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Improved Production Sequence for a Ballistic Test Barrel

V. Nezval[1*], S. Procházka[2] and E. Svoboda[2]

[1] *Prototypa-ZM, Inc., Brno, Czech Republic*
[2] *University of Defence in Brno, Czech Republic*

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Abstract:

Based on experimental verification, technology consisting of copper plating blank bores before the barrels are forged is implemented in the manufacturing process of ballistic test barrels. This technology helps to optimize the process of plastic deformation during the forging process. A barrel hammered using this technology has better roughness parameters in the rifling, which is reflected in shooting tests by improved bullet accuracy. Comparative tests revealed that barrels forged using this technology can successfully compete with button rifled barrels in terms of target shooting accuracy.

Keywords:

accuracy, ballistic test barrel, cold forging, hammering, steel 1.7765

1. Introduction

Test barrels are a special type of industrial barrels used for proof and inspection of ammunition, for comparison of weapons, or for testing protective materials. Test barrels are usually fixed in universal receivers (for example NATO M2 [1] Universal Receiver) for conducting various firing tests. The assembly of test barrels and universal receivers create test weapons. The main types of test weapons are velocity test weapons, precision test weapons, pressure test weapons and Electronic – Pressure – Velocity – Action Time (EPVAT) test weapons. Velocity test weapons are used for testing protective materials. Precision test weapons are used for precision testing of small arms ammunition. Pressure test weapons are usually used for testing of ammunition for hunting and sporting purpose produced according to C.I.P. [2] or SAAMI [3] standards. EPVAT test barrels in assembly with universal receivers are used for combined electronic pressure, velocity and action time testing of ammunition. Test barrels are exchangeable and consumable parts of test weapons. The manufacturing quality of test barrels determines the quality of test weapons. According to MC MOPI [4], each manufactured precision test barrel

* *Corresponding author: Vit Nezval, Prototypa-ZM, s.r.o., Hudcova 533/78c, 61200 Brno, Czech Republic. Phone: +420 739 54 12 41, E-mail: vit.nezval@prototypa.cz*

should meet precision requirements and an EPVAT test barrel should meet the EPVAT requirements for reference ammunition shooting.

Generally, for users the most important parameter of test weapons is accuracy. Accuracy of test weapons is created above all accuracy of the test barrels used in assembly with universal receivers. This article is focused on improving the production technology of accuracy test barrels manufactured using cold forging technology.

2. Production Technology

Cold forging [5] is widely used for the efficient production of gun barrels. Prototypa–ZM, Ltd. (hereafter Prototypa), a well-known producer of ballistic test equipment, uses this technology for producing test barrels up to 12mm calibre. Test barrels are produced from barrels blanks manufactured in cooperation with Česká zbrojovka, Corp. (hereafter CZ) on a GFN SHK-10 radial cold forging machine. Production of barrel blanks used for production of test barrels has to meet certain manufacturing requirements. Ballistic test barrels have tighter manufacturing tolerances than gun barrels, especially for the land diameter of the bore of the barrel, the groove diameter of the barrel and the dimensions of the chamber. The reason for the tight manufacturing tolerances is the necessity to produce test barrels with reproducible ballistic parameters for reference ammunition. Furthermore, stability of the ballistic parameters during the life of the test barrels is required. All these aspects are the reason why the production sequence for barrel blanks for manufacturing test barrels is more demanding than the production sequence for barrel blanks for gun barrels.

2.1. Barrel Steel

Undoubtedly, the barrel steel affects the class of the barrel blank. Chromium – molybdenum – vanadium steel is suitable for the long service life of a test barrel. The alloy DIN 1.7765 (32CrMoV12-10) was chosen from available gun steels due to its chemical composition (Tab. 1).

Tab. 1 Chemical composition of alloy steel DIN 1.7765 (32CrMoV12-10)

Chemical composition [%]							
C	Mn	Si	Cr	Mo	V	P	S
0.30 ÷ 0.35	≤ 0.6	≤ 0.35	2.80 ÷ 3.20	0.80 ÷ 1.20	0.25 ÷ 0.35	0.025 max	0.010 max

A benefit of the steel DIN 1.7765 is the possibility of hardening or nitride oxidation after the production of the barrel. Before the production starts, it is necessary to treat the initial material bars to a material strength of 900 MPa. After this process, bars should be stress-relieved prior to cold forging, in order to obtain optimum straightness during cold forging.

