

AUGUSTIN KEG

# **COLD FORGING**

of

# **RIFLE BARRELS**

**with and without cartridge chamber**

on Cold Forging Machines type GFM SHK und SKK 06 resp. 10

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Steyr, January 1995

**SUMMARY:**

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### 1.) Material employment when cold forging barrels:

For cold forging of rifle barrels it is recommended to use a highly pure material. In total P & S should not exceed 0,025%. In order to achieve a material of such a pure degree it is normally re-melted once or twice in an electric arc furnace and then vacuum degassed. Impurities in steel have a negative influence on the deformation characteristics during cold forging.

The required material purity is essential in order to achieve a surface quality of the forged groove and land profile as far as possible without segregation lines. These segregation lines have a dark color and appear longitudinally on the barrel.

The more P % S exists in the material, the more the formation of folds can be observed in the entry area of the blank bore to forward of the forging profile. Of course, this effect of fold formation is increased the greater the diameter difference is between the blank bore and the caliber dimension. The fold formation is moreover increased if the hammer entry angle is laid out too steeply.

The problem of fold formation will be the most frequent one when forging cartridge chambers. Thus, for this kind of forging, it is essential to use a high grade of steel. The more homogeneous the material structure is for cold forging, the less risk of cracks which might occur during the forging process. The safety of the rifleman always has priority.

If possible the barrel blank should be stress relieved prior to cold forging, in order to obtain an optimum straightness during cold forging. After forging the barrel should again be stress relieved to make sure that during further processing no stress can be released which would negatively influence shooting accuracy.

The material strength of the barrel blank lies between 750 and 1050 N/mm<sup>2</sup>. After cold forging normally the strength of the barrel material increases by approximately 10%

Common barrel materials:

32 Cr Mo V 1210

21 Cr Mo V 511

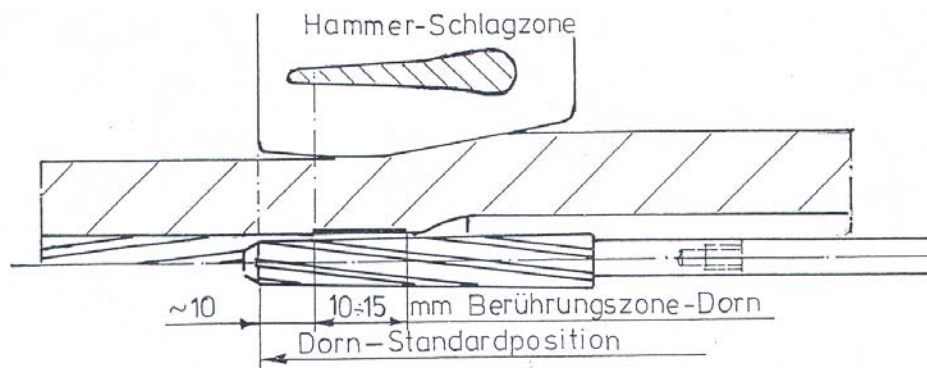
14 Ni Cr 14

50 Cr V 4

## 2.) General information on cold forging technique:

Corresponding to the entry angle of the hammer blow face, the length of the cylinder as well as its run out with a particular forging reduction, a contact zone will show on the mandrel. Thereby the taper of the mandrel has already been determined. Normally this contact zone on the mandrel should be about 10-20 mm.

If the mandrel contact zone is too short, consequently a wave - like structure in the surface of the forged grooves & lands will result. A too long mandrel contact zone damages the flank (trailing edge) in the groove /land profile, due to excessive friction forces.



Brief mandrel information: (Standard design)

Forging mandrel without cartridge chamber:

Mandrel taper 0.1 mm – 0.15mm over a length of approximately 60 mm

Forging mandrel with cartridge chamber:

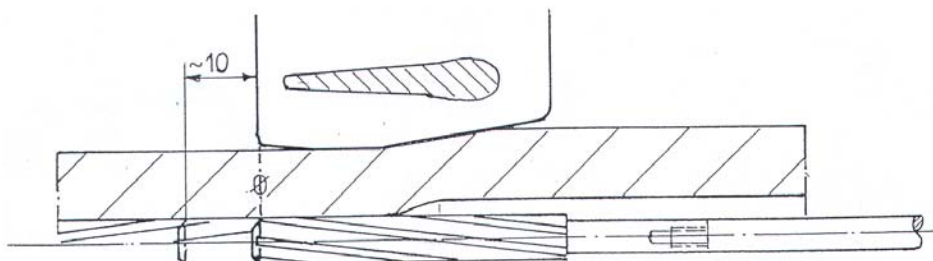
Mandrel taper 0.03mm – 0.05mm over a length of approximately 40 mm

For a detailed description, see paragraph 6.

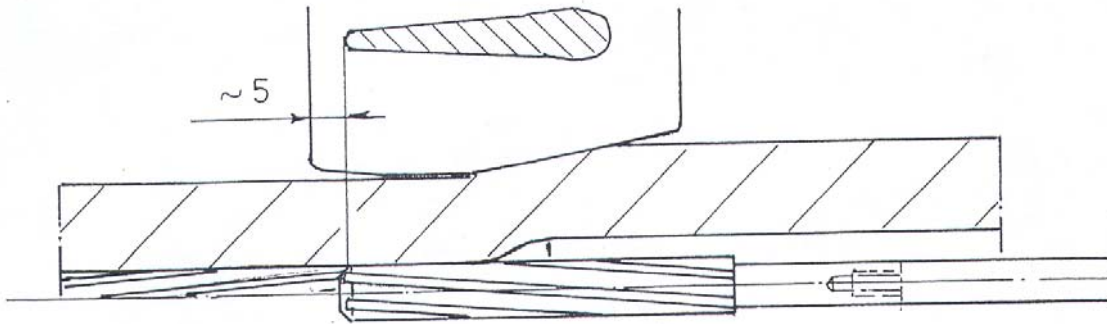
Since the rifling twist of the forged barrel will always be different from the mandrel twist, it is important to pay special attention to the mandrel forging position. The smaller the rifling twist of the barrel, the more important is the mandrel position.

The most essential mandrel settings:

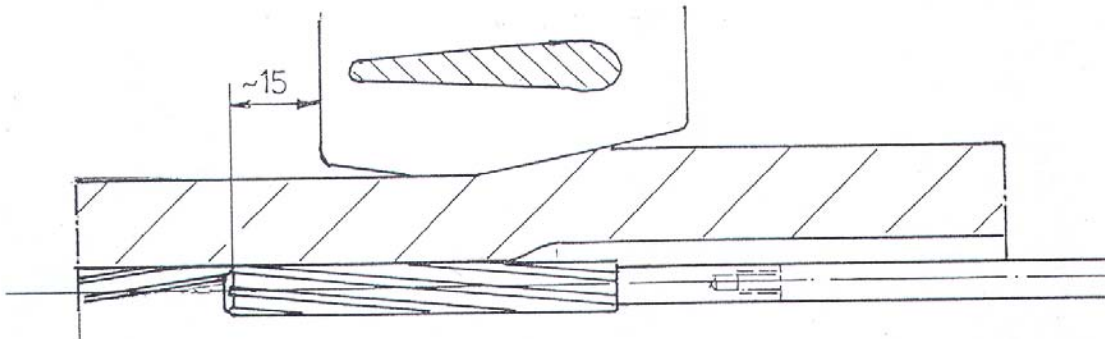
Standard position at the start of forging: the mandrel edge coincides with rear hammer edge. Forward mandrel adjustment is then possible by approximately 10 mm.



The following mandrel position will become necessary with particularly small rifling twists. A forward mandrel adjustment is possible; however, not more than 5 - 10mm.

