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# INTERACTION BETWEEN DESIGN REQUIREMENTSOF THE HIGH SPIN-STABILIZED ROCKETS AND BALLISTIC PERFORMANCES

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***Abstract:*** *Design of the high spin rockets is confronted by the series of contradictory requirements. Increase of the range is acquired by better aerodynamic design (reduced drag), greater velocity and lower passive mass of the rocket. The stability conditions (gyroscopic and dynamic), in the case of the high spin rockets, demand an increase of the angular velocity of the rocket, longitudinal main inertia momentum and rocket slenderness limit to maximum eight. These requirements lead to the increase of the passive mass of the rocket and a part of the rocket propellant energy, intended for creation of the axial momentum. The target efficiency depends on the form and dimension of the warhead, quantity and type of explosive, kind of shell material, fuse type, etc.*

***Key words:*** *ballistic, rocket, acceleration, spin, propellant.*

## 1. INTRODUCTION

From the design point of view, the high spin rocket is characterized by the absence of stability fins, and the stability of the rocket in the space is obtained by a great longitudinal angular velocity and the slenderness ratio somewhat bigger than the one determined for the artillery projectiles. Primer requirements faced by a designer of the projectile are: reduction of aerodynamic drag, fulfillment of the required maximum axial and angular velocity at the end of the motor running and the target efficiency. The reduction of aerodynamic drag with these rockets is possible only by better aerodynamic design of the ogival. It is possible to achieve higher axial velocity of the rocket by increasing the total motor impulse and higher propellant mass respectively, by reducing of the rocket passive mass through selection of structure material having better mechanical features and by using up-to-date technology for the structure processing as well as by using the propellant with higher energy properties. The range increase causes increase of the rocket angular velocity, that is of the part of the rocket propellant energy intended for creating the axial momentum of reactive force. The target efficiency can be increased by changing the form and dimension of the warhead, quantity and type of explosive, kind of shell material, fuse type, etc. The target efficiency as the fragment mass distribution in the space and its kinetic energy are restricted by the design limits (projectile slenderness and aerodynamic properties of the rockets ogival) and are the result of the external and internal ballistic requirements. Requirements related to the structural resistance of the projectile and the limitations caused by the level of available technological knowledge and equipment, have a great influence on creation of the optimal rocket design and on total external ballistic performances.

## 2. EXTERNAL BALLISTIC PARAMETERS

Range of the high spin rocket depends directly on the rocket velocity and the value of the aerodynamic drag coefficient $C_x$. Aerodynamic rocket velocity is a function of total rocket motor impulse, characteristics of combustion products and passive rocket mass. Aerodynamic coefficient of the drag depends on the rocket shape, air friction on the external area and the air flow braking, due to the low pressure behind the rocket. High spin rockets are characterized by constant static instability, and therefore it is necessary to obtain dynamic stability (Jankovic, 1999). The condition of gyroscopic stability is fulfilled if its coefficient is:

$$s_g = \frac{I_x^2 \cdot \omega^2}{4 \cdot I_y \cdot M^{\sigma}} \geq 1 \qquad (1)$$

The condition of gyroscopic stability is satisfied in the case of the existence of a great angular velocity ω, sufficient ratio between axial and transversal main inertia momentum $I_x^2/I_y$ (mechanical and geometrical characteristics of the rocket) and a small value of destabilizing momentum $M^{\sigma}$. Due to that fact it could be said that shape, dimensions and velocity of the projectile, together with air density, influence the stability. In practice it is proposed to have slender ratio of λ = 6 do 8, while the relation between axial and transversal main inertia momentum, after active phase of flight, should be $I_y > 30 \cdot I_x$. During the flight both aerodynamic velocity $V$ and angular velocity $\omega$ decrease, whereas first one decreases faster than the latter. Passing from supersonic to subsonic flight may cause increase of aerodynamic momentum derivatives $m^{\sigma}$ above the critical value, as well as instability of the rocket. In order to make the high spin rocket stable, besides gyroscopic stability, it is necessary to satisfy the condition of dynamic stability too:

$$1/s_g \leq s_d \cdot (2 - s_d) \qquad (2)$$

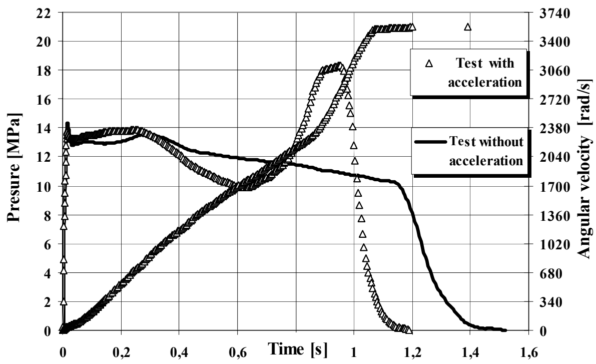
Dynamic stability means automatically the existence of gyroscopic stability of the projectile. If dynamic stability coefficient $s_d$ is placed in the interval [0,2], the projectile can be stabilized by sufficiently high angular velocity, even if it is statically instability.

By increasing the slenderness of rocket ogival from 2,0 to 2,5 the aerodynamic properties of the rocket were improved and by decreasing the passive mass (through selection of the chamber material having higher mechanical characteristics and application of the flow-forming technology ) and increasing of the propellant mass by approx. 50%, maximum rocket velocity was higher by 300 m/s and the rocket range by 50% respectively. The rocket was very sensitive to intensive change of ratio of the rocket inertia momentum, center of the mass and decrease of maximum angular velocity at the trajectory entrance since stoppage of motor function until passing from supersonic to subsonic flight. These disturbances caused the rocket instability as well as turning and falling of the rocket before reaching the target (Zecevic, 1999).