However, steel DIN 1.7765 does not have such good ductility as other gun steels, e.g. DIN 1.7225 (42CrMo4 / steel 15 142, or steel 15 230. During the production of barrel blanks from steel DIN 1.7765, many small cracks were discovered in the land and groove diameters of the bores of the barrels – see below Fig. 1.

2.2. Rifling Roughness

Cracks also have a negative effect on the rifling roughness. Roughness of the forged barrel blank sample No. 11 was measured on a Talysurf CLI 1000 machine. Reference sample No. 10 was chosen for roughness comparison (Tab. 2).

Sample No. 10 – barrel blank calibre 7.62 × 51 produced by buttoning technology by the Lothar Walther company from DIN 1.6582 steel treated to 800 MPa. The barrel blank from Lothar Walther was used as a reference sample for twist roughness.
Sample No. 11 – barrel blank calibre 7.62 × 51 produced by cold forging by Prototypa from DIN 1.7765 steel treated to 900 MPa.

After comparing samples No. 10 and No. 11, it is possible to claim that sample No. 10 has markedly better roughness than sample No. 11. Roughness of the land and groove diameter is similar on sample No. 10, but on sample No. 11, the roughness of the groove diameter is evidently higher than the roughness of the land diameter.

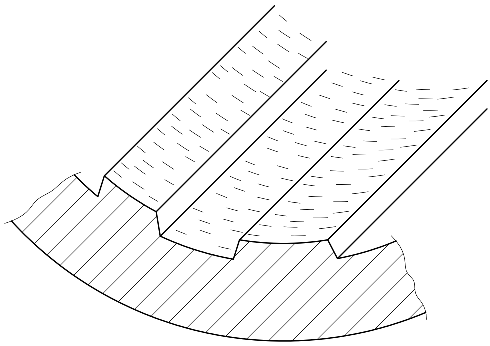


Fig. 1 Cracks in rifling of barrel

Tab. 2 Measured roughness of barrel rifling Ra [μm]

Sample No.	Land diameter of bore				Groove diameter of bore			
	1	2	3	Avg.	1	2	3	Avg.
10	0.0471	0.0544	0.0708	0.057 ± 0.012	0.0687	0.0493	0.0613	0.060 ± 0.010
11	0.0849	0.0823	0.1080	0.092 ± 0.014	0.2890	0.1360	0.2450	0.223 ± 0.079

3. Improving Production Sequence

The production technology for barrels by buttoning and by cold forging is a forming of material process. There are several dissimilarities between these processes, but the main difference is in the lubrication of the tool. In cold forging, the blank bore is lubricated by spraying forging oil before hammering, while the blank bore for buttoning is chemically plated by copper and additionally lubricated by forming oil before the buttoning process.

Authors hypothesized that keystone for the improvement of production sequence is chemical plating of the blank bore before cold forging the barrel to optimize the process of plastic deformation during forging to achieve better roughness of the rifling twist. For details please read through a literature [6] and an article [7].

3.1. Chemical Plating of Blank Bore by Copper Before Forging

Chemical plating consists in depositing a chemical solution in the blank bore using a gun horsehair brush mounted on a cleaning rod. The chemical solution consists of:

- distilled water ……………….. 800 ml,

- copper sulphate ……………… 150 g,
- tin dichloride ………………… 50 g,
- sulphuric acid 96% ………… 90 g.

After chemical plating of the blank bore by copper it is necessary to dry the blank bore using cotton and to lubricate the blank bore by spraying it with forging oil.
After a 5-10 min break, the barrel blank should be hammered (Fig. 2).

Fig. 2 Barrel blank forging on GFM SHK10 machine

After hammering it is necessary to clean the barrel blank using a degreasing solution and drying with cotton. After measurement and visual inspection of the rifling twist, the copper should be removed using a brass brush with an extra strip of grinding pad STAIPOL UF (grain 1200-1500) wetted by gun cleaning oil.

