

EXTERNAL BARREL TEMPERATURE OF A SMALL BORE OLYMPIC RIFLE AND SHOOTING PRECISION

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ABSTRACT: Investigations on changes in a rifle's barrel temperature during shooting in a rhythm typical for practitioners of Olympic shooting sports are presented. Walther KK300 (cal. 5.6 mm), a typical rifle often used in Olympic competitions, R50 RWS ammunition and a high speed thermographic camera were used in the study. Altair version 5 software was used to process thermal images and a stationary wavelet transform was applied to denoise signals for all the studied points. It was found that the temperature of the rifle barrel does not exceed 0.3°C after one shot whereas the total temperature increase does not exceed 5°C after taking 40 shots and does not affect the position of the hitting point on a target. In fact, contrary to popular belief, the so-called "warming shots" are not done for barrel heating but for cleaning of remnants in the barrel.

KEY WORDS: Olympic rifle shooting, barrel temperature, precision shooting, warming shots

INTRODUCTION

Shooting sport is one of the oldest disciplines of the modern Olympic Games. In fact, shooting competitions were organized in the very first Olympic Games in Athens in 1896. Since then, the International Shooting Sport Federation (formerly Union International de Tir) has taken consistent action to ensure that shooting is not associated with military activities. Currently, all shooting targets used in the Olympic precision shooting competition, for both the rifle and the pistol, are black circles and rings in the middle of which the smallest one signifies 10. In all these competitions it is weapon precision that is a key to success, especially in rifle competitions, where a small calibre rifle (cal. 5.6 mm) is used. Shooting distance is 50 m while the bull's-eye ring diameter is only 10.4 mm. To be in the forefront and to count on entry to the finals a shooter virtually has to hit the bull's-eye every time. This requires not only great concentration of the athlete but also great rifle precision.

A popular view among shooters is that changes in the barrel temperature of a rifle have a significant impact on the shot precision. Detailed studies have been conducted for a long time, but so far mainly they deal with [3,4,8] military automatic weapons.

In the case of military automatic weapons, which are characterized by high energy (above 2000 J) generated during shooting as well as by high-frequency shots (hundreds per minute), the barrel temperature changes reach 200-300°C.

In this study, by the use of thermography, we investigate changes in rifle barrel temperature during shooting in a rhythm typical for shooters practising Olympic shooting sports. Thermography consists of observation and registration of infrared radiation emitted from a body by creating a real-time map of the distribution of this radiation in the form of colour visible images [10]. This method proved to be useful not only for the measurement of temperature changes on the surface of the investigated objects but also for the detection of internal heat intrusions and heterogeneity of the thermal properties within the bodies [5]. The time resolution of modern thermal imaging devices enables one to measure surface temperature of rapidly moving objects and enables their geometric resolution to be changed using lenses with various angular fields of view [1]. The applied technique is completely non-contact and non-destructive.

MATERIALS AND METHODS

Walther KK300 (cal. 5.6 mm), a typical rifle, often used in Olympic competitions, and R50 RWS ammunition were tested in the study. The rifle was placed in a vice along with the gunstock. The vice was closely attached to the concrete block (see Figure 1). Special attention was paid to not touch the stock of the rifle when triggering. To ensure proper trigger operation all the shots were done by a qualified rifle shooter (co-author of the article, GG). The experiment was conducted in a closed hall to avoid any influence of the wind. A control sheet was used in order to verify the total angular spread of hits, which was measured as the distance between the two most distant hits in the group of 40 shots (the centre-to-centre measurement). An SC7600 thermographic camera (FLIR Systems, Inc., USA) was used to measure temperature changes in the rifle barrel. The spectral range of its sensitivity lies between 3 and 5 μm . The detector (InSb) with the format 640 \times 512 enabled recording at 100 Hz in full resolution. The system's thermal sensitivity NETD (noise equivalent differential temperature) was 20 mK at the object temperature of 25°C. The spatial resolution of the camera was 1 mrad. The connection with a PC was possible via a Gigabit-Ethernet port. A lens with an angular field of view of 11 $^{\circ}$ \times 8.8 $^{\circ}$ was used. Measurement of radiation temperature distribution on the rifle barrel during the shots was made under controlled external conditions. All measurement series were performed at air temperature of 12°C and relative humidity of 70% in artificial light. The distance between the camera lens and the investigated gun surface was fixed at 3.5 m.

