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PROGRESSIVE TECHNOLOGIES OF FORGING LARGE PARTS WITH RESPONSIBLE DESTINATION

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The technological features of forging the main types of forged pieces in the monograph, which are often manufactured on hydraulic presses with a shorter length of waste for plates were considered; the production of crankshafts with reversal of crank in the process of forging; the principal issues of developing technology for forging hollow spherical forged pieces were stated; many other technical processes of forging large forged pieces were described, taking into account the latest advances in inventions and new technological solutions. The technological processes, which were developed by technologists of the Bureau of Large Forged pieces, which were applied to the production conditions of the machine-building plant for the needs of heavy engineering in this monograph were used.

The monograph can be used as a textbook for undergraduates and bachelors in relevant specialities.

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CONTENTS

INTRODUCTION

A big variety of forged pieces for steel grades and molds with various cross sections and lengths are made in the forge shops.

It includes the following types of forged pieces in most cases: smooth round and rectangular cross-sections, round and square cross-sections with ledges, cylinders with holes, rings and bandages, gears and discs with holes and without holes, etc. The product range listed above is certain groups of forged pieces, similar in forging pattern and configuration. It makes it possible to consider and study the technological features of various forged pieces and it is quite logical to further improve the production of large forged pieces in hydraulic presses. Recently, the main direction becomes increasingly hot-top to receive forged pieces that are similar in shape and size to the finished parts. This problem is solved by using specialized forging tools for forging and stamping, using washers and dies of various shapes, narrow anvils for both forging and rolling-off forged pieces, blades of various shapes (cylindrical or triangular), linings, etc., and also due to the manufacture of individual forged pieces with relatively small allowances and a smaller tolerance field when achieving increased ductility of the metal, which can be achieved with combined modes of forging and heat treatment. At the same time, it is necessary to consider the experience and achievements of leading enterprises in improving the production of large forged pieces when developing technological processes and the rational consumption of metal and improving the quality of manufactured products [1].

SECTION 1
CHOICE OF INITIAL INGOTS FOR FORGING BY HYDRAULIC PRESS

The source material for forging is the blacksmith ingots. Due to the directional solidification of the ingot, its internal structure in cross-section and length is distinguished by the heterogeneity of the metal and includes a surface fine-crystalline layer of the ingot, a layer of columnar dendrites, and a zone of uniaxial dendrites [2; 3]. Thus, in the middle of the ingot, a large dendritic structure with equiaxed dendrites is obtained.

Therefore, it is important to determine the optimal size of the forging ratio, when designing forging technological processes, in which the dendritic structure of the ingot is destroyed, and the dendrites are crushed and extended in the direction of the main deformation. According to the literature data [4], the middle part of the ingot acquires a fibrous structure after a 2 ... 3-fold forging ratio, while the columnar dendrites only begin to deviate from the original direction. The macrocracks present in the middle of the ingot are welded during forging and the metal is compacted. The compaction and improvement of the quality of the axial part are significantly affected by the taper of the ingot, where with increasing taper the axial part of the ingot increases significantly. Moreover, the ratio of the height of the ingot (H) to its diameter (D) has a greater effect. In ingots with a ratio $H / D \approx 1.0$, axial defects are practically absent and they are widely used for the manufacture of forged pieces of critical parts such as large rotors of turbines and generator shafts, etc., or for casting large ingots weighing 300 ... 500 tons [5; 6]. The high taper ingots with the ratio $H / D = 1.5 \ldots 1.6$ also contribute to improving the quality of the axial zone and are used in the manufacture of critical forged pieces for welded rotors and disks of turbines and other products. The normal ingots with the ratio $H / D = 2 \ldots 2.5$ are widely used in industry. When forging such ingots, high-quality forged pieces are ensured. The ingots with the indicated ratio can be made up to 200 tons in weight from carbon, alloy, and high alloy steel grades.

Many enterprises use elongated and non-hot top ingots, etc., besides specified ingots. Using elongated ingots in the forge and press production significantly increases the output fit and reduces the consumption of metal in the manufacture of forged pieces. The elongated ingots can be used for forging hollow forged pieces such as rings, cylinders, bushings, etc., disks with holes and shafts with an extended axis, etc. A noticeable reduction in metal consumption can be achieved by using non-hot-top ingots due to the use for each forged piece of ingots of the required mass, i.e., they cast the required portion of liquid metal into the ingot mold without hot top extension [7]. It should be noted that the absence of an insulated part of the ingot mold leads to a noticeable deterioration in the quality of the axial zone of the ingot, especially in its upper part. Therefore, it is advisable to cut such ingots during forging concerning hollow forged pieces into two or more billets, and billets obtained from the upper half of the ingot should be stitched with a larger piercing punch diameter than the diameter when piercing punch the holes of previous billets.

During forging one workpiece from an ingot, one should be guided by the technical solution [8], which improves the quality of the obtained forged pieces due to the displacement of the shrinkage cavities from the ingot into waste and compaction of the axial zone of the ingot. To achieve this result, the ingot after billeting is drawn in cut-out anvils in the direction from the bottom to the top with a degree of deformation of the latter of at least 20 %. Moreover, this deformation is achieved by the fact that the ingot should be cast into the ingot mold one or two sizes larger than the ingot mold is provided according to the normal of the plant for casting this weight of the ingot.

The electroslag remelting ingots for the manufacture of high-quality forged pieces are used. Such ingots have a high density and low content of non-metallic inclusions and gases in the metal. However, electroslag remelting is an expensive process, and the significance of its use has recently decreased markedly. It is because steel smelting is currently carried out mainly in electric arc furnaces with its subsequent processing in a ladle furnace to a sulfur content of less than 0.01 % in the metal, and casting into the mold is carried out using vacuum degassing in a stream (vacuum below 1.0mm Hg), which significantly improves the quality of the original ingot by reducing non-metallic inclusions and gas saturation of steel. In recent years, in metallurgical engineering in the total production of forged billets, forged pieces from ingots are 65…70 %.

SECTION 2
USING OF FORGING WASTE IN STEEL PRODUCTION AND REDUCING OF ELECTRICITY CONSUMPTION DURING STEEL MELTING IN ELECTRIC ARC FURNACES

As known, in the forge shops, the waste (ingots bottom, hot-top, and part of the suitable residue) which are obtained after forging the ingot and chopping the forged pieces are inevitable technological waste, which is transferred after cooling to the workshop temperature to the pile mill for the conversion of the charge or to the steel mills for remelting for its intended purpose. In metallurgical production in conditions of a shortage of energy, gas, fuel oil, etc., energy saving is a paramount task. Concerning, this section discusses an unconventional method of using hot forging waste for steel smelting in open-hearth or electric arc furnaces. First of all, it is necessary to solve the organizational issue of the timely transfer of waste in the hot state from the forging shops to steelmaking and their mandatory use in smelting. In this case, it is necessary to plan group steelmaking for a certain period from waste and with a similar chemical composition or with a subsequent increase in the content of alloying elements.

It should be noted that the most important indicators in the production of steel are daily productivity and fuel consumption per 1 ton of smelted steel. So, for example, at present, in steel mills in machine-building plants, fuel consumption reaches 320 kg. at. t. per 1 ton of steel smelted. When forging waste is used in steelmaking directly after forging, the fuel consumption coefficient can be calculated by the formula

$$Q = 320(Tm - Tc) / Tm$$

where Tm – metal melting point, 1 500°C;

Tc – forging waste temperature, 600°C;

320 – planned fuel consumption rate in the steel mill.

As a result, we will get Q = 192 kg. at. t., therefore, the solution to the above production problems, even when using blacksmith waste having a temperature of 600 ... 700°C on the surface, which is considered cold, will allow for the production of steel in the amount of 50 000 tons to get an economic effect of about $ 1 million per year [9].

Besides, the technical solution to reduce the energy consumption during steelmaking in electric arc furnaces deserves special attention due to the pre-heating of the metal charge in a flame furnace to 700°C, which reduces the duration of its heating and melting in an electric arc furnace. In this case, the specific costs of heating and melting the metal charge, its preheating temperature, and the melting temperature of the mixture are related

$$Q = K(Tm - Tp) / Tm$$

where Q – unit electricity consumption per 1 ton of liquid steel;

Tp – metal charge preheating temperature, 700ºC;

K – the planned coefficient of energy consumption per 1 ton of steel, K = 700…800 kW / h.

The temperature of the pre-heating of the metal charge, which components 700ºC, is optimal for maximum heat transfer. With the increasing heating temperature of the charge, the heat transfer coefficient decreases, which leads to excessive consumption of fuel.

Based on the equality indicated in the formula, we determine the specific cost of electricity when heating and melting a metal charge in an electric arc furnace per 1 ton of smelted steel

$$Q = 800(1\,500 - 700) / 1\,500 = 426.6 \text{ kW / h}$$

Considering the approximately equal cost of 1 kWh and 1 m^3 of natural gas, we determine the energy savings per 1 ton of steel produced

$$(800 - 426.6) - 123 = 250 \text{kW / h},$$

where 123 is the consumption of natural gas when the mixture is heated in a flame furnace to 700°C.

Compared with the above coefficient of energy consumption per 1 ton of steel, equal to = 800 kW / h, we get a new specific rate of electricity per 1 ton of steel

$$(800 - 250) = 550 \text{kW / h}.$$

Thus, the efficiency of the method is ensured by a significant reduction in energy consumption. Based on the foregoing, it follows that in steelmaking workshops it is advisable to have heating furnaces of the mine type, this is especially important for the operation of steelmaking shops in the winter.

SECTION 3
FEATURES FORGING OF INGOTS

In the processing of metals by pressure, the manufacture of large forged pieces is more advisable to produce on the press than on the hammer. Due to the low rate of metal deformation during forging on presses, softening processes, recovery and recrystallization occur more fully and hardening is removed [10]. It is necessary to choose the appropriate forging ratio during the development of forging technology, which depends on the grade of material, type of ingot, technical conditions for the supply of forged pieces, and forging methods. The forging ratio and the degree of upsetting are recommended to take in the following limits:

- when billeting the ingots of normal form У = 1.1…1.2;
- with ingot upsetting У = 2.0 (50 %);
- when drawing ingots after upsetting У = 2.0;
- when forging ingots of carbon steel grades, a sufficient amount of forging ratio is considered from 2.0 to 2.5;
- when forging elongated ingots, which have a better initial structure, a sufficient forging ratio is from 1.8 to 2.0;
- when forging on the mandrel is not less than 1.5.

It is necessary to strive for the maximum shaping of the billet when performing procurement operations, while it is recommended to navigate with the following:

- when forging according to the scheme circle → circle = 2.5;
- when forging according to the scheme "circle → square → circle" or "square → square", "circle → plate → circle", "plate → plate" = 1.8.

A sufficient amount of forging ratio for medium-alloyed and high-alloyed steel grades, depending on the weight of the ingot, is considered to be from 2.5 to 3.5, the elaboration of the structure of the ingot during drawing depends not only on the size of the forging ratio but also on its initial state, which largely determines the subsequent forged pieces material quality. Moreover, the quality of the original ingot depends on the type of ingot (regular, elongated, etc.) and the method of smelting it. In turn, the type of ingot and the method of melting depends on the purpose and responsibility of the forging. In addition, the quality of the forged pieces also depends on the weight of the ingot used. For critical parts, forging is made from an ingot for one forging. When forging general-purpose forged pieces, the mass of the ingot and the number of forged pieces obtained from it are selected considering the lowest metal consumption. After selecting the ingot, the value of the required forging ratio and the force of the press to obtain high-quality forged pieces are specified. As a rule, responsible forged pieces are made with ingot upset. The required press force for settling ingots is determined by known formulas. This calculation is associated with the search for reference values ($\sigma_В$, σ_S), which leads to certain losses of time when designing technical processes for forged pieces of the ingots.

It is advisable to be guided by the so-called specialization forging of ingots on presses (Table 3.1) in determining the required press force to facilitate calculations, where the maximum upsetting dimensions of the largest mass of the ingot under the press are predetermined, i.e., the nominal press forces are specified during the operation of the press. Therefore, the upsetting force will be much less than with the upsetting of the largest ingot for the rest of the ingots, which are smaller in mass. Concerning, it eliminates the need to calculate the required press force for the processed ingots with upsetting under the press and, accordingly, a reference search of the indicated values.

Table 3.1 –Specialization of ingots forging on presses

Press force, MN	The processed mass of the ingots, t	Maximum ingots upsetting	
		by weight, t	in diameter mm
10	1.0…5.0	2.5	600
25	2.5…15.0	8.0	1 200
32	9.0…30.0	20.0	1 500
50	20.0…80.0	50.0	2 000
100	50.0…200.0	130.0	2 800
150	80.0…350.0	200.0	3 300

The data which is given in table 3.1 are distributed for ingots of carbon and medium alloyed steel grades. It is recommended to determine the required press force by the formula for ingots forging of the tool, high alloy steels, and alloys with upset [11]

$$P = f\left(1 + 0,17\, {D_1}/{H_1}\right) \cdot \sigma_s \cdot F,$$

Where f is the maximum coefficient, the input of which is caused due to the uneven temperature of the metal over the cross-section of the ingot during its upsetting (Table 3.2) and thereby allows us to determine the actual value σ_s;

D_1 и H_1 are diameter and height of the billet after upsetting, mm:

$$D_1 = D_0\sqrt{\frac{H_0}{H_1}},$$

where H_0 and H_1 – are height before and after upsetting workpieces;

σ_s – is resistance to deformation of the metal at the temperature of upsetting, approximately equal to the tensile strength at the same temperature, MPa;

F – is the cross-section area of the forged pieces after upsetting, mm^2.

Table 3.2 – The value of the scale factor in the upsetting

Ingot mass, t	0.5	6.0	20.0	50.0	100.0
f	0.80	0.70	0.60	0.65	0.50

Table 3.3 – Temporary tensile strength of steel at forging temperatures (approximately) MPa

Depending on the tensile strength at the normal temperature (according to Schneider)						
Temporary resistance at room temperature, MPa	Temperature, °C					
	800	900	1 000	1 100	1 200	1 300
400	66	45	36	22	19	14
600	111	75	54	36	22	20
800	165	111	75	54	36	24
1 000	230	159	109	68	50	30

Example. Determine the pressing force required for upsetting a billet of steel with $\sigma_s = 600$ MPa with the initial dimensions $D_0 = 740$ mm, $H_0 = 1\,200$ mm to a height $H_1 = 600$ mm. The deformation resistance of steel at the temperature of upsetting $\sigma_s = \sigma_B = 22$ MPa, $f = 0.75$.

1) Average diameter after upsetting

$$D_1 = D_0\sqrt{\frac{H_0}{H_1}} = 700\sqrt{\frac{1200}{600}} = 1045.$$

2) The cross-section area of the forged piece after upsetting, mm²

$$F = \frac{\pi D_1^2}{4} = \frac{3{,}14 \cdot 1045^2}{4} = 860000$$

3) Press force

$$P = 0{,}75 \cdot \left(1 + 0{,}17 \cdot \frac{1045}{600}\right) \cdot 22 \cdot 860000 = 18400000\ \text{N},$$

i.e., a press of the 20 MN order.

It is necessary to consider the reduced technological plasticity of the metal at the end of forged pieces. Therefore, it is necessary to leave as little as possible the volume of work performed in the last heating in the forging technologies, as well as to choose the shape and size of the anvils correctly.

It is preferable to draw in cut-out anvils with a limitation of the amount of compression per stroke of the press and the relative feed rate within 0.5 ... 0.8, regardless of the shape of the anvils during forged pieces from hard-to-deform steels.

3.1 Drawing operation

The upsetting operation is the main form-changing operation for the production of smooth plates and stepped shafts, hot and cold rolled rolls, back-up rolls, eccentric shafts, crankshafts, and many other products [12].

The flat anvils in the manufacture of a forged piece of square and rectangular sections are used. Forging of such forged pieces is carried out either in parts, at the same time only individual sections of the billet are deformed in a certain sequence or passes, successive compression of the billet to a given size. The width of the plates is determined by the diameter of the upset ingot. In some cases, after precipitating the ingot, the billet is accelerated to the width of the forged pieces B (Fig. 3.1) when the diameter of the upset ingot is less than the width of the forged pieces.

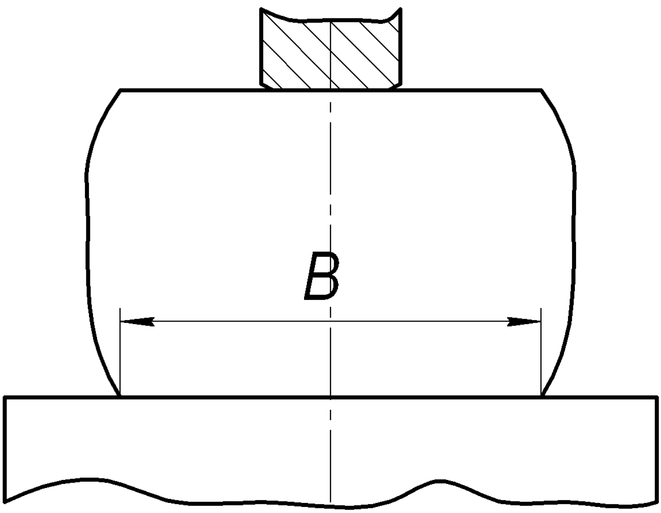


Figure 3.1 – Scheme of the acceleration plate

Wherein, before the acceleration, the upsetting ingot is installed on the lower plate along the upper anvil, after which it is accelerated to the desired width with a pitch of 180°. At the same time, during forging plates with a relatively small width, such forged pieces are produced without ingot upsetting. The minimum diameter of the ingot required to obtain the geometric dimensions of the forged pieces is determined by the formula

$$D_{min} = 0{,}83H + 0{,}65B,$$

where H and B are the height and width of the forged pieces, respectively (table. 3.4).

This formula has been tested in practice in the manufacture of plates with different sizes for the cross-section of the forged pieces and the preparation of rectangular and square forged pieces with sharp angles have been checked by the total deformation of the ingot, the value of forging ratio, which must be at least 2.0.

It should be noted that during forged pieces forging with a rectangular cross-section, the billet is also broadened if it is pressed with the full width of the anvil. This widening can be used for similar forged pieces if during deformation of the ingot a minimum forging ratio is obtained within 1.8 ... 1.9, then the billet must be reduced only with the full width of the anvil, i.e. when it is necessary to have a large widening, it is necessary to provide a large feed. Conversely, intensive elongation of the billet occurs during drawing operation with relatively lower feeds.

The high-quality billets with a rectangular cross-section are achieved with a relative feed in the range of 0.5 ... 0.8 of the anvil width.

The main technological feature of forging such as plates with flat anvils is the uneven deformation of the metal over the cross-section of the billet, especially in its middle part. This unevenness is expressed in the form of the formation of the forged pieces butt of a convex-shaped form from the bottom of the ingot, which leads to an increase in the consumption of metal. There are the following methods of forged pieces such as plates to reduce end waste and increase the yield of metal, as well as improving the quality of billets through the use of special forging techniques and a special tool.

A more accurate and smooth cylindrical shape of the billet is obtained during the drawing in cut-out anvils. The ductility of the metal increases and the risk of axial crack formation decreases during forging with a cut-out die, due to the creation of a four-focal deformation scheme. Therefore, cut-out anvils are widely used for the forging of low-plastic high-alloy steel and alloys. Forging by cut-out anvils accelerates the process of drawing the billet, limiting the expansion of metal to the sides compared to combined anvils. However, cut-out anvils have a narrow range of diameters of worked forged pieces, i.e., they limit forged pieces in one pair of cut-out anvils, which leads to the decrease in the forging process due to the numerous changes of cut-out anvils.

When drawing workpieces and forged pieces, the combined anvils were widespread (upper – flat, lower – cut-out). The combined anvils are universal because of the wide range of diameters of the manufactured forged pieces in one pair of the anvils. The combined anvils are used as the main tool for large forged pieces. That’s why the schemes of the acting forces arising during the forging of forged pieces in combined anvils depending on the cut angle of the lower anvil are interesting (Fig. 3.2 – 3.5).

Table 3.4 – Formulas for determining the maximum possible cross-section forged pieces, depending on the initial cross-section of the billet

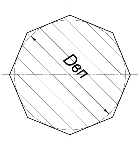
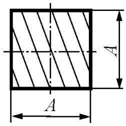
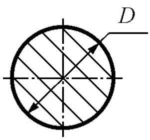
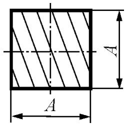
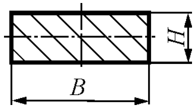
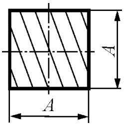
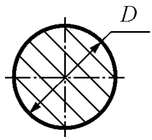
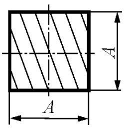
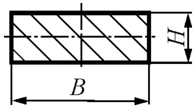
Workpieces cross-section	Forged pieces section	Calculation formula
		$D_{вп} = 1{,}3A$ $A_{max} = 0{,}77D_{вп}$
		$D_{min} = 1{,}48A$ $\left\{ \begin{array}{l} A_{max} = 0{,}68D \\ D = \dfrac{A_{max}}{0{,}68} \end{array} \right\}$
		$D_{min} = 0{,}83H + 0{,}65B$ $B_{max} = 1{,}52D - 1{,}27H$
		$A_{min} = 0{,}97D$ $D_{max} = 1{,}03A$
		$A_{min} = \dfrac{2H + 3B}{5}$ $B_{max} = \dfrac{5A - 2H}{3}$

Table 3.5 – Parameters of cut-out dies

Billet section	Bottom anvil angle, α			
	90°	105°	120°	135°
Components	The magnitude of the components			
X	0.35 P	0.3 P	0.25 P	0.19 P
Y	0.35 P	0.4 P	0.43 P	0.46 P
X / Y, %	35 / 35	30 / 40	25 / 43	19 / 46

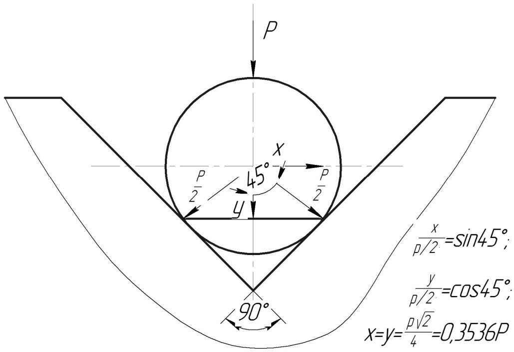


Figure 3.2 – Lower anvil with a cut angle α = 90º

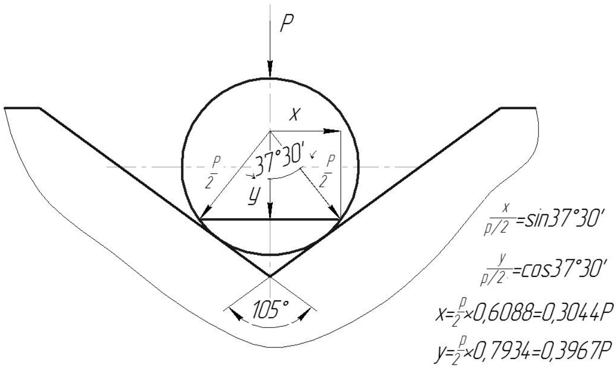


Figure 3.3 – Lower anvil with a cut angle α = 105º

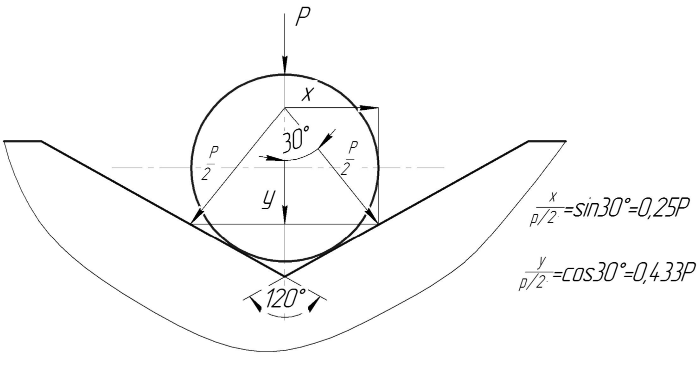


Figure 3.4 – Lower anvil with a cut angle α = 120º

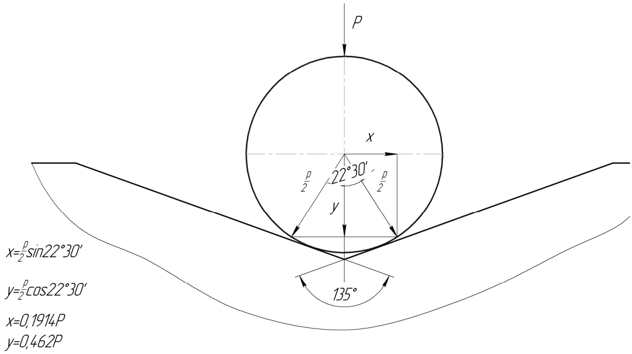


Figure 3.5 – Lower anvil with a cut angle α = 135°

We can conclude next when we have analyzed schemes of power loading during forging in combined anvils and summarized the calculation data in Table 3.5:

1) at an angle of the anvils cut-out equal to 90°, the tensile components of the force X correspond to the compressive component Y of the same force equal to 35 % of the force P;

2) with an increase in the cut-out angle of the lower anvil, the tensile component X decreases, and the compressive component increases;

3) the cross-section of the billet does not affect the studied process parameters.

