AN INVESTIGATION INTO THE INTERRELATION BETWEEN THE INTERNAL AND EXTERNAL BALLISTICS OF FIRING A TP-T TANK AMMUNITION

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ABSTRACT

The factors affecting the ballistic parameters of a target practice with tracer (TP-T) tank training ammunition have been investigated. Several ballistic firings have been carried out to measure the ballistic performance of more than 200 TP-T tank ammunition cartridges. It was found that regularity of ballistic parameters for similar fired cartridges of an ammunition lot doesn't exceed 70% of testing trials; as well test cartridges would give better ballistic performance than that of the calibration cartridges. The factors which would cause such irregularity were discussed. Some conclusions have been made such as: i) there is no absolute relation between the internal ballistic parameters of accurate weights of propellant of a group of fired cartridges, ii) there is no absolute relation between the velocity of a cartridge and its longitudinal impact on the target, and as well although some cartridges showed very high standard deviation in the velocity, they showed low standard deviation in their longitudinal impacts on the target, iii) there is no absolute relation between the homogeneity in impacting the target at both traverse and longitudinal directions, the traverse dispersion being mostly greater than the longitudinal one, vi) the effect of wind is significant on dislocation of the actual traverse impacts on the target.

1. INTRODUCTION

Any type of ammunition is produced according to standard manufacturing specifications for either the individual components or the final whole cartridge. The components and the whole cartridges are subjected to serious testing procedures to assure both the quality of production and the ballistic performance of the relative armament system. This is assured by performing different testing of the visual, chemical and mechanical characteristics. These types of testing must result in complying of every minute component of the ammunition to its specifications.

To assure the main function of the ammunition in fulfilling the requirement of the user, i.e. the ballistic performance at the target, the internal and external parameters of the whole cartridge must seriously comply with the specified specifications of this type of ammunition. The internal ballistic parameters to be tested and evaluated are mainly, the velocity, standard deviation of the velocity and the pressure of gases evolved from the combustion of the propellant. The external ballistic parameters evaluated are specified mainly in certain values for the longitudinal and traverse impact dispersion of the shot on the target.

In this investigation the quality of produced lot of TP-T tank ammunition is tested for its internal and ballistic performance. The testing is performed according to the relevant testing procedure stated in the detailed military specifications of this type of ammunition. The results are statistically and graphically analyzed in order to check the compliance of the ammunition to the specification and also to explain any abnormality in the measured values which would affect the acceptance of the ammunition.

2. EXPERIMENTAL

All firings were conducted from a facility mount with ballistically acceptable gun tube. All cartridges were conditioned to the specified temperatures for a period of 48 hours minimum prior to firing. A cloth or screen target was positioned at 2000+10 meters from the gun tube muzzle. The target size was 6.05 x 6.05 meters, minimum. Anemometers were located at the gun and at 200, 400, 700, 1000, 1400 and 2000 meters from the gun, immediately adjacent and parallel to the line of fire. Wind velocity was measured during the firing of each cartridge and used to calculate a wind correction to be applied to the TID.

The cartridge when fired at 21°C must achieve a mean muzzle velocity of 1137±10 meters per second with a maximum standard deviation of 6 meters per second. Individual pressure values, measured at a location of 8.9 cm from the rear face of the tube, must not exceed 4757 bars. Target impact dispersion (TID) results (standard deviation), at each temperature (-32 °C, 21°C and 52°C), for each test and calibration group, which have been pooled and factored are utilized to determine compliance with the requirements.

3. RESULTS AND DISCUSSION

3.1 Internal Ballistics Characterization

The ballistic firings of this work had been performed at five temperatures, ranging from -46°C up to +63°C. The internal ballistic parameters of all the fired group of cartridges have been measured (viz. velocity and pressure). The internal ballistic testing had been started by firing two groups of cartridges, calibration and test, each of 10 cartridges. These cartridges were fired at 21°C. The velocities and the corresponding pressures were measured and analyzed.

It is clear from Figure 1 that although the calibration cartridges were carefully manufactured, they showed higher standard deviation (5.4 mps) compared to test cartridges which gave approximately similar velocities with a respective lower standard deviation 2.1 mps. Investigating the velocities of the calibration cartridges shows that the higher standard deviation of the calibration cartridges had resulted due to the higher velocities of the cartridges No. 9 and 10 compared to the other cartridges group. Firing of similar ammunition cartridges had showed that one or two of fired 10 cartridges, because of their irregular velocities, causes higher standard deviation of velocity. It is difficult to precisely explain the irregularity of some cartridge velocities with respect to their group fired at the same time and under the same firing conditions, but one would correlate this to the mode of combustion of the propellant inside the combustion chamber. Any irregularity in the pressure time curve of burned propellant weight would result in lower or higher velocities with respect to the expected velocity.

