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Innovative Method of Fuze Settings by a Number of Own Turns of a Projectile

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Abstract. This work presents a fuze setting method for ammunition for cannons and grenade launchers with a calibre of 25 to 40 mm, with a projectile body, that generates fragments by burst, on its trajectory during projectile flight. This setting method is based on fuze data delivery with a number of projectile turns between a muzzle and accurately predetermined point on its trajectory. The proposed method for fuzes setting is intended for precise determination of the distance travelled by the projectile, and should provide an alternative method for time setting fuzes. The method utilizes the phenomenon when the projectile, launched from the rifling barrel, overcomes a distance, in one turn path, equal to the barrel rifling pitch. This distance, independent of the projectile muzzle's velocity and the number of turns made by the projectile, will determine the path travelled by it. In this work, important factors were presented, that apply to functioning the fuzes with spin detecting and turns counting features and that were omitted in descriptions of similar fuzes' known solutions. These factors are: "idle gun elevation angles", when signal is not generated; electromagnetic interferences, affecting quantity of impulses that are counted and random projectile initial orientation after a gun loading, in relation to projectile airbust point on a trajectory.

Consideration of those important, from the ballistic point of view, factors in fuze construction makes it an innovative one. This publication shows also a proposition of the fuze electronic subassembly, that includes all of the questions that were mentioned.
Keywords: mechanical engineering, turns-counting fuze, magnetic field of Earth, induction coils

1. INTRODUCTION

Airburst projectiles, that are fragmented in the air, ammunition for cannons and grenade launchers with a calibre of 25 to 40 mm have small amount of explosive and generate small number of fragments. So, it is important that the projectile burst could be at an optimal point (from the point of view of efficiency of projectile impact on a target), with respect to the target.

Application of the proposed in this work the setting fuze, which with high accuracy determines a path, travelled by a projectile, by counting its own turns, regardless of the time and muzzle velocity, will significantly increase the efficiency of this type of ammunition, mainly by decrease in dispersion of burst points of projectiles on the flight trajectory.

The proposed here fuze, will affect also ballistic characteristics and construction of the gun (weapon) itself. It will cause, among others, the gun simplification (e.g. cannon and grenade launcher) because a device for measurement of the muzzle velocity will not be necessary. A function, responsible for counting the time settings, after measurement of the projectile muzzle velocity, will be deleted from a ballistic computer. As a result, the gun's mass and its dimensions will be smaller what will result in the lower gun's cost.

Further considerations and the results presented in the paper were obtained for 40 × 53 mm HV grenade launcher ammunition.

2. RESEARCH PROBLEM AND ITS PRACTICAL MEANING

The essence of fuzes setting, by a number of the own projectile turns, is connected with a phenomenon, in which a projectile launched from the rifling barrel, will travel, during one turn, a path equal to a barrel rifling's pitch. The path travelled by a projectile, is independent of its muzzle velocity.

A number of turns, which will the projectile make on the flight trajectory will determine the travelled projectile's path. In order to cause the projectile initiation, at the strictly determined point of the flight trajectory, the fuze setting will be necessary by giving an adequate number of turns which the projectile will make till it achieves the burst point and the fragments are generated. An idea of determination the path travelled by projectile, due to counting the projectile turns, is shown graphically in Fig. 1.

Figure 2 presents comparison of the dispersion of projectile burst points, in the case of timer setting of fuzes and fuzes setting with a number of the own projectile turns.