Thus, the best metal processing will be ensured at large cut angles of the lower anvil with the maximum allowable reductions. Therefore, a lower anvil with a cut angle α = 135° should be preferred during the forging of the large forged pieces.

Ingot upset is used in the manufacture of large forged pieces, as a rule, a drawing follows after upsetting. Ingots upsetting is carried out at a height of 50 % and it is used to improve the quality of the metal, obtain a given diameter of the billet and increase the forging ratio. The upsetting plates are most often used in the following combinations for large ingots and billets upsetting:

- the lower plate with a working concave surface and a hole for the shank and the upper plate with a spherical concavity (used mainly for cylindrical forged pieces);
- the bottom plate with a working concave surface and a hole for the shank and upper flat plate (used for forged pieces of square and rectangular sections);
- the lower and upper plates are flat (used for forged pieces such as discs, gears, and under hole punching, billets for relatively small forged pieces such as rings, bandages, and short cylinders).

The upper spherical plates align the metal flow in the middle part of the upset ingot during the next subsequent upsetting and thereby eliminate the formation of defects in the form of cracks and clamps in the axial part of the billet. The formation of such defects is because after ingot upsetting, the relative supply is small and the metal in the peripheral layers flows faster during drawing than in the middle ones. The spherical concave plates extend to the main weights of the ingots, when the end notch length (L) is less than 0.3 of the diameter at which the notch is made, i.e. (Fig. 3.6).

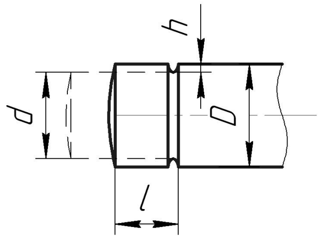


Figure 3.6 – End-notching scheme

In other cases, when cutting metal $L \le 0,3D$ to eliminate the formation of defects on the end part of the forged pieces, such additional forging schemes are used:

- pre-drawing of the end portion of the billet on flat anvils to obtain its length equal to the width of the anvil;
- the forging of the end section is reduced to forging size after cooling its surface to a temperature of 900 ... 950ºC.

The notch is an auxiliary forging operation in which surface metal separation occurs for the subsequent formation of a ledge or groove on the forged piece. The tool is blades in the following forms: round cylindrical, triangular – two-sided, one-sided, and others. The metal is tightened during cutting, depending on its depth and the size of the tool used. It is necessary to provide additional allowances for the dimensions of the forged pieces on which the cutting is carried out for eliminating the tightening during cutting, considering the following:

- no notching up to a depth of 50 mm is performed, but an allowance of 20 ... 30 mm is provided for at the initial forging size;
- during notching to a depth of 150 mm by the cylindrical blade, an allowance of 5 ... 8 % is provided relative to the diameter at which the notching is performed;
- during notching with a depth up to 250 mm by the triangular blade, an allowance of 8 ... 10 % is provided relative to the diameter or size of the forging on which the notching is carried out.

Wherein, notching must be performed to a depth equal to 1/3 of the difference between the diameters of the billet (D), considering the provision of the above allowance for tightening and the step or groove of the forging (d), i.e., the depth of cutting $h = \frac{1}{3}(D - d)$ (Fig. 3.6).

After marking and notching, the ledge or the notch is squeezed to the forged piece dimensions, then smoothing is performed to the extent of those sections of the billet on which an additional allowance for tightening is provided.

The special interest is the shaping of the cone sections on the forging during cutting by the equilateral triangular blade. The characteristic feature of this process is the formation of the main part of the cone, about 2/3 of its total length, which is obtained during the notching process, and the other of the cone is reduced by the anvils when the ledge or groove is deformed to forged piece dimensions. This method allows to perform a relatively small length of the cone sections from 150 to 250 mm with a cone angle $\alpha \leq 45^o$. It leads to an increase in metal consumption and laboriousness during mechanical treatment.

Example. A sketch of the spindle forging is shown in Figure 3.7. The material is steel 34Cr1Ni3Mo1. The mass of forged pieces is 7 700 kg. Spindle forging is carried out on a press with a force of 30 MN. The weight of the ingot is 11 200 kg.

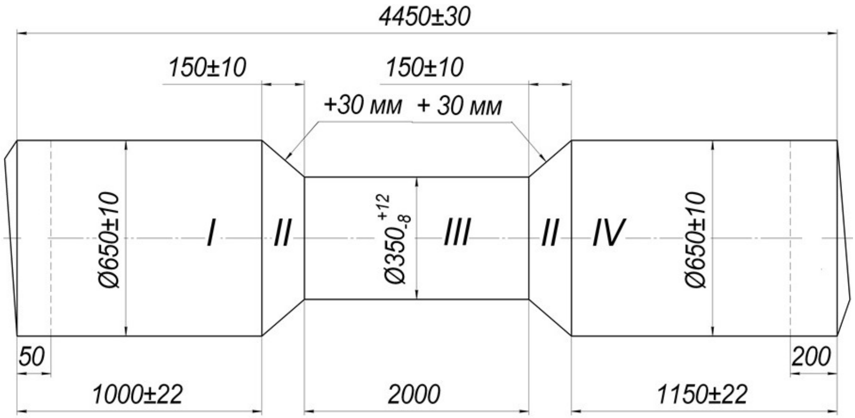


Figure 3.7 – Sketch of the forged piece

A cutting sketch of metal before and after notching with a triangular cutting is shown in Fig. 3.8. The technological calculations of metal forging differ from the generally accepted ones in that, before notching, the metal is redistributed in the conical part of the forged piece II. First of all, the metal part (Q) is determined to continue forging the cones by the anvils, based on the obtained dimensions of the billet after triangular notching by the blade to the indicated depth (see notching the billet, Fig. 3.8). We obtain the initial mass of the cone (the outline of the design cone is shaded by a thin line)

$$Qk = Fk \cdot l \cdot 7.85 = 1\,319 \cdot l \cdot 7.85 = 62\,152g = 62.15kg,$$

then determine the mass of the billet from the bottom of the ingot

$$Qb = [Qf(I+II) – Qe + Qr] = [(2\,600+250) – 62+500] = 3\,288kg,$$

where $\mathrm{I} - \mathrm{II}$ are the masses of forged sections of $\mathrm{I} + \mathrm{II}$;
Qe – the end section mass of the cone;
Qr – removable ingots bottom mass.

Then we determine the mass of the middle part of the billet

$$Qev = Qf(III)+2Qe = 1500+2\cdot62 = 1\ 624\ kg,$$

with considering of forging for positive tolerance, accept Qev = 1 650kg,
where III – mass middle part of the forged piece.
Then, we determine the mass of the billet from the hot-top part of the ingot

$$Qh = Qf(IV+II)–Qe = (3\ 000+250)–62 = 3\ 188\ kg,$$

where $\mathrm{IV}+\mathrm{II}$ – mass forged pieces $\mathrm{IV}+\mathrm{II}$.

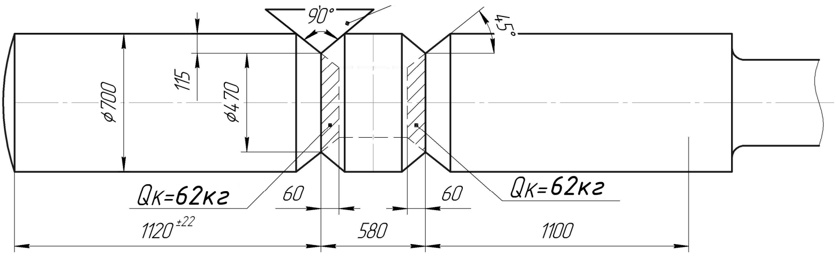


Figure 3.8 –the sketch of the spindle billet during notching triangular corner

3.2 Rolling-off

Rolling-off is the main operation in manufacturing hollow forged pieces such as rings and shells. An increase occurs in the outer and inner diameters of the ring or shell in the process of rolling-off hollow workpieces due to a decrease in the wall thickness. Rolling-off racks (goats), a mandrel, and a wide anvil or a narrow anvil depending on the diameter of the rolled forged pieces and their height during rolling-off are used. So, it is allowed to rolling-off hollow forged pieces with a height of not more than 600 mm and with an outer diameter of up to 3 500 mm due to the high height of the anvil body, which is characteristic of presses with great forces with an anvil width of 800 mm. A narrow anvil is a rolling-off tool that is used when rolling-off hollow forged pieces up to 3 000 mm high and with a maximum outer diameter that is slightly less than the distance between the press stops, a rolling-off tool. A pre-drawing of the hollow workpieces on the mandrel to a predetermined height (length) is used, and then rolling-off to a predetermined size according to the outer and inner diameters is performed to obtain large forged pieces. It should be noted that when developing technical processes for rolling-off forged pieces, it is necessary to consider the height of the upset billet (H_0), it's widening (elongation), depending the size of the rolled diameters, and the design of the anvil. The practice has found that the widening along the height of the workpiece during rolling-off of the inner diameter for every 100 mm is:

- planed anvil – 5 ... 6 mm;

- worked-out anvil – 10 mm;
- longitudinal anvil – 2 ... 3 mm.

The required height of the upsetting billet (H_0) before final rolling-off is determined from the calculation

$$H0 = Hf - n \cdot \Delta b,$$

where Hf – forging height;

n – the number of rolling-off of 100 mm (internal diameter);

Δb – widening depending on the tool used.

The height of the workpiece is taken to be equal to the peeling height of the forging as an exception, with a small rolling-off.

Uncontrolled is one of the disadvantages of manufacturing large-sized rings and bandages the sphericity (convexity) at the ends, the presence of which increases the rate of metal consumption and additional laboriousness during machining. The following is a method of manufacturing large-sized forged pieces such as rings and bandages with the elimination of sphericity at the ends.

3.3 Mandrel drawing

The mandrel drawing is used for a hollow forged pieces such as smooth cylinders, stepped cylinders, short sleeves, bushings, etc. The length of the billet increases due to a decrease in its cross-section during drawing on the mandrel drawing. The hollow workpiece forging on a mandrel drawing has several technological features, in particular:

1) it is necessary to remove the burr by autogenous cutting directly under the press after flashing the upset billet with a hollow piercing punch, as well as by rolling-off, to level the walls of the billet along the entire length with its subsequent height addition to preventing skewing during the subsequent forging drawing;

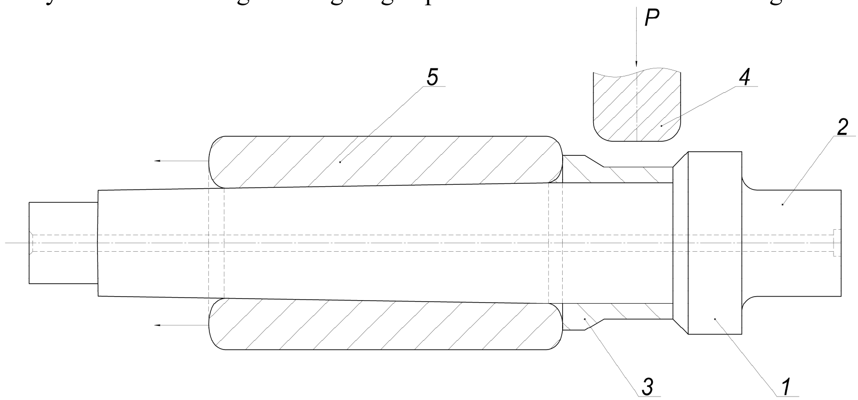
2) it is advisable to perform the billets with the upper spherical plate, and preferably in two spherical plates (upper – spherical, lower – with a concave surface), especially during forging thick-walled cylinders for more uniform deformation of the metal during the forged pieces on the mandrel drawing;

3) uniform heating of the billet is one of the important conditions for obtaining high-quality forged pieces forging on the mandrel drawing;

4) the working part of the mandrel drawing should be lubricated with a mixture of graphite and oil before forging, while the hollow forged pieces forging, the mandrels must be cooled with water, and after forging the dressing should be immediately removed from the forging;

5) a four-fold extraction of the hollow billet is allowed at the optimum wall thickness due to an increase in the specific pressure from the mandrel side.

The forging of the hollow forged pieces on a mandrel is carried out by lower cut and upper flat anvils. As a rule, first of all, the forging starts from the ends of the billet with a preliminary reduction to the width of the anvil, then the forging is performed to the shoulder of the mandrel drawing until its end contacts the mandrel shoulder, then forging is conducted from the end of the billet opposite to the shoulder. The billet begins to gradually slide off the mandrel drawing with each subsequent reduction. In some cases, a removable ring is put on the mandrel drawing (Fig. 3.9) during forging thick-walled cylinders before forging. Use it when it is difficult to remove the forged pieces from the mandrel drawing. The upper press anvil 4 is located between the shoulder of mandrel 1 and the shoulder of the removable ring 3. When the press anvil 4 is pressed down by the force of the press P, the upper anvil acts as a wedge, which allows you to move the tight-fitting forged piece 5 from the mandrel drawing 2.



1 – shoulder mandrel; 2 – mandrel; 3 – removable ring;
4 – upper press anvil; 5 – forged piece
Figure 3.9 – Removal scheme of forged pieces from the mandrel drawing

SECTION 4
TECHNOLOGICAL POSSIBILITIES FOR INCREASING THE PROCESSED MASS OF INGOTS ON HYDRAULIC PRESSES

The maximum possible upsetting by weight of the ingots from the conditions of using the maximum press force and the maximum lifting capacity of the forging cranes that serve this press were shown in Table 4.1. Thus, continuous forged pieces weighing up to 85 tons are produced on a press with a force of 100 MN, with ingots up to 132 tons being upset in the industrial conditions. In this case, the ingots are held and tilted using a previously drawn shank from the hot-top part of the ingot and cartridge with a tilter, suspended to a crane with a lifting capacity of 250 tons. However, it is impossible to obtain large forged pieces from ingots exceeding 132 tons in weight by the indicated forging scheme due to the limitation of the lifting means. An analysis of the technological capabilities forging of large workpieces has shown that an increase in the processed mass of forged pieces under a press with a constant lifting capacity of forging cranes is possible due to a change in the forging scheme and ingot settlement. In particular, it is proposed that the shank be rolled out from the bottom of the ingot, and in the process of billeting it, a hot-top of 100 % should be removed by trimming. The ingot is installed on the lower concave plate with the shaft drawn up, where the plate with the hole is placed, and the draw is carried out to the specified dimensions. Such an ingot upsetting scheme significantly reduces the mass of processed ingots under a press. So, when forging an ingot with a mass of 200 tons, its weight decreases by 40 tons, which ensures manipulation of the billet with the same lifting capacity of forging cranes, based on the following conditions:

1) during billeting, a 200-ton ingot with a tilter on two anvils $200 > (200 - 6) = 194$tons,

where 200 is permissible payload capacity, tons;

(200 – 6) is ingot mass after first heating;

2) after upsetting of the ingot with preliminary removal of hot-top by mass 40.0 t $250 > [(194 - 40) - 2.5] + 48.4 + 15.8 = 215.7$tons,

where 250 is hoisting capacity, tons;

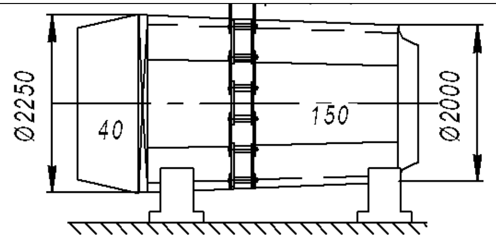
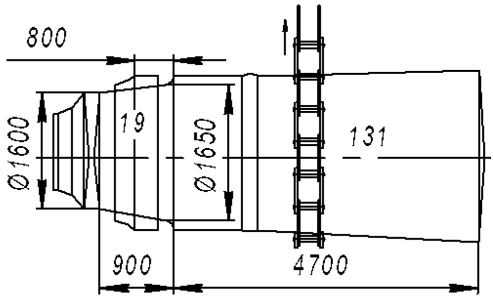
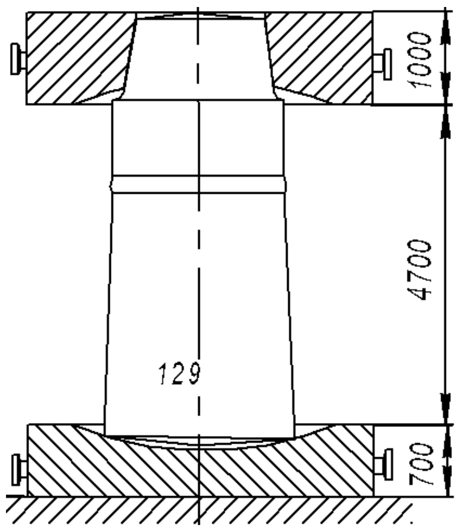
[(194 – 40) – 2.5] is ingot mass without hot-top after the second heating;

48.4 is a mass of spherical bottom plate Ø3 300×750 R 7 500 mm;

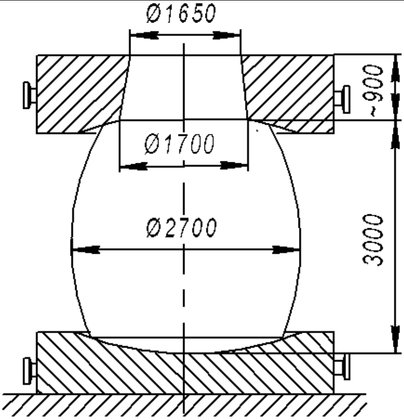
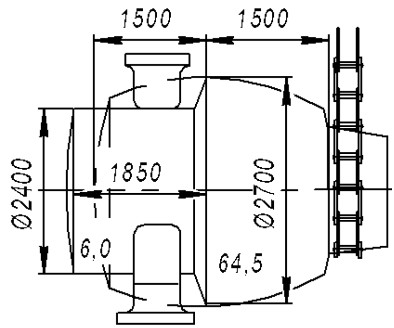
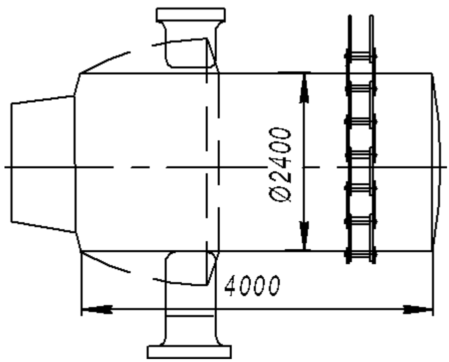
15.8 is chain anchor 250 tons.

The calculations, which we can see above, the possibility of upsetting and forging ingots weighing up to 200 tons inclusive with constant load-lifting means. It will increase the mass of used ingots in the press by up to 200 tons (table 4.1).

Table 4.1 – Forging scheme with upsetting ingot weighing 200 tons

Name of operations	Transition Sketches
1. In the first heating, an ingot from the furnace is fed to the press with chains of the item of 250 tons and mounted on two anvils. 2. The tilter of the payload capacity of 200 t is started between the anvils. 3. Billeting hot-top part of the ingot. 4. Install the housing with a movable ax. 5. Mark and chop up hot-tops. 6. Turn the ingot and forge it onto a cone. 7. Notching the bottom end and reduction onto a Ø1 650 / 1 600 cone, cut off the bottom of the ingot. 8. An ingot in chains is put into the furnace	 
In the second heating 1. The ingot is pullet out from the furnace by chains. 2. Put the ingot on a flexible bracket and turn it over. 3. Set the ingot under the press on the lower concave plate. 4. Install the top plate.	

Continuation of table 4.1

5. The ingot is seated at a height of 600 ... 700 mm. 6. Install the upper upsetting plate. 7. Upsetting the ingot up to Ø2700 mm, H ≈ 3000 mm. 8. Remove the top plate and the backing ring.	
9. Take the lower upsetting plate in chains and turn the ingot at an angle of 90° behind the press. 10. Take the ingot with ticks and serve under a press. 11. Take the ingot on the tilter according to the sketch and reduction the half-ingot on Ø2 400 with a conical ledge. 12. Turn the ingot in chains at 180˚. 13. Take the ingot with the manipulator and the tilter according to the sketch and draw the rest of the ingot to Ø2 400, the last part of the reducing and tilting of the ingot is performed with the movement of the press table. 14. The ingot is put into the furnace with chains. After the workpiece is used for its intended purpose for the manufacture of forged pieces such as rolls, shafts, etc.	 

SECTION 5
FORGING WAYS OF LARGE PLATES

The continuous improvement of technological processes in the direction of reducing metal consumption while ensuring high-quality forged pieces is one of the main tasks facing forging technologists. There is a known method of forging rectangular forged pieces (such as plates) by flat anvils with normal billet feed in the forging industry, that is when the longitudinal axis of the billet is at right angles to the front edge of the anvils [13].

