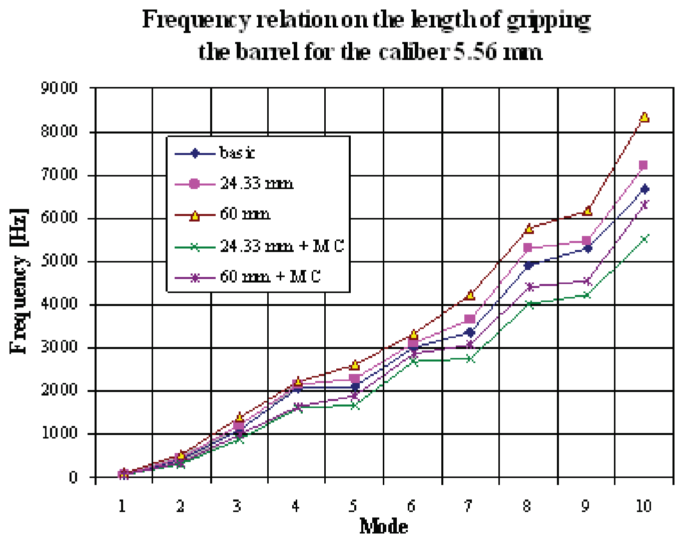


Fig. 5. Variation of natural frequencies vs. modes with modification in gripping

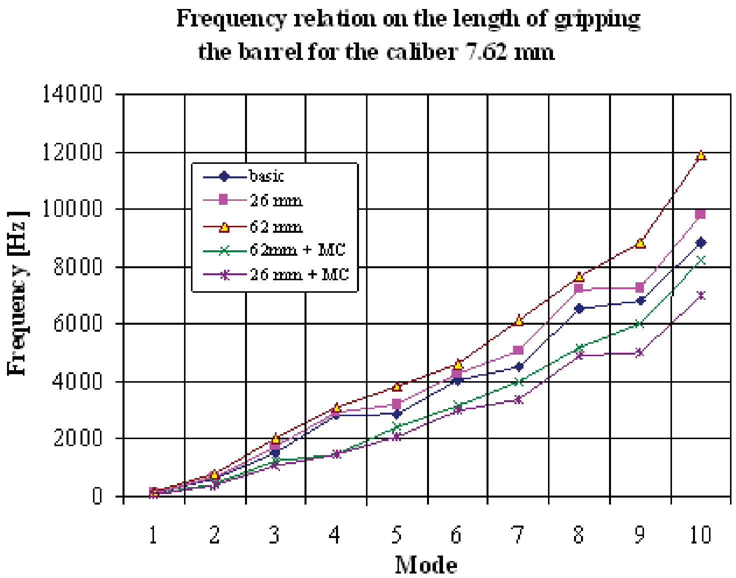


Fig. 6. Variation of natural frequencies vs. modes with modification in gripping

In Figures 7-9 comparison of natural frequencies with mode numbers among three different barrels at three different grippings are shown. It is therefrom evident, that natural frequencies depend on the length of the barrel. The biggest natural frequencies occurred for the shortest barrel at caliber 7.62 mm at all three grippings lengths.

Therefore, the natural frequencies are inversely proportional to the length of the barrel. It is also evident from Figures 7-9 when comparing the first (cylindrical) and second barrel (without muzzle compensator) which have the same length, but different wall thickness, that the second barrel which has a greater thickness also has higher natural frequencies at all the three events of gripping. It is possible to say, that natural frequencies are proportional to barrel thickness.

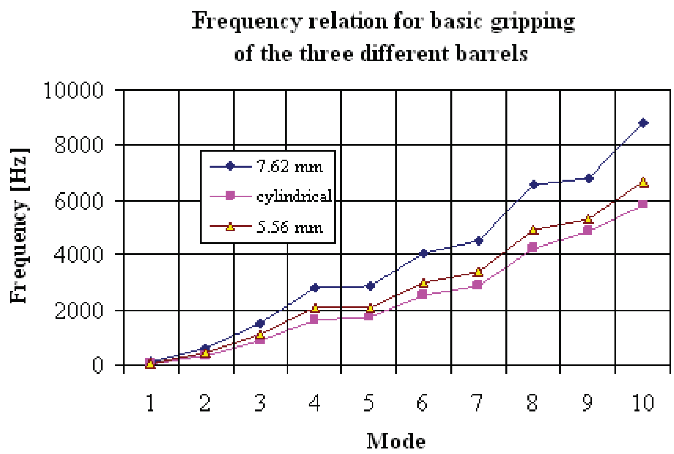


Fig. 7. Comparison of natural frequencies vs. modes among three different barrels at basic gripping