Obtaining high frequency to record the quick temperature increase on the barrel directly after the shot was crucial in this study. Therefore, the detector window was reduced to 496 \times 56 pixels to achieve a frequency rate of 750 Hz. This frequency was applied when recording image sequences during the shot and directly after it. Other parameters of image storage were used for the experiment in the case when a series of 40 shots was carried out with frequency of one shot per 30 seconds. In this case the thermograms were registered in a sequence consisting of 7500 frames acquired with a frame rate of 5 Hz. The emissivity of oxidized steel of the barrel was assumed to be 0.8 for all registered thermograms [2].

For acquiring and processing of thermal images from the camera Altair version 5 software (FLIR Systems 2009, USA) was used. This system enables one to control all camera parameters and to

export temperature data as text files to other programs. Analysis of changes in the barrel temperature consisted in selecting 13 points along the centre of the barrel and plotting temperature changes at these points as a function of time. From the values of temperature recorded during and before the shots, the temperature difference was calculated. Because of a significant noise factor observed within the temperature course, stationary wavelet transform (SWT) was used to denoise signals for all the studied points [6]. In comparison with other denoising techniques such as moving average, exponential moving average or even traditional discrete wavelet transform (DWT), this technique reveals some advantages [6,9]. It achieves excellent root mean squared error (RMSE) properties when used for only piecewise smooth functions and exhibits better behaviour in the neighbourhood of discontinuities. SWT has been designed to overcome a lack of translation invariance of DWT. It is done by removing downsamplers and upsamplers in the DWT and, consequently, by unsampling filter coefficients by the $2^{(j-1)}$ factor in the j -th level of the algorithm [7, 11]. The main requirement in the SWT algorithm is to zero out small wavelet coefficients whose absolute values are less than the assumed threshold λ . Further, the thresholded detail coefficients are reconstructed on the signal and the intact $a_{j0}[n]$. The signal length $N = 1, \dots, n$, where $N=2^J$ for some integer J . For a given signal $s[n]$, a low-pass filter $h_1[n]$ and a high-pass filter $g_1[n]$, defined by an orthogonal wavelet, can be given. The first level of SWT involves convolution of $s[n]$ with $h_1[n]$ to give approximation coefficients $a_1[n]$ and to result in detail coefficients $d_1[n]$, with $g_1[n]$, according to the relations:

$$a_1[n] = h_1[n] \cdot s[n] = \sum_k h_1[n-k] \cdot s[k], \quad (1)$$

$$d_1[n] = g_1[n] \cdot s[n] = \sum_k g_1[n-k] \cdot s[k]. \quad (2)$$

The next level of the SWT is to split $a_1[n]$ into two parts using the same scheme but with modified filters $h_2[n]$ and $g_2[n]$ obtained by unsampling $h_1[n]$ and $g_1[n]$. For the next levels the same process is continued recursively. From among many wavelet families the Daubechies wavelet [6,11], which is a compactly supported orthonormal wavelet, was used. The denoising analysis was performed by MATLAB 7.9.0 (Natick, Massachusetts, U.S.A.).

The experimental work was in accordance with the Helsinki Declaration. There was no conflict of interest in preparing this manuscript.