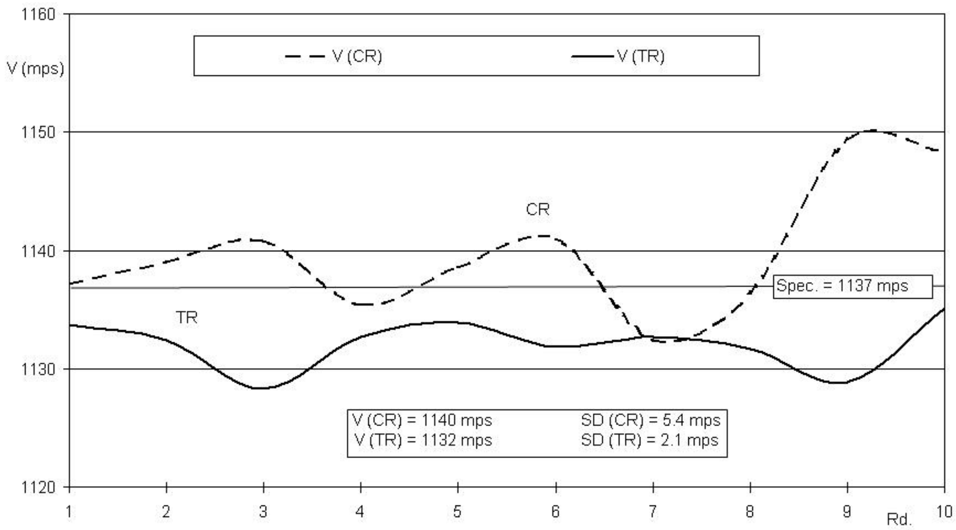

Figure 1. Comparison of velocity deviation of calibration and test cartridges from the specification

Investigating the relation between the velocity and the pressure of test group of 10 cartridges fired at 21°C has shown that three cartridges, which showed higher velocities with respect to the other cartridges, gave corresponding higher pressures. Comparing the results for velocities and pressures of this fired group with their dispersion on the target shows that although velocity is in full conformity with pressure, the dispersion on the target is not. The discrepancies in pressure values which represent about 30% of the measured values support the obtained results of this work that the similarities in results or their lower standard of deviation can not be guaranteed even if it is related to internal combustion of the propellant inside the combustion chamber of the gun. There are many possible variants which would cause this discrepancy such as the primer efficiency in starting burning of the propellant, the way by which the propellant bulk would burn, the time interval between the fired cartridges which affect the temperature of the combustion chamber... etc, all these variants are assumed considering the fixed weight of the propellant in all the fired cartridges.

Further investigation has been carried out to compare the internal ballistics parameters resulted from firing a group of 10 cartridges at different days (7 consecutive days), under the same conditions. The velocity and pressure values of the fired cartridges were recorded and analyzed.

