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Additional Effect of Gases on Strain Gauges at Barrel Muzzle

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Abstract:

The paper deals with the analysis and measurement of stress and strain of the barrel when the projectile goes through the muzzle. A muzzle of the barrel is stressed in a special way. This fact can influence the accuracy of firearm performance. The paper describes the issues of measurement; precisely an adverse influence impacting the strain gauges which takes place in the nearness of firearm muzzle of the experimental barrel, calibre 30 mm. The development of the experiment is presented. The amount of deformation, as well as the value of pressure at the muzzle will be checked by means of the quasi-static dynamics conditions that are described in this paper.

Keywords:

Firearm barrel, barrel muzzle, strain gauge, piezoelectric sensor, gas pressure, barrel strain.

1. Introduction

With respect to the basic requirements [1], such as **strength, reasonable lifespan, optimal weight** and others, the barrel has to withstand a load up to very high pressures ranged over hundreds Mega-Pascal, heat shock of the inner surface up to 1200 °C and that is all in time from about 0.5 to 10 milliseconds.

This shows the great dynamics of the process as well as problems associated with a thermal stress and a pressure load of the barrel and then with the lifespan of the barrel.

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2. The Measurement of Strain

2.1. Lead-in Strain Gauge

In case of the barrel with the average ballistics performance there are usually strains valued in the order of tens to hundreds of micrometers. To measure such small strain values, measurement of relative strain is applied. These methods are known as strain gauge methods.

We can determine the stress from the measured values of relative strains. We work on the assumption of static stress and others conditions, listed e.g. in [2, 3, 8, 9]. We might use the laws of physics, exactly Hook's law for the given stress state; see [5, 6].

If we know the directions of the main stresses, it is sufficient to measure strains ε_1 a ε_2 in two planes, which are perpendicular to each other the values of stress are given by the following relations (the plane stress):

$$\sigma_1 = \frac{E}{1-\mu^2}(\varepsilon_1 + \mu\varepsilon_2) \tag{1}$$

$$\sigma_2 = \frac{E}{1-\mu^2}(\varepsilon_2 + \mu\varepsilon_1) \tag{2}$$

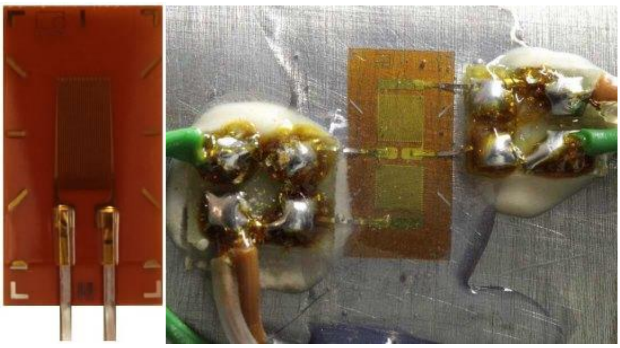


Fig. 1 a) Single strain gauge, 1 b) Strain-cross gauge

The complete error of measurement of deformation is impacted by various factors – by the tolerance of a constant of the strain gauge, by the quality at which the strain gauges were pasted, by the precision of the apparatus and inconsistent compensation or correction of temperature effects on the sensors and wiring. Normally, it should be about several percents.

3. Measurement of Deformation

The measurement was carried out in a ballistic tunnel with using experimental barrel calibre 30 mm, type 53/59. The experimental barrel was made by adjustment of the ballistic barrel of the anti-aircraft automatic cannon PLDvK type 53/59 and muzzle thread for mounting equipment was cut off. The description and location of the sensors are shown in Fig. 2, the detailed description of the measurement is given e.g. in [7, 8].