The disadvantage of the method of forging with the specified feed was a large waste of metal from the bottom of the ingot, due to the uneven deformation over the cross-section of the workpiece, especially on those workpieces that had a ratio of width (B) to height (H) of more than 2 [14]. As a rule, in practice, with this ratio, the length of the end waste (l) is determined by the formula

$$l = 0.4B,$$

where B is the largest size of the workpiece, mm.

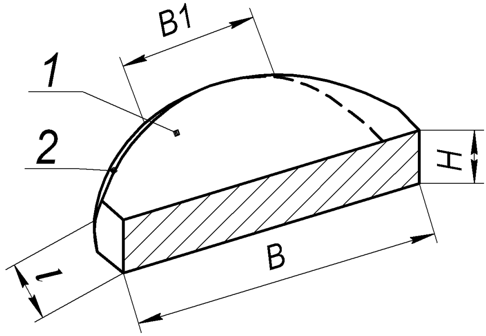
Figure 5.1 shows the waste that is obtained when forging plates. It has a convex shape. This shape is caused by uneven deformation during the drawing of plates with a ratio of width to height of more than 2. In practice and experimentally, it has been established that the degree of uneven deformation is especially high in the central part of the plate (approximately at a width equal to half the width of the plate) and decreases in the direction of the section width.

In this case, the volume of waste is defined as the volume of the prism, the basis of which are the dimensions $H\ B$, and the height is $\frac{2}{3}l$,

$$V = \left(\frac{2}{3}\right) l \cdot H \cdot B,$$

where H is workpiece height, mm.

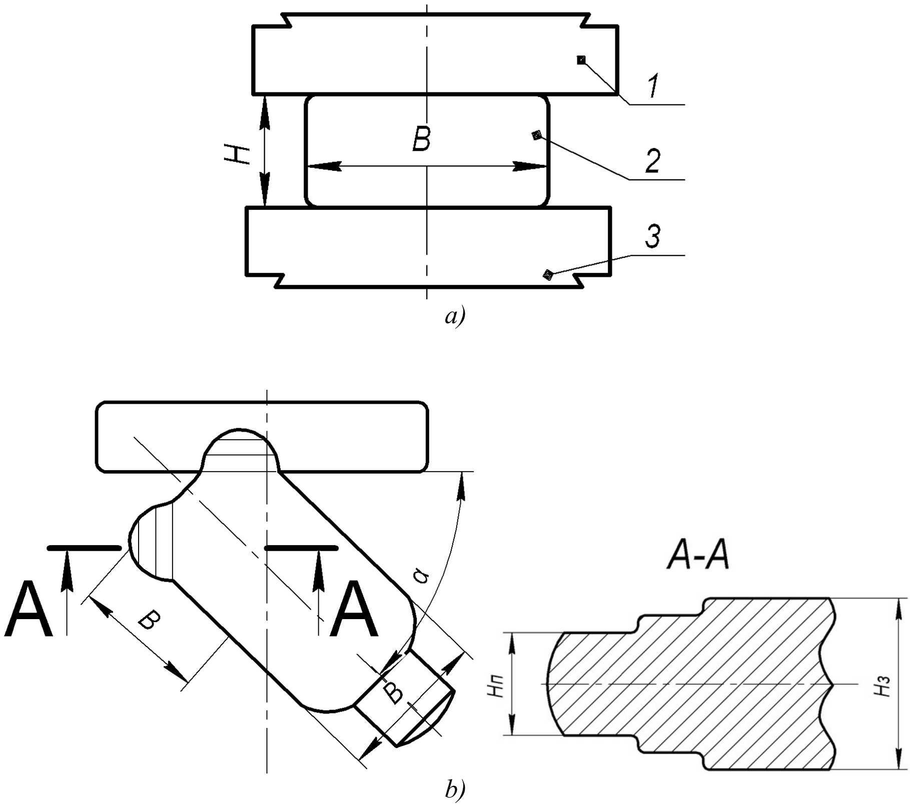
Of course, the amount of metal waste during plate forging with a width of about 2 000 mm and more is very significant and reaches 10 ... 15 % of the mass of the ingot. The forged pieces with the indicated cross-section were made from ordinary forging ingots with a yield in the range of 55 ... 60 %. A known method of forging plates [15] by feeding the workpiece at an acute angle to the leading edge of the anvils, compressing the workpiece in several passes, alternating with a canting of the workpiece by 180°, as well as compression, in which the forging is carried out with an even number of passes, observing the conditions for equality two adjacent passages, starting from the first, after which they produce a canting of the obtained forging by 90° and compressing it along the side surfaces. In this method of forging, subject to the specified conditions, it is not possible to use high-performance forging manipulators of the forge-and-press shops, since their rotary mechanism does not provide rotation of the workpiece by a given angle. Forging is carried out using forging cranes, and this reduces the productivity of the forging process.



1 – section of the forging zone with the greatest metal deformation;
2 – areas of zones with difficult deformation
Figure 5.1 – The shape of the end waste when forging plates with a ratio > 2.0

According to the method [16], the drawing of waste is produced by anvils with a convex non-working surface, which reduces the value of end waste. However, a large amount of special equipment is required, which leads to an increase in the cost of manufacturing forged pieces in the manufacture of a wide range, with a wide range of cross-sections in the conditions of a small-scale and single production.

A new forging method was developed and implemented [17] to reduce metal costs in the manufacture of the plate by reducing end waste from the bottom of the ingot. Its essence is: holding workpiece 2, holding the manipulator, is forged by flat anvils 1 and 3 (Fig. 5.2, *a*) until the ratio of width (B) to height (H) is obtained no more than 2.0, at which the minimum length of the waste is reached, $l = 0.3B$. After that, the ingot's hot-top is freed from the pliers of the manipulator and held by the tilter chain, while positioning the bottom of the workpiece on the lower hammer 3. Then, workpiece 2 is turned by the tilter so that one of the diagonals of the square (Fig. 5.2, *b* shows the outline of the square with sides B) was $\alpha = 30...45°$ to an angle concerning the front edge of the anvils 1 and 3 (anvil 1 in Fig. 5.2, *b* is not shown). After that, the angle of the workpiece is drawn with intermediate ledges to the height of the forging ($H_п$, section A – A) with the maximum allowable reductions per stroke of the press. Then the second corner of the workpiece is set and reduced similarly. Then, workpiece 2 is held by the manipulator and drawn to the forging size with the same maximum allowable compressions per stroke of the press. When squeezing the bottom of the ingot, the drawn corners inhibit and even out the metal flow in the longitudinal direction, which prevents the length of the waste from increasing from the side of the bottom of the ingot. Ultimately, waste metal losses are significantly reduced.



a – workpiece after preliminary drawing; b – tightening corners

Figure 5.2 – Transitions of forging corners on the plate

Analysis of the manufacture of plates by this method showed that the reduction in the length of the end waste was associated with the formation of a groove located in the central part of the workpiece from the side of the bottom of the ingot, after drawing its angles in height. It led to the idea of developing a new forging technology for the plates with the formation of a groove in this part of the workpiece after the ingot is upset [18]. This aim is achieved by the fact that in the process of the billeting, the kumpel 2 (Fig. 5.3, *a*) is removed from the ingot, and after the ingot is upset at a diameter equal to the width of the plate, a billet is formed on its end surface that overlays the diameter of the billet, a groove with a step and two adjacent protrusions, the width and height of which is determined from the relations:

$$B_1 = 0.5B;$$

$$B_2 = 0.25B_1;$$

$$h = 0.35H,$$

where B_1 и B_2 is the width of the protrusion and ledge of the groove, respectively;

B – is plate width;

h – is groove height;

H – is plate height.

Figure 5.3, *a* shows the initial ingot after billeting, in figure 5.3, *b* is the upsetting ingot after forming a groove with two protrusions adjoining it, in figure 5.3, *c* is forging after drawing to forging sizes.

During forging plates with a ratio of width to height of more than 2.0, the length of the end waste is determined by the formula. In this case, the volume of the waste is defined as the volume of the prism with the dimensions of the base $H\ B$ and height $\frac{2}{3}l$, i. e.

$$V_w = 2/3 \cdot l \cdot H \cdot B,$$

using the formula $l = 0.4B$, we receive

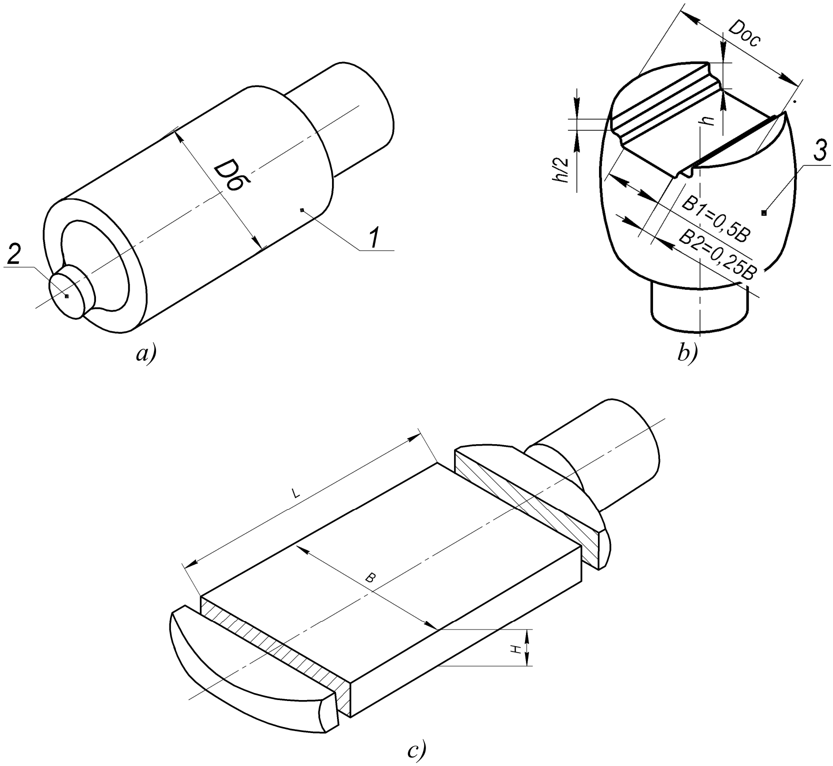
$$V_w = 2/3 \cdot 0.4 \cdot B \cdot H \cdot B.$$

So, it is necessary to give the upsetting ingot on the ingot's bottom side a certain profile of the groove with dimensions B_1, B_2 и h (fig. 5.3, b), dimensionally dependent plate sizes $B\ H$, and where the end surface of the waste during drawing the plates took the shape of a regular rectangle when drawing the plates.

From the condition of equality of volumes, we obtain $V_w = V_{led}$

$$2/3 \cdot 0.4 \cdot B \cdot H \cdot B = 0.75B \cdot h \cdot D_{up},$$

predefined $B_2 = 0.125B \cdot D_{up}$, based on the fact that the indicated volume of metal at the end of the deformation is displaced due to widening into the peripheral zone of the workpiece.



a – billeting; b – the formation of concavity in the upsetting billet; c – forged piece after drawing and cutting

Figure 5.3 – Transitions forging of the plates with reduced end waste

Figure 5.4 – Drawing the workpiece after groove formation in the end

From the last expression, when $B = D_{up}$, we find h = 0.355H. So, it is necessary to press a notch to such a height. Thus, during the formation of a groove with the indicated dimensions and subsequent compression, the metal flow is aligned in the transverse direction, which reduces the significant length of the end convexity of the waste from the bottom of the ingot and improves the quality of the forging by reducing the heterogeneity of deformation in the middle part of the ingot.

The forging method occurs this way. First of all, ingot 1 is billeted (see Fig. 5.3, *a*) and the kumpel 2 is separated from it. Then it is upset by plates (not shown in the figure), then a groove is formed in the end part of the ingot with a depth of (h), width $B_1 = 0.5B$, and two adjacent protrusions to it with a depth ($h/2$) and a width $B_2 = 0.25B_1$ (see Fig. 5.3, b) of the upper flat anvil, overlapping the diameter of the upsetting ingot. Then, an ingot is turned over and drawn mainly in a plane perpendicular to the longitudinal axis of the groove, to forge sizes in the direction from the hot-top part to the bottom (Fig. 5.3, c).

Example. The forging of the plate has a thickness $480^{\pm 9}$, width $1470^{\pm 12}$, and length $1750^{\pm 36}$, the material is steel 40Cr, weight is 9 900 kg. Forging was carried out from an ingot weighing 15 600 kg under a press force of 30 MN. In the first heating, the ingot was billeted to a diameter of 980 mm, after having first knocked down the kumpel and was upset to a diameter of 1 500 mm. Then, with the upper anvil in the end part of the ingot, a groove was formed in the center of a depth of 170 mm, a width of 750 mm, and two adjacent protrusions to it with a depth of 85 mm and a width of 190 mm. An ingot with a cross-section of 600×1 500 mm was drawn mainly in the size of 1 500 mm in the direction from the hot-top part to the bottom.

In the second heating, the workpiece was drawn to the final section size of 480 × 1 470 with tilting at an angle of 90°, after which the forging was straightened and cut (see Fig. 5.3).

The obtained height h = 0.35H was tested in practice in the manufacture of plates and with various heights on industrial orders when deforming workpieces with a forging ratio of at least 2.5 (Fig. 5.4). According to this method, in contrast to the previous one, the operation of turning the workpiece under the forging corners on the ingots bottom side using the tilter chain is excluded, which increases the productivity of the process of forging under the press. In addition, the ingot undergoes additional deformation during forming grooves, which has a positive effect on the development of the axial one of the ingot and the welding of shrinkage defects in it [19].

SECTION 6
METHODS FORGING OF LARGE-SIZED SLABS

A typical technological process for the production of forged pieces such as slabs with a rectangular cross-section includes ingot-billeting operations, reduction of the hot-top for the hole of the upsetting plate, the ingot upsetting, and the workpiece drawing to forged piece dimensions. According to the specified technology, as above mentioned, on a press with the 100MN power, solid forged pieces weighing up to 85 tons are made from ingots weighing up to 132 tons, according to the following equation

$$250 - (68 + 40 + 15) = 127 > (103.5 + 17) = 120.5 \text{ tons},$$

where 250 – lifting capacity of the forge crane, tons;

(68 + 40 + 15) – forging chuck weight, chains of the tilting and counterweight, tons, respectively;

(103.5 + 17) – ingot`s body weight – 132 tons including dross and trunnion.

According to this calculation, the forging of large forged pieces with the ingot upsetting exceeding 132 tons in weight, together with the trunnion, is not technologically possible due to the limitation of the lifting capacity in the forge crane.

The forged pieces of the specified range are considered very important parts and are used in the operation of powerful hydraulic stamping presses and rolling mills. They are subject to high requirements both for ultrasonic control and for the mechanical properties of the metal [20]. Based on the above mentioned, the forging of large-sized forged pieces is associated with solving problems both to improve the quality of forged pieces and to increase the processed mass of forged pieces produced under the press and of ingots exceeding 132 tons in weight.

To expand technological capabilities by increasing the mass of forged pieces with a rectangular cross-section under the press and, respectively, increasing the processed mass of ingots with a constant lifting capacity of the forge cranes, a new technological solution was adopted. With the axial hole in the part, it displays the orthogonal way to forge large-sized slabs [21]. The essence of this method consists in the fact that after cutting a block (billet) from the ingot, there is it's upsetting, followed by the metal spread both across the width and across the length of the billet until its forged piece dimensions with tilt and turning it under the press will have been almost obtained. After cutting the end waste, the billet is processed with a manipulator load capacity of 120 t and is drawn to forged piece dimensions. Such a scheme for the large-sized slabs manufacture allows forging such workpieces without the lifting and transport devices (forging crane) when performing the shaping forging, upsetting, and spread operations almost to forged pieces dimensions, that significantly increases the processed mass of both forged pieces and ingots under pressure. Besides, this forging scheme allows matching the axis of the ingot with the axis of the central hole in the part, to eliminate the axial defect zone of the ingot when boring out the axial hole during machining. This provides an increase in the quality of the manufactured product and also allows to reduce the metal consumption in the manufacture of large-sized forged pieces such as slabs due to a significant reduction in the length of the end waste by 2 ... 3 times as compared to the known methods, where the upsetting of the billet occurs in two mutually perpendicular directions [21].

In production conditions a unique forged piece "Frame" was manufactured according to the proposed method for the first time, its dimensions 1 050×3 200×3 300 mm from the ingot weighing 155 tons from ST52-3 steel on a press with 100 MN power. Steelmaking was carried out in the open-hearth furnace and electric furnaces with processing at the "Ladle-furnace" unit in a mixing mode, followed by vacuum casting.

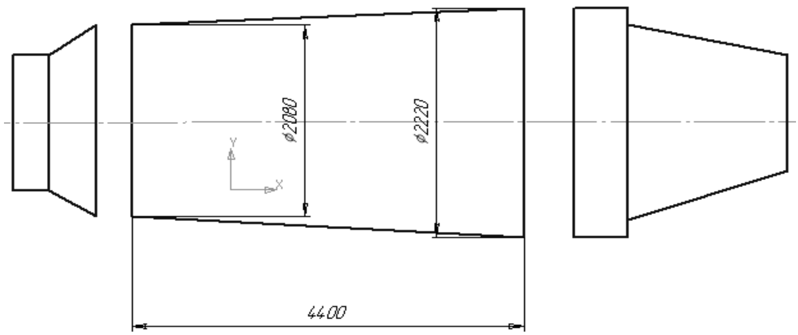
In the first heating (Fig. 6.1, *a*), the ingot was billeted into the cone, the block was cut with the ingot operation, and the fit was heated to 1200˚C.

In the second heating (Fig. 6.1, *b*), the block was upset to the 2 700 mm diameter, H = 2 600 mm; the billet was turned to the 90˚ angle under the press with the help of the upper anvil supported by a mandrel and manipulator; the anvil was fed to 2 300 mm diameter (Fig. 6.1, *c*); the billet was turned using a mandrel and a manipulator, turning the axis of the ingot into a vertical position; then there was loading into the furnace for heating up to 1 200˚C.

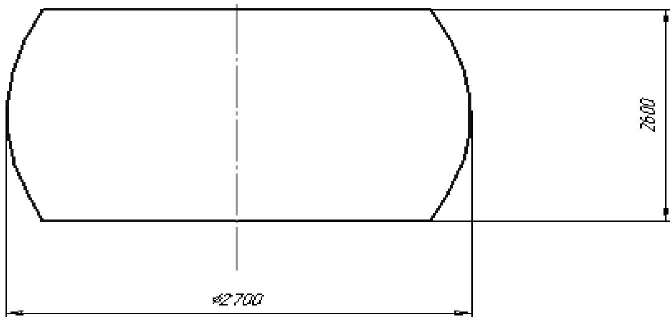
In the third heating (Fig. 6.1, *d*), there was the workpiece upsetting to H = 1 500 mm, B = 2 800 mm width, and L = 3 100 mm length with a 90˚ turn, having set the extension L = 4 700 mm; anvil spread in the direction A – A up to H = 1 350 mm (Fig. 6.1, *e*) from the size 2 800 to 3 000 mm; turning the workpiece by 90˚ and tilt with an anvil by 180˚ supported by a mandrel and a manipulator; anvil spread in the direction B – B to H = 1 200 mm (Fig. 6.1, *f*) from the size 3 100 to 3 500 mm, turning the workpiece by 90˚; tilt by 180˚ supported by a manipulator; loading in a furnace for heating up to 1200˚C.

In the fourth heating, setting the anvil L = 4 700 mm, it was spread with an anvil in the B – B direction up to H = 1 100 mm (Fig. 6.1, *g*) from the size 3000 to 3 300 mm; turned the workpiece by 90˚; turned the axis of the ingot into a horizontal position with the support of a mandrel and a manipulator; corrected the sphericity to L = 3 500 mm, after tilting the workpiece outside the press; sent the workpiece to the furnace for heating up to 1 200˚C.