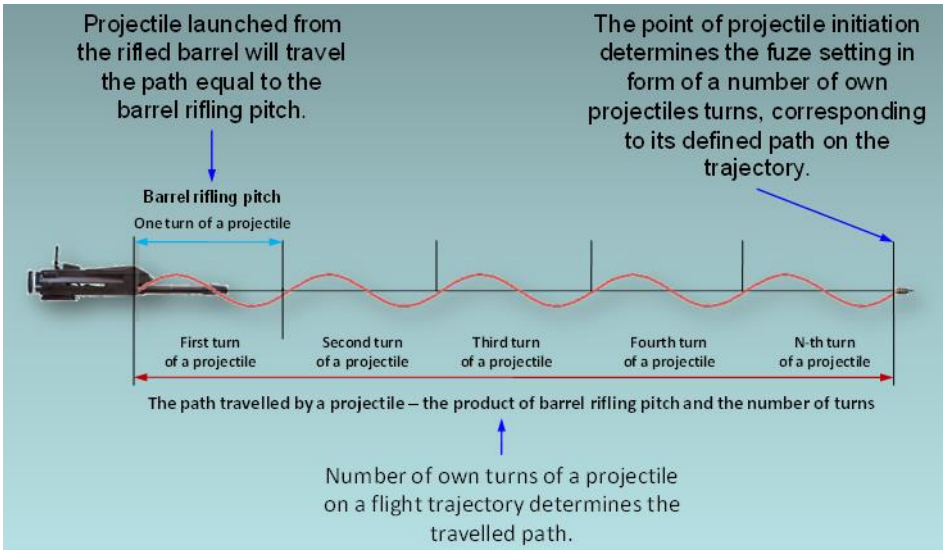

Fig. 1. Scheme of the concept of projectile's path determination by counting the own projectile's turns (*own study*)

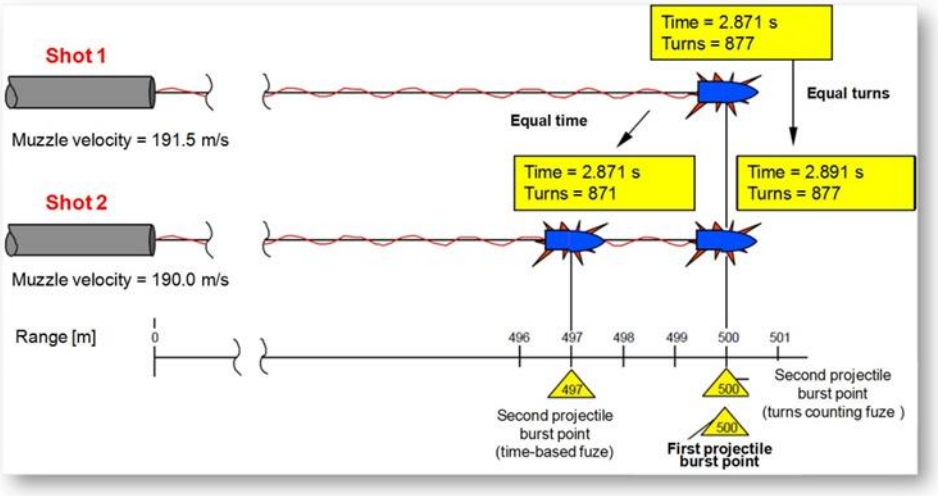

Fig. 2. Comparison of dispersion of projectiles burst points for time setting method and number of own projectile turns setting method (*own study based on* [4])

3. NOVELTY OF THE PROPOSED CONSTRUCTION OF A FUZE

As it results from foreign publications [1-7], the concept of operation of a system for counting turns of a projectile and construction of adequate sensor, are not complicated and difficult undertakings. However, it results from the analysed in the literature subject, that a lot of problems affecting operation of the systems detecting and counting own projectile turns have been omitted. Till now, first of all, the below mentioned problems were not considered:

a) "idle gun elevation angles"
b) distortions generated by ground power lines,
c) influence of random projectile orientation in a barrel chamber on the accuracy of determination of a point of projectile initiation.

Therefore, it was taken that the designed mechatronic system of the fuze, incorporating, the omitted till now, the above-mentioned factors, will additionally comprise:

a) two induction coils,
b) band-pass filter
c) synchronous rectifier

Consideration of these additional elements in a fuze construction, will make the solution a novelty one. It will ensure also better construction-ballistic characteristics in comparison with the hitherto known solutions.

3.1. Idle gun elevation angles and elimination of their effects on accuracy of projectile turns counting

A term "idle gun elevation angles" has been introduced by the authors for the need of hitherto work. This definition is connected with the lack of the voltage signal, generated by an induction sensor of the fuze. Such a signal occurs for some mutual angular positions between the longitudinal axis of the rotating projectile, a main axis of the sensor, and a vector of the lines of the Earth's magnetic field.

