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Comparative Stress Analysis of an Artillery Projectile Body

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Abstract

This paper presents comparative stress analysis of an artillery projectile body using FEM and classical theoretical method. The aim of this analysis is to show that results of stresses in characteristic cross sections obtained by the classical theoretical method and stresses obtained by FEM calculation gives good agreement. The projectile 105 HE M1 was used as an example for the comparative stress analysis. Based on the results and their good match, it can be concluded that the numerical FEM analysis can be reliably used for strength analysis of various types of artillery projectile bodies.

Keywords: artillery projectile body, 105 mm calibre, stress analysis, FEM, axisymmetric finite element

1. INTRODUCTION

Artillery projectiles are subjected to extremely high loads during firing. Because of that the design of artillery projectiles presents a very serious task. During the design process it is necessary to predict lot of issues: safety during exploitation (primarily during projectile travel through the barrel), proper effects on the target, achieving a maximum possible range for the given launching conditions, low cost production, maximum productivity and etc. All of these requirements are often contradictory and it is necessary to find some kind of appropriate compromise for optimum design. However, safety conditions are at the first place.

During the movement process through the barrel, the projectile is exposed to the effect of force and momentum caused by action of the gunpowder gas pressure. The parts of the projectile, especially artillery projectile body and the driving band, must be dimensioned so that the stresses that occur during the process of firing do not cause large deformations which would trigger a projectile explosion in the barrel or on the trajectory. In order to satisfy safety conditions it is necessary to determine the state of stress in the projectile body during the process of firing.

There are many diferent methods strength assesment of artillery projectile body during the process of firing. Some analytical calculation methods are developed, unabled and presented in [1-3]. In addition to analytical calculations, some authors also developed some numerical methods for stress analysis of artillery projectile body during the process of firing [4-5].

The aim of this paper is to present comparative stress analysis of an artillery projectile body using FEM and analytical calculation method. As an example projectile 105 HE M1 was used.

2. CLASSICAL THEORETICAL METHOD

Until the appearance of modern computers, the methods for stress analysis of the projectile body were very limited. The load and boundary conditions which appear during firing process of projectile exclude the possibility of direct experimental measurement of stresses and strains. Because of these facts classical theoretical methods based on analytical calculation were the only way to determine stress state of artillery projectile body. The projectile 105 HE M1 (Figure 1.) was used as an example for analytical calculation and further for comparative analysis of obtained results. All the data necessary for analytical calculation the axial stresses in the artillery projectile body are given in Table 1.