4. Accuracy

Generally, barrels produced by using cutting or buttoning technology have the best accuracy. By contrast of it forged barrels have generally unwell accuracy. The improvement of barrel forged technology used by manufacturers in order to produce accurate forged barrels, consists in making conical rifling of the barrel in proportion from the chamber to the muzzle from 0.01 mm to 0.03 mm. The mandrel used for forging barrels is always conical. Because it is possible to shift the mandrel during forging and to change the position of the mandrel against hammers, this mandrel cone allows precise adjustment of the dimensions of the forged barrels. For cylindrical barrels, the position of the mandrel against the hammers is fixed. For conical barrels, the mandrel is constantly moving against the hammers and the final barrel rifling is conical.

For producing barrel blanks for ballistic test barrels it is not possible to use conical barrel blanks, because the dimensional tolerances of the land and bore diameters of the barrels are too tight. Usually, the tolerance of the land diameter is 0.02 mm for ballistic barrels for testing hunting and sporting cartridges and the land diameter tolerance for ballistic test barrels for testing military cartridges is 0.012 mm.

Barrel blanks from steel DIN 1.7765 forged using standard production methods have always small cracks in the barrel twist which influence the accuracy of bullets on the target. It is expected that a test barrel produced from a barrel blank using the improved production sequence consisting of chemical plating of the blank bore before forging will have better accuracy.

4.1. Comparison of Barrel Blanks Accuracy

Two test barrels for the UZ-2002 Universal receiver of the calibre 308 Win. and the length of 600 mm (Fig. 3) were produced to compare barrel blanks accuracy:

- test barrel SN.5181 from the barrel blank manufactured by Lothar Walther from gun steel LW19 (DIN 1.6582 – 34CrNiMo6) treated to plastic limit 800 MPa. Production technology for the barrel blank was buttoning,
- test barrel SN.5182 from the barrel blank manufactured by Prototypa (forged in CZ) from gun steel DIN 1.7765 (32CrMoV12-10) treated to plastic limit 900 MPa. The production technology for the barrel blank was cold forging and chemical plating of the blank bore before forging during production of this barrel blank.

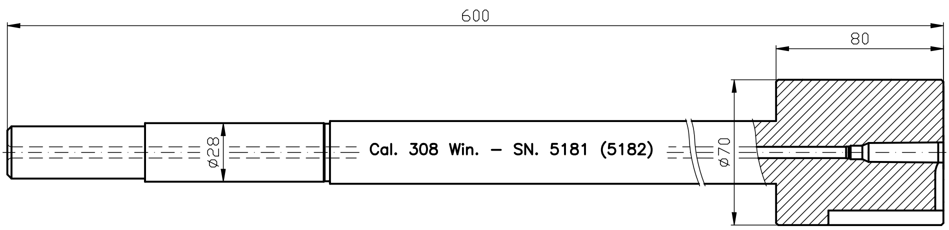


Fig. 3 Test barrel sketch SN.5181 and SN.5182

Lothar Walther produces respected accuracy barrel blanks. The test barrel SN. 5181 is supposed to be a reference sample for accuracy comparison. Before testing, approximately 80 rounds were shot from each barrel during high pressure proof and running-in.