In order to explain this concept, we will consider the following two cases of fire with 40 × 53 mm HV grenade launcher, differing in angles of barrel elevation at the launching moment. The considerations have been carried out for the following firing conditions:

- angle between the main axis of the induction sensor in a fuze and the longitudinal axis of the projectile is 90°,
- magnetic azimuth of the barrel is 180° (shot in the south direction)
- firing is carried out north to the Equator
- inclination of the Earth's magnetic field on the place of firing is 25°,
- distance to the target is 400 m,

- fuze setting is 326 impulses,
- angles of the barrel elevation were: 3° for the first case and 27° for the second case.

In the first case, when the angle of the barrel elevation is 3°, high difference was observed (reaching the value of 25°) between the inclination of the Eart's magnetic field and the angle between the horizontal plane and the tangent to the projectile's trajectory. Moreover, at the whole trajectory, the angle between the horizontal plane and the tangent to the projectile's trajectory was not equal to the inclination. This situation is shown in Fig. 3.

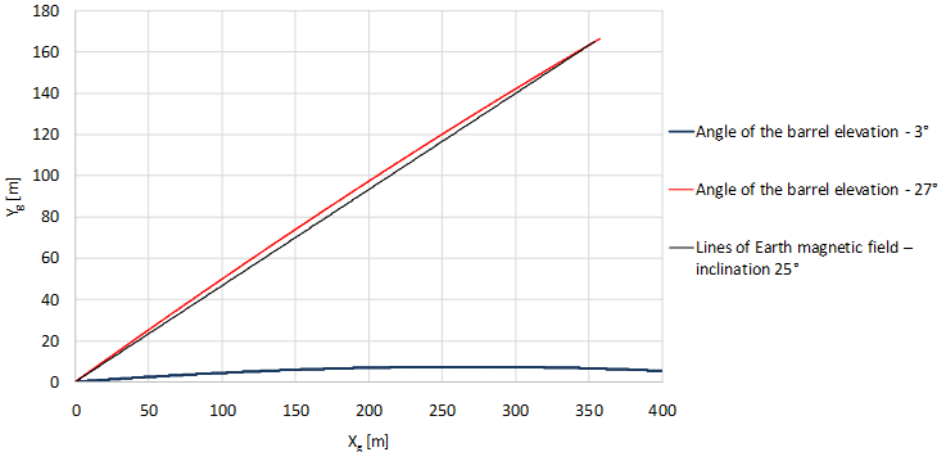

Fig. 3. Location of a trajectory of 40 × 53 mm HV projectiles of grenade launcher ammunition with respect to the lines of the Earth's magnetic field, for different angles of barrel elevation for firing to the target, situated at the distance of 400 m (*own study*)

For this case, rotational motion of the projectile can cause, that induction sensor of the fuze, during the entire flight time of the projectile, will be in a variable magnetic field. A voltage signal will be generated, the frequency of which will be equal to the rotational velocity of the projectile and the electronic system of the fuze will count the performed turns.

In the second firing case, in which the angle of the barrel elevation is 27°, we can observe insignificant difference between the inclination of the Earth's magnetic field and the angle between the horizontal plane and the tangent to the projectile's trajectory.

As it can be seen in Fig. 3, at some section of the trajectory, the tangent to the projectile flight is parallel to the inclination of the lines of the Earth's magnetic field. In such conditions, the induction sensor of the fuze will not generate a variable signal, reflecting the projectile rotational motion, because for some time, the lines of the Earth's magnetic field will be perpendicular to the main axis of the sensor, the same they will be parallel to the coils plane.

The above means that winding of the induction sensor will not be in a variable magnetic field, thus an electronic system of the fuze will not properly count the turns. The results of the performed simulation, for the second case, in which the above-mentioned conditions are considered, shows Fig. 4. The impulses setting was 326 and the number of the impulses, counted in disadvantageous conditions of the sensor's operation, was 117.