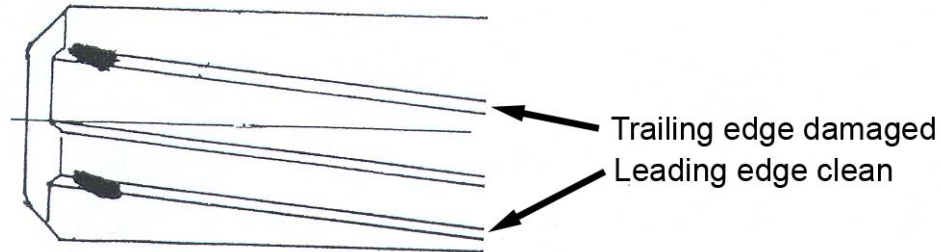


A more forward mandrel position as shown below must be avoided at forging start. This position would have a very disadvantageous influence on the groove and land profile, as the length of elongation over the mandrel is excessive.



Reasons: The rifling twist of the forged barrel will always be somewhat superior to the rifling twist of the mandrel. The two twists will cross each other shortly after the hammer run-out range. Consequently, the lateral pressure of the barrel material onto the groove/land trailing edge will be strongly increased and will have a tendency to adhere due to friction. The trailing edge in the forged barrel will be damaged. A cold weld onto the tungsten carbide forging mandrel will result and will necessitate the discharge of the mandrel.

The following figure shows mandrel damage on account of lateral material weld-on due to disadvantageous mandrel position during forging (mandrel too far forward).



When forging barrels with and without cartridge chamber it is possible on modern types of cold forging machines to produce the caliber bore over the total barrel length not only cylindrical but also conical (tapered bore). For this purpose - depending on the program - the conical mandrel is moved forward. Thus the exact caliber reduction at the muzzle can be determined.

On account of this measure a decisive improvement in the shooting quality can be achieved.

### 2.1) Barrel blank

The precondition for impeccable barrel straightness during cold forging of rifle barrels is the perfect bore in the blank. Care shall be taken that after the honing process a cylindrical and straight bore is produced. The straightness of this blank bore is the basis for the straightness of the forged barrel.

The surface quality (roughness) should not exceed the range of Ra-0.15-0.25  $\mu\text{m}$ . The better the quality of the blank bore, the better will be the quality in the groove/land range of the forged barrel. For further processing of the blank one starts from the finished blank bore.

In case of drilling deep holes one must pay attention that on the surface of the bore no excessive hardening results. This hardening would have a negative influence on the formation of the groove/land profile (cracks might occur).

Subsequently during turning the outer shape of the blank, one must take care that the maximum difference of wall thickness does not exceed 0.05mm. Any wall thickness difference of the blank will degenerate into a bend during forging.

## 2.2) Machine adjustment:

The perfect adjustment of the forging machine is a further precondition for forging a straight barrel.

The allowance from the chuck head to the connecting rod positions No.1, 2, 3, 4 should be within 0.05 mm. The counter holder position to the connecting rod positions No.1, 2, 3, 4 should be within 0.03 mm. The chuck head clearance should be within 0.5 mm and should not exceed 0.7mm.

The straightness of the piston rods of the chuck head feed cylinders are an important factor in the forging process. In case of bent rods the arc should always run from the top towards the bottom. Subsequently the piston rods should be fixed on the chuck head housing against torsion. If the piston rod bend runs laterally, the chuck head, too, would be pressed laterally to the chuck head. Thereby the forged barrel would be bent. A positive point for the barrel straightness furthermore is the fixation of the piston rods on both sides of the chuck head housing. So far the piston rods have only been guided in the chuck head housing by means of a bushing with approx. 1 mm clearance. On account of the high accuracy standards concerning the counter holder, utmost care has to be taken with regard to its fixation in the foundation in respect to the foundation frame.

The ideal setting parameters of the machine are normally found by a test forging run.

### General Guiding values:

Chuck head feed: depending on reduction and dimension, between 90 mm/min. and 200 mm/min.

Chuck head rpm: between 30 rpm and 56 rpm

Number of spring bars: between 12 and 20 pes. Bracing pressure: between 25 and 40 bar

## 2.3) Hammer shapes and their influences:

Basically with each hammer shape an exact reduction has to be forged. Never do aspire to overfill the barrel profile, rather forge the contrary.

When forging barrels without cartridge chamber generally there are no problems with barrel straightness, provided the blank has been optimally produced and the machine is properly adjusted.

Normally with this kind of forging all 4 hammers have an identical hammer blow face. One has to pay attention to the fact that in one set of same hammers the hammer height (tolerance +- 0.02 mm) as well as the hammer shape can be kept uniform in the individual angles and lengths. (Length tolerance in the angle steps +- 0.05 mm).

Various shapes of hammer blow faces are shown in paragraph 7.

When forging cartridge chambers the forging is done principally with 2 shapes in one set (A-B shape).

This A/B shape is necessary for the reason that the filling effect at the material entry is increased.

When forging a cartridge chamber on the one hand the big blank bore diameter has to be reduced to the caliber dimension and at the same time the cartridge chamber should be ideally filled. Actually forging the chamber's shoulder is the problem, whereby in the same process the small shoulder and the twist runout must be produced without overfilling. The hammer blow zone where the A/B difference of the hammers causes the greatest filling effect must be followed by a longer flat planishing zone towards the cylinder in order to guarantee acceptable straightness.

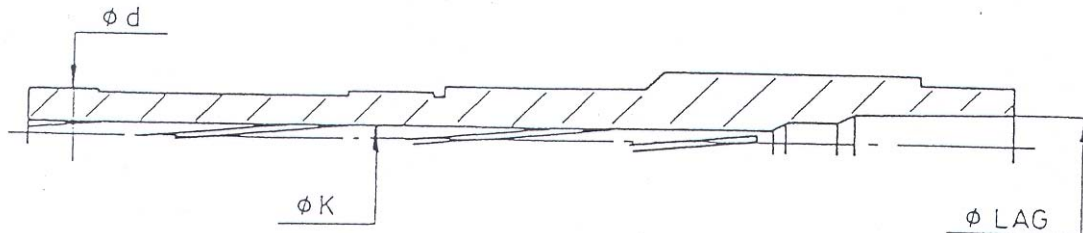
With the hammer design the distance between the big and small shoulder as well as their diameter differences must be observed. Thereby the wall thickness of the barrel plays a vital role.



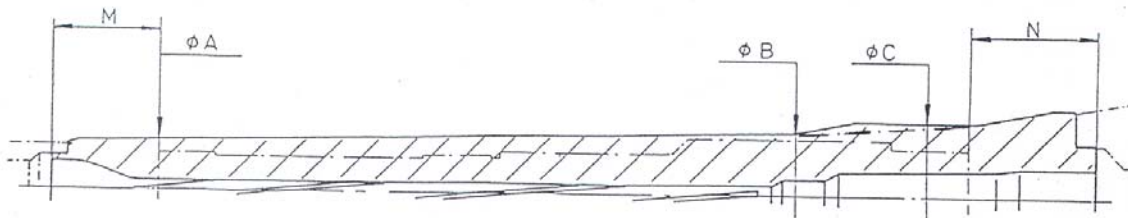
### 3.) Design of forging form and of blank forged with cartridge chamber

#### 3.1) Forging form

Contour of the finished barrel



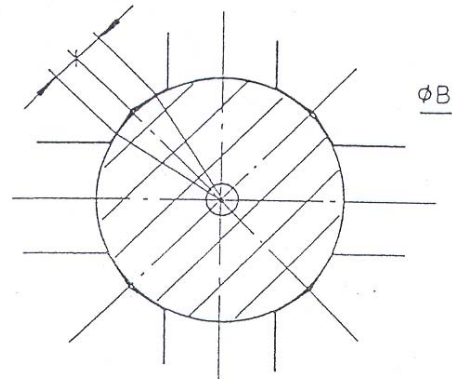
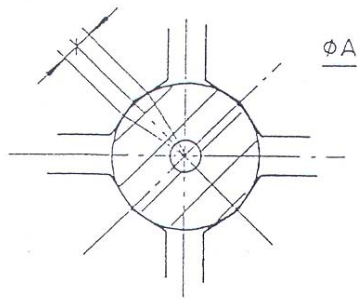
The forging form can be laid over the contour of the outer shape of the finish - machined barrel. The allowance for the cutting procedure after forging must be paid attention to. In order to achieve an optimum of quality of the forged tube, the outer shape should be a cone without breaks respectively a cylinder without steps. In the range of the cartridge chamber one step or taper has to be produced due to forging reasons.



