Abstract: This article explains complete procedure of profiling and quality control on mandrel for gun barrel cold hammering. Gun barrels are produced on GFM machine by technique of Rotary Forging. The mandrel is the most significant element for final quality of gun barrels. Paper present one original developed technology method and quite different from the method used in Zastava Arms factory. Paper explains mandrel profiling on CNC grinding machine with two simultaneously controlled linear and one rotary axis. The developed method enables grinding mandrels, not only on machines specialized for that purpose.

Key words: Gun barrel, Rotary Forging, Grinding, CAD/CAM

1. INTRODUCTION

Most modern pistols, revolvers, rifles, and some shotgun barrels have what are called rifling in their barrels. Rifling consists of grooves cut or formed in a spiral nature, lengthwise down the barrel of a firearm.

Rifling is placed in the barrels of firearms to impart a spin on the bullets that pass through it [1]. Because bullets are oblong objects, they must spin in their flight, to be accurate.

Oldest method is the CUT RIFLING technique [1]. Cut rifling creates spiral grooves in the barrel by removing steel using some form of cutter. Up until WW2 rifling was the most time consuming operation in making a rifle.

BUTTON RIFLING is a cold forming process in which a Tungsten Carbide former, which is ground to have the rifling form in high relief upon it, is pulled through the drilled and reamed barrel blank [1]. The lands on the button engrave grooves in the barrel as it is pulled through.

The technique of ROTARY FORGING rifle barrels was developed by Germany before WW2 [2]. In this process the barrel blank is usually somewhat shorter than the finished barrel. It is drilled and honed to a diameter large enough to allow a Tungsten Carbide mandrel, which has the rifling in high relief on it, to pass down the blank. The blank is then progressively hammered around the mandrel, figure 2, by opposing hammers using a process called rotary forging. The hammered blank is squeezed off the mandrel like tooth paste and finishes up 30% or so longer than it started [2].
3. BASIC ELEMENTS OF MADREL

Mandrel for rotary forging on GFM machine (Gesellschaft für Fertigungstechnik und Maschinenbau – GFM - Steyr, Austria) is key element for the barrel quality. Mandrel defined a diameter (caliber) and makes grooves inside the barrel.

Typical drawing of mandrel [3] is shown of figure 3. and consists of next elements:
1. Grooves
2. Transition cone
3. Capsule
4. Transition cone
5. Shell casing

3.1. Geometry of the groove

Figure 4. defines a radial section of mandrel. All the drawing section have same shape, but different angular position and different dimensions.

That difference defines a pitch of grooves, and lead varies from 250mm to 400mm. Mandrel have between 4 and 8 grooves, depending on caliber: for example

Cal. 5.56 → 4 grooves; Cal. 7.62 → 6 grooves; and Cal. 13 → 8 grooves. Depth of grooves is between 0.100mm and 0.150mm.

Differences in dimension define forging cone, and angle is approximately between 10 and 20 angular minutes. Tolerances for all section are very narrow: ±2µm.

Mandrel is made from two different material: Holder made from a high alloy Chrome Molybdenum steel, and forging area made from Tungsten Carbide hard metal. The connection is made by soldering process.

Grooves on mandrel are made by grinding; using profiled artificial diamond disk (fineness 0.5 – 0.8 carat) with Bakelite or metal connective.

To get spiral-shape it is necessary three simultaneous motions: two linear and one rotary. In addition, is necessary put profiled diamond disk in starting position-according slope of leading spiral curve. That angle is approximately between 4 and 5 degrees.

4. CAD DEFINITION OF THE MANDREL

All previous analyzed mandrel’s drawings have a couple typical errors. Factory’s internal instructions [3] have a couple remarks about these errors on the mandrels drawing. Dimensions from barrel drawing are simply copied on the mandrel drawing without taking care about production process. In the Zastava Arms Factory production engineer creates new drawings only for profiling mandrel.

Our approach in solving the manufacturing problem starts from a three-dimensional modeling on CAD/CAM system. Design of parts and components compatible with the principles of total quality management is called "design for manufacturing" [4]. The drawing is just auxiliary information for operator on the machine tool.

We analyzed more than 20 foreign and domestic different mandrel drawings. All looks same one to each other. Obviously, the draftsmen just simple copy a sample, but the wrong one.

On all drawings, sections are shown with deformity. In addition, angular position for all definition section is the same. Reason is very simple, all drawings are made on old-fashion way: using a paper and pencil, view and section explain the model.

In the reality, view and section are result of object, not contrary. After creation of 3D model, drawing (with sections and views) is representing the object (mandrel), and some time drawing is unneeded. Modeling (CAD) process must follow production process (CAM). Except the 3D model, we have, also, and graph of creation process. The same logic we will follow during the grinding. All mandrel’s drawing shows changes of definition radius of groove (bottom of the groove), by the linear low. To get that, it is necessary to change, all the time, profile of grinding diamond wheel. In the reality, it is not possible. That request is illogical.

Figure 5. displays the correct 3D model model of mandrel. One definition section from drawing “travel” along spiral curve (line wrapped around cone).

Choosing a middle section (between typical AA and BB section on mandrel’s drawing) you made an error.
smaller than 1µm. For profiling diamond disk it is necessary to choose section perpendicular to spiral curve. That is a conic section, and profile of wheel is a part of ellipse. None of analyzed drawing not pay attention on previous remarks.

5. PREPARING GRINDING WHEEL

Two diamond disk, one for rough and another for finishing are mounted on same holder, figure 6. Cutter for this profiling is natural diamond, mounted on special holder. CNC program for profiling and sharpening is write according definition profile but in mirror position. In addition, you need very sensitive sensor for contact artificial diamond wheel and natural diamond. Temperature is very high even for small cutting depth (1µm). Holder of natural diamond needs a lot of cooling water and that’s reason for cooling ON.