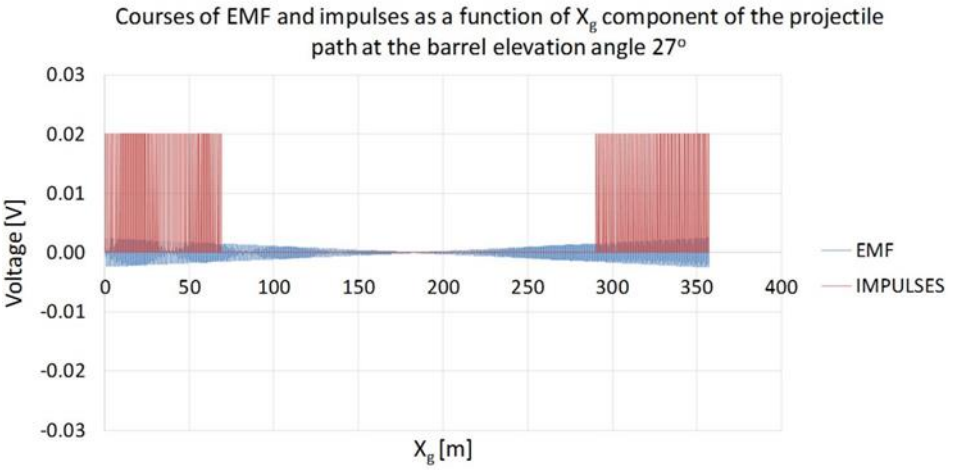

Fig. 4. Simulation results presenting EMF courses and counted impulses for disadvantageous orientation of a sensor axis with respect to the lines of the Earth's magnetic field. Electronic system with a single sensor stops generating the possible to be counted impulses (*own study*)

Application of two induction sensors, situated under some angle, relative to each other and relative to the longitudinal axis of the projectile, will allow for reliable operation of the fuze counting the turns, regardless of the firing direction and the angle of barrel inclination. Simulation results of EMF course and the counted impulses, for the second case, in the conditions of disadvantageous orientation of the sensor axis, relative to the lines of the Earth's magnetic field, for the system with two induction sensors are shown in Fig. 5.

In the performed simulation, the results of which are presented in Fig. 5, the impulses setting was 326 and the counted impulses number in disadvantageous conditions of operation of the fuze with two induction sensors was 326.

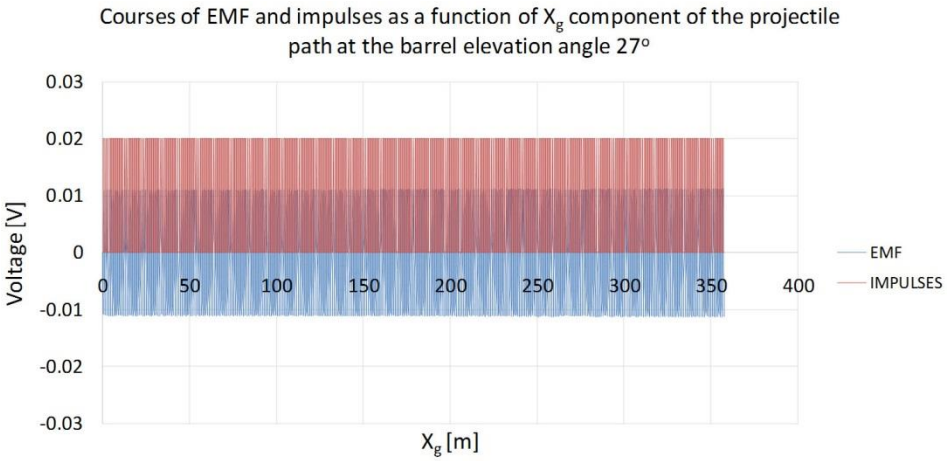

Fig. 5. Simulation results of EMF course and counted impulses in the conditions of disadvantageous orientation of the sensor axis, relative to the lines of the Earth's magnetic field. Electronic system with two sensors does not stop generating the impulses that are possible to be counted (*own study*)

3.2. Elimination of influence of random projectile orientation in a chamber on the spread of explosion points of projectiles

The designs of fuzes, known from literature [1-7], employ for determination of the projectile path, the counting of full turns of the projectile around its longitudinal axis. Precise analysis of such solutions showed their imperfection, caused by random projectile orientation in the barrel chamber and the same random orientation of the main axis of the induction sensor with respect to the lines of the Earth's magnetic field. At the start of the firing cycle, the rotating induction sensor begins to generate a sinusoidal voltage signal. However, in dependence on the initial position of the sensor axis, an initial value of the generated voltage for the projectile's motion start, is characterized by a random value in the range of the voltage signal amplitude. It has influence on generation of rectangular impulses by the comparator and on the system counting the impulses. Description of the above-mentioned phenomenon is shown in Fig. 6.

It can be noticed, from Fig. 6, that dispersion of the points of the projectiles burst can reach about 1.2 m.