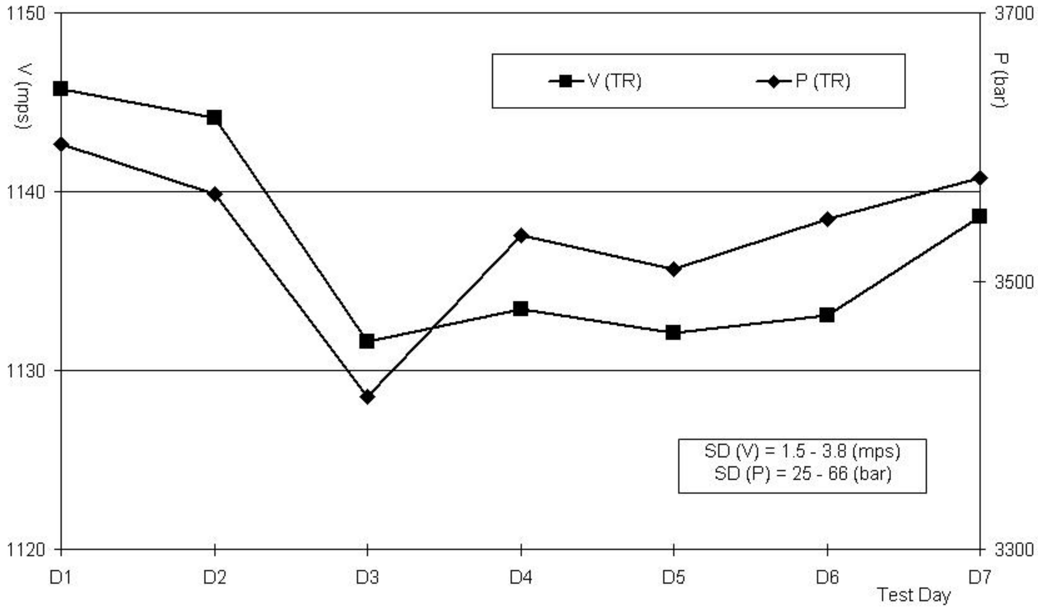

Figure 2. Relation between velocity and pressure at 21°C

Figure 2 shows that for the velocities recorded during days D1 and D2, although they are approximately equal (about 1144 mps), they are quite different from the others fired at the other days, the difference is about 12 mps. These results support the aforementioned conclusion. The great difference in velocities (12 mps) obtained would imply careful analysis of abnormal results obtained during repetition of firing group of cartridges of the same lot under similar conditions. The higher velocities obtained during days D1 and D2 is difficult to be explained for two reasons: i) these cartridges were subjected to careful and strict quality controls during manufacture, and ii) repetition of firing of the same cartridges under similar conditions for four consecutive days gave very similar velocities with standard deviation of these groups of less than one. Although the values obtained for the pressures of these fired cartridges at the different dates are in good comparison with the corresponding values of the velocities, the pressure at day D3 is lower than the other cartridges which showed similar velocities (viz. D3-D6). As said this is the ordinary expected case of firing ammunition cartridges even under similar conditions. The lower pressure showed at day D3 would be a consequence of different mode of combustion of the propellant, especially if compared with the pressure obtained at day D1, the difference in these pressures reaches about 200 bars. This difference is not comparable with that obtained between the other testing days (viz. D4-D6) which showed a difference of maximum 40 bars.

Statistical analysis of the homogeneity of the ballistic performance of fired cartridges of the same lot produced under careful and strict quality control measures have been carried through computing and analyzing the standard deviation of both the velocity and pressure data. Ten-cartridge groups of the same lot have been fired on consecutive seven days under similar conditions. It was shown that the standard deviation is significantly changing for either the velocity or the pressure. The most significant result is that the standard deviation of pressure simulates the values obtained for the velocity. Comparison of the standard deviation of velocity and pressure at any two days of testing shows that in about 30% of the tested groups, when the standard deviation of velocity decreases the corresponding deviation for the pressure increases.

From the aforementioned, it is concluded that: i) homogeneity of the ballistic parameters for similar fired cartridges, i.e. similar quality of one ammunition lot fired under similar conditions, doesn't exceed 70% of the testing trials, and ii) there is no absolute relation between the values of these ballistic parameters, i.e. the velocity and pressure, and the homogeneity in their standard deviation. All of these conclusions could be related to the mode of burning of the charge of propellant in each cartridge. The factors which would affect this would be: i) the efficiency of start of burning of the propellant charge by the primer, ii) homogeneity of the configuration of propellant grains in each charge, iii) the temperature of the combustion chamber of the gun for each cartridge, and iv) the temperature of the propellant charge before loading into the gun which is significantly affected by the interval time between loading two consecutive cartridges. Other factors could cause these changes.

3.2 External Ballistics Characterization

For every testing of internal ballistic parameters, the external ballistic parameters were evaluated through determining the target impact dispersion of each group of fired cartridges, calibration or test ones.

3.2.1 Effect of changes in velocity on target impact dispersion

A group of 10 calibration cartridges was fired at 21°C; the impacts of these cartridges on the target were recorded. To clarify the relation between the velocities and the longitudinal impact coordinates of the fired cartridges, the velocities in Figure 3 were arranged in an ascending order and the corresponding impacts coordinates were automatically presented.