In the fifth heating, setting the anvil L = 4 700 mm, the workpiece was fed under the press with a manipulator, marked out, chopped off one end, unfolded the workpiece, took with the manipulator, marked, and chopped off the second end, removed the workpiece from the press, set it on gaskets of at least 2 m height, cooled on the bay to the temperature of the metal surface (850 ... 800˚C), loaded the workpiece under the press, took it with a manipulator, the reduction it sufficiently in height and width with a turn, straightened in length (Fig. 6.1, *i*), marked, heat-treated. The results of industrial approbation are presented in Figure 6.1 k; l.



a)



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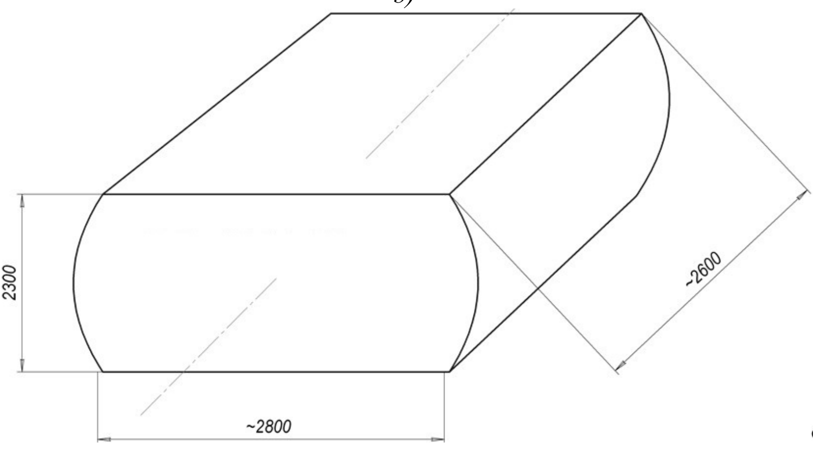
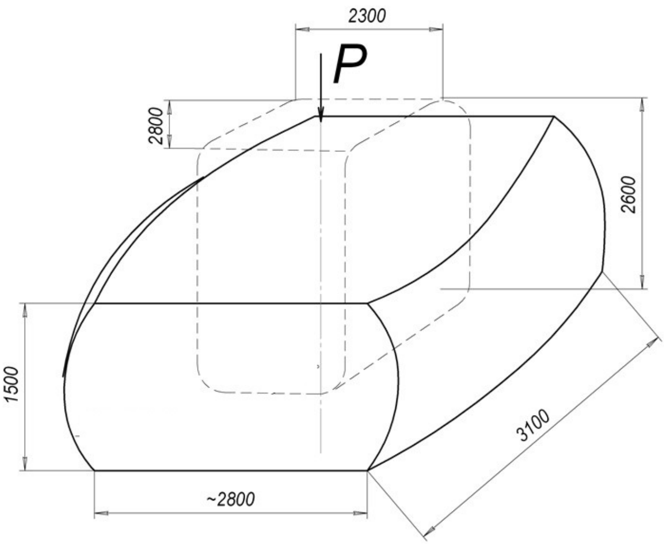
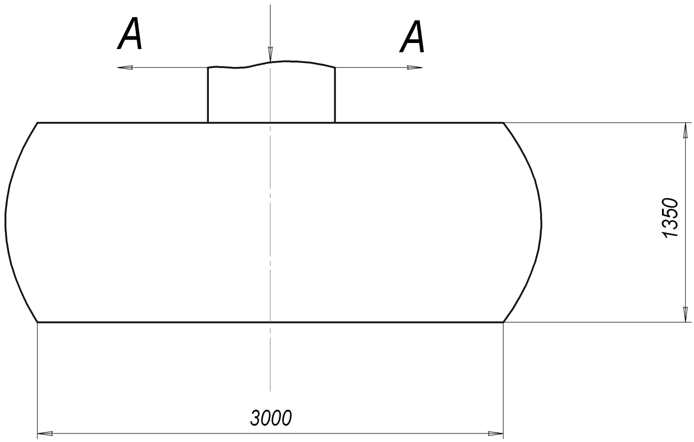


c)

Figure 6.1 – Transitions forging of the "Frame"

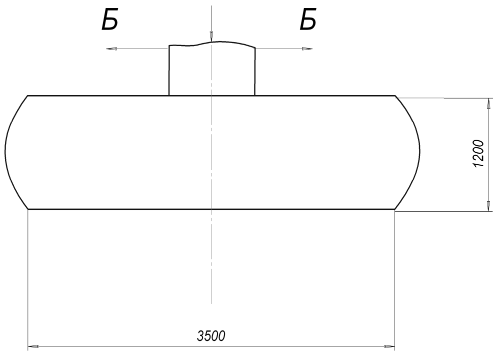


d)



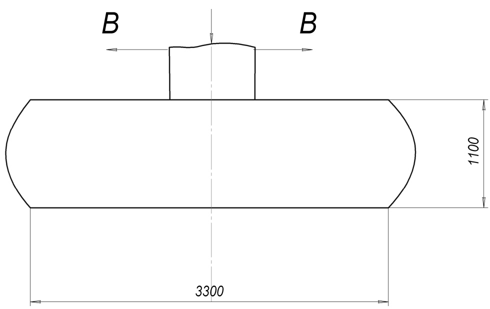
After the spread of 2 800 size
e)

Figure 6.1, sheet 2



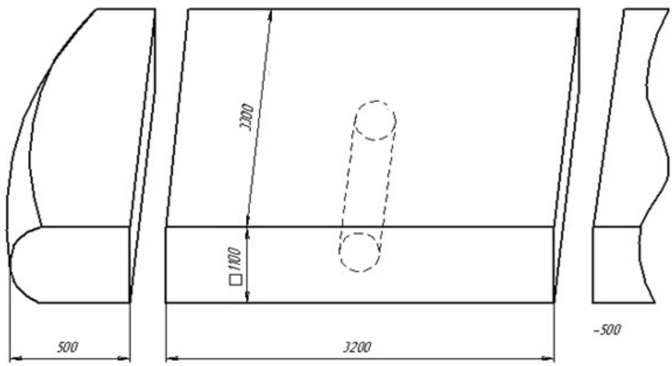
After the spread of 3 100 size

f)



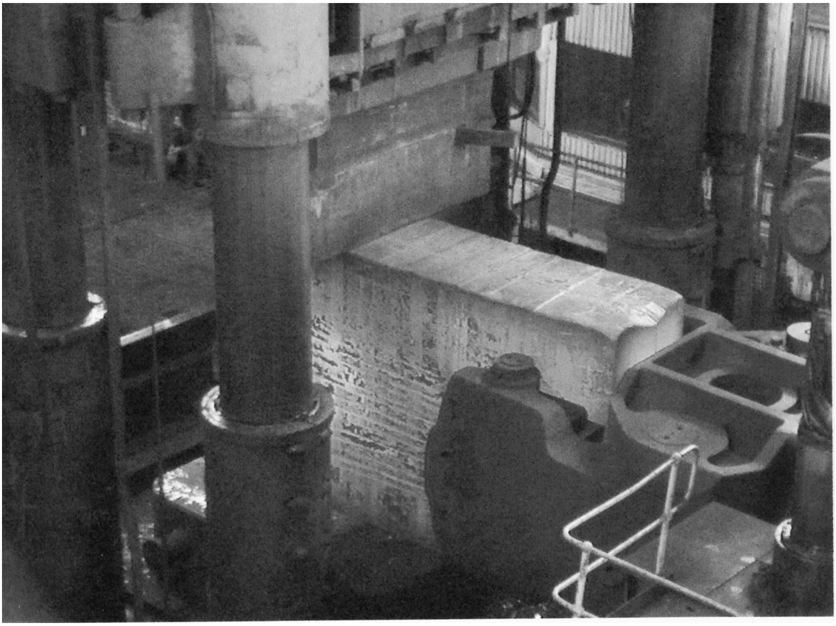
After the spread of 3 000 size

g)

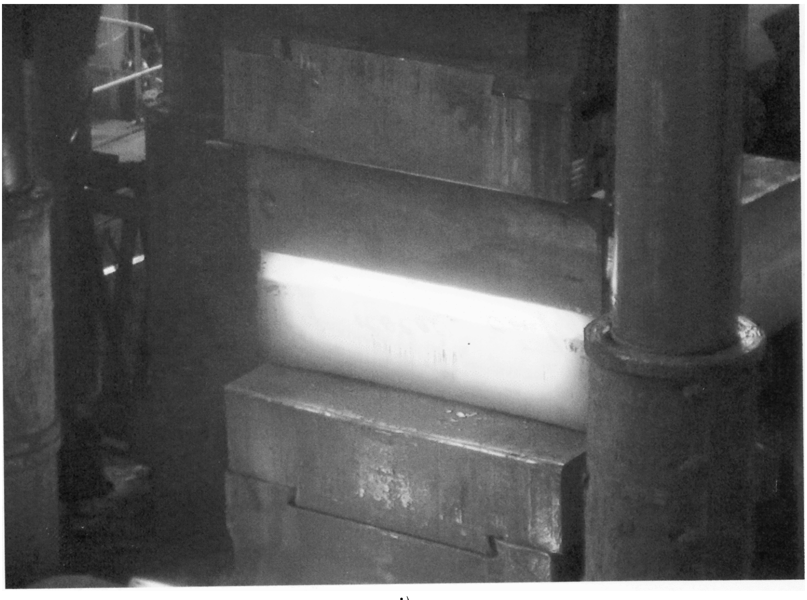


h)

Figure 6.1, sheet 3



i)



j)

Figure 6.1, sheet 4

This chapter considers the standard slab forged pieces with high requirements for their manufacture quality, but they do not have a central hole in the part so that it would be possible to forge them in an above-mentioned way. In this regard, it is proposed to manufacture similar products by the method of obtaining large forged pieces [22]. According to this way, in the process of presaging, the workpiece is formed as a bar thickened in the middle, and after cooling its surface during the subsequent drawing, using anvils of a width exceeding the width of the forged piece, the middle part of the workpiece is first reduced along the whole length, then the workpiece is drawing to the final dimensions.

In this case, the middle part of the workpiece is reduced with a reduction value of 8 ... 10 % per press stroke until a rectangular cross-section is obtained with the following tilt by 90˚ around the axis. When reducing with flat anvils, the pressing force is transferred mainly to the core part of the workpiece, its temperature is higher as compared to the outer metal layer, cooled at the surface. Such a forging scheme creates favorable conditions for welding-up internal defects throughout the whole workpiece. For the slab and other forged pieces, the proposed method can significantly increase their durability during operation.

Example. The method is exercised in the manufacture of a bar forging with the 500×1 500 mm cross-section, weighing 44 tons, made from the 20Cr1Ni1Mo1 steel. Steel was smelted in an electric furnace and the ingot weighing 68 tons was cast in a vacuum chamber. After that, the ingot was transferred in the hot state to the press shop and put into the furnace for heating before forging. The ingot was forged under a press with 100 MN power in four heating (Fig. 6.2).

In the first heating (Fig. 6.2, *a*), the trunnion was forged for taking by the manipulator from the hot-top part of the ingot and billeted to the 1 510 mm diameter. In the second heating (Fig. 6.2, *b*), ingot 1 was upset to the 2 400 mm diameter and drew to the 1 570×2 000 mm section (Fig. 6.2, *c*). In the third heating (Fig. 6.2, *d*), using cut-out anvils 2 and 3 (the alternative to the longitudinal flat anvils), the extreme lateral parts of the workpiece were drawn along the whole length to the 1 250 mm height. After that, the workpiece was cooled in the open air to the surface temperature of 880˚C, and the middle part of the workpiece was reduced with flat anvils 4 and 5 overlapping the width of the forging (Fig. 6.2, *e*) to the 1 250 mm height. In the fourth heating, the final forging was carried out to the forged piece dimensions, the forging temperature range was 1220…850˚C. After the forging finish, the forged piece was placed in a furnace for isothermal annealing. Investigation of this forged piece quality was carried out by ultrasonic control (USC). In comparison with the products manufactured according to the known method, the experimental forged piece is characterized by a sufficiently dense metal throughout the whole volume and meets the USC standards.

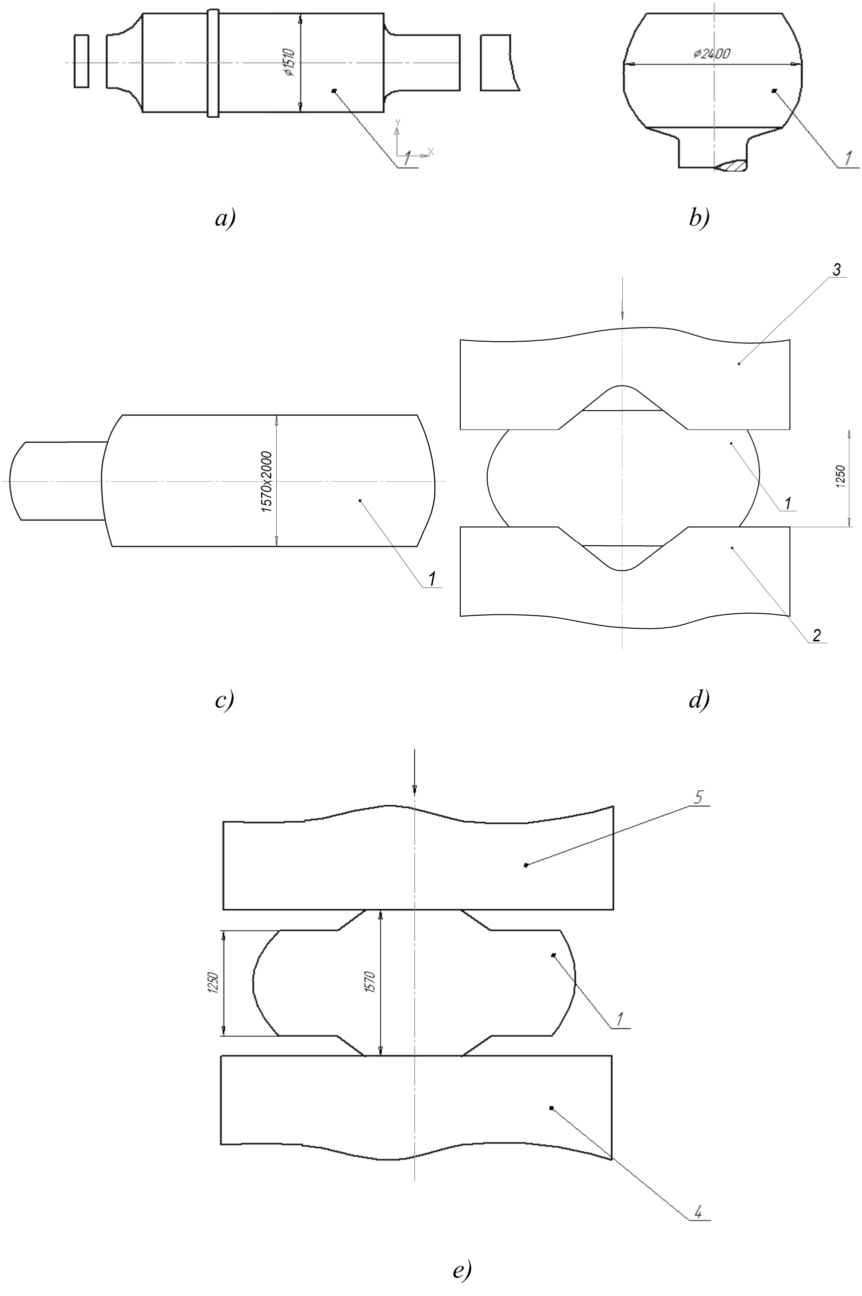


Figure 6.2 – Transitions forging of the bar

Recently, at the customers' request, the demand for steel slab forged pieces with both low and high sulfur content has become rather popular. The supplied forged pieces are used by customers as die workpieces for stamping, for example, plastic products. These workpieces are subjected to high requirements both for the purity of their processing and for the uniformity of the metal's mechanical properties, therefore, each forged piece is subjected to ultrasonic testing by the requirements of the European standard (SEP 1921, class D / d), according to which the permissible level of recorded defects is 2 ... 3 mm [23].

Besides, large ingots with a high sulfur content are prone to the formation of metallurgical cracks and defects, such as shrinkage, sinkholes, liquation phenomena, etc. These defects during forging are redistributed throughout the forging body and are fixed in the middle part of the forging (predominantly), and in the peripheral zones, which is confirmed by the results of ultrasonic control.

According to the existing technical processes, the manufacture of the forged slab was carried out in three heatings according to the scheme including the following operations:

1 heating – ingot billeting and hot-top rounding;

2 heating – ingot upsetting, workpiece spread;

3 heating – preliminary and final drawing of the forged piece dimensions.

At the same time, before forging, the ingots were subjected to prolonged diffusion (homogenizing) annealing to reduce the chemical heterogeneity of the cast metal. One of the drawbacks in the dies manufacture was their low quality, because during the formation of their cavity, the most qualitative forged piece layer is removed from its surface by mechanical processing, and the working cavity, the so-called stamp mirror, depending on its height, is located closer to the middle part of the forged piece corresponding to the axial area of the ingot. This area differs from the surface one by the heterogeneity and different density of the cast and forged metal structure, depending on the maturity degree during forging. Also, the development of the ingot axial area is influenced by the size of the slabs and their size ratio (B / H) [24]. Experience in large slabs manufacture shows that the greater the height of the slab, the less the possibility to weld metallurgical defects in it is.

Based on the above-mentioned, it follows that the existing technology for the large critical slabs manufacture does not provide high requirements for the homogeneity of the metal, and the various known methods and techniques of forging do not give the desired effect to eliminate the imperfection of a forging ingot of a conventional shape during the forging process. A fundamentally new method of forging allows for eliminating the indicated shortcomings in the existing technologies of forged slabs [25]. Its essence lies in the fact that after the preliminary drawing of the workpiece into a rectangular section along its longitudinal axis, the angle is pressed to the h = 500 mm depth, thus creating a favorable diagram of the compression stress state for the ingot axial defective area maturity and welding of metallurgical production defects in it. In the process of the billet drawing by the combined anvils, the open axial area of the ingot is forced to move towards the surface of the forging.

The redistribution of the ingot axial zone in the forged pieces allows to provide standard high-quality workpieces of large mass. One of the gains in forging the slabs using new technology is the favorable location of the forging areas with the die working surface. Thus, the proposed technology for the manufacture of slabs allows manufacturing a product of great height, meeting the high requirements for high-level products. Based on obtaining ultrasonic testing of high-quality metal on forged pieces manufactured by the proposed method, the operation of diffusion annealing on ingots before forging is excluded, which significantly reduces the consumption of energy (gas and electricity) during their manufacture [26].

Example. The slab forging has dimensions: 590×1 290×4 700 mm (Fig. 6.3, *f*), the material is 40CrMnNiMo8-0-9 steel, weight is 27 000 kg. Forging was carried out from the ingot weighing 36 000 kg on the press with the 100 MN power. In the first heating (Fig. 6.3, *a*), the hot-top was drawn under the upsetting plate, the ingot was billeted to the 1 220 mm diameter. In the second heating (Fig. 6.3, *b*), the ingot was upset to the 1 950 mm diameter and drawn to the size with the 1 300×1 500 mm section. In the third heating (Figure 6.3, *c*), a hanging angle 1 was installed along the workpiece axis and pressed into the 500 mm depth. After that, the workpiece was spread by the upper flat anvil 2 to dimensions of 800×1 600 mm (Figure 6.3, *d*). In the fourth heating (Fig. 6.3, *e*), the workpiece with an open axial area was installed on the lower cut-out anvil 3 and with the upper flat anvil 4, it was upset along the whole length to H = 650 mm. Then the workpiece was drawn with flat anvils along the section to forged piece dimensions. It was adjusted along the axis, cut with a turn, marked, and transferred to isothermal annealing. The temperature range of forging is 1 200 ... 800˚C.

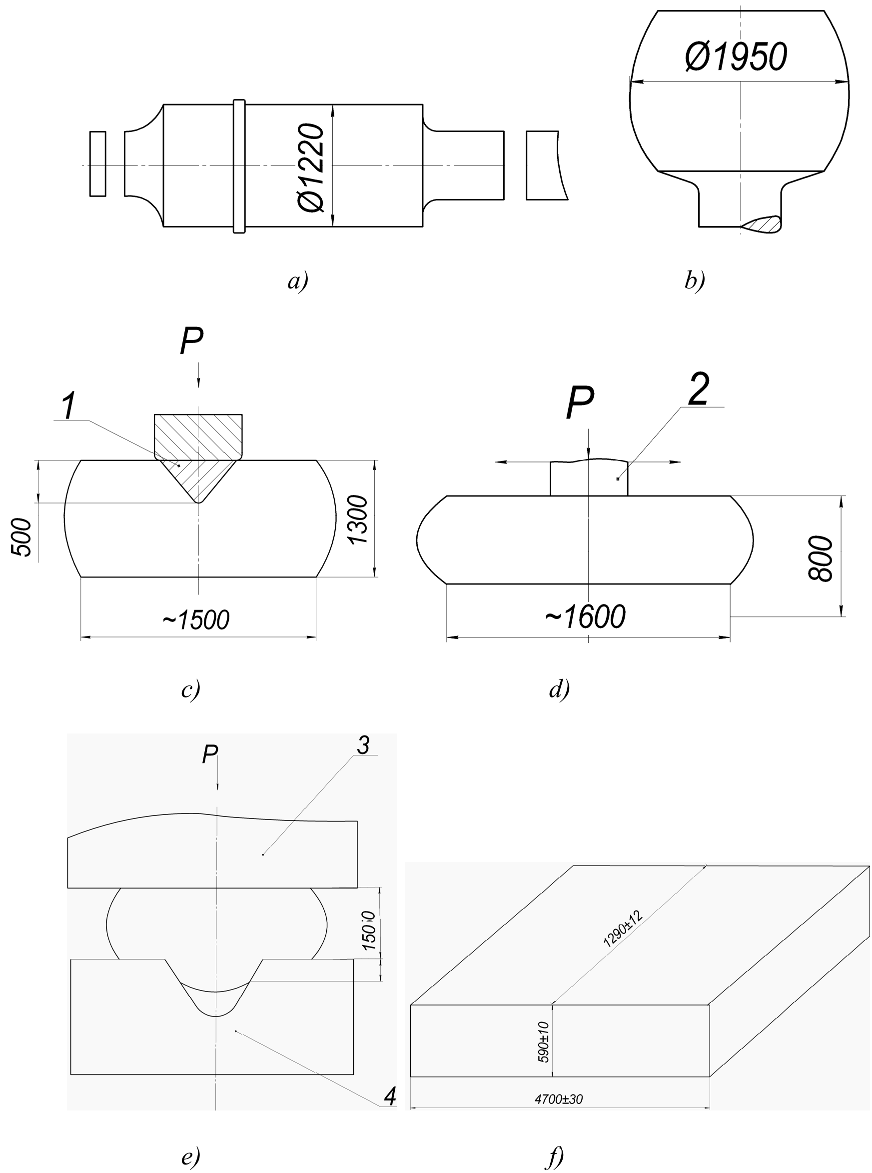


Figure 6.3 – Transitions forging of the slab

SECTION 7
WAYS TO REDUCE METAL CONSUMPTION AND TO INCREASE THE MECHANICAL PROPERTIES DURING THE FORGING OF SOLID CYLINDRICAL PRODUCTS

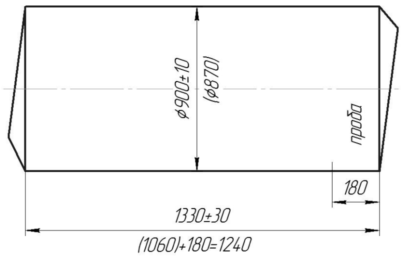
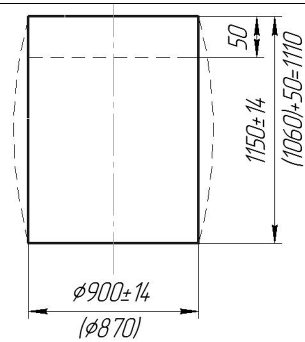
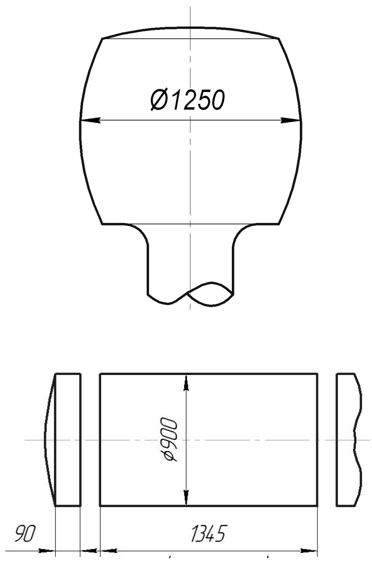
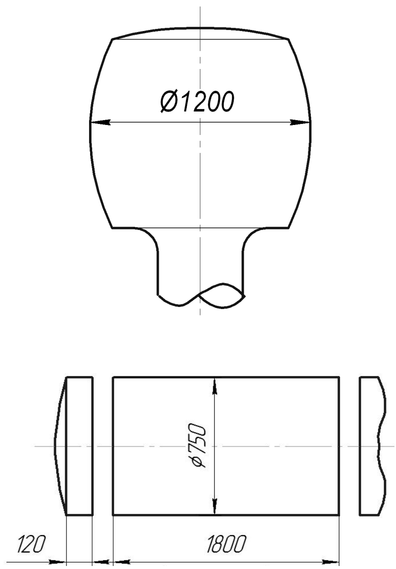
7.1 Improving the quality of large forged pieces

In forge-and-press production, there is a known method of forging solid cylindrical forged pieces [27] with the ratio of the part height to its diameter more than or equal to 1.2, in which the main operations are a combination of upsetting and drawing. In this method, the ingot upsetting is carried out before drawing, which allows obtaining a macro-structure in which the fibers are oriented mainly in the direction of drawing. This method of forging increases the anisotropy of mechanical properties, i.e., the difference in the properties of longitudinal and transverse specimens. For forged pieces such as gears and toothed hubs, it is important to have high mechanical properties in all directions [28 – 30]. It should be kept in mind that, depending on the method of manufacturing forged pieces, tests of mechanical properties are carried out mainly on the longitudinal or tangential specimen. For example, in the manufacture of forged pieces by drawing, the tests of mechanical properties are carried out on longitudinal specimens, and in the manufacture of forged pieces by upsetting – on tangential ones. However, allowances for mechanical tests are provided for each forged piece with dimensions in the range of 150 ... 180 mm or 40 ... 50 mm over the whole section of the workpiece, respectively.