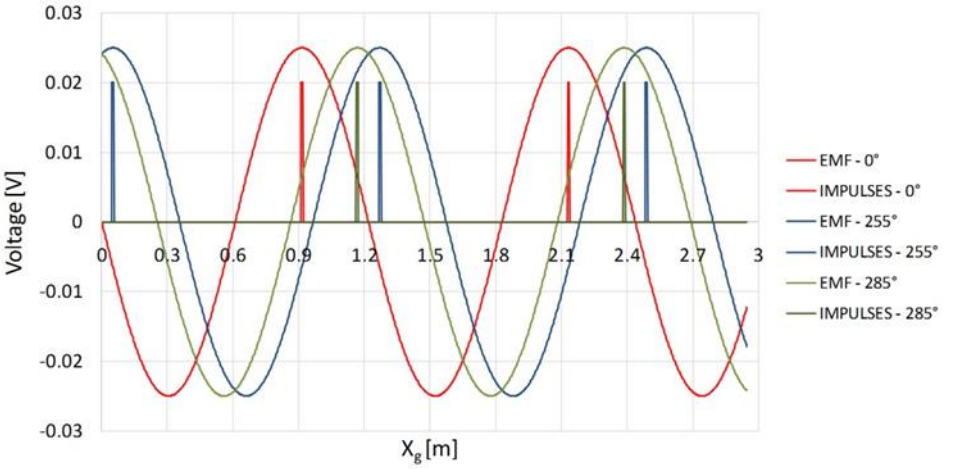

Fig. 6. Spread of the counted impulses, used for determination of the path travelled by projectile, in dependence on an initial position of the sensor axis relative to the lines of the Earth's magnetic field (*own study*)

Precise analysis of the results, shown in Fig. 6, allowed for graphical illustration of the influence of an initial projectile orientation in the barrel chamber on the dispersion of the points of the projectile explosion, what is schematically presented in Fig. 7.

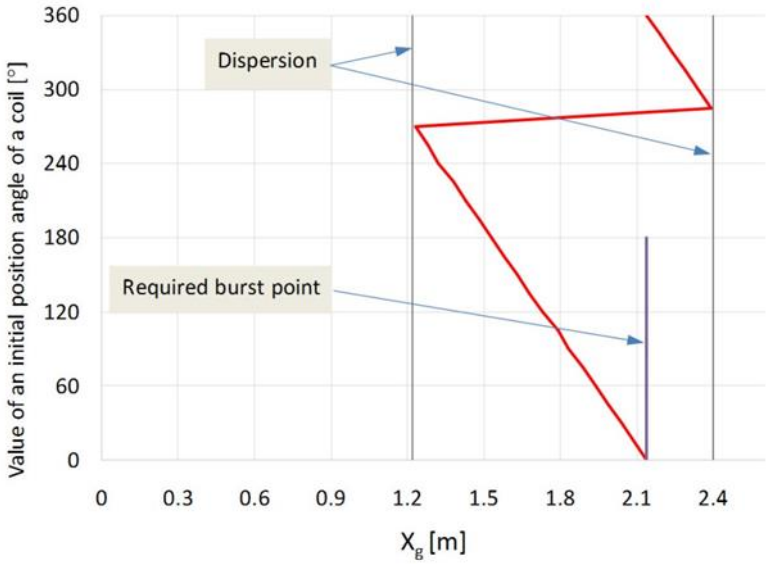

Fig. 7. Dispersion of the projectiles burst points in dependence on an initial position of the sensor axis in relation to the lines of the Earth's magnetic field (counting full projectile's turns) (*own study*)

For the considered here 40 × 53 mm HV grenade launcher ammunition, this spread will correspond to the barrel rifling's pitch. It is very high value, from the point of view of applicability requirements of such combat means.