Figure 3 clearly shows the following:

i) Although the fired cartridges were calibration ones, there is a big difference between the lowest and highest values of velocities (about 18 mps). This results in a high standard deviation in velocity. Looking at velocity values clearly shows that the cartridges No. CR9 and CR10 have much higher velocities compared to their group fired at the same time and under the same conditions. Ideally firing of calibration cartridges should give a narrow range of difference in velocities (about 3-5 mps at the outmost). The other cartridges CR2-CR8 showed low standard of deviation.

ii) There is no absolute relation between the velocity and the longitudinal impact on the target. Theoretically, the cartridge fired with higher velocity should hit the target at a point with higher longitudinal value (on the Y-axis). Investigating the actual impacts of the fired calibration cartridges in the figure shows four odd impacts. The other cartridges showed hitting the target somewhat in accordance with the corresponding velocities. In this respect it is interesting to notice that cartridge No. 1 approximately hits the target at the same longitudinal Y-axis coordinate as cartridge No. 10, although they have the greatest difference in velocities which reaches about 18 mps.

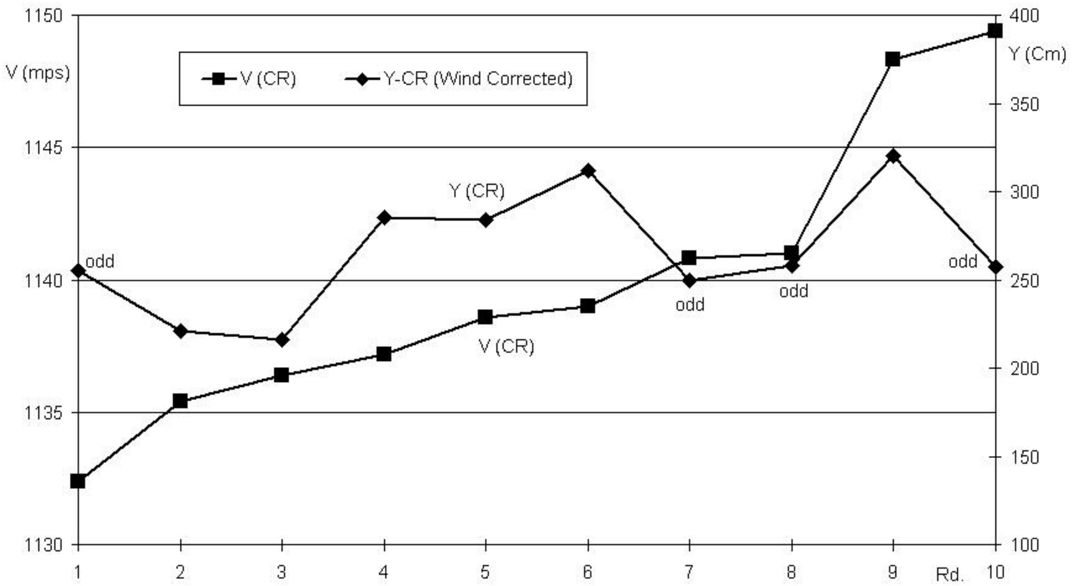

Figure 3. The relation between velocity of critical cartridges and their longitudinal impacts

iii) The most interesting observation is that although the fired cartridges showed very high standard deviation in the velocity, they showed low standard deviation in their longitudinal impacts on the target. This would help to explain the abnormalities in ballistic parameters values and their inter-correlation. It was thought that the lower standard deviation in velocity must result in good dispersion on the target, which is not absolutely correct.

Further investigation had been carried out by firing a group of 10 test cartridges under the same conditions as that performed for the above 10 calibration cartridges. The following is noticed: i) although the standard deviation of the velocity is low, the standard deviation of the longitudinal dispersion of impacts is much higher, and ii) four cartridges had hit the target at an odd positions with respect to the theoretical ones which are relevant to their corresponding velocities.

The observations obtained from firing the two groups of cartridges, calibration and test ones, have confirmed the following conclusions: i) there is no direct and absolute effect of the low or high standard deviations of the velocities of fired group on their dispersion on the target, ii) it is expected that some cartridges to hit the target at odd impacts different from the theoretical positions, and iii) test cartridges would give better performance results for the ballistic parameters, either internal or external ones, compared to the calibration cartridges.

3.2.2 Changes in target impact dispersion values by repetition of firings

Statistical analysis of the target impact dispersion values obtained by firing groups of 10 cartridges each, of the same ammunition lot, at different 7 testing days under the same conditions have been carried out to determine the changes in the external ballistic parameters by repeating testing of similar cartridges of the same lot under the same firing conditions at 21°C. It was clearly shown that: i) The values for both the traverse or the longitudinal dispersion at each day are approximately equal, but not equal for the different days, except for one day which gave big difference between the traverse and longitudinal dispersion, and ii) values of the dispersion for three testing days are not in good agreement with the dispersion values obtained for the other days.