Determination of diameter "B": When forging the cartridge chamber, diameter "B" is in the range of the collar of the cartridge chamber. The position of this diameter can vary based on the actual caliber of the barrel.

Determination of diameter "C": In order to forge the powder bag of the cartridge chamber (between the base and shoulder) without any problems and not to cause faults at the twist end and at the small shoulder, the step has to be designed to accommodate the diameter difference between diameters B and C and amounts to approximately 2 - 5 mm (with smaller calibers) and up to approximately 9 mm with larger calibers with a larger forging diameter.

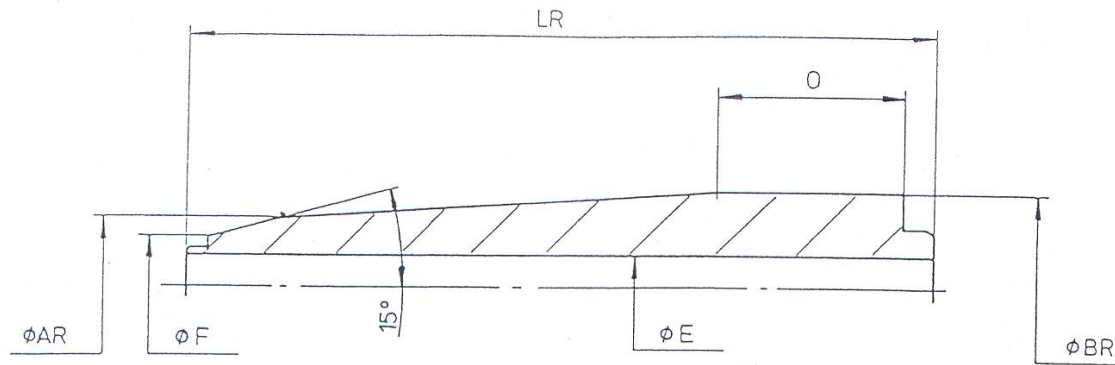
Determination diameter "A" : This diameter is on one hand determined by the finish shape of the barrel. On the other hand the geometry of the forging hammer and the counter holder insert determines the minimum dimension of diameter A. As the forging hammers are provided with some allowance for regrinding (wear) to a minimum forging diameter, there is a certain width on the contact area. If the difference between diameters A and B gets too much, the material bends over from the big diameter over the edges of the hammer during the forging procedure. When forging with cartridge chamber, the diameter A can be smaller by about 35 % than diameter B.



Due to the small deformation at diameter C no further extension of the contact area can be expected.

The surplus lengths M and N are necessary for the acceptance of the forging tools (driver, counter holder insert). Moreover, it is necessary to obtain a transition from the unmachined end of the blank to the forged barrel. These surplus lengths amount to 25 - 50 mm - depending on the dimension of the barrel.

### 3.2) Blank form

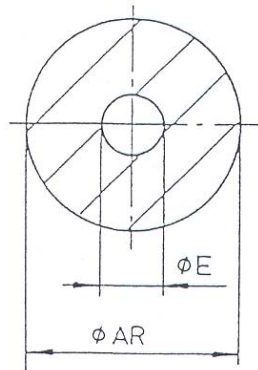


Determination of diameter "E": As the forging mandrel is pushed through the blank bore when starting forging at the outlet of the barrel, it is necessary to leave a backlash between the maximum diameter of the mandrel in the range of the cartridge chamber and the blank bore.

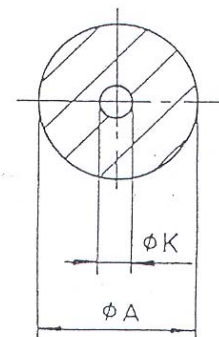
$$\phi E : \phi LAG + 0.2 \text{ to } 0.5 \text{ mm}$$

Determination of diameter AR/diameter BR: These two blank dimensions mainly determine the rate of deformation respectively the reduction between blank and forged barrel.

The rate of deformation is the ratio of ring space blank to ring space - forging part.



$$\varphi = \frac{AR^2 - E^2}{A^2 - K^2}$$



The reduction "R" (%) is the percentage by which, the ring space of the blank is reduced during the forging procedure.

$$R = \left(1 - \frac{1}{f}\right) \cdot 100 \quad (\%)$$

$$\varnothing_{AR} = \sqrt{\frac{\varnothing A^2 - \varnothing K^2}{1 - \frac{R}{100}} + \varnothing E^2}$$

$$\varnothing_{BR} = \sqrt{\frac{\varnothing B^2 - \varnothing K^2}{1 - \frac{R}{100}} + \varnothing E^2}$$

The reduction "R" (%) depends on several factors:

- Forging diameter
- Wall thickness
- Ratio of blank bore to caliber diameter
- Profile depth and profile form of the caliber
- Material quality and tensile strength of the blank.

The exact degree of reduction, therefore, can only be determined by forging tests. When forging without cartridge chamber the reduction rates are approximately 17 - 30%, with cartridge chamber forging the reduction rates are in the range of 30 - 45%.

Determination of  $\varnothing F$ : In order to avoid damages of the counter holder insert, the  $\varnothing F$  has to be smaller than the forging diameter A by approx. 2 mm.

Determination of length O: The conical forging of barrels is always done between  $\varnothing A$  and  $\varnothing B$ .  $\varnothing C$  over the powder bag is always designed cylindrical. The range O on the blank has also to be designed cylindrical, whereby the length approximately corresponds with the distance between the small shoulder and cartridge chamber end.

Determination of length LR: The length LR of the blank results from the same volume of the forged barrel to the blank.

#### 4.) Forging sequence during cold forging of barrels:

By means of a forging proposal a barrel type is defined in its forging shape and consequently in its blank shape, that means the outer forging contour of the barrel to be forged is outlined to be either cylindrical or conical.

With the cylindrical barrel type the cylindrical forging shape is laid over the known turning shape with an allowance of approx. 2 - 4 mm in diameter.

With the conical barrel type an outer taper with an angle of 0.7 to 1° should not be exceeded. It should be possible to regrind the forging hammer set designed for that purpose as often as needed, in order to guarantee the profitability of this type of forging. Based on the barrel forging shape now defined, the barrel blank is calculated. Here the caliber sizes of groove/land and the cartridge chamber dimension have to be considered. See the layout of the forging shape and of the blank.