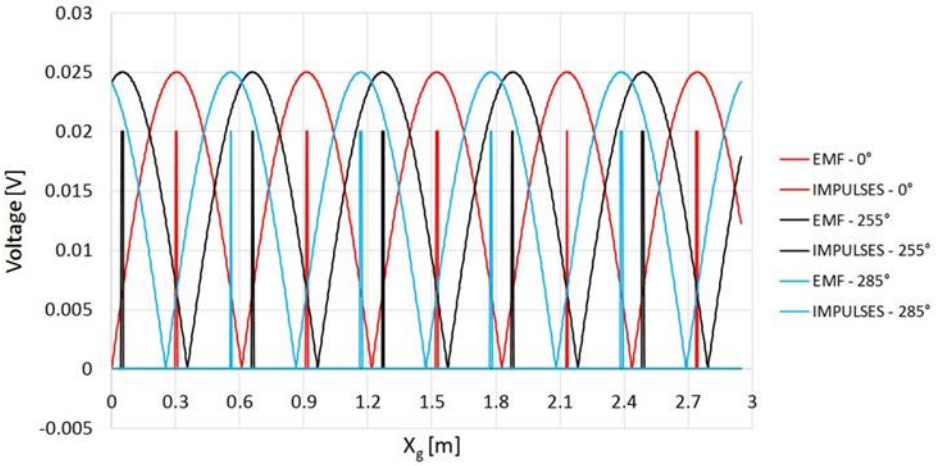

Fig. 8. Dispersion of the counted impulses used for determination of the projectile path, in dependence on an initial position of the sensor axis, with respect to the lines of the Earth's magnetic field - for counting the halves of turns (*own study*)

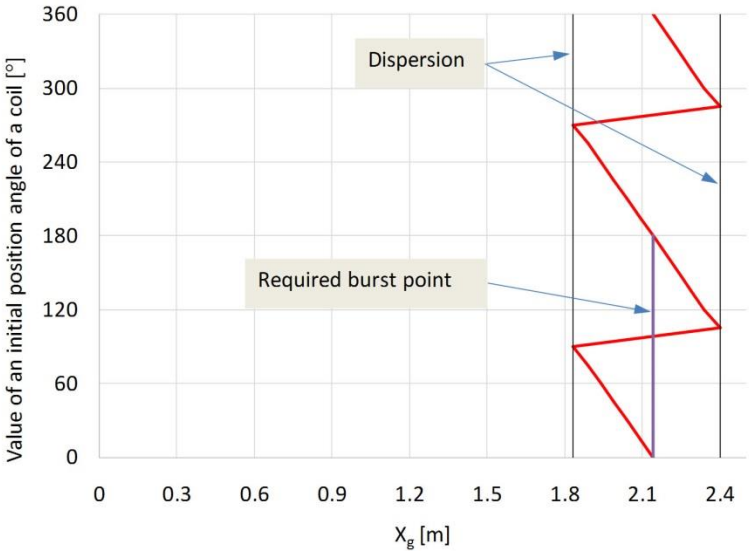

Fig. 9. Dispersion of the points of projectiles burst in dependence on an initial position of the sensor axis with respect to lines of the Earth's magnetic field - for counting the halves of turns (*own study*).

In the present work, in order to decrease the value of this dispersion, it is proposed that the distance travelled by the projectile on its trajectory can be determined on the basis of the counted halves of the projectile turns. The suggested approach will make possible to decrease by 50% the dispersion of points of projectile burst on the path, resulting from random projectile orientation in the barrel chamber, in comparison to the methods in which full turns are counted. Exemplary simulation results of impulses counting, due to counting the halves of the own turns of the projectile are shown in Fig. 8. Dispersion of the points of projectiles burst for the system counting the halves of own projectile turns is presented in Fig. 9.

3.3. Elimination of influence of external electromagnetic disturbances on counting the own turns of a projectile

In order to ensure proper operation of the system counting own turns of the projectile on its trajectory, additionally to application of two induction coils and the proposed method of counting halves of turns, an electronic system of the fuze will have built-in additional band-pass filter. Its task it to pass to the comparator, only the frequency resulting from rotational motion of the projectile. The range of the transmitted band will consider the change of rotational speed on the trajectory. The frequencies that will not be passed: frequency generated by energetic lines and the whole range of the frequencies, higher than the frequencies resulting from the own projectiles turns. The band-pass with the marked frequency of the non-passed frequencies is shown in Fig. 10.