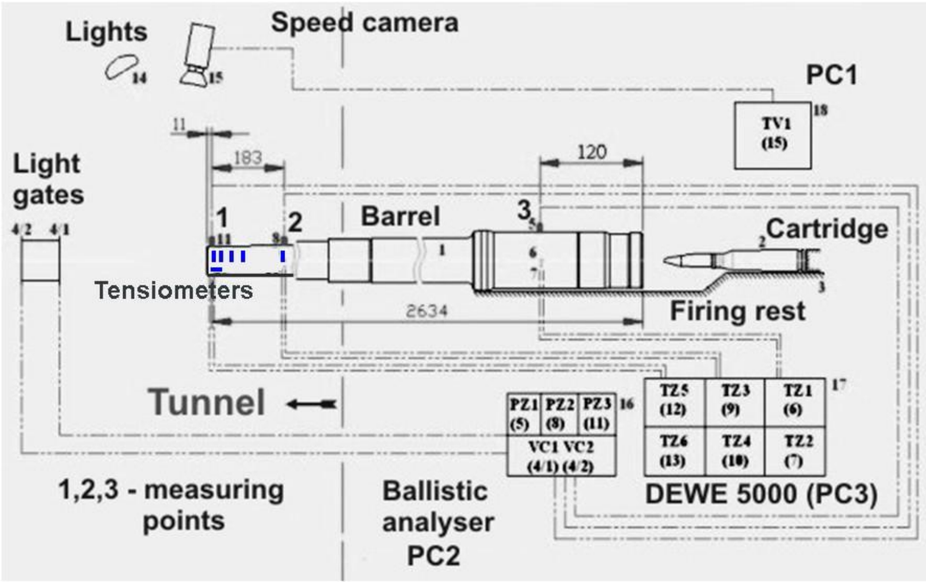
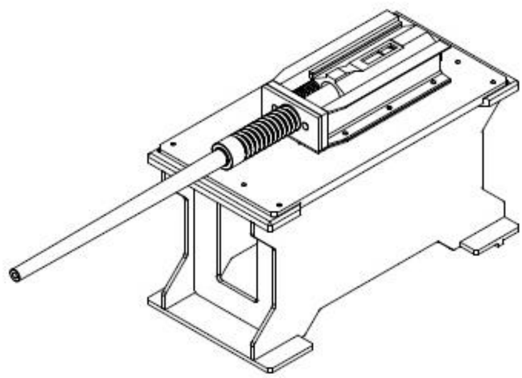


Fig. 2 Experimental workplace scheme

3.1. Standard Measuring Arrangement

To calculate the coefficient of dynamism in the proximity of the muzzle, it is important to measure both tangential and axial deformation at the selected location of the cross-section and time behaviour of pressure when the bullet is passing the muzzle.

Considering that the speed of the process is too high, it is impossible to determine precisely the moment when the bottom of bullet passes the studied cross-section.



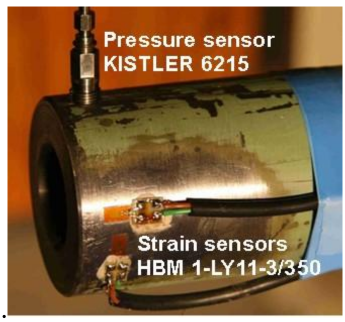


Fig. 3 a) Experimental weapon, 3 b) Pressure sensor and strain sensors

Deformation of the muzzle part does not primarily correspond to a present theory based on the assumption of the barrel as a thick-walled tube. In other parts of the barrel there are results which are consistent with existing knowledge, such as published in [3, 7, 9.].

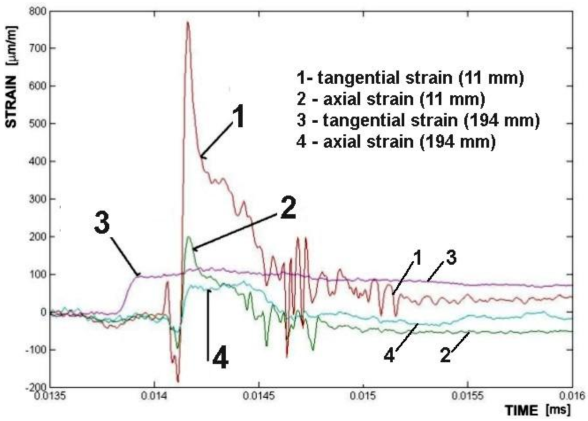


Fig. 4 Strain – time dependence around muzzle

It is evident that in the very muzzle of barrel, it is not possible to accomplish the solution by the static (quasi-static) methods, as previously thought. Therefore it is advisable to apply a dynamic calculation, or possibly to deal with rebound of the longitudinal wave motion in the material of the barrel, which can add to the deformation of the radial pressure.