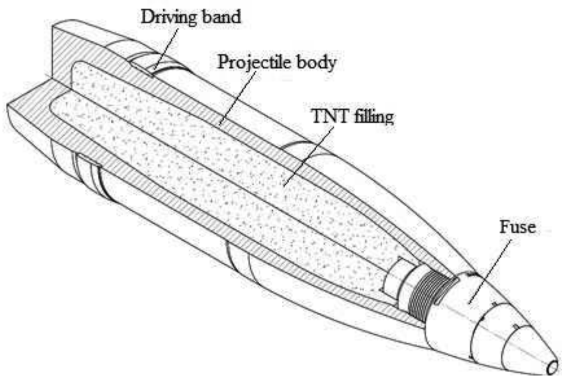

Fig. 1. 105 HE M1 artillery projectile

Table 1. Basic data for calculation

Mass of the *105 HE M1 artillery projectile*	$m = 14.95\,kg$
Maximal pressure of the gunpowder gas pressure	$p_m = 230\,MPa$
Data for barrel of Howitzer 105 mm M56 (Figure 2.)	
Number of grooves	$n = 36$
Inner diameter	$d = 105\,mm$
Outer diameter	$d_0 = 106.7\,mm$
Groove's width	$e = 5.3\,mm$
Angle of groove's twisting	$\tan\varphi = \tan 8^o$
Cross section area of the barrel	$s_c = \frac{d^2\pi}{4} + \frac{ne}{2}\left(d_0 - d\right) \quad [MPa]$
Forces and pressures	
Calculated pressure	$p_{pr} = k_1 k_2 k_3 p_m \quad [MPa]$
Corection factors	$k_1 = 1.15 - 1.18;\ k_2 = \frac{1}{1 + \frac{1}{2}\frac{\omega}{\varphi_1 m}};\ k_3 = 1.15$
Total from gunpowder gas pressure	$F_b = p_{pr} s_c \quad [N]$
Normal force on active surface of driving band's tooth	$N = \frac{I_x}{n}\frac{4}{d^2}\frac{\tan\varphi}{\cos\varphi}\frac{p_{pr}}{m} s_c \quad [N]$
Axial moment inertia of projectile	$I_{xx} \quad \left[mm^4\right]$
Axial force on one tooth of driving band	$F_{na} = N\left(\sin\varphi + f\cos\varphi\right) \quad [N]$
Friction coeficient (steel – cooper)	$f = 0.2$
Total axial force of driving band	$nF_{na} \quad [N]$
Acceleration	$\frac{d^2 z}{dt^2} = \frac{1}{m}\left(p_{pr} s_c - nF_{na}\right) \quad \left[\frac{mm}{s^2}\right]$

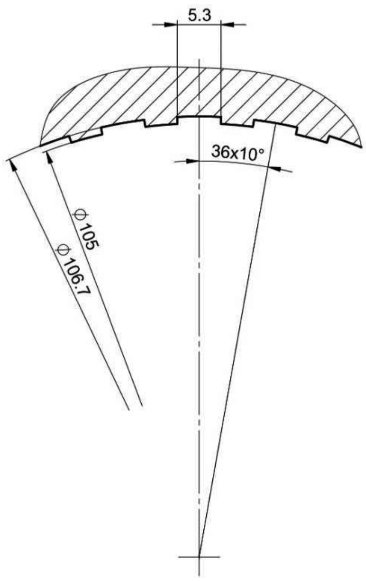

Fig. 2. Cross section of Howitzer 105 mm M56 barrel

In order to calculate the stress state, it is necessary to split the projectile body into cross-sections, which are placed in characteristic places where suddenly changes in the geometry of projectile body occur, Figure 3. For each cross section *i-i*, the inner and outer diameters of the projectile body are determined, as well as the mass of the part of the projectile in front of the cross section.

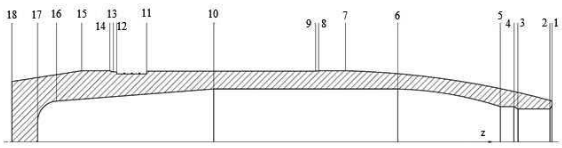

Fig. 3. Cross-section of projectile body for calculating stress state

The stresses in the projectile body were calculated with different equations in dependence on position of the cross section. The stresses in the zone in front of driving band (cross sections 1-11) were calculated using equation

$$\left(\sigma_p\right)_{i-i} = \frac{m_A}{S_{i-i}} \frac{d^2 z}{dt^2}. \tag{1}$$

The stresses in the zone behind of driving band, in front of rear cone (cross sections 12-15) were calculated using equation

$$\left(\sigma_p\right)_{i-i} = \frac{1}{S_{i-i}} \left(m_A \frac{d^2 z}{dt^2} + nF_{na} \right). \tag{2}$$

The stresses in the zone of rear cone (cross sections 16-18) were calculated using equation

$$\left(\sigma_p\right)_{i-i} = \frac{1}{S_{i-i}} \left(m_A \frac{d^2 z}{dt^2} + nF_{na} - p_{pr}\left(s_c - r_o^2 \pi\right) \right). \tag{3}$$

In equations (1) - (3) m_A represents mass of projectile's part left from cross section *i-i* (including mass of fuse and TNT filling). S_{i-i} represents area of projectile body in cross section *i-i* which can be calculating using equation (4)

$$S_{i-i} = \pi\left(r_o^2 - r_i^2\right), \tag{4}$$

whereas r_o and r_i are outer and inner radius of projectile body in cross section *i-i*.

Stress distribution of 105 HE M1 artillery projectile body in characteristic cross sections calculated using classical theoretical method are shown in Figure 4. Maximum value of the stress in projectile body is 467.25 MPa and occurs at the place of groove for driving band.

