Predicted heat losses when shooting of artillery gun barrel

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Abstract: *Calculation of heat loss heat transfer to barrel when shooting from classical artillery barrel is also an interesting problem in calculating the losses that detract energy when burning powder charge for granting the required speed and rotation to artillery shoot. Temperature and heat generated by powder charge burning are conducive to attrition of barrel thus reducing its life. Various kinds of losses are also discussed in NATO - STANAG 4367 documentation „Thermodynamic interior ballistics model with global parameters", which contains mathematical model of shot movement in rifled bores of weapons without outflow of dust emissions using split ammunition.*

Keywords: *Interior ballistics, interior ballistics characteristics, ammunitions, gun*

1. Input parameters, measured values and assumptions made

For calculation of heat loss by heat transfer, measured data from artillery weapon system *155 mm ShKH ZUZANA 2* – figure 1, in shooting program of KONŠTRUKTA-Defence, Inc., Dubnica nad Váhom were used.

Fig. 1. 155 mm ShKH ZUZANA 2

Weapon system was fitted with barrel of 52d length. Measurement was carried out in the first four shots, including the first - warm-up shot. For individual shots was used ammunition as shown in Table 1.

Tab. 1. Used ammunitions

Shot no.	Shot label	Projectile weight [kg]	Powder charge weight [kg]	Powder charge temperature before the shot [°C]
1	155 mm RdCv	46.1	6.535	+19
2	155 mm OFdM3	44.0	16.738	-51.4
3	155 mm OFdM3	44.0	16.738	-51.4
4	155 mm OFdM3DV	44.0	16.738	+51.2

Powder charge is made by modular charges compiled from seven-perforated powder, completely combustible casing and ignition system from black powder. Physical-chemical characteristics were taken from powder charge manufacturer's laboratory protocols. For calculation were used values of modular charges powder gases specific heat – given in Table 2.

Tab. 2. Modular charges specific heat Q_v

	Modular charge	
	A	D
Igniter Q_{vZi} $[kJ.kg^{-1}]$	3000	
Combustible casing Q_{vSPi} $[kJ.kg^{-1}]$	2600	
Powder Q_{vi} $[kJ.kg^{-1}]$	3134	3570

Entire barrel was divided into 8 sections, in which were monitored values of barrel´s surface temperature. Sections were determined by design of the barrel and its location in weapon system. Measurement locations were graphically marked by circles and numbered – figures 2 to 5.

Fig. 2. Measurement location no. 1 – cartridge chamber

Fig. 3. Measurement location no. 2 – near the transition cone

Fig. 4. Measurement locations no. 3 and 4 – the barrel

Fig. 5. Measurement locations no. 5 to 8 – the barrel

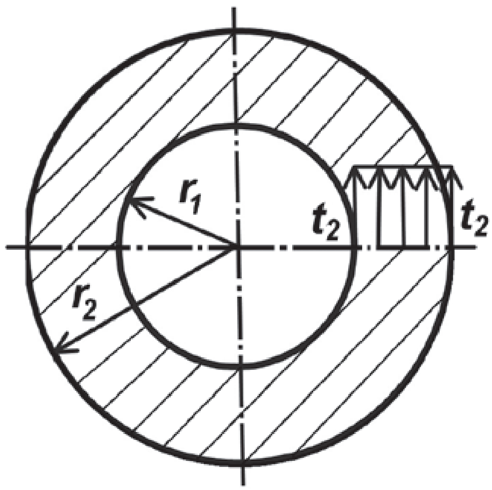

Fig. 6. Continuance of temperatures t_1 and t_2 - its constant throughout cross section

Assumptions adopted for calculation of heat losses:

a) temperature measured at individual measurement points on the outer surface of barrel is the same as temperature of given section in the whole barrel body cross-section; temperatures = t_2:
b) outside air temperature did not affect temperature of barrel,
c) heat transfer in the areas of barrel mounting and heat transfer to components that are in contact with the barrel are not considered,
d) recorded and monitored for temperatures were for calculation Δt:
   – 1st value – t_1 – temperature before the shot,
   – 2nd value – t_2 – maximum value of barrel surface temperature after the shot.

Whole barrel was for the needs of calculation divided into sections and weights of individual sections were calculated – Table 3. Individual sections were calculated on the basis of available drawing documentation and density value of barrel body material $\rho_{HL} = 7859\ kg.m^{-3}$.

Tab. 3. Dimensions and weight of the barrel

Section	Length [m]	Barrel body volume [m³]	Weight [kg]
1	0,950	0,0578	454,31
2	1,213	0,0647	508,24
3	1,133	0,0397	311,70
4	0,905	0,0245	192,32
5	1,000	0,0225	176,62
6	1,000	0,0179	140,85
7	1,000	0,0136	107,15
8	1,000	0,0096	75,63
Total	**8,201**	**0,2503**	**1966,82**

Individual temperatures were measured after shot by laser thermometers and recorded for each section until steady decrease of barrel surface temperature was recorded. Maximum measured temperature was subtracted from measured barrel surface temperature before firing and individual values of temperature increments Δt recorded in Table 4.