As a rule, in the first case, the axis of the specimen for mechanical testing is located parallel with the axis of the forged piece. In these cases, the dimensions of the specimens are taken with the 20 mm diameter and 150 mm length. At the same time, the manufacture of forged pieces is regulated by standards, in particular, the forging of solid cylindrical forged pieces with the ratio of the part height to its diameter more than or equal to 1.2 is provided by the drawing method at the last stage of their manufacture. In this regard, the manufacture of forged pieces such as gears, toothed hubs, couplings, etc. has not previously been carried out with specimen sizes up to 180 mm more than the provided forging allowance along the length of the part (Table 7.1). Table 7.1 shows the existing scheme of the coupling forging weighing 6.7 tons from the ingot weighing 10 tons on the press with 30 MN power. At the same time, the metal utilization factor (MUF) in the process of manufacturing forged pieces according to the existing technology is 0.8, and the cutting metal waste was 3.7 tons, i.e., the weight precision factor (WPF) of the forging is 0.448. Such losses are caused by the non-technological design of the part and the imperfection of the forging technological process due to the large allowance for the sample.

To reduce metal consumption and inhomogeneity of mechanical properties in the manufacture of solid cylindrical forged pieces with a height of 1 500 mm, developed and implemented a new technological process for forging a coupling with an outer diameter of 900 mm and a height of 1 150 mm (Table 7.1)

Table 7.1 – Scheme of forging solid cylindrical forged pieces

<table>
<tr><th>Standard</th><th>New</th></tr>
<tr><td colspan="2">Forged pieces</td></tr>
<tr><td>
$M_f = 6.7$ t $M_{in} = 10$ t</td><td>
$M_f = 5.85$ t $M_{in} = 9$ t</td></tr>
<tr><td colspan="2">Sketches of transition</td></tr>
<tr><td></td><td></td></tr>
</table>

The drawing of the new forged piece provides taking into account a 50 mm sample allowance for testing mechanical properties on tangential specimens instead of mechanical tests on longitudinal ones, the material is 34Cr1Ni3Mo steel. The weight of the forged piece was reduced to 5.85 tons, the rate of metal consumption is 9.0 tons, the cutting metal waste decreased by 850 kg, and the weight accuracy coefficient of the forging increased to 0.515. The steel was smelted in an electric furnace.

The essence of the proposed technical process lies in the fact that the billet in the process of drawing is reduced below the forged piece dimensions, then it is upset with a total degree of deformation of at least 35 % and is finished with subsequent design to forged piece dimensions, i.e., rolling-off in diameter and feeding ends.

A characteristic feature of this process is that the formation of the forged piece at the last stage of its manufacture is performed due to additional deformation of the reverse sign – upsetting. As a result, the fibers after upsetting are located in all directions along the radius, and the mechanical properties at points equally distant from the center are relatively the same and quite high. This allows performing mechanical testing on tangential specimens on the relatively high forged pieces without reducing the norms of mechanical properties in comparison with the required norms forged with longitudinal samples. After heat treatment, the forged pieces were tested for mechanical properties. Table 7.2 shows the indicators of the mechanical properties in forged pieces made by the traditional method and by the new forging scheme.

Table 7.2 – Mechanical properties of manufactured forged pieces

Method of manufacturing	Mechanical properties				
	σ_B, MPa	σ_S, MPa	δ, %	Ψ, %	α_H, J / sm^2
TC for the part drawing	≥600	≥750	≥10	≥30	≥50
Well-known (mechanical properties obtained on longitudinal samples)	620	800	21.0	52.0	94…95
New (mechanical properties obtained on tangential samples)	700	845	10.8	30.0	117…112

A comparison of the obtained results allows establishing that the required characteristics got by the proposed forging scheme, satisfy the conditions of the part drawing. The specified value of the deformation degree, accepted at the stage of additional upsetting, is optimal from the perspective of achieving the required level of mechanical properties for the given section of the forged piece. The proposed forging scheme can be used in forge-and-press production mainly in the manufacture of large forged pieces such as solid gears, toothed hubs, couplings, etc., subject to subsequent tests for mechanical properties.

7.2 Piercing punch of forging ingots with simultaneous removal of hot-top

As a rule, piercing punch is the main forging operation in the manufacture of hollow forged pieces such as rings, shell rings, cylinders, etc. According to the existing technical processes for forging specified forged pieces, the piercing punch operation is performed after the billets upsetting to the required height, and the billet is cut from the ingot with the removal of the bottom and hot-top parts of the ingot. With such a forging scheme, a significant amount of metal yield in the middle part of the ingot is removed as waste, and these operations also lead to unnecessary forging labor costs.

To increase the productivity of forging and the metal utilization factor (MUF) by eliminating the cutting operation, when the whole body of the ingot is used, the method of piercing punch of the forging ingots can be applied [31]. According to this method, in the process of piercing punch, together with the bulkhead, the hot-top part of the ingot is removed to waste due to the reduction of the waste by a diameter smaller than the outer diameter of the hollow piercing punch. To implement this method, it is reasonable to use a device for a piercing punch of the forging ingots [32]. Figure 7.1 schematically shows a device for piercing punch of the forging ingots with a shank at the end of the piercing punch (general view). Piercing punch of upset billets according to the proposed device is carried out the following way. Insert 1 with the stuffer 2 is installed in the hole of the upsetting plate 3 and the backing ring 4. After that, the ingot 10 with the shank is installed in the cavity of the stuffer 2 and is upset on the backing ring 4 to a given height. Then, guideposts 6 are secured into the eyes 5, after that the strickle 7 and the hollow punch 11 are installed on the guideposts 6 and the upset ingot 10, which is pierced with the hollow punch 11 to the full height.

After that, the upsetting plate 3, together with the guideposts 6 and the stuffer 2, are lifted by a crane (not shown), the base of the centering insert 1 is removed from the backing ring 4 with the ingot 10, dropped onto the backing ring 4 and the final piercing punch is performed. In this case, stuffer 2 remains on the separated part of the waste and the bulkhead.

The proposed device ensures the axes coincidence of the pierced hole with the hole of the upsetting plate and excludes the possibility of removing the good metal into the bulkhead, and due to the application of the proposed method, the whole body of the ingot is used, that significantly increases the metal utilization factor. This eliminates the need for cutting the bottom and hot-top part of the ingot, which increases the productivity of forging in the manufacture of hollow ingots.

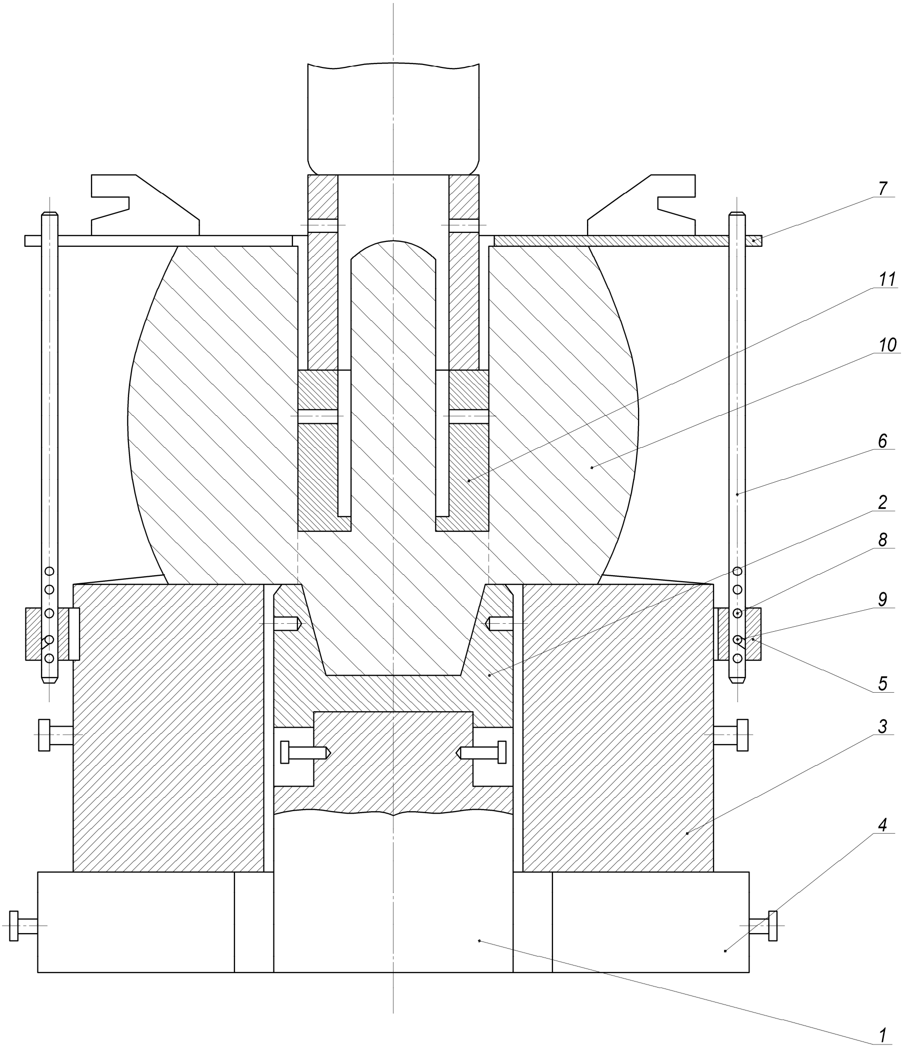


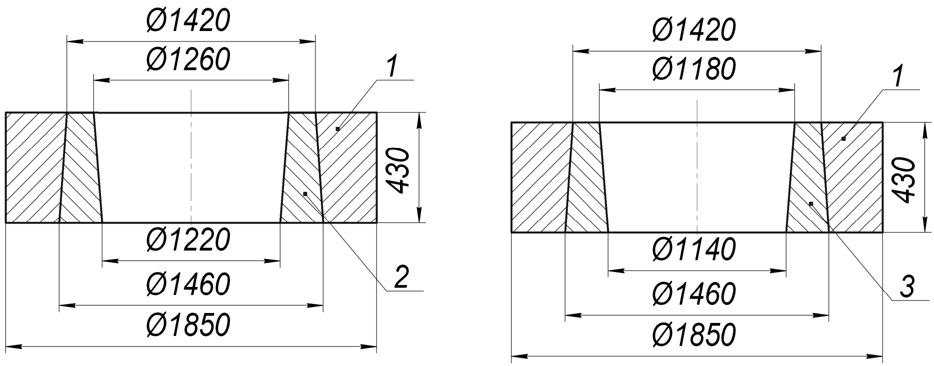
Figure 7.1 – Device for a piercing punch of the forging ingots

7.3 Forging of gearwheel with their subsequent step rolling-off

According to the existing technology, forged pieces such as toothed hubs were forged without ledges along the outer diameter because the technological possibility doesn't allow to form them in the forging process, associated with the small length of the drawn metal obtained by cutting metal on a large diameter of the billet. So, their production was carried out with large metal waste along the outer diameter and, accordingly, with increased metal consumption and high labor intensity during machining (see the sketch of the forging – table 7.3). To reduce the metal consumption and the labor intensity of machining, a technological solution was adopted, that allows performing ledge along the outer diameter on the indicated forged pieces due to the billet upsetting in the newly developed replaceable inserts placed in the existing backing rings [33 – 35]. In this case, after the billet piercing punch and rolling-off, there is a rolling-off along the forging steps to forged piece dimensions. The formation of ledges on these forged pieces allows to significantly reduce the consumption of metal by 1 ... 2 standard ingot sizes in comparison with the existing technological processes of their manufacture and, accordingly, reduce the labor intensity in the product machining.

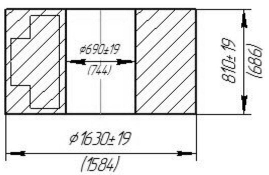
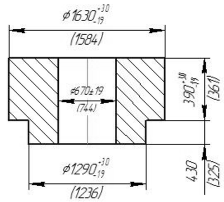
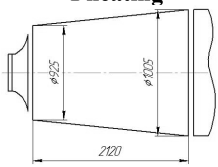
Moreover, the metal consumption for the manufacture of replaceable inserts is required much less than the expected savings from the introduction of the proposed technology. It should be noted that replaceable inserts are made with an inverted cone to tilt the upset billet together with the backing ring by 180º for the hole piercing punch and its subsequent extraction from the backing ring. Comparative technical processes for forging toothed hubs (basic and new) are shown in Table 7.3. Sketches of backing rings with replaceable inserts are shown in Figure 7.2.

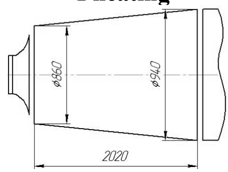
Thus, the combination of the billet upsetting operations in the backing rings (on the rings with holes) followed by rolling-off along the forging steps allows obtaining forged pieces of a new configuration, moving it closer in shape and size to the finished dimensions of the part. That significantly reduces metal consumption and labor intensity of mechanical processing in comparison with the existing methods of their manufacture.

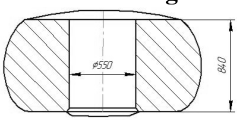


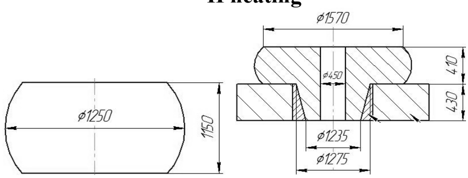
1 – backing ring; 2, 3 – replaceable inserts
Figure 7.2 – Sketches of backing rings with replaceable inserts

Table 7.3 – Technological process for forging toothed hubs

<table>
<tr><th>Basic option</th><th>New option</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>I heating


1. Drawing the hot top with a turn.
2. Billeting on the cone.
3. Cut off the ingot`s bottom.
4. Cut off the block with a turn, put it in the furnace</td><td>I heating


1. Upset the hot top with a turn.
2. Billeting on the cone.
3. Cut the ingot`s bottom.
4. Cut off the block with a turn, put it in the furnace</td></tr>
<tr><td>II heating


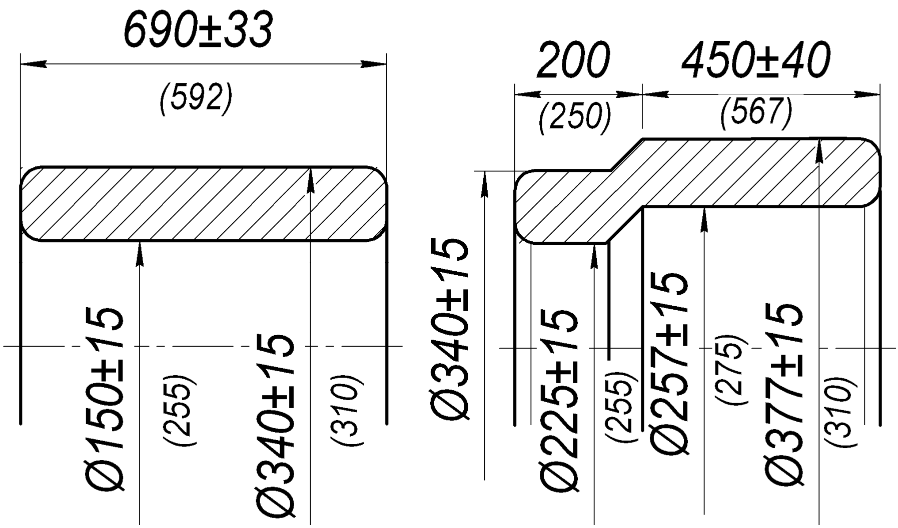
1. Upset the block to H = 840 with the upper spherical plate.
2. Piercing punch Ø550 / 300 mm.
3. Barrel reduction on the mandrel and rolling-off to Ø = 650 mm.
4. Feed on the ends sufficiently.
5. Rolling-off sufficiently, correction.
6. Mark and transfer to heat treatment</td><td>II heating


1. Upset the block to H = 1150 mm.
2. Install the billet into the backing ring.
3. Upset to H = 410 mm.
4. Remove the workpiece from the backing ring with tilt top to bottom.
5. Piercing punch Ø 450 / 240 on the part of Ø 1235 мм.
6. Rounding on the mandrel Ø400 / 500 to Ø1570 mm.
6. Upset to H = 820 mm
III heating
1. Take on the mandrel and rolling-off along the ledges with a reduction value of 30 ... 50 mm per press stroke.
2. Remove from the mandrel.
3. Correction the ellipse and the ends.
4. Mark and transfer to h / t</td></tr>
</table>

7.4 Production of thin-walled forged pieces such as rings and cylinders from rolling-off pipes

The practice has established that during forging such workpieces as rings and cylinders, it is possible to obtain a minimum wall thickness of the billet up to 100 mm under the press with 25 MN power since during forging with a smaller forged piece thickness, the specific press power sharply increases, that leads to a decrease in the productivity of the forging equipment. Therefore, these products with a wall thickness of 20 ... 30 mm, previously issued for production, were closed with metal pudding, which led to the increase in metal consumption and labor intensity of their manufacture.

To increase the production efficiency of manufacturing forged pieces such as rings, bushings, and cylinders of relatively small length by reducing their wall thickness, it was proposed to use the pipes (Ø377 mm, S = 60 mm and Ø480 mm, S = 50 mm) as the part, received by cooperation with metallurgical plants. At the same time, using the method of rolling-off, drawing, and closing, bring them to the shape close to the finished part. Sketches of forged pieces before and after implementation are shown in Figures 7.3 and 7.4.



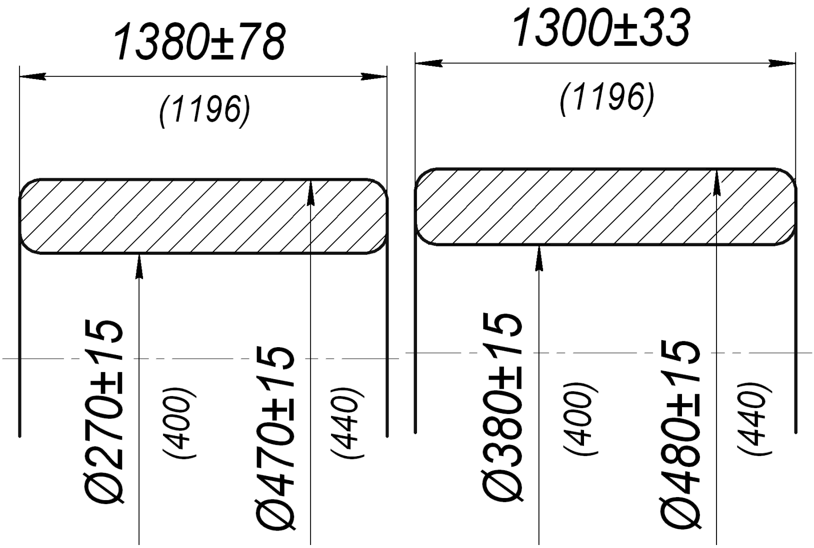
Mf = 420kg,
a)

Mf = 300kg,
b)

a – before implementation, b – after implementation
Figure 7.3 – Sketches of the forged pieces "bushing"

The proposed scheme for the manufacture of hollow forged pieces significantly reduces the consumption of metal and the labor intensity of machining in comparison with forging them from forging ingots, and also allows using of reduced power presses. Ultimately, a significant technical and economic effect is achieved in the production of these forged pieces.

As above mentioned, the use of traditional ingots for forging hollow forged pieces leads to high labor costs and high metal consumption. In this regard, the question arose of the need to change the shape of a solid ingot to a hollow [36]. The use of such ingots in forge-and-press production will significantly reduce the labor intensity when forging cylinder-type forged pieces by 40 ... 50 %, and there is a technical possibility of using them for forging rings and rims. Moreover, to reduce the specified labor intensity when forging hollow forged pieces, it makes sense to cast hollow ingots into casting forms of increased taper with the ratio H / D = 1.5…1.6 or H / D ≈ 1.0 [37]. It should be noted that the issue of changing the shape of a solid ingot to a hollow one requires deep study with conducting scientific research.



Mf = 1350kg, Mf = 745kg,

a) *b)*

a – before implementation, b – after implementation

Figure 7.4 – Sketches of the forged piece "Cylinder"

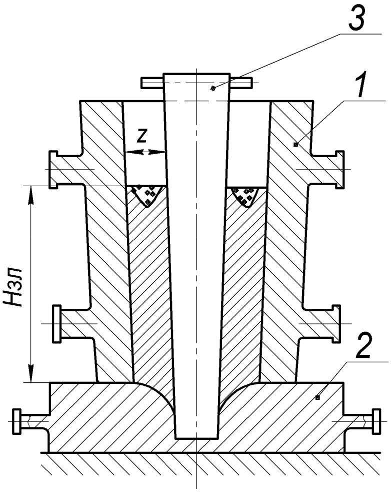
7.5 Ingots for hollow forged pieces

In the metallurgical industry, there are several ingot molds for hollow ingot manufacture. For example, there is a well-known mold consisting of a body and a tubular core, which is cooled during the crystallization of the ingot [38]. A more progressive design is a mold for the manufacture of hollow ingots, containing a central core, which is attached to the hot-top part of the mold, while the ingot is poured from the bottom, the refrigerator-crystallizer is located on the side of the plate stand, and the side surface and the upper part of the mold are insulated from the environment.

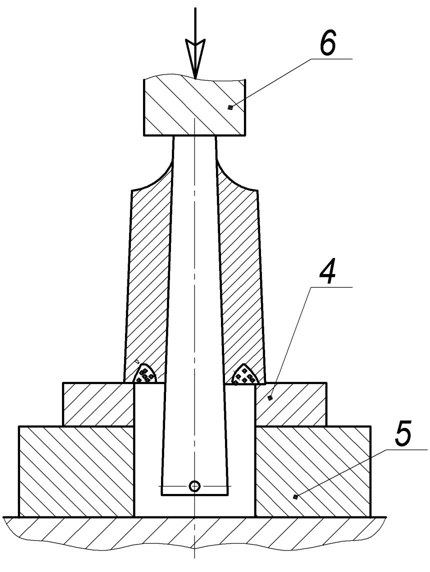
The limitation of this mold design is that the core is not reusable, made of refractory materials that will get into the molten steel and contaminate the ingot. Support in the hot-top part of the ingot and pouring from the bottom through the center hole will result in ingots with a bottom.