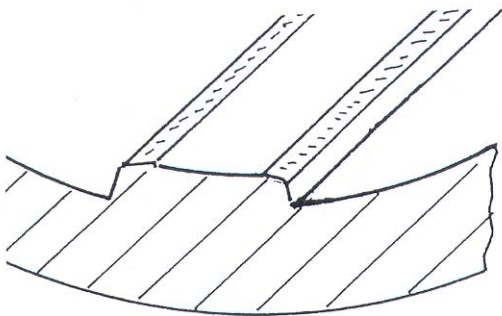
According to the blank parameters the following is now determined:

- chuck head feed
- chuck head rpm
- number of spring bars
- bracing pressure and
- plunger pressure high/low

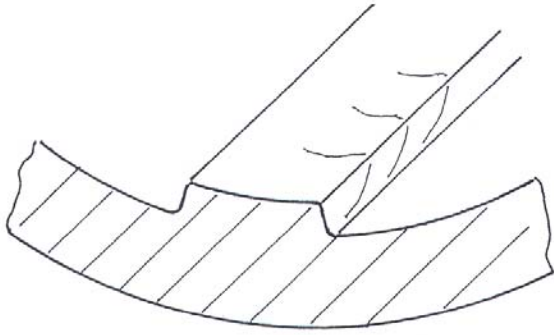
#### Practical Sequence:

During the first test only a short caliber length of the barrel is forged. Already during forging the first 50 - 100 mm the driver has to be checked as to its vibrations. If the chuck head driver vibrates too strongly, the chuck head speed should be reduced. Also, the number of spring bars might have to be corrected. After a short forging length the process is interrupted. The marks of the imprints of the driver points on the barrel are checked. The imprints are ideal in case no compression marks show on the left and the right side. The caliber part of the first work piece is checked.

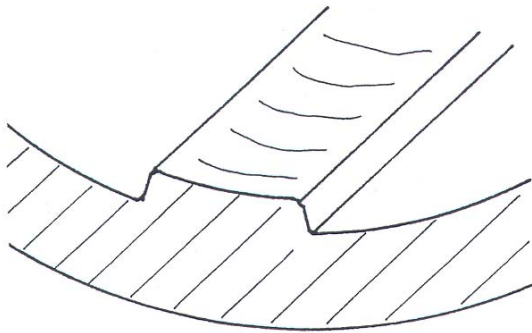
Possible sources of faults:



Leading edge and trailing edge are not adequately forged. This result, however, is ideal for the forging start. With the following trial only the outer forging diameter is reduced. (approximately 0.3 – 0.5 mm).



Trailing edge already forged too much. Outer forging diameter has to be increased.

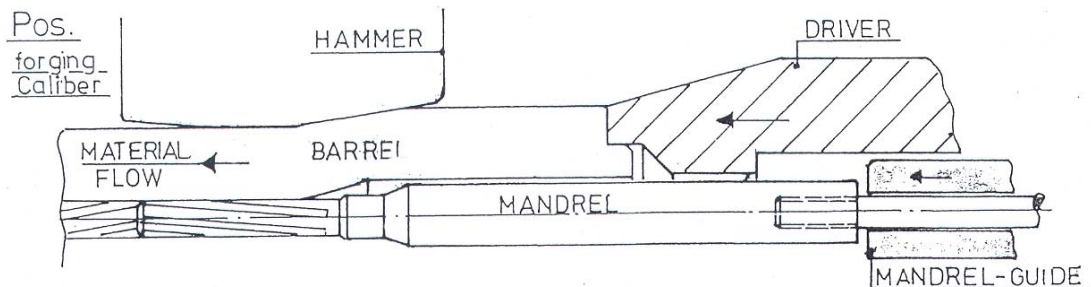


The forging mandrel is positioned too far at the rear; the barrel material is forged over the mandrel and thus causes transversal marks in the barrel. The mandrel must be adjusted towards the front.

Wave-like structure in the groove/land profile. An inadequate wall thickness of the barrel may be possible. Eventually increase cylinder length of the hammer blow face.

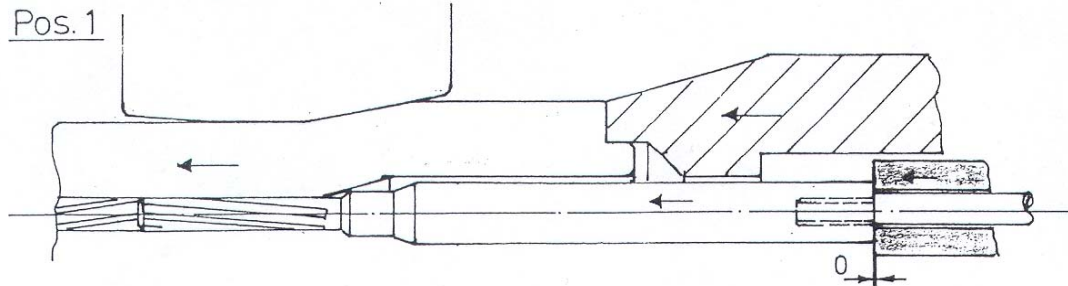
Now the caliber part is properly forged.

Position of the forging tools in the final phase of twist forging:



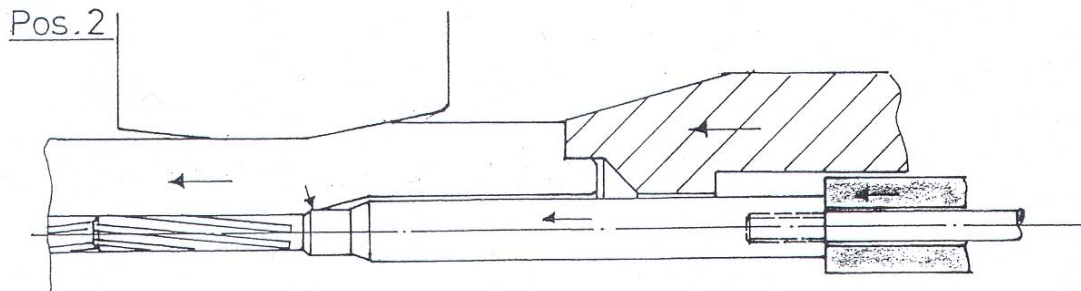
Start of cartridge chamber forging:

1. Position of the forging tools in the phase of mandrel support relative to driving the mandrel.



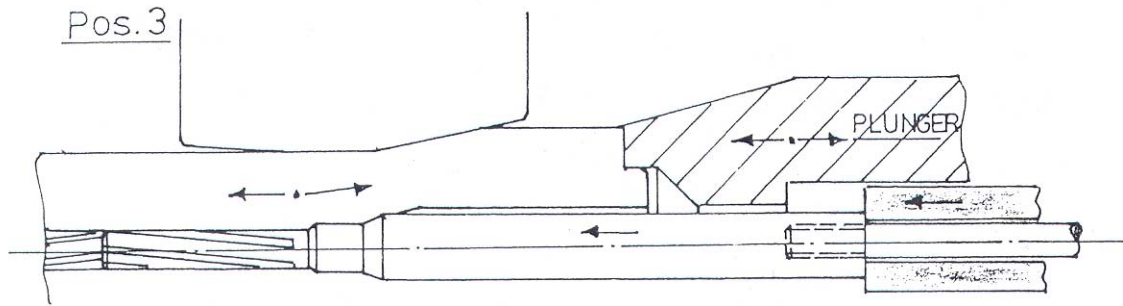
After forging the caliber the forging mandrel is moved forward towards the chuck head by means of the mandrel support through the chuck head. The chuck head position is defined at the moment the forging mandrel coincides with the mandrel support. This position is the basis for the following program.