3.2. Records and Results of the Experiments

The above mentioned solution together with records from high-speed camera resulted in opinion that shock-wave of pressure gasses during leaving the bullet of barrel has a considerable impact on obtained results.

Fig. 5a *Fig. 5b* *Fig. 5c*

Fig. 5 a-c Records from high-speed camera, moment of passing bullet through muzzle

This theory was gradually verified by several tentative pieces of equipment for protection of strain gauge which should explain the level of impact of external effects as pressure wave and temperature stress. With an increased number of these experiments, the specific shape and the way of fixing on the barrel are advisable.

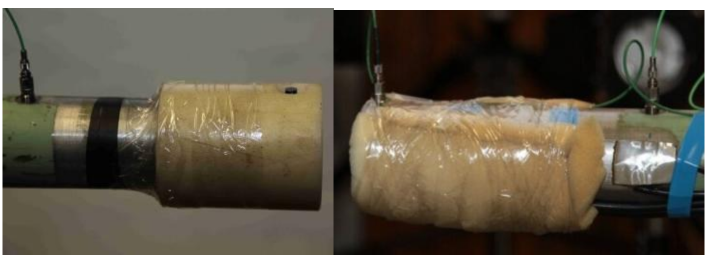


Fig. 6 Silicon jig (left) and foam substance (right) used as a fractional protection

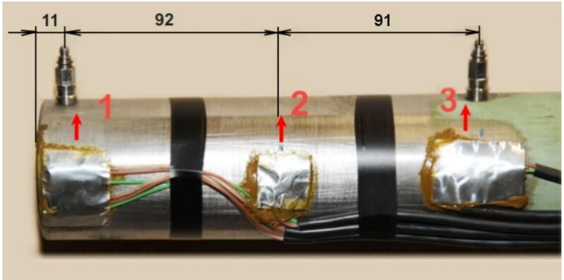


Fig. 7 Location of sensors at the muzzle, standard vibration and thermal protection

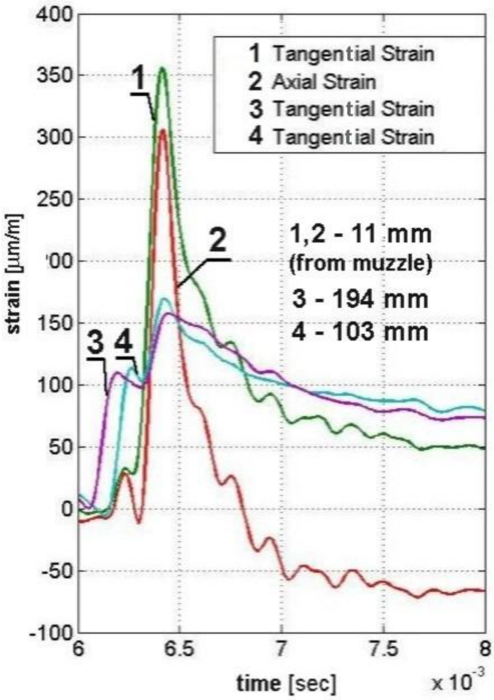


Fig. 8 Detailed view of measured strain in the area of muzzle at the fractional protection

The results have proven that the ground of the theory about impacting the strain gauges was correct. It was important to do the next experiment during which we used especially designed protection device. This equipment was improved by modifications for better and stronger fixture.