The paper proposes a new design of a mold for the manufacture of hollow ingots, that ensures an increase in the metal quality of ingots by reducing its contamination with refractory materials, including eliminating the bottom piercing punch operation by obtaining a through the hole, which will reduce the consumption of metal, and also allow to increase the durability of the central core.

The ingot mold consists of a body of mold 1, which is installed on a plate stand 2, into the central hole of which a metal core 3 is inserted to form the inner cavity of the ingot (Fig. 7.5, a). A gap z is formed between the body of mold 1 and the core 3. Liquid steel is poured into this gap from the top to a given height H_{ing}, which is determined by the volume (mass) of the ingot. Crystallization of the ingot occurs from the walls of the mold and extends to the metal core. In the top part of the ingot, an annular sinkhole is formed, which is removed during the forging process. Metal core 3 will eliminate contamination of steel by refractory materials and can be used to make other ingots. The diameter of the core must be greater than or equal to the diameter of the mandrel, on which the ingot will be deformed in the future. After ingot crystallization, it together with the core will be removed from the body of mold 1. When the temperature of the bottom end of the core reaches 600 ... 650°C, the ingot with the core is turned over and installed on the bottom plate 4 with a hole larger than the diameter of the core (Fig. 7.5, b). With a long core 3, an additional plate 5 is installed under plate 4 to be able to squeeze the core out of the ingot. The core is removed under a press. Press anvil 6 puts pressure on the bottom end of the tapered core 3 and pushes it out. Thus, the proposed design of the mold provides an increase in the metal quality of the ingot, and longer service life of the core, and also allows to reduce the consumption of metal by eliminating the operation of piercing punch the ingot bottom.



a)



b)

Figure 7.5 – Scheme for obtaining a hollow ingot

SECTION 8
MANUFACTURE OF LARGE-SIZED FORGED PIECES SUCH AS RINGS AND RIMS WITH ELIMINATION OF SPHERICITY ON THE ENDS

The method of ring forging by rolling-off them on a mandrel with the upper flat anvil is widely known in the press-forging industry. However, when rolling-off large-sized rings and rims with a diameter of more than 3 000 mm, the uncontrolled sphericity (convexity) at the ends are formed. At the same time, it is not possible to eliminate sphericity on these forged pieces after rolling-off due to the limitation of upsetting plate sizes and the working space of heating furnaces.

For the above-mentioned reasons, the manufacture of large-sized rings and rims was carried out with sphericity at the ends, which increases the rate of metal consumption and labor intensity during mechanical processing.

To eliminate the noted disadvantages in the manufacture of large-sized rings and rims, a technological solution was used [38]. Its essence lies in the fact that the billet is fed at the ends after its preliminary rolling-off to 0.85 ... 0.9 of the outer diameter of the rim. The final rolling-off is carried out in the last heating at a metal heating temperature for forging up to 1 000 ... 1 050°C. Due to the optimal redistribution of the rolling-off volumes and an additional feeding at the ends, the final rolling-off is carried out with the flat ends due to their accelerated cooling and insignificant deformation of the metal in the last heating, which generally holds the formation of sphericity at the ends.

Rolling-off large-sized rings and rims with relatively flat ends allow to reduce the metal consumption by 1 ... 2 standard sizes of the ingot in comparison with the existing technological processes of their manufacture and reduces the labor intensity in the products machining.

It should be noted that when developing technical processes for rolling-off forged pieces, it is necessary to determine the height of the billet (H_0), taking into account it's widening (elongation), depending on the size of the rolled diameters and the anvil design. It has been established in practice that the widening along the height of the billet when rolling-off the inner diameter for every 100 mm is:

- planed anvil – 5 ... 6 mm;
- old anvil – 10 mm;
- longitudinal anvil – 2 ... 3 mm.

Ultimately, the required upsetting height of the billet (H_0) before the final rolling-of is determined from the calculation

$$H_0 = H_f - n \cdot \Delta_b,$$

where H_f – the height of the forged piece;

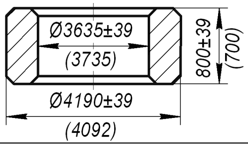
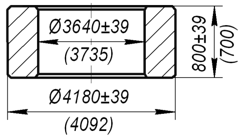
n – the number of rolling-off to 100 mm;

Δ_b – widening depending on the tool used (anvil).

As an exception, in the case of a small rolling-off, the height of the billet is taken to be equal to the roughing height of the forged piece (Fig. 8.1). Comparative technological processes for forging rims are shown in Table 8.1.

Figure 8.1 – Rolling-of the ring after the upsetting

Table 8.1 – Technological processes for rims forging

<table>
<tr><th>Basic option</th><th>New option</th></tr>
<tr><td>
</td><td>
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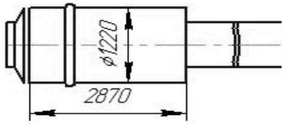
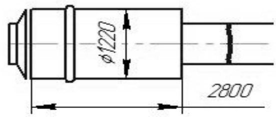

</td><td>I heating

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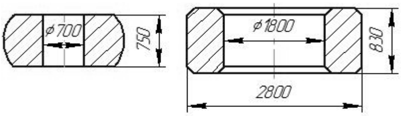
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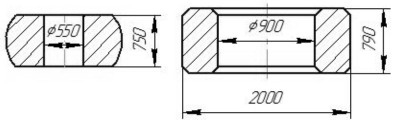
</td></tr>
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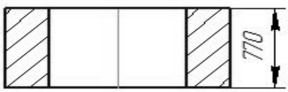
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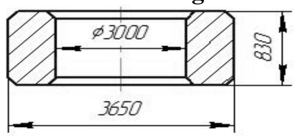
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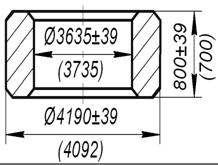
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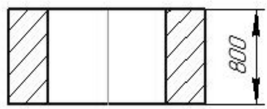
</td></tr>
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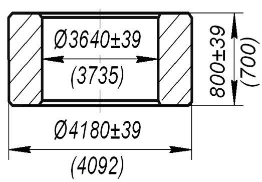
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SECTION 9
ROLLING-OFF LARGE-SIZED FORGED PIECES SUCH AS RINGS AND SHELLS OF PARTICULAR PRECISION ON POWERFUL HYDRAULIC PRESSES

As a rule, the main method for the manufacture of ring forged pieces is forging rolling-off on a mandrel with a flat anvil, during that the billet diameter increases due to a decrease in the thickness of its wall [39].

The disadvantage of rolling-off billets on a mandrel is the low accuracy of manufacturing forged pieces in terms of diameters due to imperfect processes of tilting (turning) the billet by a given angle, since the mandrel, by rotation and friction, takes the billet with it, and does not always have time to turn by a given angle before every reduction.

In connection with the above-mentioned disadvantages, when rolling-off large-sized forged pieces such as rings and shells, a maldistribution of allowances are possible, resulting from ellipticity, and concentricity of the forged pieces' outer and inner diameters, etc., which leads to an increase in labor intensity during machining. In addition, the presence of defects in the form of taper and ellipses on the surface of the ring leads to the fact that its cross-section becomes oval, that is, of irregular shape, which significantly reduces the quality of the manufactured products.

To eliminate the above-mentioned disadvantages in each technological process, after rolling-off forged piece dimensions, the operation of straightening the ellipse and taper in their certain parts is introduced. However, the manufacture of rings and shells with a redistribution of the maximum deviations relative to forged pieces' dimensions beyond the limits to their increase or decrease is not always possible to correct.

A typical technological process for producing a large-sized ring on powerful hydraulic presses includes ingot upsetting, preliminary rolling-off, feeding, and final rolling-off.

The analysis of the processes for the manufacture of ring workpieces in this way showed that rolling-off workpieces on mandrels are one of the most difficult forging operations, as a result of them the rolling-offed products have a reduced accuracy of the obtained dimensions in diameters and low surface quality of the manufactured products.

The development is based on the task of creating a more efficient method for manufacturing large-sized rings and shells, ensuring an increase in the accuracy and quality of rolling-offed pieces by minimizing the misalignment of forging allowances along their outer and inner diameters and eliminating defects such as taper and ellipse forms. The task is achieved by the fact that in the process of final rolling-off, at the final stage, the workpiece is rolling-offs with an allowance of 0.5 ... 1.0 % in terms of diameters relative to the given dimensions of the product.

After it rolling-offs without mandrel along its outer diameter to obtain the specified dimensions of the forged piece in the lower (cut) and upper (flat) anvils, the workpiece is rolled not over the total length of the circumference, but only in the sections with the greatest wall thickness. In fact, in the process of rolling-off, the wall thickness of the workpiece is leveled until its optimal allowable value is obtained, and thus that way helps to eliminate the greatest misalignment of the forging allowances along the diameters of the forging in the form of ellipse and taper, which are inevitably obtained during rolling-off.

At the same time, in the process of rolling-off the workpiece in the lower (cut) and upper (flat) anvils, the shape and dimensions of the forged piece diameters are more reliably fixed by changing the forging pattern of the ring workpiece at the final stage of their manufacture. This allows small reductions to eliminate the final irregularities in the outer diameter with the simultaneous hole closing along the inner diameter to give the forging a smooth surface and bring it to the forged piece dimensions.

Rolling-off of ring workpieces is carried out in the following sequence of operations:

- billeting and block cutting (billet);
- upsetting and block drawing;
- preliminary rolling-off of the workpiece;
- the workpiece feeding at the ends;
- final rolling-off of the workpiece to forged piece dimensions.

The rolling-off of experimental ring workpieces under industrial conditions in combined anvils has shown the effectiveness of the proposed solution, which, in particular, provides:

- increasing the dimensional accuracy of the ring workpiece due to the elimination of misalignment of forging allowances along its diameters;
- improvement of the surface quality of the manufactured forged pieces due to the absence of defects in the form of ellipse and taper on their surface.

Thus, the proposed scheme for rolling-off ring products, in comparison with the known methods, makes it possible to obtain forged pieces with relatively equally spaced allowances along their diameters, that is, the misalignment of the outer and inner diameters of the forged piece is located in the sufficiently narrow field of forging allowance. Consequently, the proposed solution increases the accuracy and quality of the manufactured forged pieces, and there are all the prerequisites for obtaining rings with significantly smaller allowances and tolerances due to a fundamentally new forging scheme adopted at the last stage of their manufacture.

SECTION 10
METHOD FOR PRODUCING OF HOLLOW SPHERICAL FORGED PIECES

Hollow sphere workpieces, reduced on both sides in height, which are used as stop-gate valves for transporting oil or gasoline in high-pressure pipelines, are widely used in the oil refining industry. Their production at some enterprises is carried out traditionally – forging a workpiece in the form of a cylindrical shell by rolling-off on a mandrel with an upper flat anvil. According to this method, the production cost of the spheres is high, due to the increased consumption of metal and the high labor intensity of machining the workpiece due to significant overmeasure of the forging.

The development of a new technical process is based on the task of creating a method for manufacturing a spherical forging reduced on both sides, providing a minimum metal consumption and a decrease in the labor intensity of manufacturing due to obtaining optimal forging allowances on the forged piece. This problem is solved with a special profiled tool, which ensures the formation of metal from the condition of obtaining a sphere workpiece, similar in shape and size to the finished part. To achieve the specified technical result, in the method of manufacturing hollow spherical forged pieces [40], after piercing punch, preliminary rolling-off of the workpiece is carried out until a spherical shape is obtained along the outer diameter (Fig. 10.1), and the final rolling-off is carried out with the upper spherical anvil (Fig. 10.2), in which the working part is made according to the profile of the forging sphere.

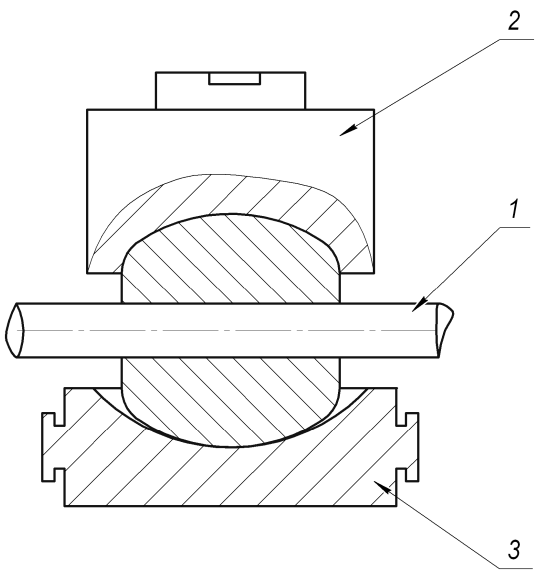


Figure 10.1 – Rolling-off the workpiece in spherical dies

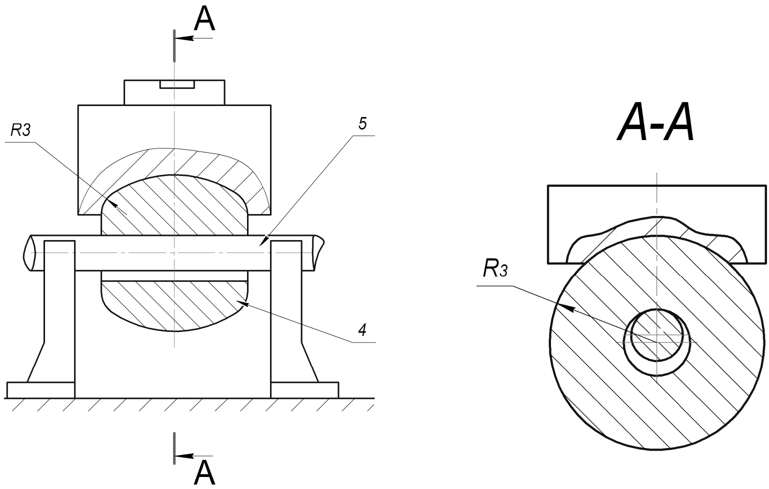


Figure 10.2 – Rolling-off a spherical forged piece

It should be noted that in the process of rolling-off the forged pieces with the upper spherical anvil, the metal flow running is mainly directed in the radial and tangential directions, which ensures the manufacture of hollow forged pieces with inner cylindrical and outer spherical surfaces close in shape and size to the finished part. With this scheme of metal deformation, the cast structure of the original steel ingot is more efficiently worked through, which increases the mechanical characteristics of forged metal and, accordingly, the durability of products in exploitation.

The proposed method was tested and implemented in the press-forging shop at the hydraulic complex, including a hydraulic press with a force of 100 MN, and a forging manipulator with a load capacity of 120 tons.

Example 1. A spherical forged piece with a mass of 13 000 kg, a height of 1 390 mm, an inner diameter of 1 105 mm, with a sphere radius of R = 925 mm, was made from the ingot weighing 21 000 kg of A488EP steel. Technological operations were carried out in the following sequence:

1. The ingot billeting by Ø 1 050 mm with the removal of the waste;
2. The block upsetting up to Ø 1 600 mm by flat dies, drawing to Ø 1 050 and cutting of a block with a length of 2 250 mm;
3. The block upsetting by the upper spherical die and piercing punch of the workpiece by the puncheon to obtain a central hole D = 550 mm;
4. The rolling-off of the workpiece to the sphere up to Ø 1 600 mm on a mandrel Ø500 / Ø600 mm in the lower and upper spherical dies;
5. The rolling-off of the workpiece on a mandrel to Ø500 mm by an upper spherical anvil with the 40 mm reduction value per press stroke to forged piece dimensions.

Comparative technological processes of spherical forged pieces (basic and new) are shown in Table 10.1. Measurements of the forged piece dimensions on the forged workpieces confirmed that the machining allowance is uniform and equal to 30 mm, i.e., minimal.

Example 2. When re-ordering, the specified forging of the sphere, in contrast to the previous method, was manufactured with some forging peculiarities, namely: in the second heating after the piercing punch of the upset workpiece, it was rolling-offed to the inner diameter of Ø650 mm; in the third heating on a mandrel Ø580 / 620 mm, by drawing a symmetrically stepped shape of the workpiece with three ledges on both sides relative to its middle part was obtained to get a more pronounced barreling during the subsequent billet upsetting; in the fourth heating, the preliminary rolling-off was carried out with a longitudinal spherical anvil with a B = 600 mm width; in the fifth heating, the final rolling-off was carried out with the same anvil.

The process of rolling-off with a narrow spherical anvil showed the possibility of obtaining spherical forged pieces to the specified dimensions, as well as with a spherical anvil, the working part of which is made in a larger volume. The technological process of sphere forging is shown in table 10.2. Thus, the proposed methods for the manufacture of hollow spherical forged pieces allowed to obtain workpieces with a geometry close to the part, and, consequently, reduce the consumption of metal and the labor intensity of their machining, and also improve the quality of the manufactured products significantly. The example of a forged piece after roughing a sphere is shown in Fig. 10.3.

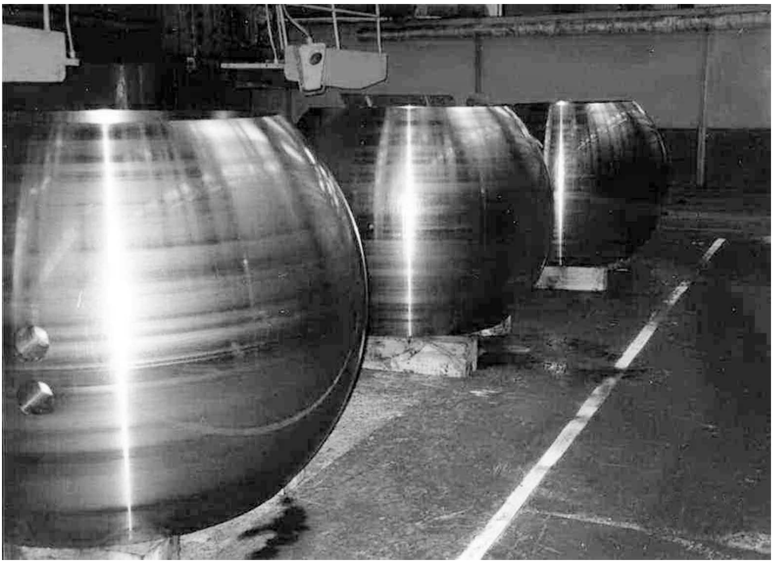


Figure 10.3 – Example of the forged piece after the sphere roughing

Table 10.1 – Comparison of basic and new technological forging processes of 48´´ spheres forging

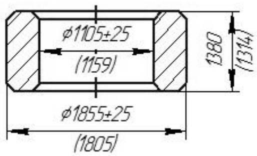
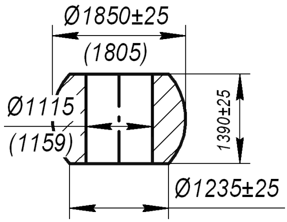
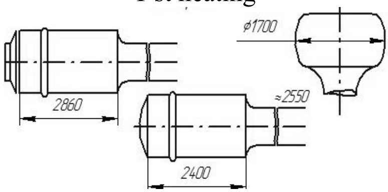
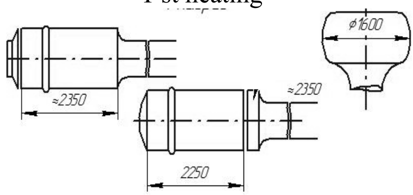
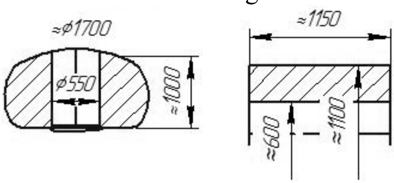
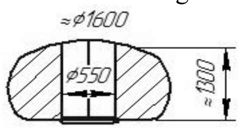
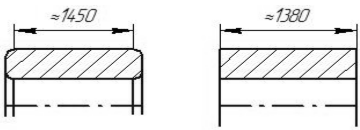
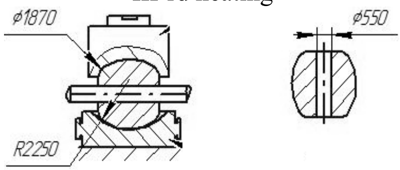
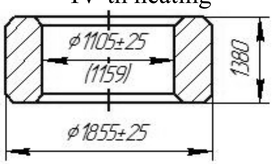
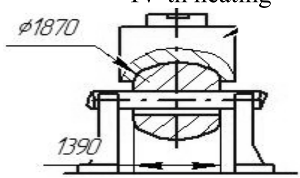
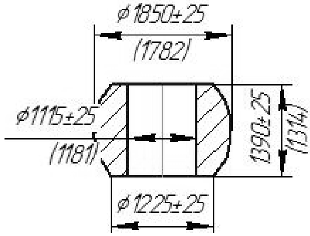
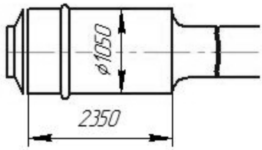
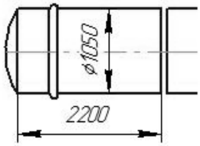
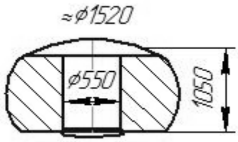
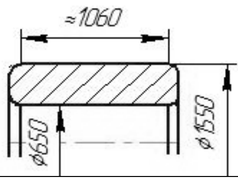
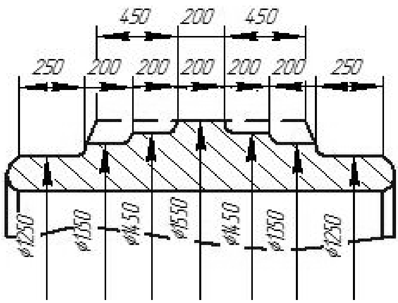
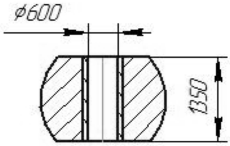
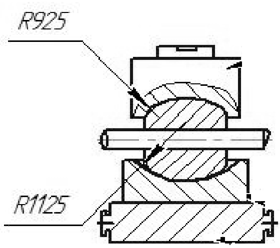
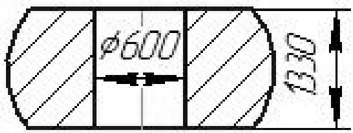
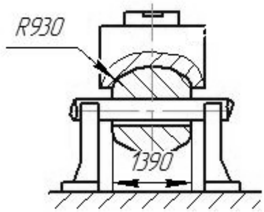
Basic option	New option
	
I-st heating 	I-st heating 
II-nd heating 	II-nd heating 
III-rd heating 	III-rd heating 
IV-th heating 	IV-th heating 

Table 10.2 – Technological process of forging the 48′′ sphere

M_f = 13 000kg; M_{in} = 21 000kg; Material – A48FP Dimensions in brackets – finishing	
Operations	Transition sketches
1. Billeting and cut off the ingot\`s bottom with a turn. 2. Cut the hot-top for the upsetting die. 3. Upsetting out with a flat die to Ø 1 600. 4. Drawing through Ø1 050 in combined anvils. 5. Mark and cut out the block with a turn. 6. Put in the furnace	
1. Upsetting workpiece by the top spherical die to H = 1 050mm. 2. Pirsing punch by the hollow puncheon strictly in the center Ø 550 / 300 / 240. 3. Trim by autogenous waste. 4. Rolling-off to $Ø_1$ = 650. 5. Correct of the ends. 6. Put in the furnace.	
1. Put the workpiece on the mandrel Ø 580 / 620. 2. Upset to Ø 1550, L = 1100 mm. 3. Mark. 4. Reduction the ends to Ø 1450 with transition to Ø 1350 and Ø 1250. 5. Remove from the mandrel.	