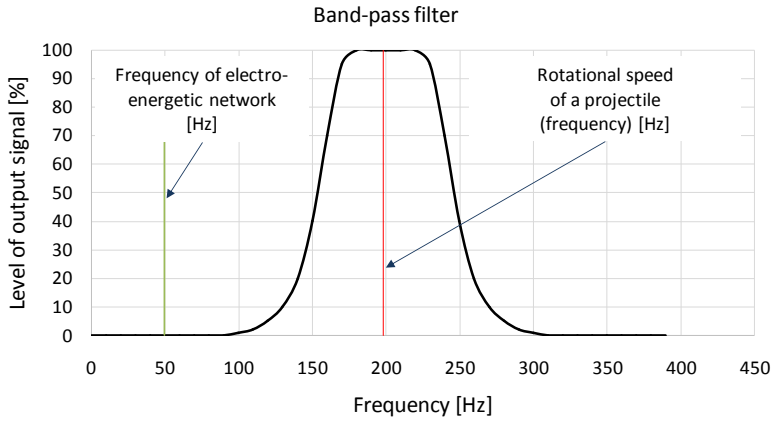

Fig. 10. A pass band of the band-pass filter with the marked frequency of electro-energetic network (*own study*)

The described phenomenon was illustrated on the example of the firing from the automatic MK-19 Mod. 3 grenade launcher with the 40 × 53 mm HV munition. For the barrel rifling's pitch of the value 1219 mm and the muzzle velocity of 242 m/s, the rotational speed of the projectile was 198 rotation/s.

The value of disturbances was taken: 50 Hz (frequency of an electro-energetic network) and > 300 Hz (all other frequencies, higher than rotational speed of the projectile, taking into consideration the safety reserve, in order not to attenuate the signal constituting the base for the impulses counting), respectively. Figure 11 illustrates the situation, considering the above-mentioned conditions, in the case when the system does not include a band-pass filter.

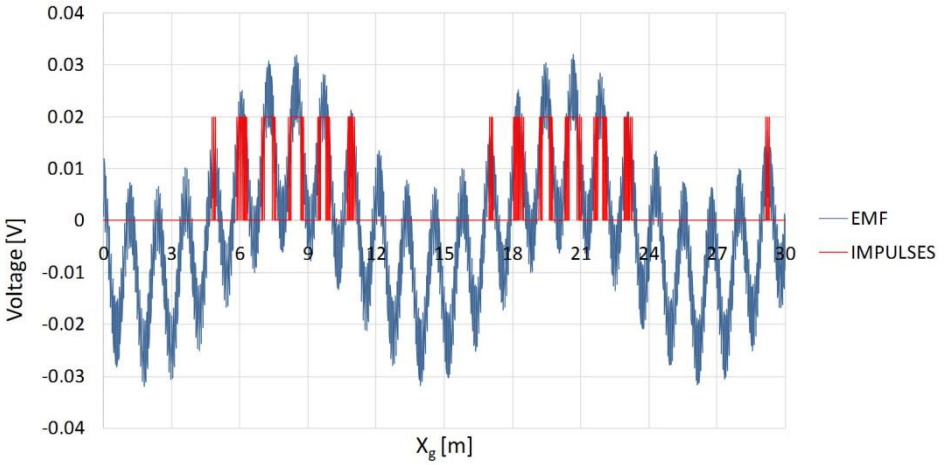

Fig. 11. Courses of EMF and the counted impulses, with the considered Earth's magnetic field disturbances. An electronic system without band-pass filter stops generating the possible to be counted impulses. (*own study*)

On the graph in Fig. 11, the fragments of the course, characterised by decay of rectangular impulses, can be seen. Rectangular impulses will not be generated in spite of the projectile turns.

Figure 12 illustrates the situation considering the above-mentioned firing conditions, in the case when the system includes band-pass filter. On the graph, one can see continuous course with no decay of rectangular impulses, while the rectangular impulses are generated properly during the projectile's rotation on its trajectory.