2. Position of the forging tools in the phase of plunger pressure switch-over.



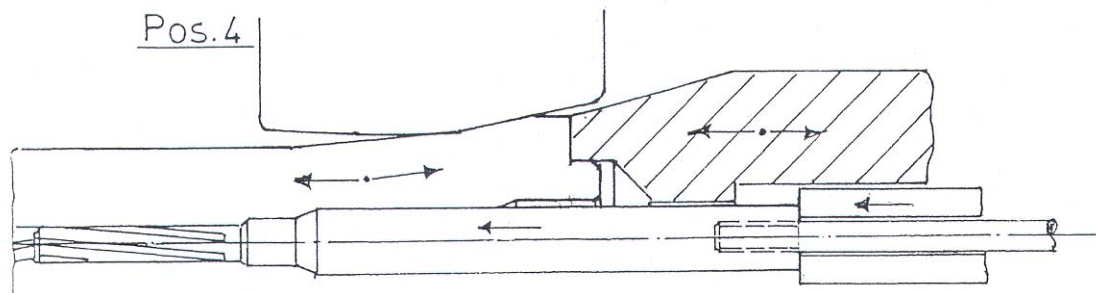
Before the plunger is switched over to low pressure, the position of the chuck head has to be found where the small mandrel shoulder edge finds support in the barrel (see arrow). The pressure switch-over is effected approximately 12 to 16 mm after the point where the mandrel is driven. The low plunger pressure shall be selected in relation to the bracing pressure in such a way that during the forging process the driver with the barrel can evade into the plunger cylinder not by jerks but in a continuous movement. This position is the key position for any correct cartridge chamber forging. In practice this position is checked in such a way that at the moment of switch-over from high to low plunger pressure the forging sequence is stopped. By means of an endoscope the barrel is now examined, that means whether in this phase the small shoulder has already been finish forged. If this finish forging cannot be observed, the switch-over point of the plunger must be programmed at a later time. If, however an overfilling shows in form of rings on the small shoulder then the switch-over point of the plunger has to be chosen earlier.

3. Position of the forging tools in the phase of forging the cartridge chamber.



Once the plunger pressure is switched to "low" the forged barrel material is not moved totally to the direction of the counter holder as so far, but it may partly evade towards the chuck head and thus forging the cartridge chamber is made possible. To fill the transition radius from the neck to the big shoulder normally is the most difficult task.

4. Position of the forging tools in the phase of forging the powder bag.

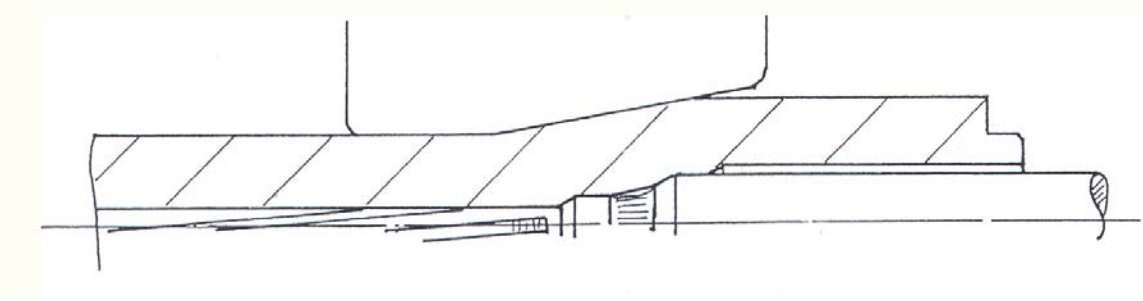


When the big shoulder is filled the hammers are opened at once or continuously up to the end of the cartridge chamber. The reduction over the powder bag is rather low, just as much that the material has contact with the big mandrel diameter.



### 5.) Various pictures of cartridge chambers, defects and their elimination:

Twist run-out with transversal marks, big shoulder not full:



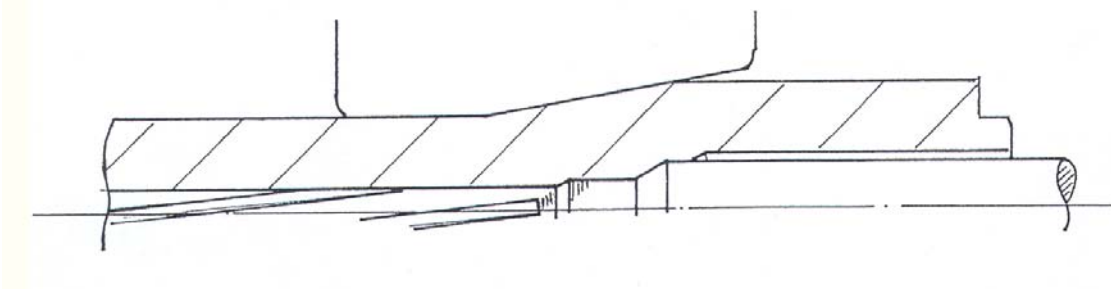
#### Observations:

The "low" plunger pressure has come into effect too early after the support. The twist run-out as well as the big shoulder do not get sufficient material.

#### Remedy

Switching of the "low" plunger pressure has to be done 2 - 3 mm later. The forging diameter could be reduced as long as the groove/land area is not damaged. The hammers can be opened later.

The twist run-out with the small shoulder is overfilled, the big shoulder is intensely started to be forged:



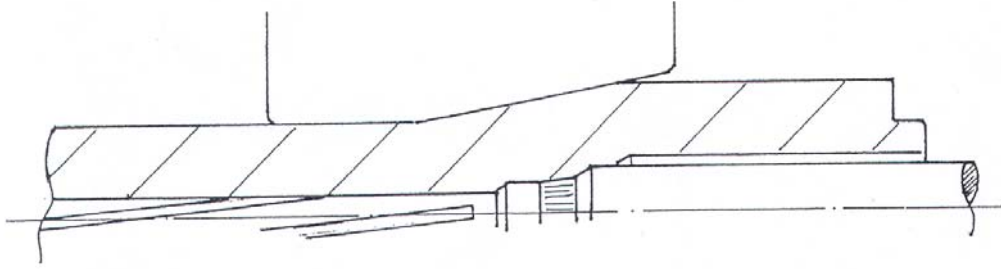
#### Observations:

Switching of "low" plunger pressure as well as "hammers open" is done too late. Too heavy accumulation of material at the small shoulder.

#### Remedy

Switching of "low" plunger pressure must be done earlier. Switch point of "hammers open" must come earlier. The forging diameter can be increased - if groove/land area remains acceptable.

Twist run-out and small shoulder are acceptable, only the big shoulder is not complete.



Observations:

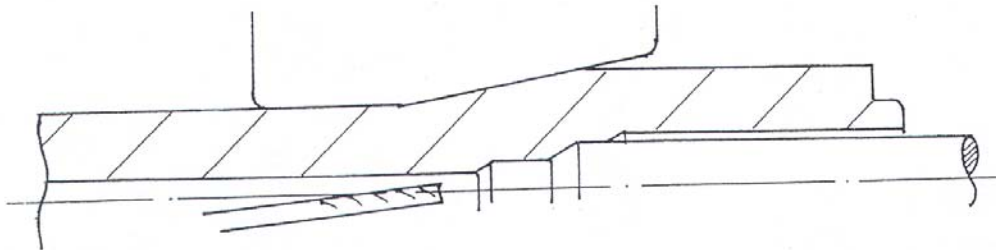
In this case the big shoulder could not be filled since the "hammers open" position has been switched too early!

Remedy

Switching "hammers open" must be done later. Normally in case of an ideal hammer shape the chuck head has to be advanced until the big shoulder is finish forged.

If, however, in this sequence the small shoulder and the twist run-out are damaged before the big shoulder is full, then the hammer shape should be modified.

In the ultimate range the trailing edge is damaged by strong marks:



Observations:

Slight over forging in twist run-out. While the mandrel is driven the rotation movement of the mandrel is reduced. The trailing edge of the mandrel can only be detached with difficulty (especially in case of a small pitch of the twist).