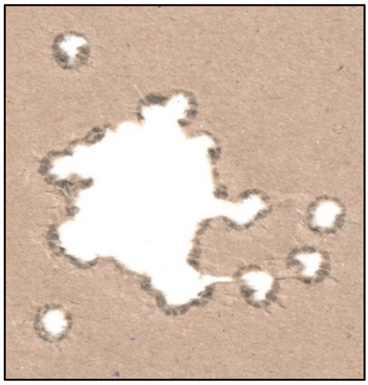
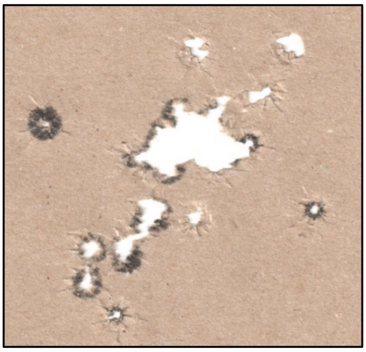
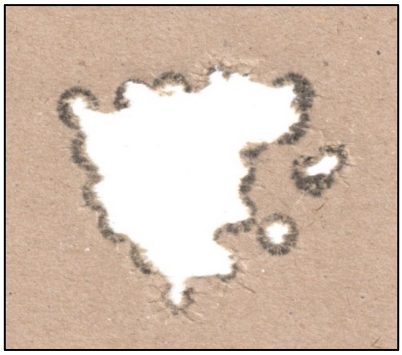
Accuracy was compared in a distance of 100 m. The following ammunition was chosen for the tests:

- reference ammunition (for tests 1-6)
  7.62 × 51 NATO BALL, bullet weight 9.55 g, Lot. 130-GGG-15 with ballistic parameters of the average velocity at 24 m v_{24} = 825.3 m/s, the average chamber pressure p_s = 330.3 MPa, the average port pressure p_p = 76.1 MPa and the average action time AT = 1.26 ms,
- hunting and sporting ammunition (for tests 7-10)
  308 WIN. HPBT, bullet weight 12.3 g, Sellier & Bellot MATCH No. 2210 Lot. 945/29, the average muzzle velocity v_0 = 800 m/s.

4.2. Accuracy Evaluations (Tests 1-2, Fig. 4)

- Both test barrels 308 Win. (SN. 5181 and SN. 5182) qualified according to MC MOPI for accuracy (required $SDx \leq 140$ mm, $SDy \leq 140$ mm in distance 550 m).
- Both test barrels qualified for velocity (reference ammunition 7.62 × 51 NATO Lot. 130-GGG-15 v_{24} = (825.3 ± 12) m/s).

Accuracy of both barrels is comparable. Test barrel 308 Win. (SN.5182) achieved approximately 10% better accuracy than barrel SN. 5181.

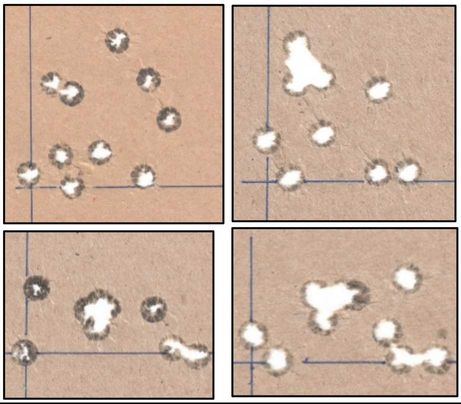
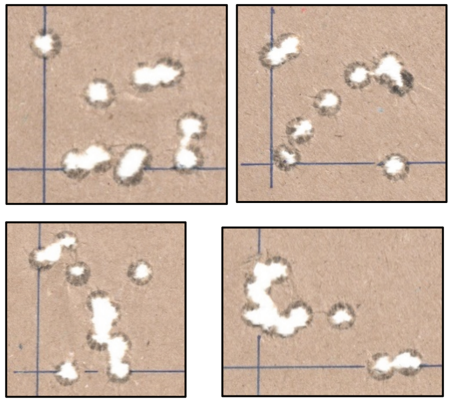
Barrel blank Lothar Walther (SN. 5181)	Barrel blank Prototypa (SN. 5182)
Accuracy results (test 1)	
	
Accuracy results (test 2)	
	
Arithmetic average (2 × 30 rounds): *SDx* = 14 mm / *SDy* = 13.7 mm v_{25} = 837.6 m/s	Arithmetic average (2 × 30 rounds): *SDx* = 13 mm / *SDy* = 11.9 mm v_{25} = 832 m/s

SDx – Horizontal standard deviation
SDy – Vertical standard deviation
v_{25} – Average bullet velocity in distance 25 m

Fig. 4 Measured accuracy of barrels SN. 5181 and SN. 5182 (tests 1-2)

4.3. Accuracy Evaluations (tests 3-6, Fig. 5)

- Both test barrels 308 Win. (SN. 5181 and SN. 5182) meet qualification criteria (Prototypa $W + H \leq 75$ mm in a distance of 100 m).
- Accuracy of both barrels is comparable. Test barrel 308 Win. (SN. 5182) achieved approximately 10% better accuracy than barrel SN. 5181.
- Test barrel SN. 5182 has comparable accuracy to test barrels produced by Prototypa exclusive of Lothar Walther blanks in years 2008-2013.