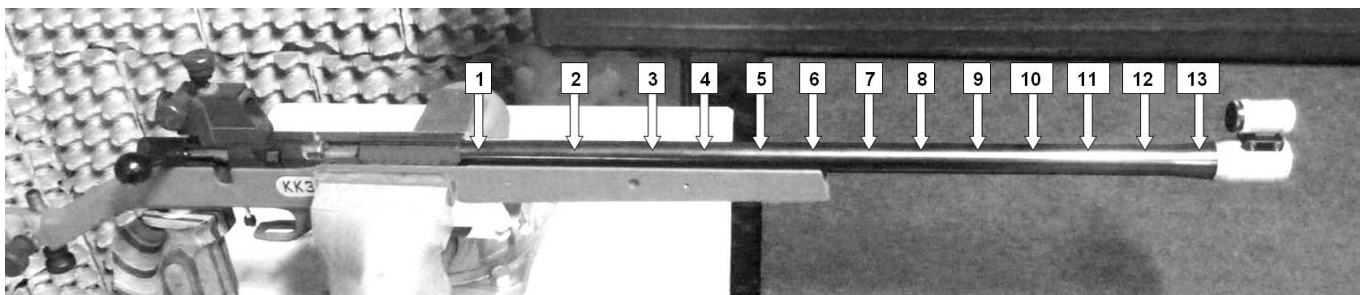


FIG. 1. EXPERIMENTAL SET-UP WITH FIXED RIFLE AND 13 MARKED POINTS ON THE BARREL

Note: Temperature measurements were made at these points

RESULTS AND DISCUSSION

Figure 1 shows the experimental set-up with a fixed rifle and 13 points marked for temperature measurement during the series of up to 40 shots. In Figure 2 the temperature changes ΔT occurring during the test at point 1 (close to the lock) are presented. The rise of the barrel temperature is clearly visible. After a series of 40 shots it reaches a value of $\Delta T = 4.2^\circ\text{C}$. A decrease in temperature, following in a natural way, associated with the cooling of the barrel of the rifle after the shooting, can be observed in the remaining part of the graph. Figure 3 shows in detail the temperature changes occurring between successive 16th, 17th, 18th and 19th shots. A sharp rise in temperature of about $0.2\text{-}0.3^\circ\text{C}$ at the time of the shot, and its slight decline during the 30 seconds before taking the next shot, can be observed. Figure 4 gives a comparison of changes in the barrel temperature occurring at the selected points 2, 9 and 13. Similar temperature changes as shown in Figure 2 are visible for point 2 as well as for point 9, relatively far apart from the lock. However, for the last point, 13, located just before the exit of the barrel, temperature changes are hardly seen. Figure 5 shows overall temperature changes in the barrel for all of the thirteen points after making the last shot in the series. It may be observed that the largest temperature changes occur not at the point nearest to the lock of

the rifle (point 1), but at subsequent points 2 and 3. They are about $4.7\text{-}4.8^\circ\text{C}$. For the following points, smaller increases in temperature may be seen, while a value of only $\Delta T = 1.5^\circ\text{C}$ is reached in the last section (point 13).

A fast temperature rise as presented in Figure 3 occurs for each shot. In order to observe this effect in detail, a one-shot test using a very precise sampling infrared camera was conducted where the temperature measurements at the desired point (no. 2) were made with a ratio of 750 fps. The temperature changes for the considered

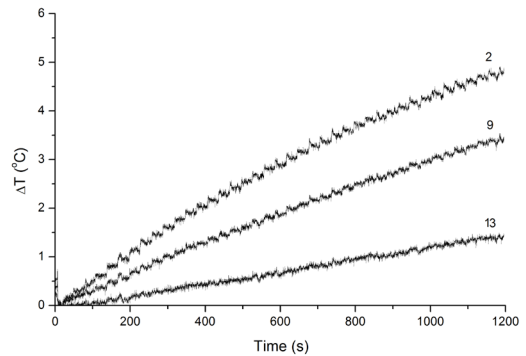


FIG. 4. COMPARISON OF THE RIFLE'S BARREL TEMPERATURE CHANGES OCCURRING AT SELECTED POINTS 2, 9 AND 13.

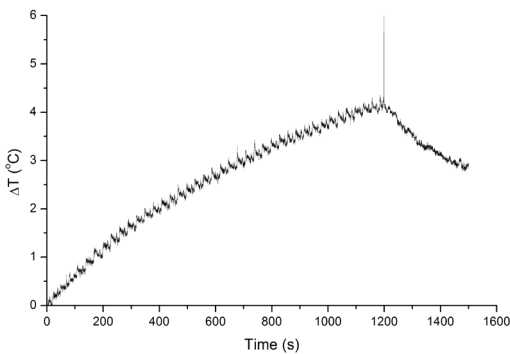


FIG. 2. TEMPERATURE CHANGES OCCURRING DURING THE TEST AT POINT 1 OF THE BARREL (CLOSE TO THE LOCK).

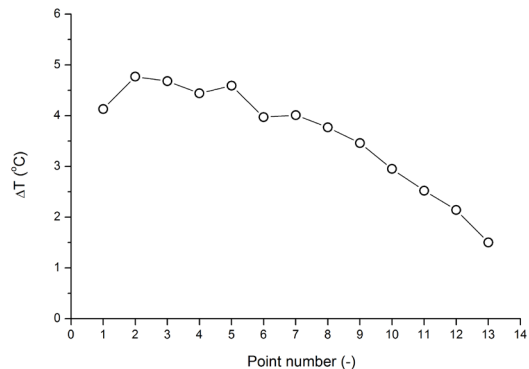


FIG. 5. TOTAL TEMPERATURE CHANGES OF RIFLE BARREL FOR THE THIRTEEN POINTS AFTER TAKING THE LAST SHOT IN THE SERIES.