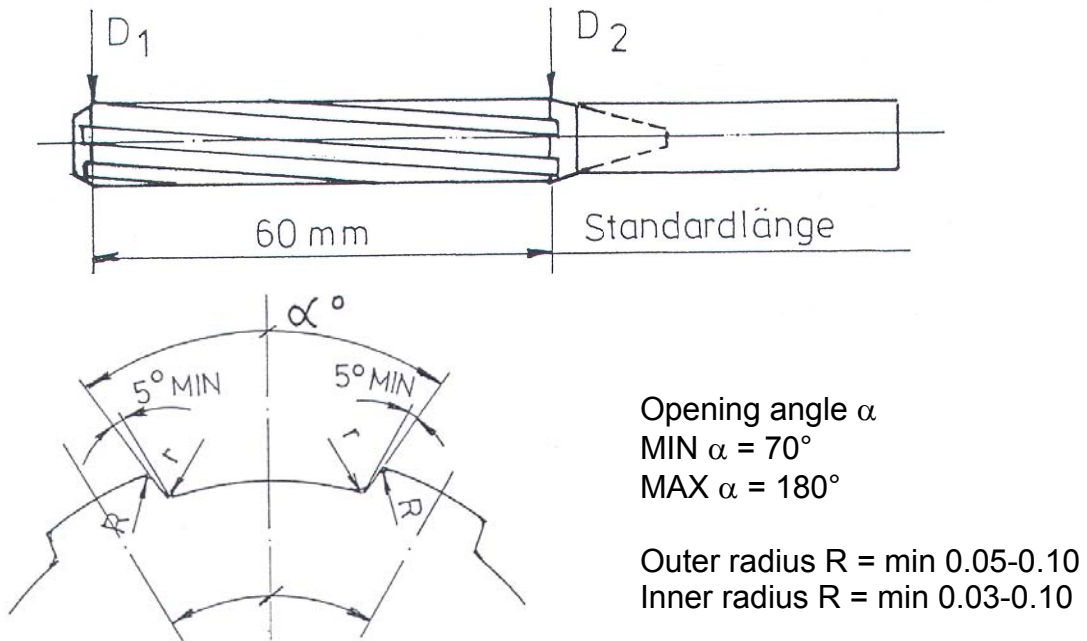
Remedy

The hammer shape should be opened slightly in the twist run-out area. Slightly polish the trailing edge on the mandrel (only the run-out). Check mandrel rod as to its smooth movement.

**6.) Layout of forging mandrels for barrels with and without cartridge chamber:**

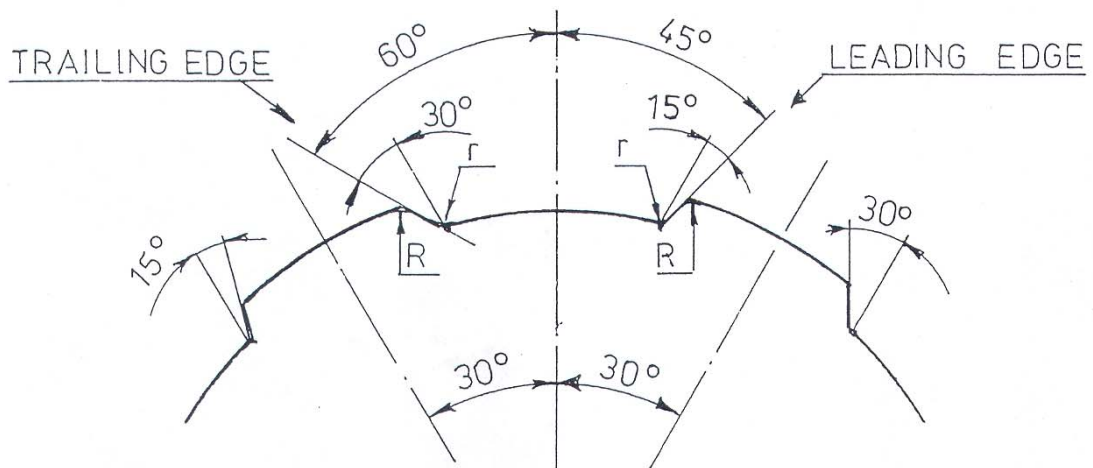
Mandrel design without cartridge chamber:

Diff. D1 to D2 = 0.1 – 0.15 mm

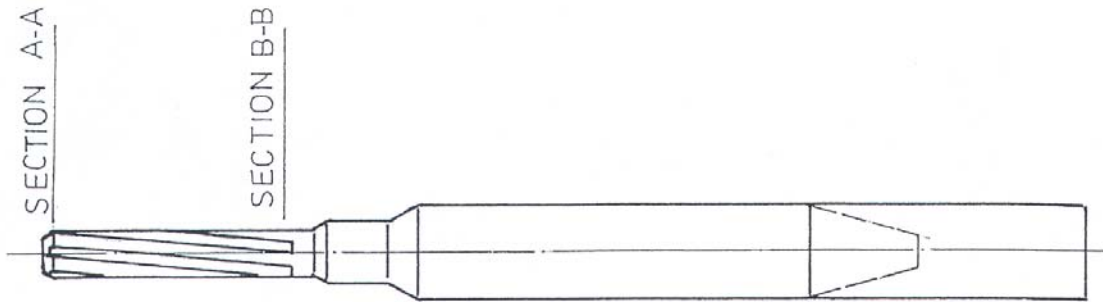


The opening angle of the trailing edge can be superior to the opening angle of the leading edge. This design of the mandrel facilitates forging and does not render any precision disadvantage when shooting with the barrel. When forging a barrel with a "right" twist the barrel material will always lay against the leading edge without problems. With the trailing edge it is contrary, the material will always move away from this edge. Therefore, it is of advantage to realize this flank angle as big as possible.

Example of a mandrel design with different flank angles cal. 5.56, 6 grooves, pitch 7", 10" or 12".

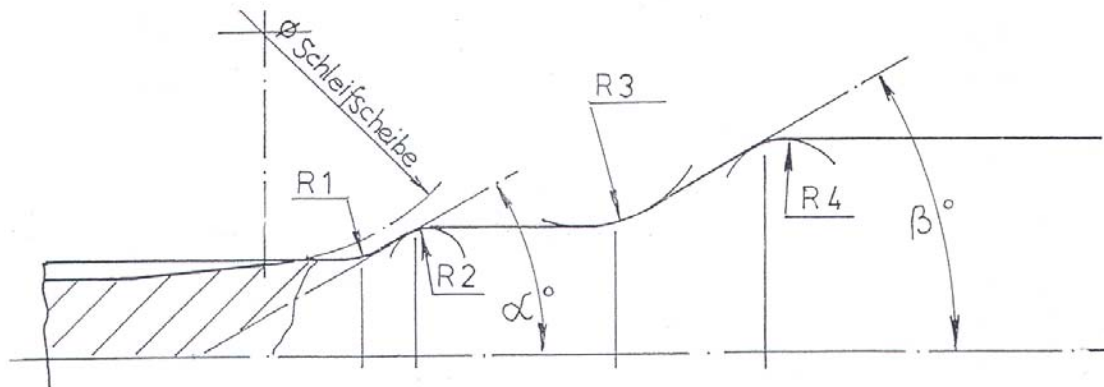


Mandrel design with cartridge chamber.



The caliber part is designed in such a way that in the section A-A range the mandrel dimension corresponds to the desired caliber dimension in the barrel. E.g. Caliber in the barrel  $5.56 + 0.03$  effectively desired caliber dimension shall be 5.56.

Mandrel dimension in the range of section A-A  $5.565 \pm 0.005$ . With this example the mandrel dimension in the section B-B is calculated with  $5.590 \pm 0.005$ .



Today it is possible to grind the twist run-out on the forging mandrels by means of CNC grinding machines exactly to requirements. Mostly limited by the small shoulder - the twist run-out is produced in form of a bag.

The diameter of the grinding disc for grinding the twist varies between  $\text{Ø } 10$  and  $\text{Ø } 25$  mm depending on the form of the desired twist run-out.

The transition radius R1 running from the caliber part to the small shoulder should not be inferior to 0.5 mm for reasons of forging technique. The shoulder angle  $\alpha$  can amount to maximum  $45^\circ$ ; in view to the forging technique, however, it would be advisable if this angle did not exceed  $30^\circ$ .