Diamond disk geometry check done on coordinate measuring machine according to the CAD/CAM computer model. Figure 7. shows the measured points and theoretical profile of the grinding wheel.

![Fig. 6. Profiling of Grinding Wheel](image)

![Fig. 7. Measured geometry of the wheel](image)

Small crosses in figure 7 represents measured points are obtained using a touch trigger contact probe on the coordinate measuring machine [4]. Measured profile obtains using least square method thru measured points.

The figure 7 shows that the measured profile wheels good, but that translated aside in relation to a given axis of symmetry. It is necessary that the correction re-profiling to achieve the required accuracy of the shape and position profile diamond grinding wheels.

The measurements were made at the CMM with MPE-E (MPE=Maximum Permissible Error, E = Volumetric Length Measuring Uncertainty) declared according to ISO10360, are given by equation (1).

\[
MPE_E = \pm \frac{L}{400} \ [\mu m]
\]  

(1)

L [mm] representing length of measuring. In this case diameter of the wheel is 40mm. CMM meets the required accuracy for measuring this class of problems.

6. MANDREL PROFILING

After completely very complex preparation, CNC controlled grinding machine with two linear (X & Y) and one rotary motion (B) is ready to start. Diamond wheel is incline and contact point at the same level like axis of rotation.

![Fig. 8. Mandrel on CNC grinder](image)

All the necessary is shown on figure 7: numerically controlled two linear and one rotary axis, cooling system and piezosensor for checking contact between wheel and mandrel.

CNC program, created on CAD/CAM system used to profiling mandrel. For caliber 5,56mm CNC program is listed below [5]:

```
N01(Cal 5.56x45 6 grooves  
Pitch=178mm)  
N05 G90 T1 F800 M8 M3  
N06 G78  
N10 G00 X40.0 Y-30.0 B0.0  
N15 G71 L100  
N20 G00 B60.0  
N25 G71 L100  
N30 G00 B120.0  
N35 G71 L100  
N40 G00 B180.0  
N45 G71 L100  
N50 G00 B240.0  
N55 G71 L100  
N60 G00 B300.0  
N65 G71 L100  
N70 G00 B0.0  
N71 G79  
N75 M05  
N80 M02  
N100 G01 X40.000 Y-27.0  
N105 G01 X42.336 Y-25.0
```
N110 G01 X42.380 Y-2.800 F50
N115 G41 X-0.750 Y-2.779 B:87.229 F800
N120 G01 X-20.750 Y-2.769
N125 G01 X-20.764 Y-30.000
N130 G00 G40 X38.0 Y-25.0 B:-27.229
N135 G72

CNC program starts first with a rough wheel, for each groove separately. Program repeats whole cycle between 40 and 50 times, depending on total depth.

Cutting depth is 2 - 3µm for each pass and for finishing, rest approximately 1/100 mm. Final, requested dimension, CNC program reach in 5 – 6 times up to 2µm. Next 5 – 6 times program repeat all position with same radius compensation of wheel until no sound signal from contact piezosensor.

7. MEASURING GEOMETRY AND ROUGHNESS

Inspection of geometry includes checking depth of grooves and roughness. Shape of grooves directly depends on the shape of diamond grinding wheel, which previously measured on CMM, figure 7. Depths are measured directly on grinding machine. Figure 9 shows measuring depth of the groove using instrument with 1µm accuracy.

<table>
<thead>
<tr>
<th>GROOVE</th>
<th>REQUESTED</th>
<th>A-A</th>
<th>S-S</th>
<th>B-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.115</td>
<td>0.115</td>
<td>0.115</td>
<td>0.117</td>
</tr>
<tr>
<td>2</td>
<td>0.115</td>
<td>0.115</td>
<td>0.116</td>
<td>0.116</td>
</tr>
<tr>
<td>3</td>
<td>0.115</td>
<td>0.113</td>
<td>0.114</td>
<td>0.114</td>
</tr>
<tr>
<td>4</td>
<td>0.115</td>
<td>0.113</td>
<td>0.113</td>
<td>0.113</td>
</tr>
<tr>
<td>5</td>
<td>0.115</td>
<td>0.115</td>
<td>0.114</td>
<td>0.114</td>
</tr>
<tr>
<td>6</td>
<td>0.115</td>
<td>0.115</td>
<td>0.115</td>
<td>0.115</td>
</tr>
</tbody>
</table>

Fig. 9. Inspection report for individual mandrel

In figure 10. shows roughness measuring. Polish using cork disk give roughness smaller than 0.1µm.

Final report, for end user, is shown on figure 11. Final report is joining for each mandrel separately. It also includes all relevant information: dimensions, depths of groove and profile of groove, surrounding temperature, etc. Actual quality of the mandrel will copy on the whole series of barrel.

8. CONCLUSION

This article on a few pages explains, actually, very complex procedure. You need also, high-skill workers, sophisticated equipment’s and high-end CAD/CAM/CAE system.

All elements existed in Serbia more than twenty years, but sometime producers (factories) have lot of inertia to speed-up production process. Reasons are very different: inertia of engineers and managers due to monopoly position on market, misunderstanding new software and hardware product, etc.

The developed method enables grinding mandrels, not only on machines specialized for that purpose.

9. REFERENCES


Author: Dr. Srdjan Živković, Head of Section, Military Technical Institute Belgrade, Ratka Resanovića 1, 11000 Belgrade, Phone: +381 66 872 14 03 Email: srdjan.vti@gmail.com, srdjan_vti@yahoo.com