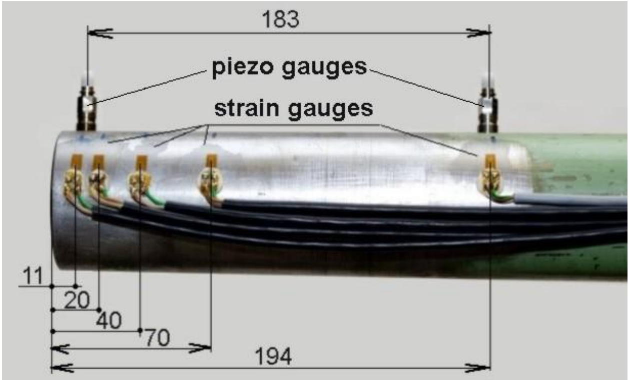


Fig. 9 Increased number of strain gauges in the proximity of muzzle

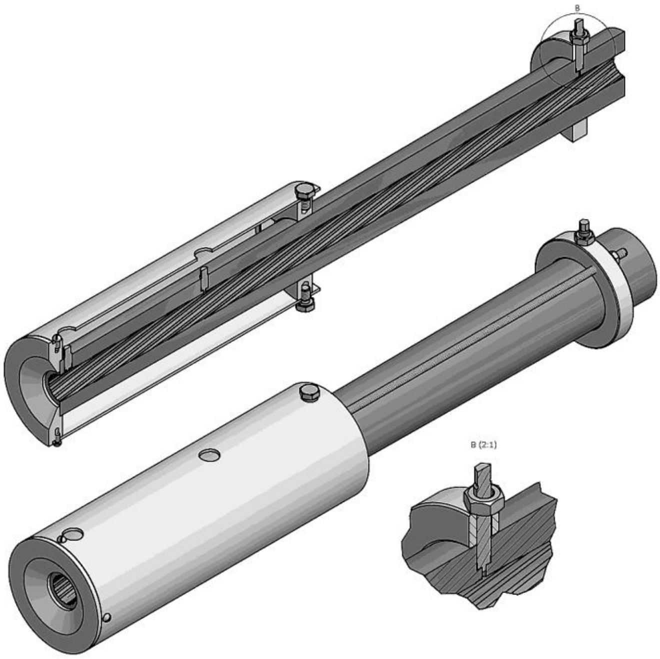


Fig. 10a Final form of protection of gauges, design of the protection

Fig. 10b Final form of protection of gauges, mounted on the barrel

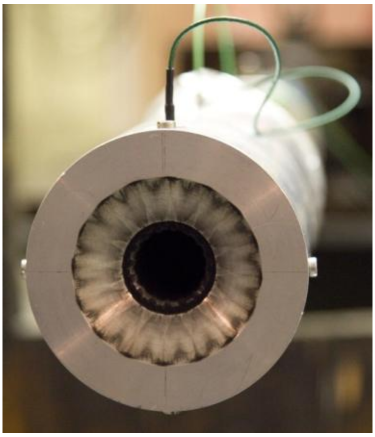


Fig. 11 Muzzle after shots

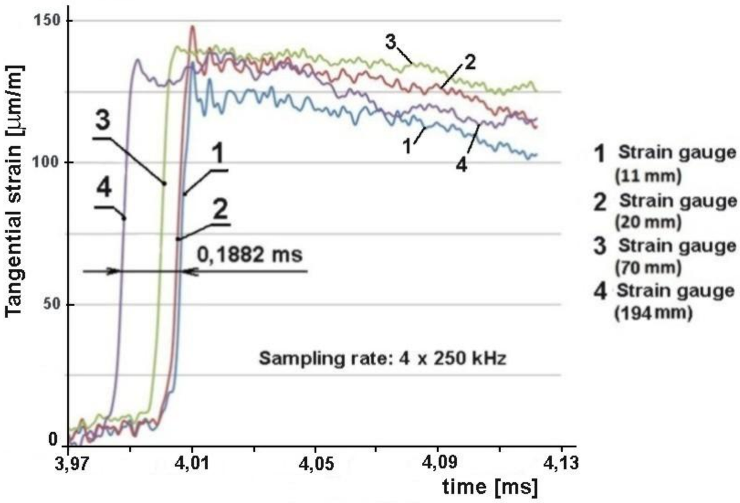


Fig. 12 Detailed view of strain in the area of muzzle with the final form of protection

4. Conclusion and Suggestion for Further Research

4.1. Conclusion

The unexplored area of the barrel muzzle load is characterized by the complexity of the system and a number of parasitic effects on the radial expansion of the barrel section, which causes the blowing-through of the dust emissions, wastage of the barrel and also reducing accuracy.

The records of the measurements and results of calculations have shown that for these powerful weapon systems it is not appropriate to use the traditional static methods of the calculation and measurement. The results of the experiment may be affected by shockwave pressure gases when projectile goes through the muzzle. Thus the measurement gauges must be protected near the barrel muzzle, as the authors have shown in this article. However, using common protection of the strain sensors is not sufficient and resistant mechanical protection is necessary. Maximum impacted area at the muzzle is approximately two calibres of the barrel.