Barrel blank Lothar Walther (SN. 5181)	Barrel blank Prototypa (SN. 5182)
Accuracy results (tests 3-6)	
	
Arithmetic average (4 × 10 rounds): $W + H = 71.5$ mm $v_{25} = 838.2$ m/s	Arithmetic average (4 × 10 rounds): $W + H = 64.5$ mm $v_{25} = 832.1$ m/s

W – Maximal width of shots pattern
H – Maximal height of shots pattern
v_0 – Average bullet muzzle velocity

Fig. 5 Measured accuracy of barrels SN. 5181 and SN. 5182 (tests 3-6)

4.4. Accuracy Evaluations (for tests 7-10, Fig. 6)

- Both test barrels 308 Win. (SN. 5181 and SN 5182) qualified for accuracy test according Sellier & Bellot ($D_{max} \leq 1$ MOA (Minute Of Anglein) distance 100 m).
- Both test barrels qualified for velocity test $v_0 = (800 \pm 15)$ m/s. Drop of velocity is 0.58 m/s per 1 m travelled.
- Accuracy of both barrels is comparable. The test barrel 308 Win. (SN. 5182) achieved approximately 16% better accuracy in MOA than the barrel SN. 5181.

5. Perspective Benefits

It was proved that insertion of a technological operation consisting in chemical plating of the blank bore before cold forging of the barrel optimizes the process of plastic deformation during forging. The barrel blank from steel DIN 1.7765 has better roughness of the twist rifling reflected by improved accuracy of the barrel. However, this improved production sequence is more demanding for manual work during the production of the barrel blank, so it is a suitable technology especially for the production of test barrels. Generally, test barrels are produced on request in small quantities and this production requires much manual work by skilful gun makers.

5.1. Comparison of the Blank Bore Roughness before and after Forging

For comparison of the effect of copper chemical plating the roughness of the barrel, blank bores were measured before and after forging (Tab. 3 and Tab. 4).

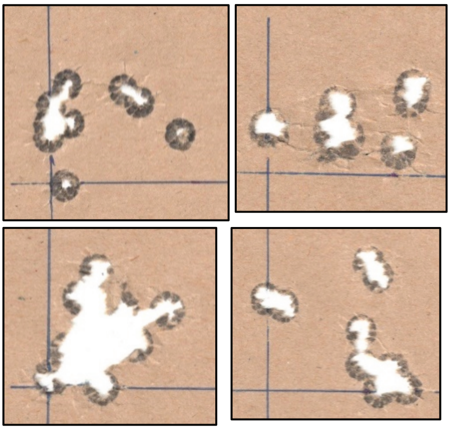
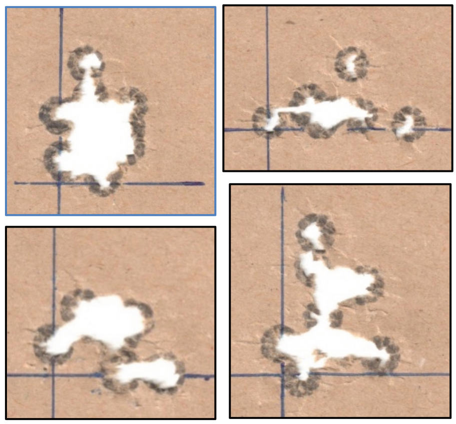
Barrel blank Lothar Walther (SN. 5181)	Barrel blank Prototypa (SN. 5182)
Accuracy results (tests 7-10)	
	