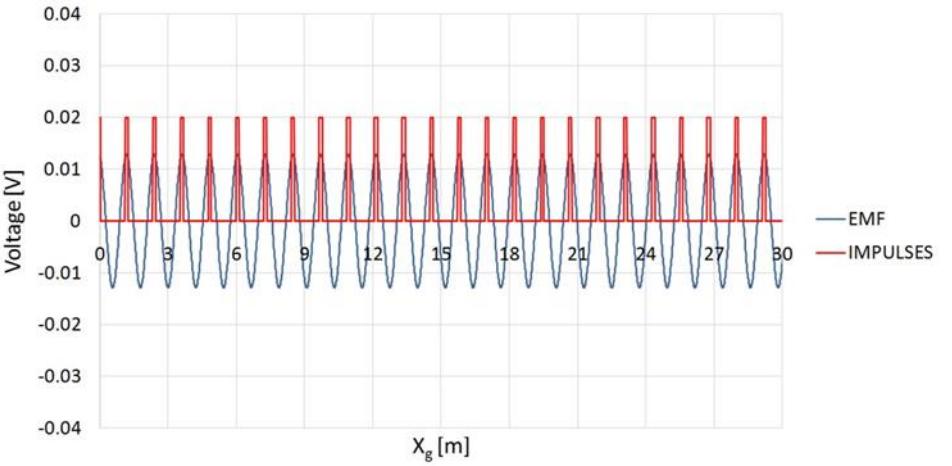

Fig. 12. Courses of EMF and the counted impulses with considerations of disturbances shown in Fig. 11, filtered by a band-pass filter. An electronic system with a band-pass filter does not stop generating the possible to be counted impulses (*own study*)

4. SUMMARY AND FINAL CONCLUSIONS

Application of the method of determination of the projectile's path, proposed by the Authors, allows for decrease in the dispersion of points of the projectiles burst on their trajectories in comparison to the projectiles, for which this point is determined on the basis of the flight time of the projectile to this point. This method will allow also for reduction of a number of devices, installed on barrelled weapon, and their functions used for fuzes setting.

Satisfactory results of the previous studies on the fuze counting its turns for determination of the path travelled by the projectile, will be the basis for further works and investigations on this type innovative construction.

In the authors' opinion, one of the aims of the next works should be a development of a universal module, devoted to counting the own turns of the projectile. Such a module should be applied in fuzes for ammunition, the designation of which is its air burst at the exactly determined point of the trajectory. The only one condition, is that the fuze, together with the projectile, should rotate with respect to the longitudinal axis of the projectile.

Current needs of the Polish Army and the possibilities of the national scientific-industrial facilities allow to state that there exists, real capability to design an electronic system for the projectile's orientation in the space, including identification of the own projectile's turns and their counting.

In summary, one can state that application of the proposed here innovative solutions will result in construction of the fuzes for medium caliber ammunition with significantly better characteristics than these previously known.

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Nowatorska metoda programowania zapalników liczbą obrotów własnych pocisku

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Streszczenie. W pracy przedstawiono metodę programowania zapalników amunicji do dział i granatników o kalibrze od 25 do 40 mm, której pociski generują odłamki na torze lotu, polegającą na wprowadzeniu do zapalnika nastawy w postaci liczby obrotów własnych pocisku po której zliczeniu następuje zadziałanie pocisku odłamkowego w ściśle określonym punkcie toru lotu. Proponowana metoda programowania zapalników ma służyć do precyzyjnego wyznaczania drogi przebytej przez pocisk oraz powinna stanowić alternatywę dla metody programowania zapalników nastawą czasową. Metoda wykorzystuje zjawisko, kiedy pocisk wystrzelony z lufy o przewodzie bruzdowanym, przebędzie w trakcie jednego obrotu drogę równą skokowi bruzd. Droga ta jest niezależna od prędkości wylotowej pocisku a liczba wykonanych przez pocisk obrotów będzie określała przebytą przez niego drogę. W pracy zostały zaprezentowane istotne czynniki (pominięte w znanych rozwiązaniach) wpływające na funkcjonowanie zapalników, w których zastosowano zaproponowaną metodę. Czynnikami tymi są: "martwe kąty podniesienia lufy", przy których sygnał nie jest generowany; zakłócenia elektromagnetyczne wpływające na liczbę zliczonych impulsów oraz wpływ losowego ustawienia naboju w komorze nabojowej na miejsce zadziałania.

Uwzględnienie w konstrukcji zapalnika pomijanych dotychczas istotnych, z punktu widzenia balistyki, kwestii powoduje, że jest on rozwiązaniem nowatorskim. W publikacji przedstawiono także proponowany układ elektroniczny zapalnika, pozwalający na uwzględnienie wpływu tych czynników.

Słowa kluczowe: budowa i eksploatacja maszyn, zapalnik zliczający obroty, pole magnetyczne Ziemi, cewki indukcyjne