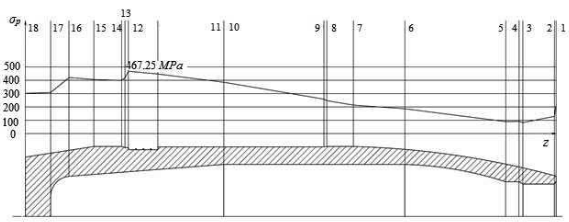

Fig. 4. Stress distribution of 105 HE M1 artillery projectile body – analytical calculation

3. FEM AND COMPARATIVE ANALYSIS

In accordance to CAD model, the artillery projectile body is modelled using the Femap software with NX Nastran solver [6], which operates based on the finite element method. The model of projectile body in all cross sections along longitudinal axis of symmetry retains the same material and geometric properties so for creating FEA model axisymmetric finite elements were used. The structure is modelled in details with 8077 elements and 8534 nodes. General element side length is about 1 mm.

As it was case in analytical calculation, the fuse is not modelled. The fuse influence is replaced with equivalent pressure acting on front area of the projectile body. The value of this pressure is product od fuse mass, acceleration and area of fuse reliance on the projectile body. Load and boundary conditions of projectile body for numerical calculation are shown in Figure 5.

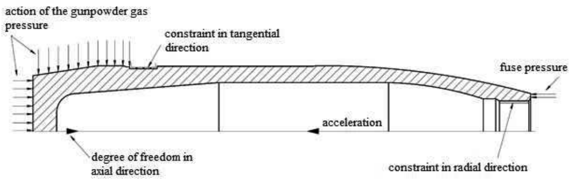

Fig. 5. Load and boundary conditions of projectile body

Stress distribution of 105 HE M1 artillery projectile body using FEM are shown in Figure 6. Maximum value of the stress in projectile body is 470.81 MPa and occurs at the place of groove for driving band.

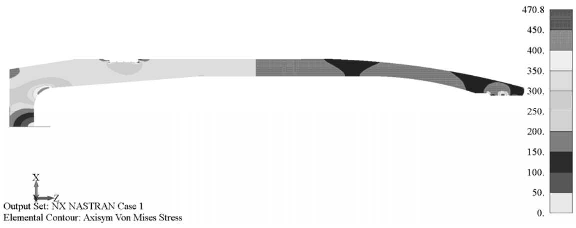

Fig. 6. Stress distribution of 105 HE M1 artillery projectile body – FEM calculation

In order to show comparative stress analysis, curves of stress distribution obtained using analytical and numerical methods are shown in Figure 7. Comparing the numerical results with values of stresses in characteristic cross sections calculated by analytical method, it is shown that difference is approximately less than 10%.

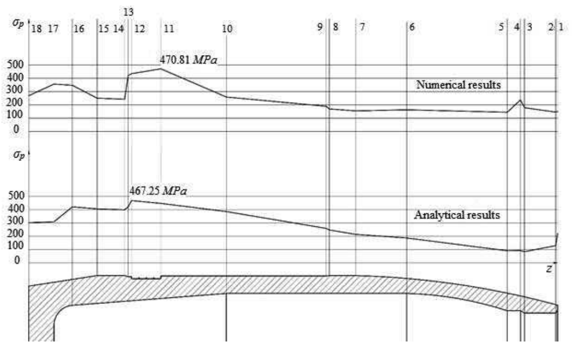

Fig. 7. Stress distribution of 105 HE M1 artillery projectile body – Comparative analysis

4. CONCLUSIONS

The aim of this paper was to present some methods for determining the stress state of projectile body during the firing process. The comparative stress analysis of an artillery projectile body using FEM and classical theoretical method was done. Comparing the numerical results with values of stresses in characteristic cross sections calculated by analytical method, it is shown that FEM gives a little higher value of stresses. Based on the fact, that it is not possible to perform a stress state analysis experimentally, it can be concluded that the numerical FEM analysis can be reliably used for strength analysis of various types of artillery projectile bodies.

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