The transition radius R2 (small shoulder to neck) normally amounts to 0.5 mm.

The dimension of the neck range on the mandrel mostly is produced with the minimum dimension, since during the cartridge chamber forging one achieves a slight increase (+ 0.015 mm) due to the hammer shape.

The transition radius R3 from the neck to the big shoulder shall not be inferior to 2.5 mm - any smaller radius would be difficult to fill.

The transition radius R4 from the big shoulder to the powder chamber is generally produced with 0.5 – 0.8 mm.

The mandrel diameter in the powder chamber after the big shoulder normally is designed 0.01 mm smaller than indicated by the cartridge chamber dimension, for the reason that when forging the big shoulder the cartridge chamber is slightly pressed open.

In case of the cartridge chamber mandrel the shaft attached by hard-soldering must have a hardness of HRc 50-54, because with cartridge chamber forging (especially during the pressure change plunger high/low) a high axial pressure is exerted onto the mandrel.

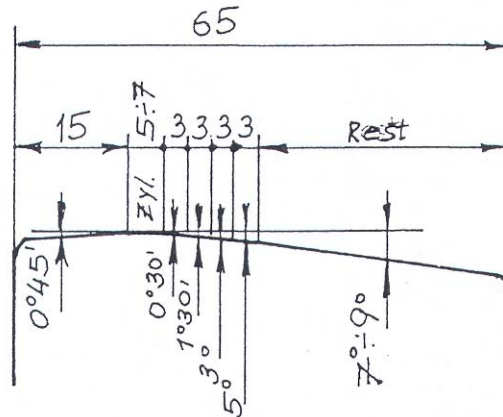
The stop face of the mandrel shaft must be adjusted exactly in a right angle; otherwise, the mandrel would not be guided concentrically during cartridge chamber forging and consequently would not allow an impeccable forging result.

The concentrically produced thread for the mandrel holder is of great importance.

**7.) Layout of hammer blow face for barrels with and without cartridge chamber:**

7.1) Shape of hammer blow face for barrels without cartridge chamber

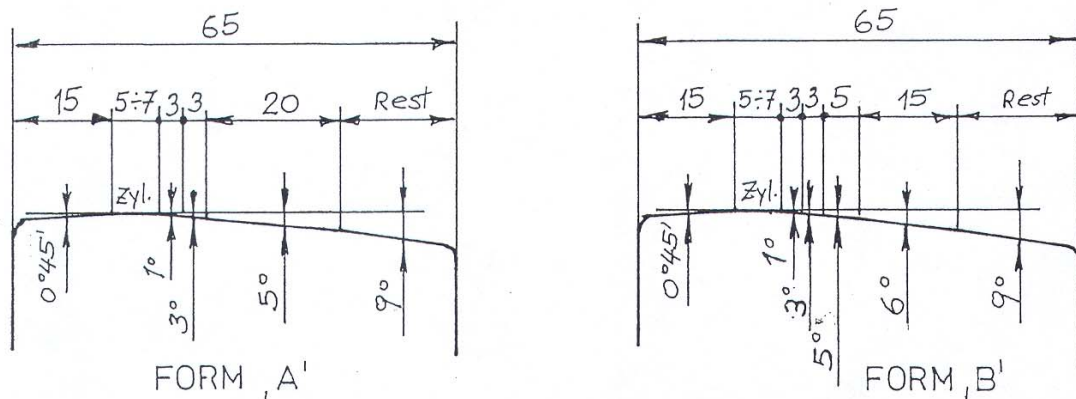
7.2.1) Standard shape for cylindrical barrel (blank bore 0.2 mm – 0.5 mm superior to maximum mandrel diameter.)



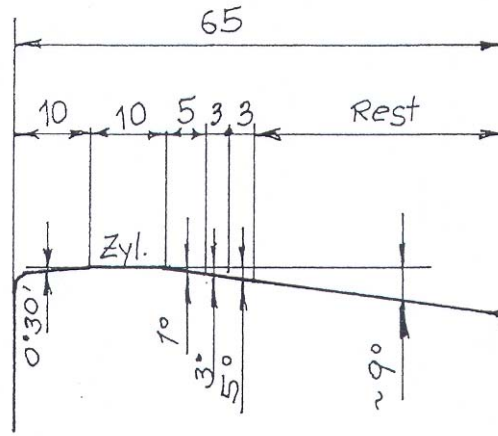
Cylinder length of the hammer blow face shall be adjusted to the pitch of the twist. The smaller the said pitch the smaller the cylinder length of the hammer blow face.

When forging extremely thick-walled tubes it is recommended to manufacture one hammer pair each higher by 0.05 mm. The filling effect thus created shall more easily detach the forging mandrel from the barrel material during the forging process.

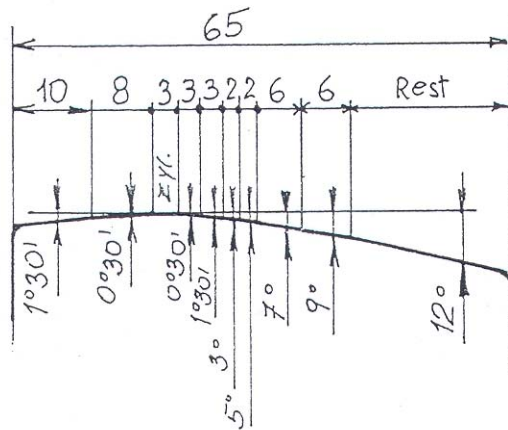
7.2.2) Standard shape for cylindrical barrel (blank bore 0.5 - 3 mm superior to maximum mandrel diameter.)



7.2.3) Shape of hammer blow face for conical barrel form:

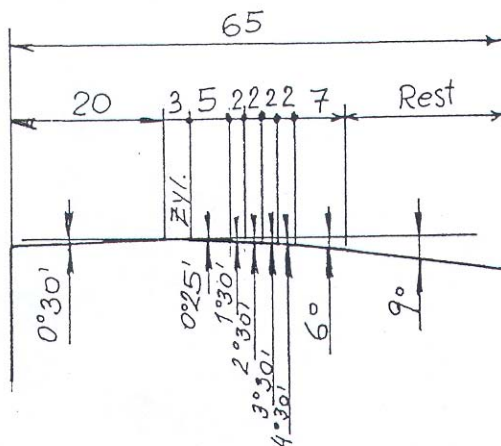


This entry angle on the hammer shall be approx.  $0^{\circ}30'$  superior to the taper angle on the forged barrel. The cylinder on the hammer acts as a hammer run-out with the conical barrel.



Proven hammer shape for conical barrel type, where on the side of the cartridge chamber a steep transition is finish forged.