Continuation of the table 10.2

Operations	Transition sketches
6. Upset to H = 1 350mm. 7. Put in the furnace	
1. Install the lower spherical die. 2. Install the upper spherical anvil. 3. Put the workpiece on the mandrel Ø 550 / 600 and roll the sphere to Ø 1600, L = 1400 mm. 4. Turn over the workpiece by 90°. 5. Remove the lower spherical die. 6. Change the spherical anvil to a flat one. 7. Place the workpiece on the lower flat die. 8. Upset to H = 1330 mm. 9. Turn over the workpiece by 90°. 10. Put in the furnace.	 
1. Install the spherical rolling-off anvil. 2. Put the workpiece on the mandrel Ø 500 and rolling-off to Ø$_1$ = 700. 3. Change the mandrel to Ø 680 and rolling-off to the extent of the 30…50 mm reduction per press stroke. 4. Check the sphericity of the forged piece by a template in height and diameter. 5. Edit ellipticity, control. 6. Pass to t / department	 (see the sketch of the forged piece)

SECTION 11
PRODUCTION OF LARGE FORGED PIECES SUCH AS CYLINDERS STEPPED ALONG THE OUTER AND INNER DIAMETERS BY FORGING ON PRESS

In the nomenclature of many heavy engineering enterprises, there are hollow products of stepped shape along the outer and inner diameters. Forging of such products is carried out with metal waste from the side of the inner diameter ledge and they are made by drawing on standard mandrels. In the process drawing of the workpiece on the mandrel, it is not particularly difficult to perform a stepped shape of the forging along its outer diameter, while a smooth shape of the hole with a diameter equal to the outer diameter of the mandrel is formed along the inner diameter. For forging cylinders with a finished diameter over 1 250 mm it is necessary to have standard mandrels with a diameter from 1 150 to 1 400 mm.

At the same time, the manufacture of such mandrels with 1 150 mm and more diameter is associated with significant labor costs, since they have a significant mass; for their transportation, it is necessary to have equipment of greater carrying capacity, which is not always available for forge-pressing shops. Concerning these circumstances, for forging large products such as cylinders, it is not always possible to make a hole in the forged piece with the required dimensions. The above-mentioned disadvantages lead to an increase in the consumption of metal and labor intensity in the machining of hollow forged pieces such as cylinders. Taking into account the complex configuration of the forged piece and the peculiarities of the technological process of its manufacture, the task of improving the technological process of producing large cylinder-type forged pieces of a stepped shape along the outer and inner diameters is solved in two stages:

- at the first stage, the possibility of manufacturing hollow cylinders of a stepped shape along the outer diameter by rolling-off the workpiece on a mandrel to obtain forged piece dimensions is considered;
- at the second stage – the formation of a forging stepped shape along the inner diameter by forging of the one workpiece steps.

The essence of the rolling-off of stepped forged pieces at the first stage is that in the process of preliminary drawing, forged piece steps are formed on a standard mandrel. In this case, the workpiece is given a shape similar to that of the forged piece, and in the rolling-off process, the shape of the workpiece does not change until the forged piece dimensions are obtained, only the diameters of the rolled steps and their length are changed [41].

When developing the technology of forging stepped rolling-off, it is necessary to take into account the widening in the diameter and length of the workpiece on the basis that when rolling-off the inner diameter for every 300 mm, the widening of the outer diameter is 100 mm, and along the length, it is up to 10 mm.

In the second stage, a stepped shape of the forged piece is formed along the inner diameter by a means of diameter reduction of the workpiece one step. In this case, the cross-section of the workpiece before diameter reduction should be 1.6 ... 1.8 times more than the cross-section after the diameter reduction. With a diameter reduction, the wall thickness has a great influence, and, the greater the wall thickness, the more metal flows in length, that is, a larger cross-section is required for the diameter reduction. Therefore, the calculation of the workpiece dimensions at this stage of forging is one of the important moments of the workpiece end. As a rule, the diameter reduction of the workpiece end is produced on a mandrel by uniform reductions in combined or cut-out anvils, depending on the chemical composition of the steel from which the forged piece is made. The combination of operations stepped rolling-off of the workpiece with the subsequent closing of the end section until a protrusion along the inner diameter of the forging is obtained makes it possible to obtain a forged piece of a new configuration, bringing it in shape and size to the finished dimensions of the part.

This significantly reduces the metal consumption and labor intensity of machining in comparison with the previous method of manufacturing hollow forged pieces such as cylinders. In addition, according to the proposed solution, in the manufacture of large forged pieces such as cylinders, the need for the manufacture of heavy mandrels is excluded and expands the range of forged pieces manufacturing both in configuration and in diameters. Comparative technological processes of forged pieces such as cylinders with holes (basic and new) are shown in Tables 11.1 and 11.2. It should be noted that in the nomenclature of many plants there are hollow forged pieces of the cylinder type with relatively small diameters up to 100 mm at the end sections of the forged piece. In these cases, it is rational to forge such end parts of the forged pieces in cut-out anvils by uniform reductions to zero, that is, until the walls of the forged piece come into contact along their inner diameter (Fig. 11.1 and 11.2).

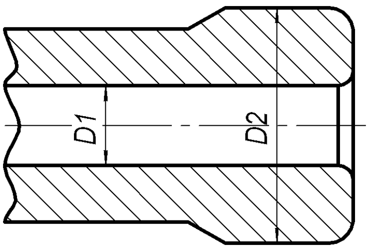


Figure 11.1 – Section before the closing bottom

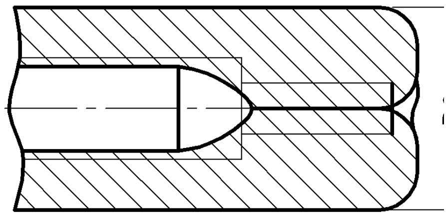


Figure 11.2 – Section after forging bottom

For a complete closing of the workpiece hole, the protrusion diameter of the workpiece is determined based on the following equation

$$\frac{0{,}785(D_2^2 - D_1^2)}{0{,}785 D_3^2} = 2{,}2 \ldots 2{,}3$$

Table 11.1 – The basic technological process of forging the "Hollow shaft"

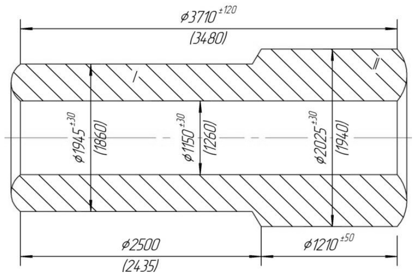
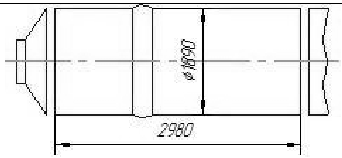
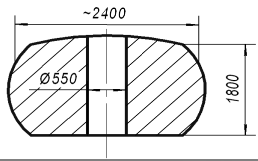
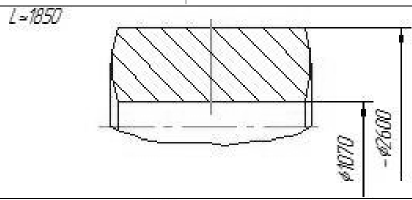
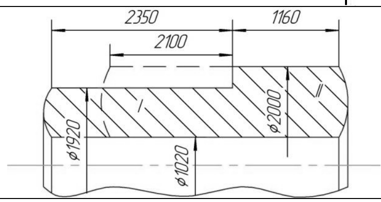
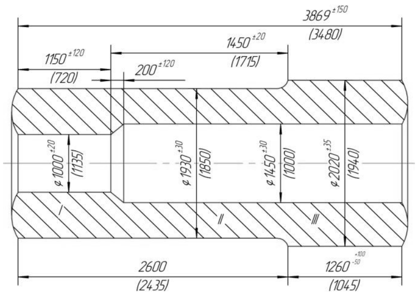
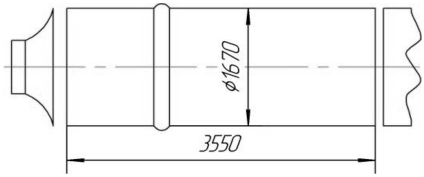
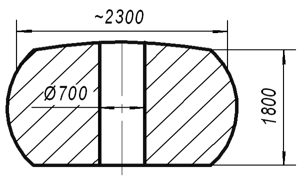
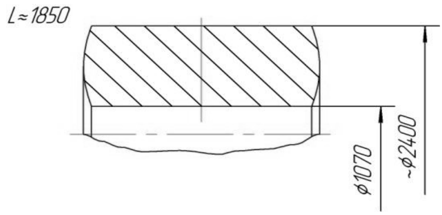
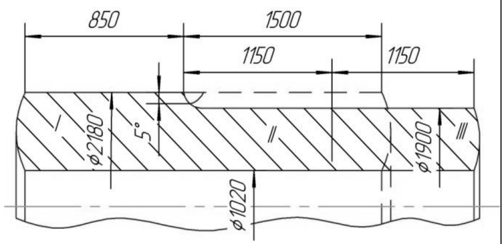
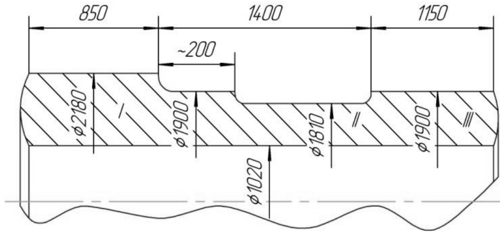
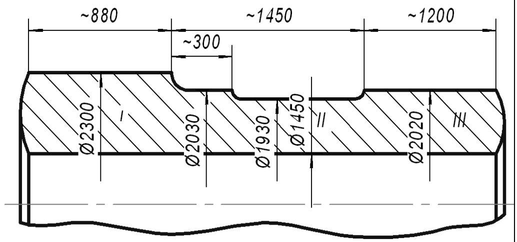
Operations	Transition sketches
Basic process M_f = 62 700 kg; M_{in} = 98 000kg; material – Steel 45; dimensions in brackets – finishing	
1. Billeting the bottom part with turning. 2. Cut off the ingot`s bottom. 3. Billeting the ingot`s residual portion. 4. Cut off the block, put in the furnace	
1. Upset the block by a spherical die to H = 1 800 mm. 2. Piercing punch with a hollow puncheon Ø 550 / 300 / 240, cut off the waste in a hot state. 3. Put in the furnace	
1. Flatten the walls by rolling-off on the mandrel up to $Ø_{in}$ = 1 070 mm. 2. Put in the furnace	
1. On the mandrel Ø 1 060 / 980 reduce by Ø 2 000. 2. Mark. 3. Reduction the ledge I by Ø 1 920. 4. Remove from the mandrel. 5. Put in the furnace	
1. Rolling-off the protrusion and ledge I on the mandrel sequentially with a reduction value of 50 ... 30 mm per press stroke sufficiently. 2. Edit along axis and ellipse. 3. Mark. 4. Pass to the thermal department	see the forged piece sketch

Table 11.2 – New technological process of forging the "Hollow shaft"

M_f = 52 500kg; M_{in} = 82 000kg; material – Steel 45; dimensions in brackets – finishing	
Operations	Transition sketches
1. Billeting the ingot with a turn. 2. Chop off the block with a turn. 3. Put in the furnace	
1. Upset the block by a spherical die to H = 1 800 mm. 2. Piercing punch by a hollow puncheon Ø 700 / 400. 3. Put in the furnace	
1. Flatten the walls by rolling-off on the mandrel up to $Ø_{in}$ = 1 070. 2. Put in the furnace	
1. Put the workpiece on the mandrel Ø 980 / 1060 using two cranes. 2. Drawing to Ø 2 180, l ≈ 2 500 mm 3. Mark and cut. 4. Reduce the areas II and III to Ø 1 900, l ≈ 2 300 mm. 5. Mark	

This significantly reduces the consumption of metal and the labor intensity of their machining and improves the quality of manufactured products.

The continuation of table 11.2

Operations	Transition sketches
6. Reduction of the middle with an expansion to Ø 1 810, l ≈ 1 200 mm. 7. Remove from the mandrel. 8. Flatten along the axis. 9. Put in the furnace	
1. Install anvils of B = 1 200 mm width. 2. Take the workpiece onto the mandrel. 3. Rolling-off the parts I – II – III successively according to the sketch with a 40 ... 50 mm reduction per press stroke. 4. Edit the ellipse. 5. Change the rolling-off stands into the lower cut-out anvil. 6. Forge the ends sufficiently (section I to Ø2 300, section III to Ø2 020), and flatten along the axis. 7. Put in the furnace.	
1. Remove the workpiece from the furnace. 2. Take on a mandrel Ø980 / 1060 with two taps. Section I by uniform reductions forge and drawing sufficiently by Ø1 930 3. Reduction of the protrusions sufficiently by Ø 1 930. 4. Remove from the mandrel. 5. Flatten along the axis. 6. Pass to the t / department.	see the sketch of the forged piece

SECTION 12
IMPROVEMENT OF FORGING PROCESSES OF ROTOR SHAFTS

At present, among the product range, which is manufactured for export, a significant part of the plant is occupied by forged pieces of the type of cylindrical rotor shafts with several steps and an end ledge (flange) of large diameter (Fig. 12.1). At the same time, according to the existing technical processes, the manufacture of rotor shafts was carried out in 2 pieces from an ingot according to a scheme that includes the following operations:

- billeting;
- upsetting;
- preliminary drawing;
- notch of flanges;
- final drawing.

The main disadvantage of manufacturing rotor shafts according to this scheme is that, after cutting the forged pieces, tapers up to 200 mm long remain on the flange ends, and the adjacent flange end taper on the billet is closed by metal extension due to its small length. Therefore, their manufacture was carried out with an increased metal consumption and high labor intensity of machining, especially on the flange part of the forged piece.

Various methods of billet upsetting are known from the technical literature [42]. In this case, the upsetting is carried out most often in two ways: in a die and without a die. When upsetting in a die, the billet diameter is equal to the diameter of the hole (diameter of the forging bar). If the billet is selected with a larger diameter, then the non-headed part is drawn. In production conditions, as a rule, after the flange upsetting, the non-headed part of the billet is drawn to the forged piece dimensions to avoid changing the dies (rings) when transferring from one standard size of the forged piece to another.

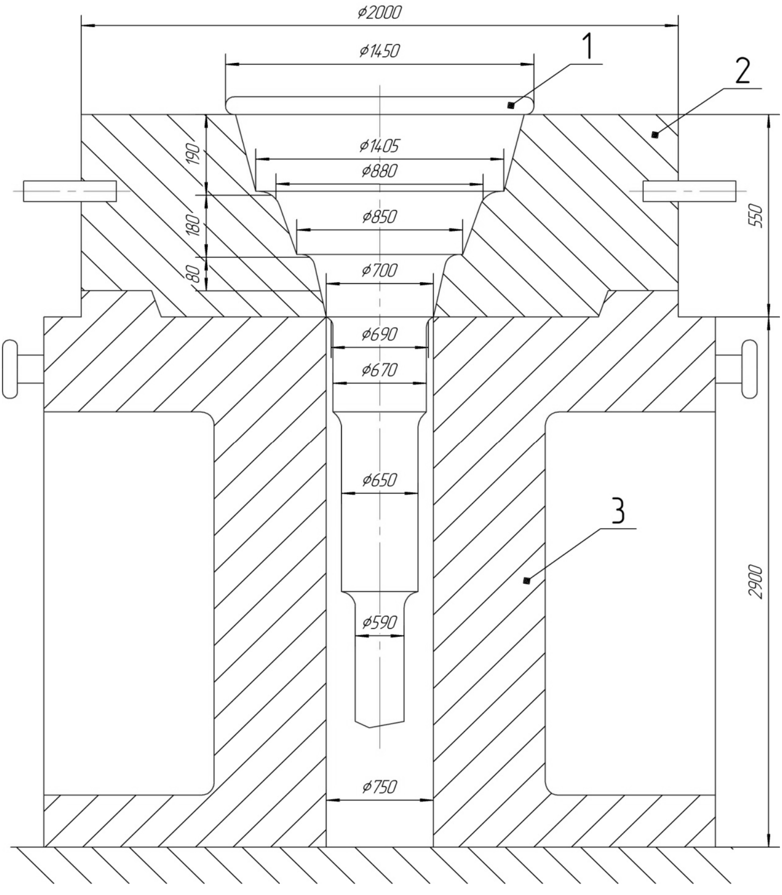
Upsetting by without die is used when you need to get a flange on long and heavy shafts and upsetting in a stamp or ring is impossible.

The disadvantage of the above-mentioned methods is the need to change the backing rings when forging rotors with stepped transitions in the forged piece tail, and the process of flanges upsetting without die is very time-consuming and adversely affects the equipment productivity and operation. In addition, the process of flanges upsetting is accompanied by excessive allowances in diameter (barreling), which leads to additional consumption of metal and laborious machining.

Based on the foregoing, it should be noted that the existing technical processes for forging rotor shafts have approximately the same drawbacks that exist in the above-mentioned analogous methods in the manufacture of such forged pieces.

To reduce the consumption of metal and the labor intensity of machining, it was proposed to make the rotor shafts forged pieces using fundamentally new technology [43]. Using this technology, the end necks of billet 1 are first drawn to the forged piece dimensions, then the flange and the adjacent ledge are formed by stamping at a metal heating temperature up to t = 1100°C in the backing ring 2 installed along the support shell 3 (Fig.12.1).

The proposed technology for manufacturing rotor shafts billets eliminates metal tapers and extensions on the flange part of the forged pieces, which significantly reduces the metal consumption and the labor intensity of machining in comparison with the existing technical processes of forging them. In addition, it is possible to forge a rotor shaft one per ingot, which allows improving the quality of manufacturing rotor billets with rational use of metal consumption. Table 12.1 shows sketches of forged pieces for the basic and new rotor shaft manufacturing options.

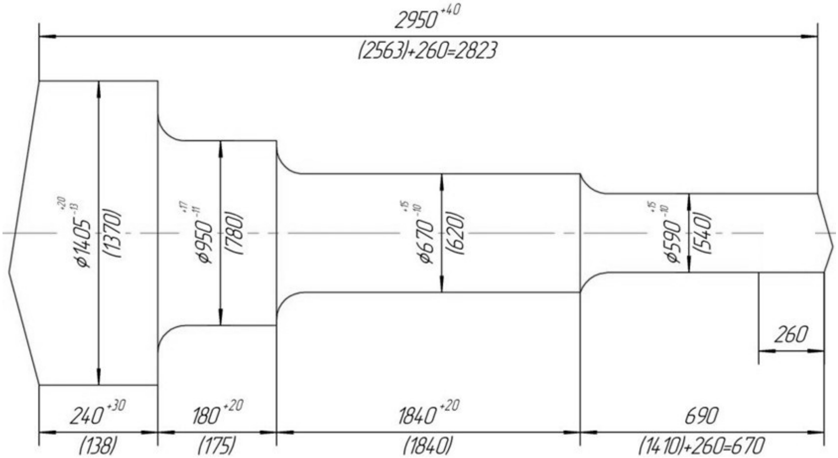


1 – billet; 2 – backing ring; 3 – support shell

Figure 12.1 – Scheme of stamping the rotor shaft flange

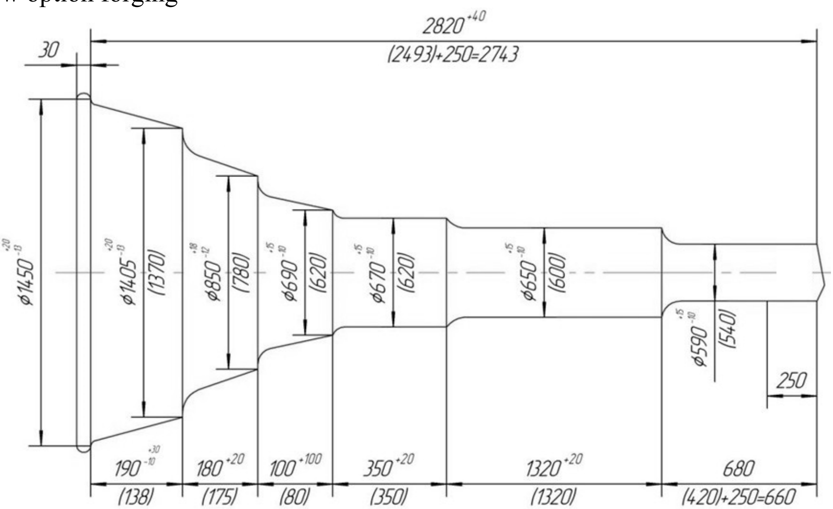
Table 12.1 – Sketches of rotor shaft forged pieces

Basic option forging



M_f = 10.8 tons

New option forging



M_f = 9.8 tons

SECTION 13
IMPROVEMENT TECHNOLOGICAL PROCESSES FORGING OF CRANK-SHAFTS

The crank-shafts manufacture is a complex and time-consuming process due to the specific features of the throw rotation, which is associated with a large number of heatings.

Example 1. A forged piece of a three-throw crankshaft is shown in Figure 13.1 with the cranked portion of a shaft at the 60º angle. The material is 40CrNi steel. The forged piece's weight is 23 000 kg. Forging and turning of the cranks were carried out on the press with a 100 MN power from the ingot weighing 36 000 kg. According to the existing technology, eight heatings were required to manufacture the crankshaft.