The numerical calculations that were used lead to the exclusion of some assumptions of Lame's theory (assumed infinitely long thick-walled tubes). However, using the form of "quasistatic" loads achieved by the measuring in muzzle area is correct.

4.2. Suggestion for Further Research

Based on the above-mentioned results which are not in accordance with the current theory and assumptions, there is a need of further investigation of these issues in dynamic area. Conducting another experiment is under consideration, which will use gradient tensometers. This could help to reveal in which point the current theory stops holding. Moreover, it would contribute to the mapping of deformation development towards muzzle cross-section.

In the area of measurement, in my personal opinion, enough steps have been done in order to reach plausible results. Nevertheless, in the area of numerical computer modelling, it is necessary to concentrate on more accurate insertion of borderline conditions including physical character of barrel matter.

Nowadays it is simulated with the assistance of software called "ANSYS – AUTODYN". The three dimensional finite model of the part of the barrel was developed and with dynamic loading gases there is simulated a study and determination of the effects of dynamics to super-load of the barrel.

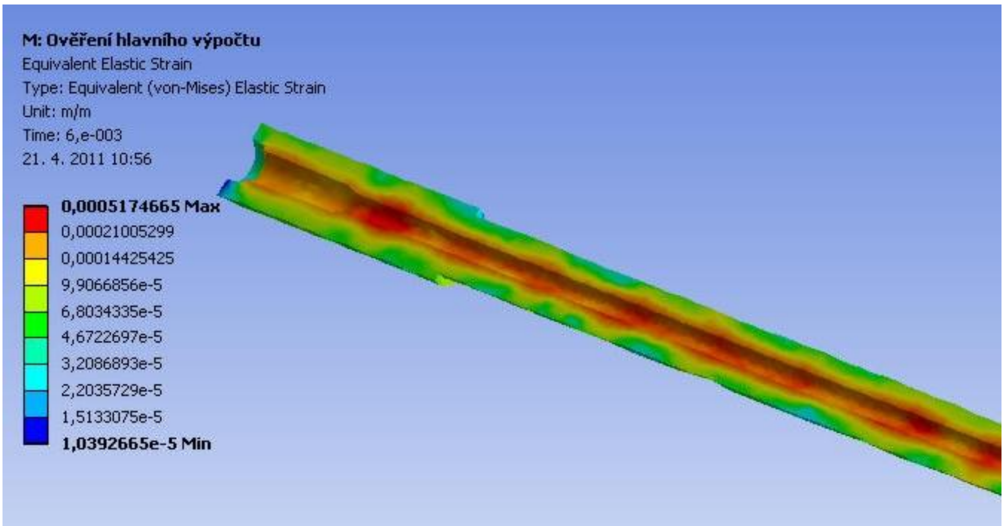


Fig. 13 AUTODYN model equivalent elastic strain

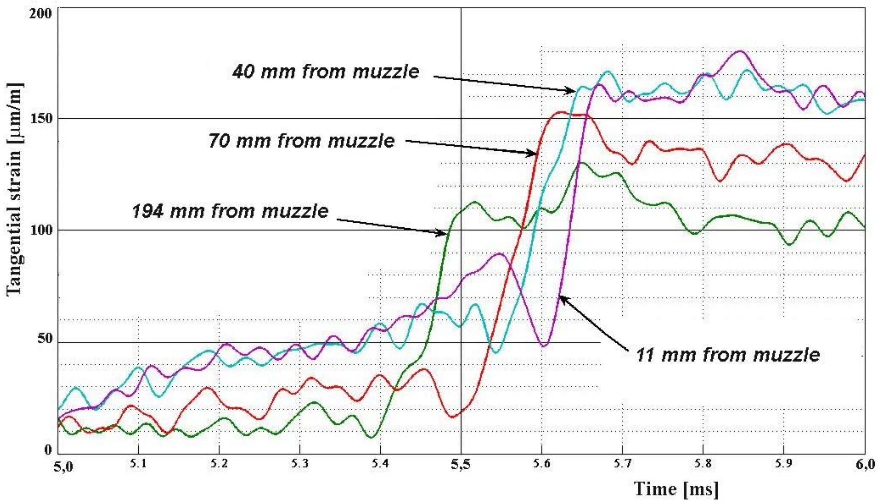


Fig. 14 Calculated equivalent relative tangential strain

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