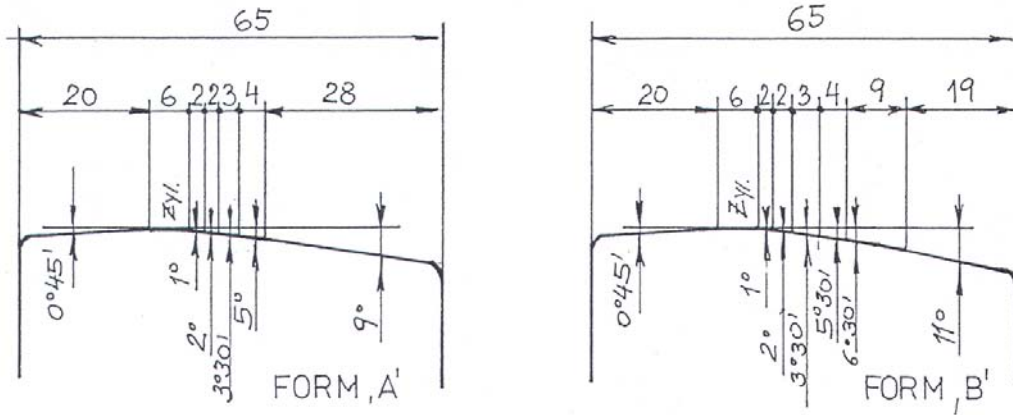
7.2.4) Shape of hammer blow face for pistol barrel:



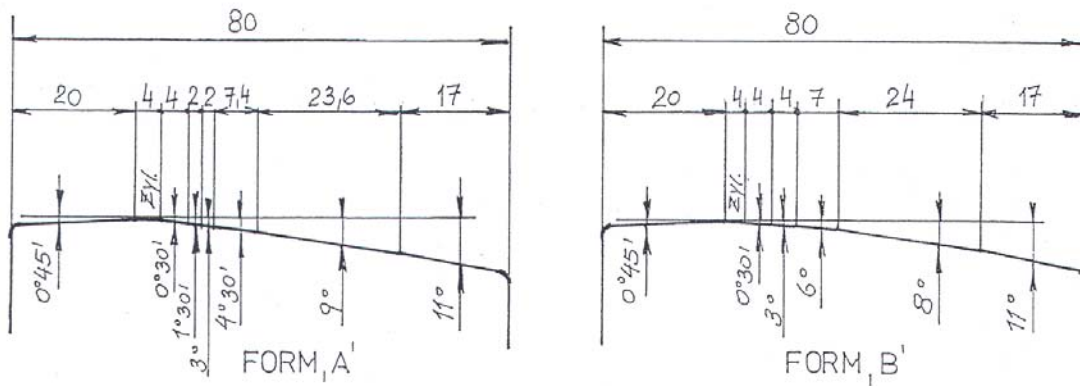
Proven hammer shape for pistol forging. The forging diameter amounts to approximately 21 mm.

7.2) Shape of hammer blow face for barrels with cartridge chamber

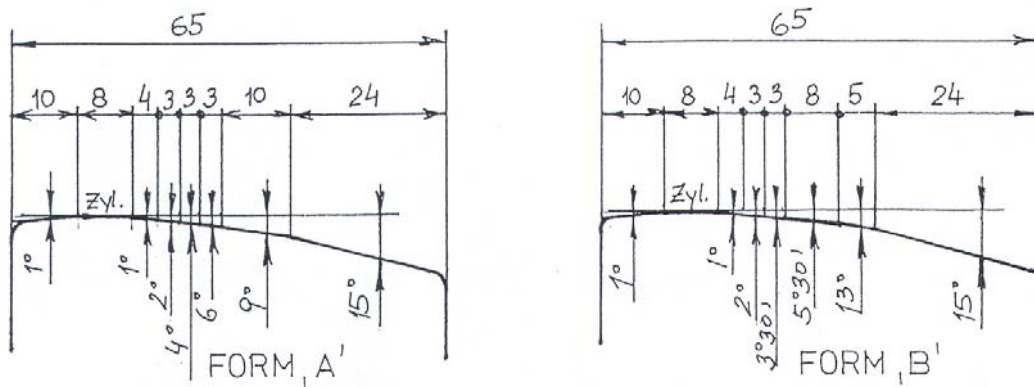
7.2.1) Barrel caliber 5.56 cylindrical blank  $\text{Ø}27.5 / \text{Ø}9.9$  forged  $\text{Ø}21.5\text{mm}$ .



7.2.2) Barrel caliber 5.56 cylindrical blank  $\text{Ø}39.51 / \text{Ø}9.9$  forged from  $\text{Ø}29.5\text{mm}$  maximum dimension for 5.56 with cartridge chamber.

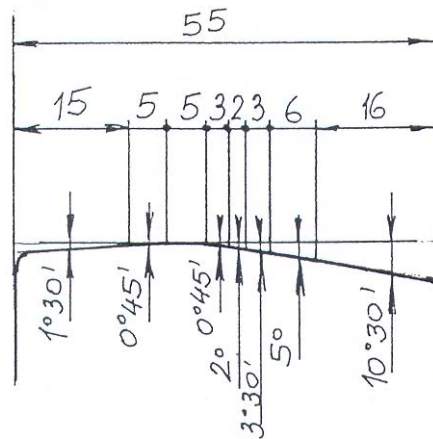
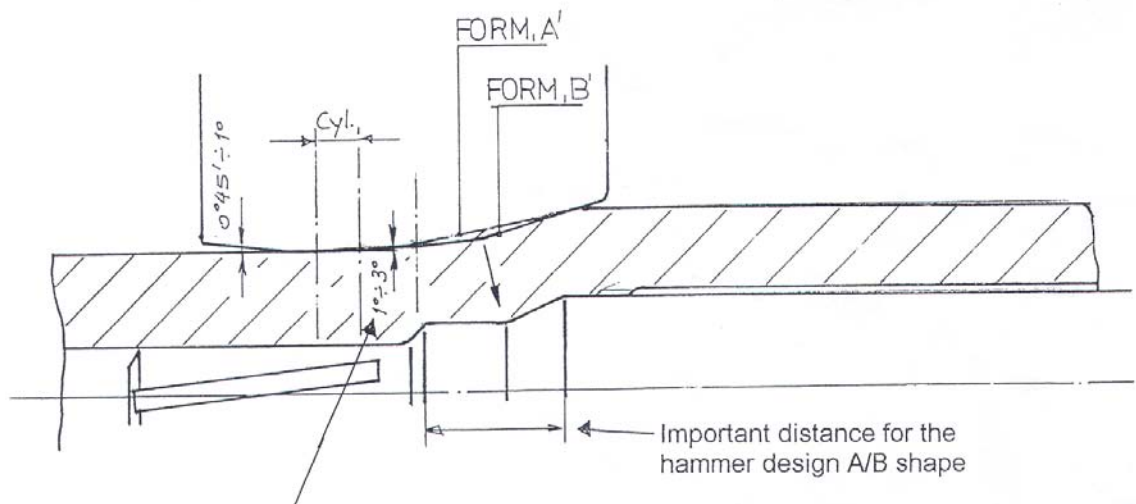


7.2.3) Barrel caliber .308 Win (7.62) slightly conical, forging  $\text{Ø}$  approximately 18 to 24mm.





## 7.2.4) Pistol barrel caliber 9mm with small shoulder.

**Hammer design:**

In this range already on the hammer a small entry angle should exist, to ensure that at the twist run-out not too much material is accumulated.

As it is shown in the above picture the cylinder range of the hammer blow face should be situated in the area of the twist run-out. Towards the small shoulder there will be a flat opening angle of  $1^{\circ}$  to  $3^{\circ}$ . Over the neck range the entry angles of the shapes A respective to B still vary slightly with approximately  $4^{\circ}$  to  $5^{\circ}30'$ , in order to allow to keep the diameter tolerances in the neck range. In the following the entry angle opens differently between the A and B shape, depending on the type of cartridge chamber. In spite of this different A respective to B shape the designer has to take care that when starting to forge the blank the impact of all four hammers should possibly be performed simultaneously.

**Editor's Notes:**

GFM is the largest supplier of hammer forging machines worldwide with equipment dating back to 1946 ([www.agfm.com](http://www.agfm.com)). The author of this book, Mr. Werner Augustin, was employed for 30 years by GFM as an engineer and cold forging specialist. In 1993, Mr. Augustin founded Augustin GmbH based in Steyr, Austria. The company specializes in tungsten-carbide tooling sales and consulting in cold forging processes. Hence, the author has vast experience in the tooling and processes used to cold forge rifle barrels. Mr. Augustin kindly gave permission for this book to be posted on an open website for all interested parties to share. A copy of the original book was scanned and lightly edited by Professor James B. Higley, Purdue University Calumet, [higley@calumet.purdue.edu](mailto:higley@calumet.purdue.edu) in early 2006.