An analysis of the dispersion value of one of the fired groups had been carried out to determine the effect of one odd impact of certain cartridge on the dispersion value, either traverse or longitudinal, of the other cartridges fired. Although the traverse impacts are more scattered, the mean value for their dispersion on the target is on the border of the required specifications. On the other hand the longitudinal dispersion value is out of specification; this is because although 9 cartridges showed good homogeneity in their impacts, one cartridge hit the target at a quite far impact from the group. If this cartridge impact coordinate is omitted from the group dispersion calculation, the dispersion of the group will be significantly reduced.

To explain the effect of gun positioning during firing on the dispersion of group of cartridges, group of 15 cartridges had been fired at 21°C. The coordinates for both the traverse and longitudinal impacts on the target are presented in Figure 4. The calculated dispersion of the group is out of the specification limits (0.43 in the traverse and 0.52 in the longitudinal direction). The figure clearly shows a significant scattering of the impacts in either direction on the target, with noticeable six odd impacts, four being in the longitudinal and two in the traverse direction, with respect to the other cartridges dispersion. If these odd impacts were cancelled from the dispersion calculation, the dispersion will be significantly reduced to be within the specifications.

Investigating the pattern of the longitudinal coordinates clearly shows the following: i) after approximately regular distribution of the impacts of some cartridges, a jump in the impact position of a subsequent cartridge occurs (cartridge No. 4), although having approximately the same velocity as the adjacent cartridges, ii) after that jump a steady decrease in the longitudinal coordinates of the following cartridges occurs (viz. cartridges No. 5 and 6), followed with another pattern of steady increase of some cartridges (viz. cartridges No. 7-10) or drop in the coordinate of certain cartridges (viz. cartridges No. 12 and 15), iii) the steady and regular pattern of longitudinal impacts happened for more than three subsequent cartridges, and iv) The scattering in the longitudinal coordinates is accompanied with similar scattering in the traverse direction, although for different cartridges (viz. a jump in the cartridge No. 7 followed by deviation to the left direction for the subsequent cartridge No. 8, the same had occurred for the cartridges No. 12 and 15.

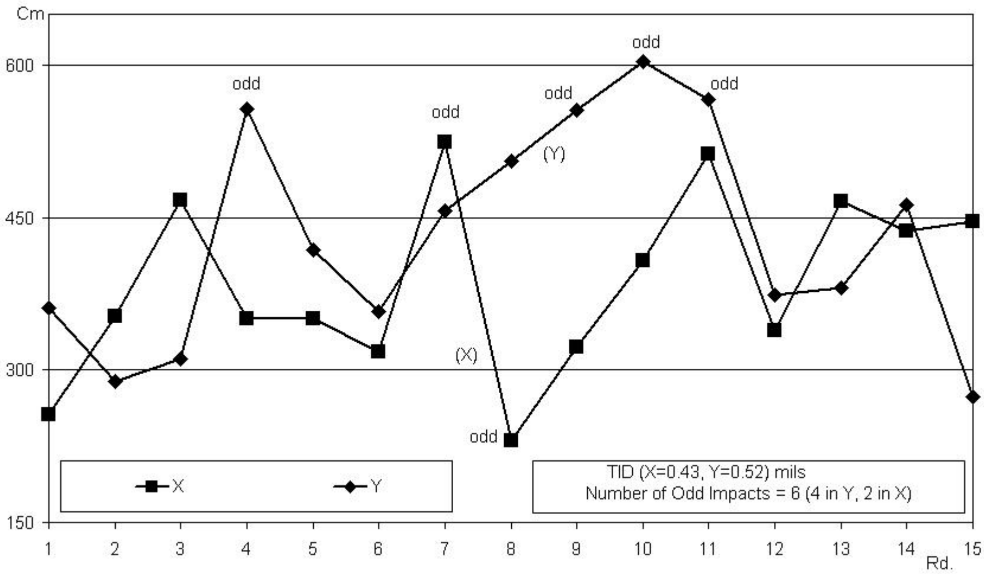

Figure 4. Observed abnormality in target impact dispersion

3.2.3 Effect of wind on the target impact dispersion values:

In all of the firings performed for either calibration or test cartridges at different conditions, the target impact dispersion was calculated after correcting the traverse coordinate for each cartridge for the effect of wind, the longitudinal coordinates being not affected by wind velocities. This is performed to calculate the actual dispersion of the group of fired cartridges.