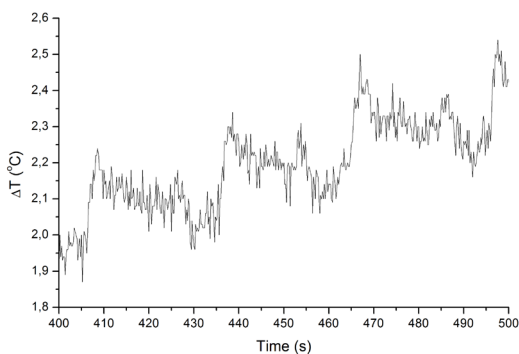


FIG. 3. TEMPERATURE CHANGES OCCURRING BETWEEN SUCCESSIVE 16TH, 17TH, 18TH AND 19TH SHOT AT POINT 1 OF THE BARREL.

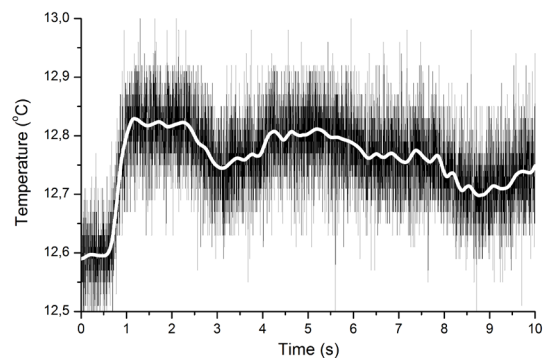


FIG. 6. ONE-SHOT TEST WITH HIGH FREQUENCY SAMPLING PERFORMED WITH THE INFRARED CAMERA. TEMPERATURE MEASUREMENTS AT POINT 2 WERE MADE AT EACH 1 MILLISECOND.

point are shown in Fig. 6. The apparent increase in the temperature at the time of the shot lasts only about 0.55 s and is 0.24°C.

The question whether temperature changes have a significant impact on the hitting point should be answered. From a physical point of view, the rifle barrel is a heavy walled tube (in the case of the tested rifle: inner diameter 5.6 mm and outer diameter 22 mm). The changes in the barrel temperature cause the barrel to change its dimensions in the process of thermal expansion of solids. How important is this change? In the case considered here, the dimensions of internal and external diameter of the barrel change according to the formula for linear expansion of solids, i.e.

$$\Phi = \Phi_0 (1 + \alpha \cdot \Delta T) \quad (3)$$

where Φ_0 and Φ are the dimensions of the considered barrel diameter before and after shooting, respectively, ΔT is the increase in barrel temperature and α is the thermal expansion coefficient of steel equal to $1.2 \cdot 10^{-5}$ 1/K.

The inner diameter of the barrel, with an increase in temperature of 5°C, would change from nominal 5.6 mm to 5.60034 mm, i.e. 0.006%, which is perceived as absolutely irrelevant and much smaller than the accuracy of the thread of a rifle barrel. This means that a bullet covers its path under the same conditions each time.

Based on the observation of the hit points on the control sheet it was found that the spread does not exceed 318 mrad. Assuming that the shooter commits no errors, even dispersion of 320 mrad still provides for the maximum result, which in the case of the test would be 400/400 points. This means that no changes in the position of the hit point are expected that could be attributed to the increase of barrel temperature.

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CONCLUSION

The experiment shows that the increase in the outer temperature of a rifle barrel does not exceed 0.3°C after one shot. The total increase in the temperature after taking 40 shots at a rate of 2 shots per minute does not exceed 5°C. No correlation of the hit point with the change in temperature was observed. Regardless of the barrel temperature, all shots showed an angular scatter less than the maximum ensuring 100% hit effectiveness.

Competitors in 50 m rifle usually see the difference between a predicted point of hitting and the first shot (in the so-called test shots). The conducted experiment shows that this should not be associated with the commonly called "warming shot" and has no connection with an increase in the rifle barrel temperature. The first shot is usually taken after mechanical cleaning of the barrel (both after the last use as well as before the competition). Therefore, it is essentially a ritual barrel "purgation", removing remnants of the cleaning agents, and not a "barrel warm-up".

From this study it can be concluded that:

- (1) The rifle barrel external temperature increased mainly in its near-lock area (up to 5°C). With growing distance from the lock the increase in temperature is lower and it is just 1.5°C at the end of the barrel.
- (2) The observed maximum increase in the rifle barrel temperature of 5°C does not affect the hitting point.
- (3) Contrary to popular belief, the purpose of the first shots taken during a competition (test shots) is not barrel heating but cleaning of remnants in the barrel.

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