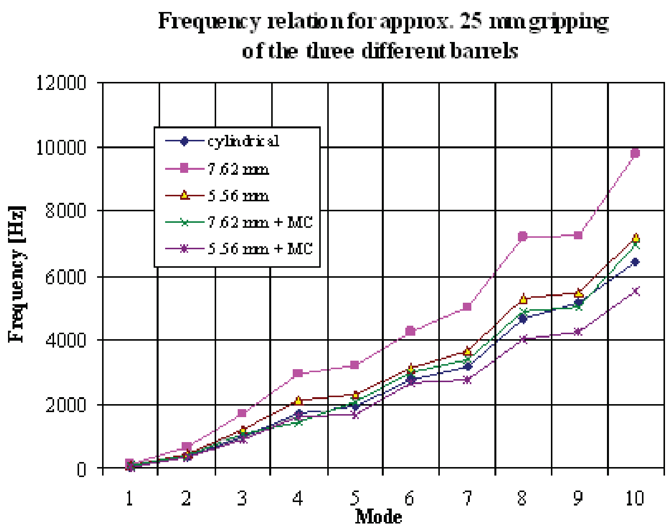


Fig. 8. Comparison of natural frequencies vs. modes among three different barrels at approx. 25 mm gripping

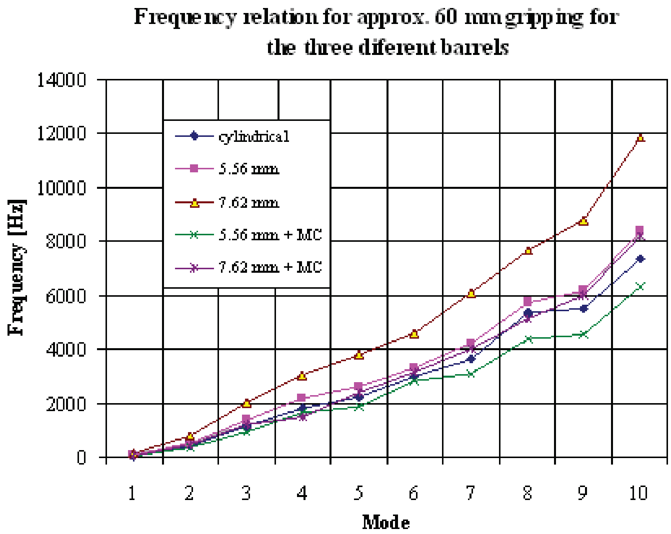


Fig. 9. Comparison of natural frequencies vs. modes among three different barrels at approx. 60 mm gripping

Figures 5, 6, 8 and 9 show a variety of natural frequencies also between similar barrels (second and third) which were equipped with a muzzle compensator placed on the free end of the barrel. The weight of the MC was taken into overall account, therefore increasing weight of both barrels. Result of this is the decrease of natural frequencies in comparison with the same barrels without a muzzle compensator.

## 4. CONCLUSION

The results show, that the natural frequencies:

1. with the length of barrels gripping on one side (which is connected with fastening of the barrels to the case of the weapon) increase i.e. that the longer the gripping of the barrel, the higher the natural frequencies are;
2. are smaller with the presence of additional weight (e.g. with an MC) on the muzzle of the barrel, in comparison with barrels without additional weight;
3. are the smallest in the 5.56 mm cylindrical barrel in comparison of all three barrels together and that they are highest in 7.62 mm barrels for all three grippings;
4. increase with increased barrel wall thickness and are inversely proportional to the barrel length. It can be expected, that the stiffness of larger caliber barrels is also larger.

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