# Mechanism of Interior Ballistic Peak Phenomenon of Guns and its Effects

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## INTRODUCTION

The erosion and wear in the gun barrel will get worse with the increasing of the number of projectiles fired. The chamber diameter will get larger than that of a new gun, and the chamber length longer. It may lead to the position of the loaded projectile moving toward the muzzle and the chamber volume increasing. Generally speaking, the engraving pressure $p_0$ of the projectile will decrease and the use of propellant energy will be less efficient. So the maximum pressure $p_m$ and muzzle velocity $v_0$ of the gun will decrease gradually due to gun barrel erosion. However, the effect of erosion and wear on ballistic performance as is analyzed above does not agree with the firing test data of certain types of guns, especially of some small-caliber guns. The ballistic performance of such guns will exhibit an increase to their peak values followed by a gradual decrease with the number of rounds fired. This is the so-called interior ballistic peak phenomenon, also named the hump effect.

The test data of a 76mm gun, a 57 mm gun and a 100 mm gun are listed in separate tables (omitted). Test results show that there are two types of interior ballistic peak effects: one with single peak, the other with double peaks, which can be seen in Figure 1. Curve I shows the gradual decay of muzzle velocity $v_0$ of ordinary guns which show no ballistic peak effect. Curve II is the variation of muzzle velocity $v_0$ of a gun with a typical ballistic peak effect. And curve III exhibits the double ballistic peak effect, a 100 mm naval gun for example.

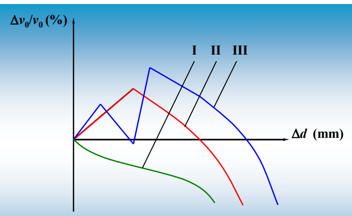



**Figure 1.** Variation of muzzle velocity $v_0$ of guns with erosion and wear: $\triangle d$ is the enlargement of diameter at the commencement of the rifling; $\triangle v_0/v_0$—the relative variation of muzzle velocity $v_0$

## MODELING OF INTERIOR BALLISTIC PEAK EFFECT

Taking a 76 mm gun and a 100 mm gun as examples, we calculated the engraving pressure $p_0$ of the guns by an approximate method, i.e. Eq. (1) given below, and built a lumped-parameter interior ballistic model of the guns that exhibits the effect, according to the classical interior ballistics theory of guns.

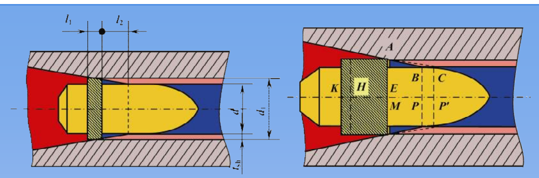
### Calculation of the Engraving Pressure $p_0$

The engraving pressure of the projectile is usually taken as the shot start pressure of a gun in classical interior ballistics, noted as $p_0$, which is one of the initial parameters of the ballistic model. We gave an approximate formula for the calculation of $p_0$:

$$p_0 = \frac{R_{\max}}{S} = KN'\frac{A}{B}\sigma_s\left(\frac{d_2}{d_4}\right)^2\left[\left(\frac{d_2}{d_4}\right)^{2B} - 1\right] \qquad (1)$$

where $R_{\max}$ is the maximum value of the deformation resistance during the engraving process of the driving band and $S$ the cross-sectional area of the gun bore. Eq. (1) shows that $p_0$ is determined by the dimensions of the shoulder and the driving band, the yield limit $\sigma_s$ of the band material, etc. $K$ is the ratio of the driving band length to the shoulder length, i.e. $K = l_1/l_2$. As the number of rounds fired increases, $K$ will decrease due to the increase of $l_2$, so will the engraving pressure.

The deformation resistance of the driving band can be taken as to be proportional to its length engraved. If $KE$>$MP$ for a new gun in Figure 2 ($b$), when the band is engraved into the full length of the shoulder, the maximum deformation resistance $R_{\max}$ is obtained. After that, the deformation resistance is no greater than $R_{\max}$. Figure 3 shows the deformation resistance curve in the engraving process for the structures in Figure 2 ($b$).




($a$) an ordinary gun ($b$) a gun with the ballistic peak effect

**Figure 2.** Sketch of the shoulder and the driving band: $t_{sh}$ = ($d_1$-$d$)/2, $d$ is the diameter of the gun (between the lands), $d_1$ is the diameter between the grooves, $l_1$ is the axial length of the driving band, i.e., $KE$, and $l_2$ is the axial length of the shoulder, i.e., $MP$

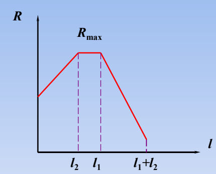



**Figure 3.** $R$-$l$ curve in engraving process

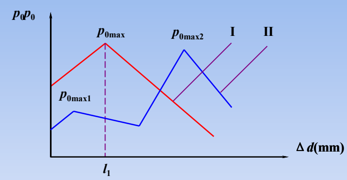



**Figure 4.** Typical change of $p_0$ in ballistic peak effect

With the erosion and wear of the gun bore, the length of the shoulder increases from $MP$ to $MP'$, the engraved length of the band increases to $MP'$, and $p_0$ increases as well. When $KE$ = $MP'$, the full length of the band is engraved into the worn shoulder, then the maximum value $p_{0\max}$ is obtained, which can be calculated using Eq. (1). Afterwards, $KE$ will be less than $MP'$, and $p_0$ will decrease from its peak value $p_{0\max}$, just like an ordinary gun, see curve I in Figure 4.

The double peak phenomenon shown by curve II in Figure 4 can be explained by Figure 5 in the same way.

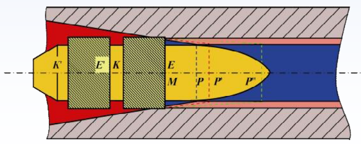



**Figure 5**. Structure of shoulder and driving bands for guns with double peaks

## Interior Ballistic Modeling of Guns Including Ballistic Peak Phenomenon

The performance indicators such as $v_0$ and $p_m$ will vary with $p_0$. Taking the variation of the engraving pressure $p_0$ and of the chamber volume $V_0$ into account, one can establish a classical (lumped-parameter) interior ballistic model of guns including the interior ballistic peak phenomenon.

The results of the modeling under different wear conditions are close to the test data, showing the existence of the peak values of $p_m$ and $v_0$. The simulation results of some other guns also show good agreement. (See Table 4 and 5 in the paper)

## SUMMARY

It was proven that the mismatch of the structure and dimensions of the gun bore with those of the projectile driving band is the fundamental cause of this effect. Due to the mismatch, the engraving pressure will first increase and then decrease with the enlargement of the bore dimensions caused by barrel erosion and wear. The variation of the engraving pressure $p_0$ will inevitably lead to variation of the interior ballistic performance in the life cycle of the gun; this observed process appears to explain the interior ballistic peak phenomenon.

The phenomenon brings difficulties to the design and use of the guns. The effects of the ballistic peak phenomenon on the ballistic performance of the guns, such as that on the barrel strength design, the qualification of standard ammunition and modifying the muzzle velocity, are analyzed. The cause of the errors of the modeling is explained and problems existing in the study summarized.