## 3. INTERNAL BALLISTIC PARAMETERS

The basic goal in the solid propellant rocket motors design process is selection of such a type of propellant grain and nozzle characteristics which will allow the change in *pressure vs time* curve, in accordance with the requirements of

the rocket projectile mission. Ordinary motors of the high spin rockets have four or seven tube propellant grain requiring thicker wall of the motor case because of direct exposure to combustion products, high temperature and pressure. By applying the concept of one propellant grain with internal combustion of star-shape type, the combustion products did not establish contacts with the rocket motor chamber, the thickness of the chamber wall was reduced, available propellant mass was increased and the rocket passive mass optimized. Internal ballistic parameters of the double-base propellants rocket motor were exposed to the influence of highly variable field of radial acceleration up to 80.000 g intensity. Character of occurred changes is not equal. It depends on the intensity of radial acceleration field, current position of the flame front during the combustion process, geometry of propellant grain, type of propellant, type and granulation of ballistic modifiers and technology of workmanship of solid propellant grain. Besides the loss of total impulse, due to slope on the nozzle axes in order to create a variable field of radial acceleration, an increase of specific impulse efficiency. The increase of the specific impulse efficiency level depends on combustion pressure, propellant grain channel geometric features, type of propellant composition and the intensity of radial acceleration field. It varies between 5-12 percent (Zecevic, 1999).
Change of the combustion pressure, under the influence of radial acceleration variable field, is strictly non-linear, and it is a function of propellant type and grain geometry. Change of the maximum pressure at the end of combustion process is strictly non-linear too, and the influence of propellant composition is higher than the one related to the geometry of the propellant grain. For some compositions the increase of combustion pressure of 150 % has been perceived, compared to conditions without acceleration. For angular velocities of rocket motors needed for stability purposes of high spin rockets, burning rate

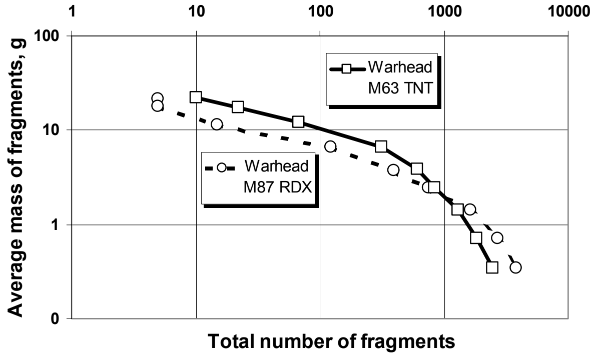



growth can reach even 100 % (Zecevic, 1999).

Fig.1 Change of the combustion pressure under the influence of radial acceleration

## 4. TERMINAL BALLISTIC PARAMETERS

Efficiency of the HE warhead is a function of velocity, geometry and mass space distribution of the natural fragments. Velocity of fragments depends on the ratio between the mass of explosive and warhead metal body, detonation velocity and explosive density. Geometry and mass space distribution of the natural fragments is a function of internal and external warhead geometry, mechanical characteristics of the shell (strength and toughness) and energetic characteristics of the explosive.
By means of the Held's formula, based on the experimental data obtained in the course of fragmentation of similar warheads, it is possible to estimate the mass and the number of natural fragments for each mass group, independently of fragments space distribution. By change of the warhead design (better slenderness) and application of higher energy explosive (warhead M87 RDX) with the same mass of shell metal there was achieved a higher number of fragments with lesser average mass (Fig. 2) and higher kinetic energy (greater lethal radius – Fig. 3) in relation to the standard model of the warhead M63

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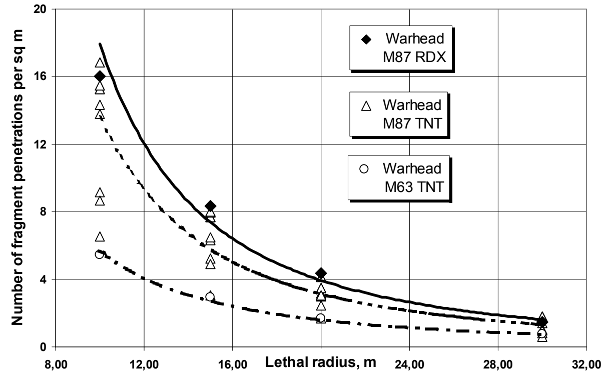


Fig. 2 Mass Fragment Distribution

Fig. 3 Lethal Effect Radius of the Warheads

## 4. CONCLUSION

Recommended limitations of the rocket slenderness and the requirements for its stability are basic limitations faced by a designer in the process of meeting the requirements determined by the mission goals of high spin rocket.
Better aerodynamic design of the rocket ogival can lead to considerable range extension (up to 5 %).
By application of the flow forming technology and materials having better mechanical features as well as new design of propellant grain it is possible to obtain lower passive mass of the rocket and considerably higher rocket velocity at the same time, with the range extension of 50 %.
Larger number of fragments having lower average mass and higher kinetic energy, and lethal effect respectively are obtained by the warhead design as well as application of material with more favorable mechanical features and explosives of higher detonation velocity and density.

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