Statistical analysis performed on the effect of wind on all the cartridges fired in this work have shown the following: i) the effect of wind is significant on dislocation of the actual traverse impacts on the target; sometimes this dislocation has reached about 200 cm, ii) in most of the cases the dislocation of traverse coordinates is nearly regular through the group of cartridges, and ranges between 50 and 150 cm, iii) the regularity of the effect of wind on the fired cartridges, which is accompanied by dislocation in the traverse coordinates, cannot be guaranteed for more than five successive cartridges. This might be the reason for pooling the calculation of fired cartridges in groups of five cartridges to calculate the accurate dispersion value representing the quality of an ammunition lot, iv) it is not necessary that the calibration cartridges hit the target in a proper pattern compared to that of test cartridges, and v) although the traverse coordinates have been corrected for the effect of winds by successive anemometers placed in the trajectory of the fired cartridges, the accuracy of these equipment for monitoring and correcting the effect of wind might not be quite accurate. This is supported by comparing the accuracy of hitting the target by other groups of cartridges which resulted in low dispersion in the longitudinal direction whilst gave higher traverse dispersion. Nevertheless these equipment are very important in correcting the significant effect of the wind on the cartridge in its trajectory.

A group of twenty cartridges have been successively fired under the same conditions. The time interval between fired cartridges was monitored and kept constant. It was clearly shown that: i) the effect of wind on displacement of the actual traverse impacts on the target is quite significant; the difference between the minimum and maximum corrections reaches about 160 cm, ii) the corrections made were not in one direction, nearly half of the fired cartridges were negatively corrected (to the left), whilst the other cartridges were positively corrected. These corrections were made relative to the initial zeroing of the gun, iii) corrections of some successively fired cartridges were regular; nevertheless this didn't occur for more than three successive cartridges, iv) significant corrections had occurred as jump or drop between two successive cartridges. This significantly shows the importance of using the anemometers to give as best as possible the accurate traverse dispersion of the fired cartridges on the target, and v) the noticeable and significant correction made between two successive fired cartridges supports the aforementioned that the regularity in ballistic parameters measured compared to the actual ones, which might be representing the quality of the produced ammunition lot, is somewhat difficult to be attained in some cases. This must be taken into consideration when abnormality in results has to be transferred to referral to investigate the reasons for such cases.

4. CONCLUSIONS

i) Test cartridges would give better ballistic performance parameters compared to the calibration cartridges which were subjected to more strict measures in either the quality of production or the sampling technique.

ii) Regularity of the ballistic parameters for similar fired cartridges doesn't exceed 70% of the testing trials. There is no absolute relation between the values of these ballistic parameters, i.e. the velocity and pressure, and the homogeneity in their standard deviation. In most of the cases an increase in the standard deviation of velocity results in a corresponding increase in that for the pressure.

iii) It is difficult to precisely explain the irregularity of some cartridge velocities with respect to their group fired at the same time and under the same firing conditions. The factors which would affect the unexpected irregularities would be: the efficiency of start of burning of the propellant charge by the primer, homogeneity of the configuration of propellant grains in each charge, the temperature of the combustion chamber of the gun for each cartridge, and the temperature of the propellant charge before loading into the gun which is significantly affected by the interval time between loading two consecutive cartridges. Other factors could cause these changes.

iv) There is no absolute relation between the velocity of a cartridge and its longitudinal impact on the target, some cartridges hit the target at odd impacts different from the theoretical positions. The great difference between the lowest and largest velocities of the fired cartridges in a group should result in a corresponding difference in impacting the target, which didn't happened.

v) The regularity of the effect of wind on the fired cartridges, which is accompanied by dislocation in the traverse coordinates, cannot be guaranteed for more than five successive cartridges. This might be the reason for pooling the calculation of fired cartridges in groups of five cartridges to calculate the accurate dispersion value representing the quality of an ammunition lot.

vi) The regularity in ballistic parameters measured compared to the actual ones, which might be representing the quality of the produced ammunition lot, is somewhat difficult to be attained in some cases. This must be taken into consideration when abnormality in results has to be transferred to referral to investigate the reasons for such cases.

5. REFERENCES

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