Tab. 4. Increments of temperatures

Shot no.	Increment of temperature	Measurement location							
		1	2	3	4	5	6	7	8
		[K]							
1	**Δt_1**	2,9	4,4	4,6	5,7	12,3	12,0	12,1	12,4
2	**Δt_2**	2,1	3,8	5,0	5,8	10,0	9,8	11,2	13,7
3	**Δt_3**	7,1	8,1	10,1	10,6	2,0	3,2	5,6	8,0
4	**Δt_4**	4,7	5,1	7,1	7,8	6,5	6,7	7,5	9,7

To heat m kilograms of barrel body on the temperature increase dT we must give the volume of heat:

$$dQ = m \cdot c \cdot dT \tag{1}$$

On the basis of temperature increments values were calculated values of heat Q_{HLi} required to heat barrel body, from the relation:

$$Q = m \cdot \int_{t_1}^{t_2} c \cdot dT = m \cdot c \cdot (t_2 - t_1)$$

$$Q = c \cdot m \cdot \Delta t \ [J], \tag{2}$$

where: c – is material specific capacity; for calculation was further determined specific capacity of barrel material $c = 465$ $[J.kg^{-1}.K^{-1}]$; m – is material weight; Δt – *i*s temperature difference.
For calculating interior ballistic parameters to the procedure under prof. Sluchockij to modification calculating the geometrical coefficients listed in [1,3].

2. Calculation of system heat parameters

For calculated weight of the barrel and corresponding temperature increments in various sections of barrel body is important to add heat in values listed - for individual shots - Table 5 and the sum of energy required to heat whole barrel body - Table 6.

Tab. 5. The heat required for barrel heating – individual sections

Shot no.	Heat	Measurement location							
		1	2	3	4	5	6	7	8
		[kJ]							
1	Q_{HL1}	612.63	1039.9	666.73	509.73	1010.2	785.95	602.86	436.08
2	Q_{HL2}	443.63	898.06	724.71	518.68	821.30	641.86	558.02	481.80
3	Q_{HL3}	1499.9	1914.3	1463.9	947.93	164.26	209.59	279.01	281.35
4	Q_{HL4}	992.88	1205.3	1029.1	697.53	533.85	438.82	373.67	341.13

Tab. 6. The heat required for whole barrel body heating

Shot no.	Heat	[kJ]
1	Q_{HL1}	5664.1
2	Q_{HL2}	5088.1
3	Q_{HL3}	6760.2
4	Q_{HL4}	5612.3

In individual shots powder gases of igniters, combustible casings and seven-perforated powder have delivered heat to the system, value of which was determined by manufacturer and calculated on the basis of principles applicable to calculation of inner ballistics parameters. Summarization of resulting heat delivered for individual shots is shown in Table 7.

Tab. 7. The heat delivered by modular charges

Shot no.	Heat	[kJ]
1	Q_{v1}	20058.4
2	Q_{v2}	58223.8
3	Q_{v3}	58223.8
4	Q_{v4}	58223.8

3. Percentage expression of losses

We express total energy lost due to heat transfer to the chamber walls for individual shots as a percentage by simple formula:

$$E_{Qi} = \frac{Q_{HLi}}{Q_{vi}} \cdot 100 \ \ [\%], \tag{3}$$

where are energies lost due to heat transfer to the chamber walls for individual shots reaching values given in Table 8. It is ratio of heat required to barrel body heating by certain (measured) temperature increment and heat delivered to weapon system based on a calculation from known parameters of modular charges.

Tab. 8. Percentage expression of heat losses

Shot no.	Loss	[%]
1	E_{Q1}	28.24
2	E_{Q2}	8.74
3	E_{Q3}	11.61
4	E_{Q4}	9.64

The results show that the first - warm-up shot has its justification for practical firing tests. “Full” shots losses values are reaching expected values of heat losses and their average value is **9.997 %.**

4. Conclusion

Area of detection of heat loss is practically empirical method and authors of this report believe that results of further measurements can also be used in calculations for detecting inner ballistics parameters of individual weapon systems.

In calculations are used measured values of barrel surface temperatures, which were prime in firing experiment. In the future, it is necessary to replace laser thermometers for temperature measurements with much more accurate (contact) technique. For solution of energy lost due to heat transfer to the chamber walls is necessary to take into account other factors, such as artillery missile guiding ring friction interacting with barrel surface together with relations used in thermo mechanics.

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