Arithmetic average (4 × 10 rounds): $W + H = 51$ mm $D_{max} = 1$ MOA $v_{25} = 796.6$ m/s	Arithmetic average (4 × 10 rounds): $W + H = 39.2$ mm $D_{max} = 0.84$ MOA $v_{25} = 794.9$ m/s

Fig. 6 Measured accuracy of barrels SN. 5181 and SN. 5182 (tests 7-10)

Tab. 3 Roughness of barrel blank bores Ra [µm] *before forging*

Blank bore [mm]	**Measured from chamber side**				**Measured from muzzle side**			
	1	2	3	Avg.	1	2	3	Avg.
Ø 6.1	0.1250	0.1840	0.1970	0.169 ± 0.038	0.1160	0.0763	0.1730	0.122 ± 0.049
Ø 8.2	0.1040	0.1040	0.1130	0.107 ± 0.005	0.1200	0.1060	0.1080	0.111 ± 0.008

After measurement of roughness, the forged barrel blanks calibre was 5.45 × 39 and 5.56 × 45 from blanks with bore ∅ 6.1 mm. From blanks with bore ∅ 8.2 mm (Fig. 7) the forged barrel blanks calibre was 7.62 × 51 (Fig. 8). The copper chemical plating process was applied before forging.

From the measurements of the barrel blanks roughnesses before and after forging it is evident that the roughness after forging is better than it was before forging. Further, it is possible to see that the barrel blanks land diameter of the bore roughness is conformable to the groove diameter of the bore roughness. It was observed using a borescope that the barrel blank cracks inside the rifling are smaller than without using copper chemical plating before forging. Unfortunately, the roughness of the reference sample barrel blank from Lothar Walther was not achieved.

Future study could be probably oriented to crack initiations, surface waviness and others factors important for optimization the process of plastic deformation during forging.

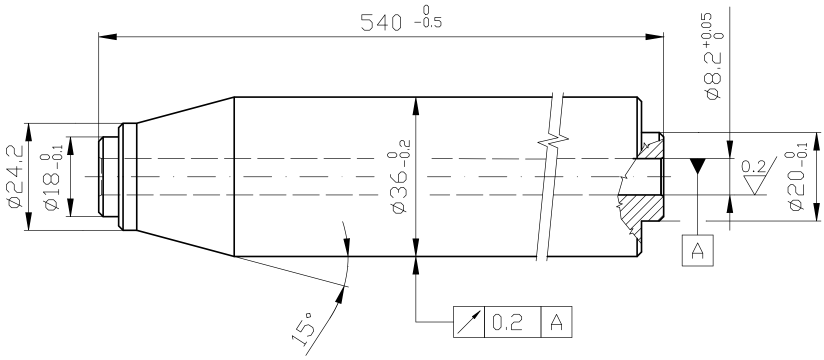


Fig. 7 Barrel blank before forging

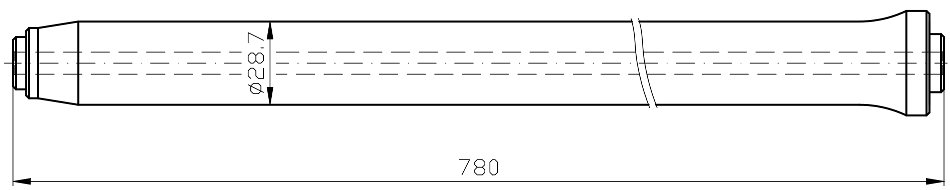


Fig. 8 Barrel blank after forging

Tab. 4 Roughness of barrel blanks bore Ra [µm] *after forging*

Calibre	**Land diameter of bore**				**Groove diameter of bore**			
	1	2	3	Avg.	1	2	3	Avg.
5.45×39	0.1030	0.0987	0.0949	0.099 ± 0.004	0.1490	0.1150	0.1270	0.130 ± 0.017
5.56×45	0.1400	0.1380	0.0900	0.123 ± 0.028	0.0875	0.0950	0.0887	0.090 ± 0.004
7.62×51	0.0836	0.0665	0.0709	0.074 ± 0.009	0.1070	0.0911	0.0757	0.091 ± 0.016

Acknowledgement

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