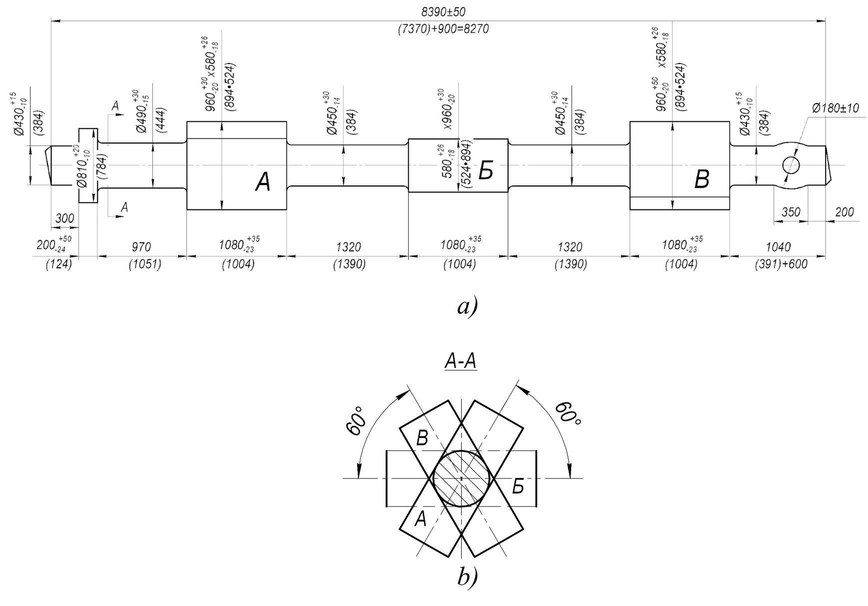


Figure 13.1 – Sketch of a three-throw crankshaft (a) and section A – A (b)

In the first heating, the workpiece was billeted and the hot-top was forged (Fig. 13.2, a). In the second heating, the ingot was upset to Ø 1 600 mm and drawn to Ø 1 200 mm (Fig. 13.2, b, c). In the third heating, drawing was carried out at 1 060×800 and 1 060×600 mm, marking and notching of the throws and flange, drawing of the bottom end to Ø 810 mm and Ø 430 mm (Fig. 13.2, d; e; f). In the fourth heating, the necks were flatted to the 850 mm length by narrow anvils of 300 mm width (in the sketch is not shown).

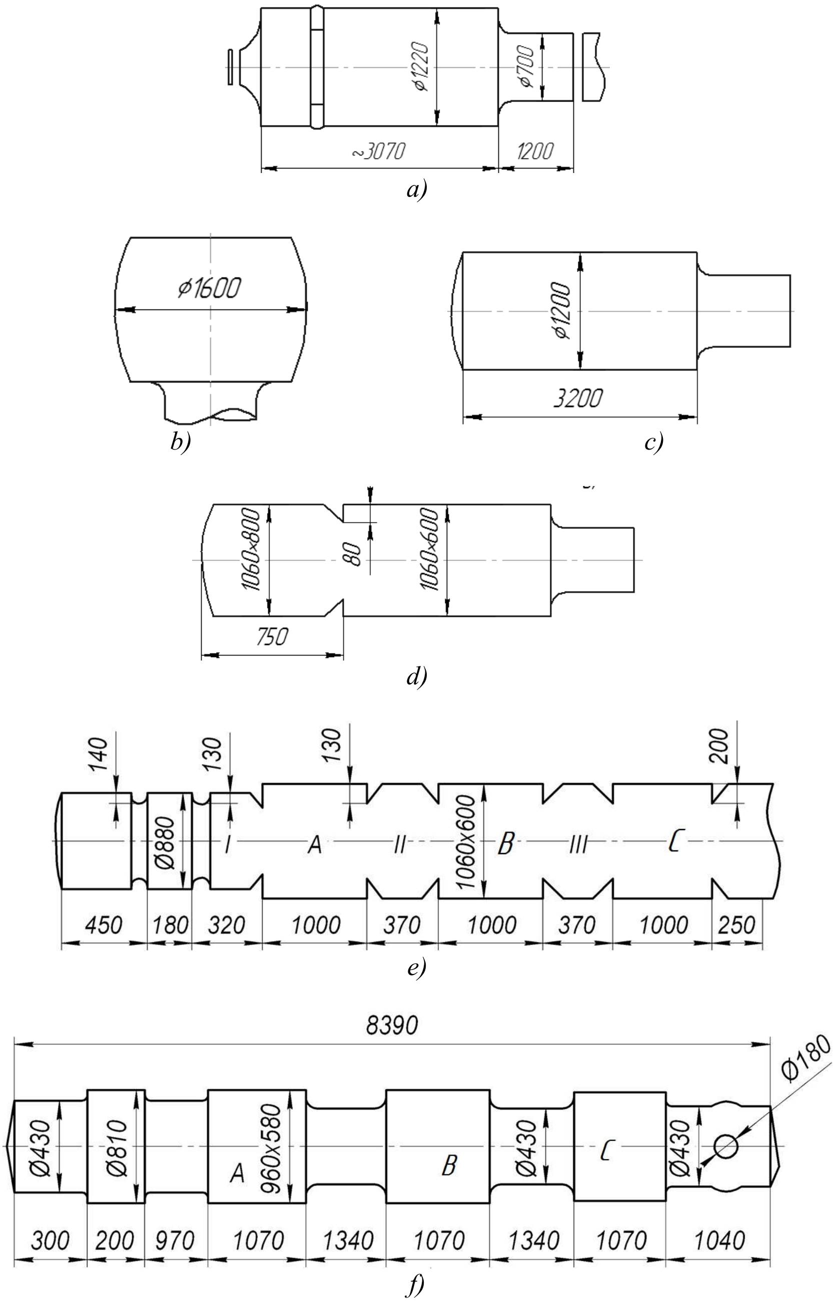
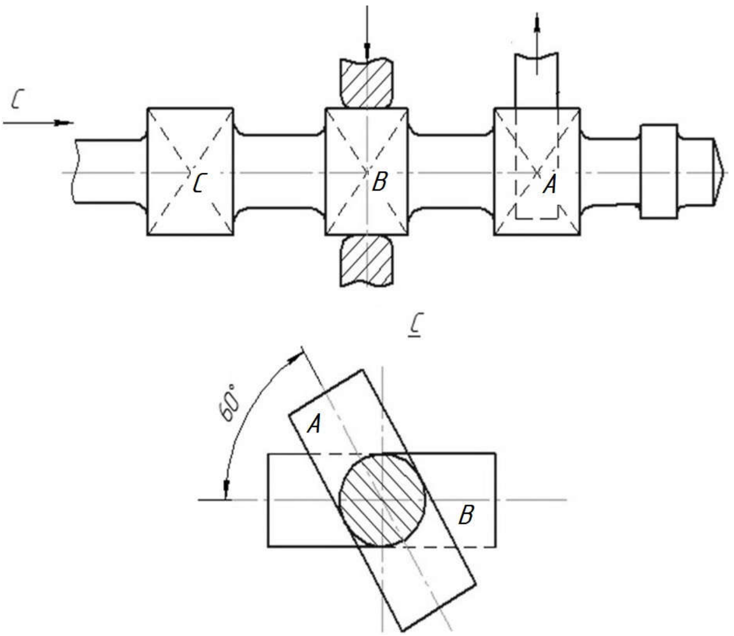
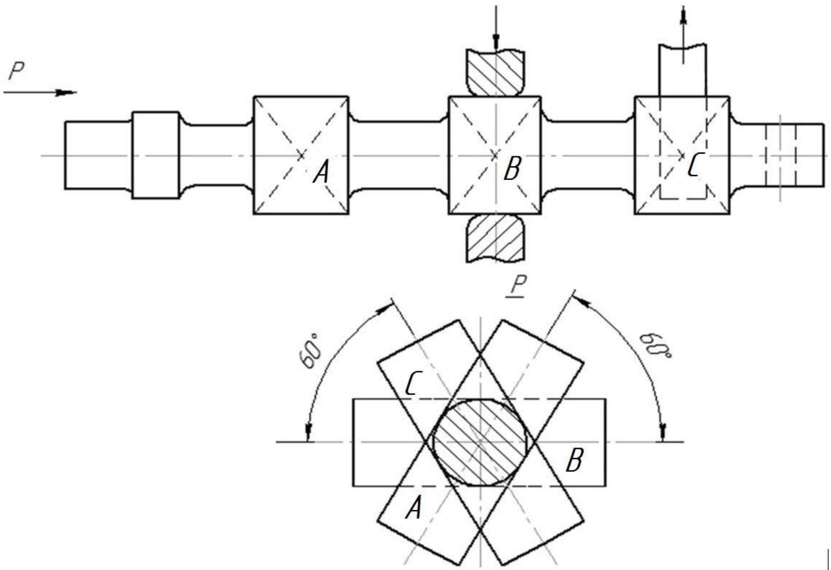


Figure 13.2 – Transitions forging of the three-throw crankshaft with the throws turn



j)



h)

Figure 13.2, sheet 2

In the fifth heating, the neck I was reduced to Ø 490 mm, the necks II and III – to Ø 450 mm, and the throws A, B – sufficiently. The flange was flatted sufficiently (Fig. 13.2, d; e). In the sixth heating, the ingot`s hot-top was reduced by 430×430 mm square and the corners were forged down by Ø 430 mm. The throw C was flattened sufficiently, and then the end was laminated by the flat anvils and was piercing punch Ø 180 on both sides (Fig. 13.2, f). After that, the billet was sent to the thermal department for isothermal annealing. After the isothermal annealing, the workpiece was sent to the mechanical shop for facing the necks for subsequent throws turning. The sketch of the workpiece after the necks facing is not shown. In the seventh heating, the neck between ends A and B was heated to 950 ... 1000° C, after heating, throw B was installed in the anvils, and by a key, throw A was turned at the 60° angle (Fig. 13.2, j). In the last heating, the neck between throws B and C was heated to 950 ... 1000°C, after heating, throw B was installed in the anvils, and throw C was turned by a key at the 60 ° angle (Fig. 13.2, h). After the forging finish, the forged piece was sent to the thermal department for isothermal annealing. Turning the throws according to this pattern is a very difficult and time-consuming process. At the same time, the productivity of the forging process decreases, due to the use of isothermal annealing and preliminary facing of the necks before the operation of turning the throws.

To eliminate the above-mentioned shortcomings, a new process for forging a large three-throw crankshaft has been developed and implemented, taking into account the technical solution [44], the essence of which heatings are as follows. First, the forging of the throws is carried out on a cylindrical section, then by upsetting and reducing, they are formed into a rectangular section, and the turning of the throws by a given angle is performed by tilting the workpiece before reducing each subsequent throw to the final dimensions. In this case, the ratio of the throw cross-section after preliminary and final forging is kept equal to 1.25 ... 1.35. According to the new technology, the three-throw crankshaft forging considered above is manufactured in five heatings.

In the first heating to the forging temperature, the ingot is billeted to Ø1 220 mm, the hot-top is reduced under the die, upset to Ø1 600 mm, and drawn to Ø 1 200 mm (Fig. 13.3, a; b; c). In the second heating, the ingot is drawn to Ø 950, marked and notching, the bottom end is drawn to Ø 850 and Ø 430 mm, the flange is flattened sufficiently, and the hot-top is reduced for clamp (Fig. 13.3, d). In the third heating, the narrow anvils with 300 mm width are installed, and the necks are reduced to the anvil entrance (l = 850 mm). In the fourth heating, neck I is reduced up to l = 930 mm, and the necks II and III – up to l = 1 150 mm (Figure 13.3, e). In the fifth heating, the throw C is installed on the plate and reduced to the extent (Fig. 13.3, e), then the throw C is turned by the 60° angle and is reduced to the extent on the plate (Fig. 13.3, g), then the throw A is installed on the plate and turn the throw B by the 60º angle, then reduce the throw A to the extent (Fig. 13.3, i). This method excludes preliminary facing of the necks for turning, as well as intermediate isothermal annealing and subsequent heating of the necks for turning the throws using a key and a crane, which significantly reduces the production cycle of crankshafts.

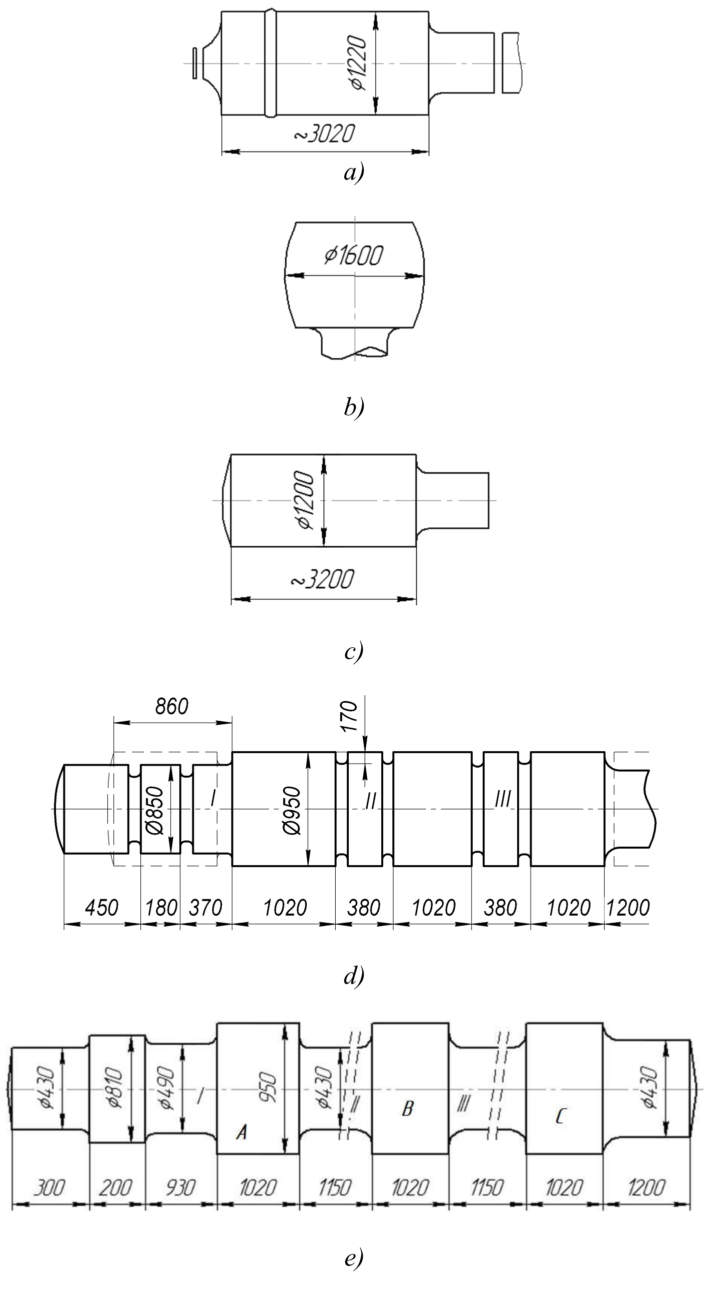
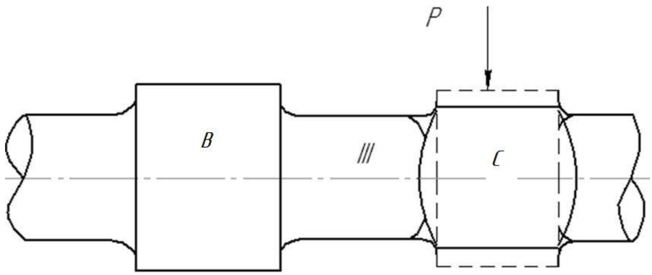
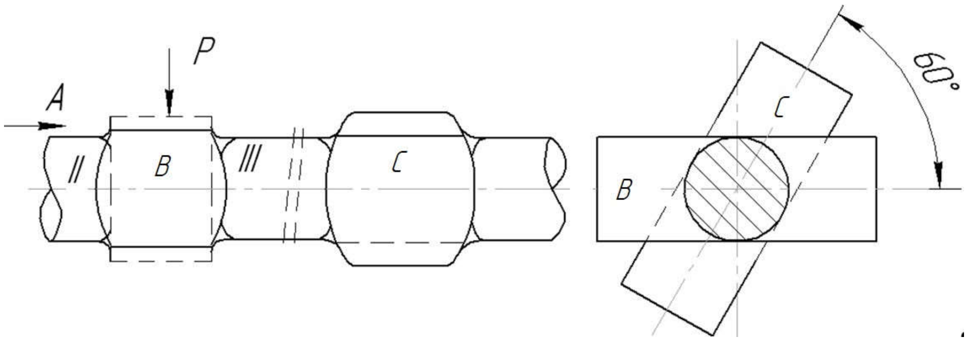


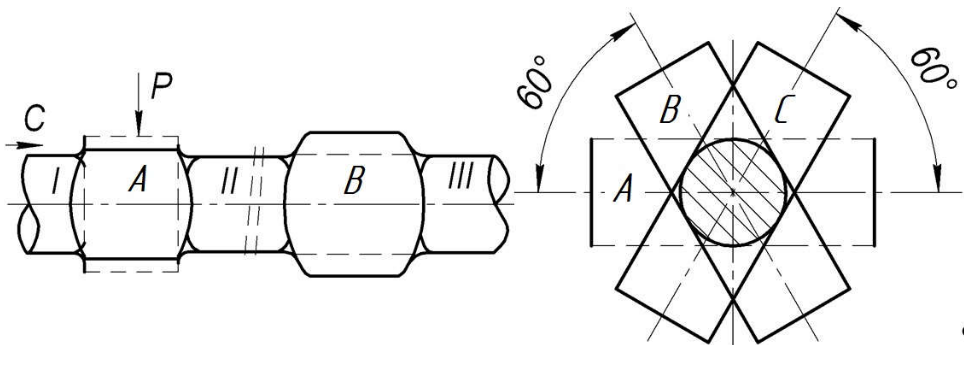
Figure 13.3 – Transitions forging of the three-throw crankshaft and turning the throws



f)



g)



h)

Figure 13.3, sheet 2

Example 2. Figure 13.4 shows a sketch of a six-throw crankshaft for the subsequent throws turn, where the throws are in the same plane before turning. Material is the 34CrNi3Mo steel. Forged piece weight is 7 600 kg. Forging and turning of the throws were carried out on a press with the 30 MN power from the ingot weighing 11 200 kg. Manufacturing of crankshafts with the position of the throw at the 120º angle with relatively short main necks excludes the possibility of their manufacture using the previous method. In this regard, the turn of the throws by the required angles was carried out using special forging die with a preliminary facing of the necks mechanically after isothermal annealing of the workpiece. The scheme forging and turning of throws are shown in Fig. 13.5 According to the existing technology, 6 heatings were required for the manufacture of the specified forged piece.

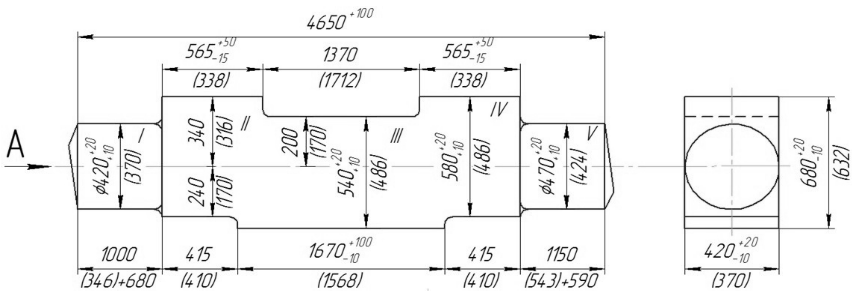


Figure 13.4 – Sketch of the six-throw crankshaft under the throw turn

In the first heating, the ingot was upset by Ø 1 200 mm and drawn by 600×900, l = 2 300 mm (Fig. 13.5, a). In the second heating, drawing was carried out by 770×450, l = 3 500 mm, marking and notching of the middle III was on the plate, the middle III reducing was by 630×420, l = 1 230 mm (Fig. 13.5, b), then there was workpiece turning by 180º, marking and notching of the throws II and IV on the plate (Fig. 13.5, c). Then, on the plate and the anvil, the bottom end I + II was reduced by 670×460, l = 1 050 mm, after that the hot-top end IV and V were reduced on the plate and the anvil by 670×450 mm with a turn (Fig.13.5, d), maintaining the size of 2 310 mm on the throw areas II – III – IV. After that, the bottom end I was reduced to Ø 520, l = 900 on the plate, and the anvil in 520×520 mm, the hot-top end V was reduced to Ø520 on the plate and the anvil with a turn, the hot-top was cut off (Fig. 13.5, e). Then the workpiece was put into a furnace for heating up to 1 050°C. In the third heating, the middle III was reduced on the plate and the anvil to the extent, the throws II and IV were reduced to the extent, the end sections I and V on the Ø 500 mm with a turn and change of the lower anvil, the workpiece was flattened along the axis. The workpiece was sent to the thermal department for isothermal annealing under the necks facing (Fig. 13.6) for the subsequent operation of turning the throws. In this case, the workpiece for turning the throws should be heated to a temperature of no more than 1 000°C.

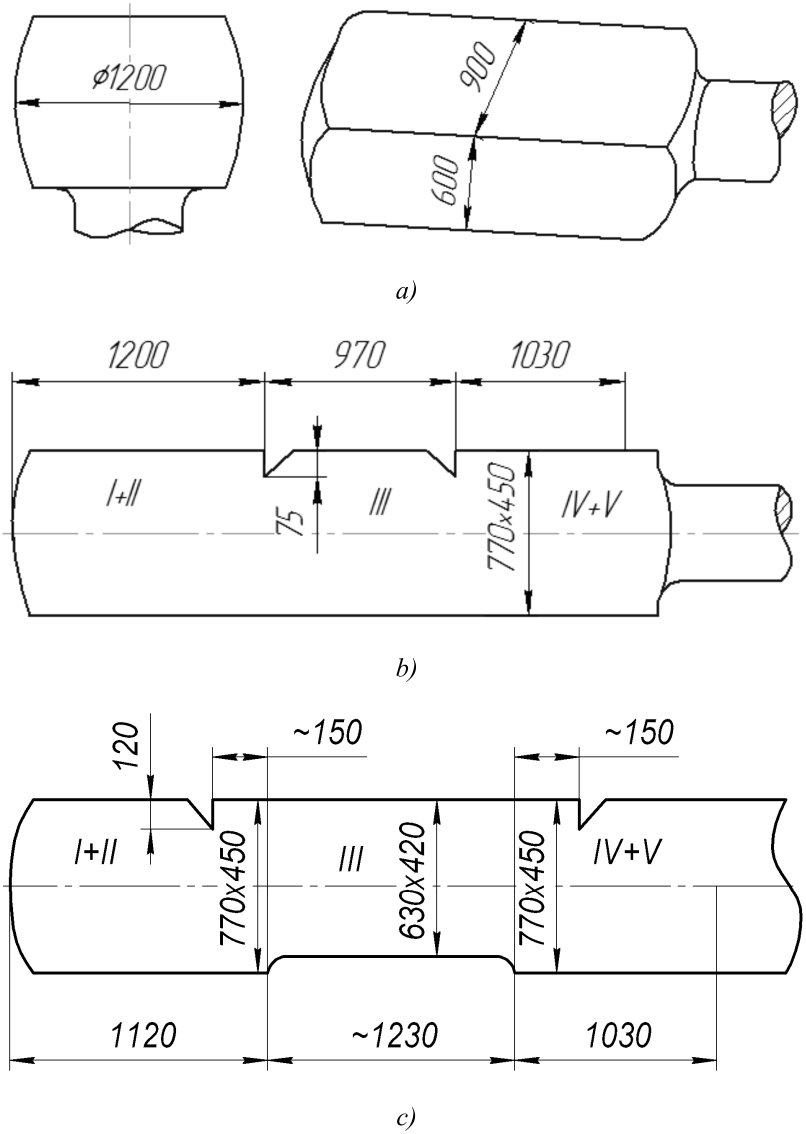
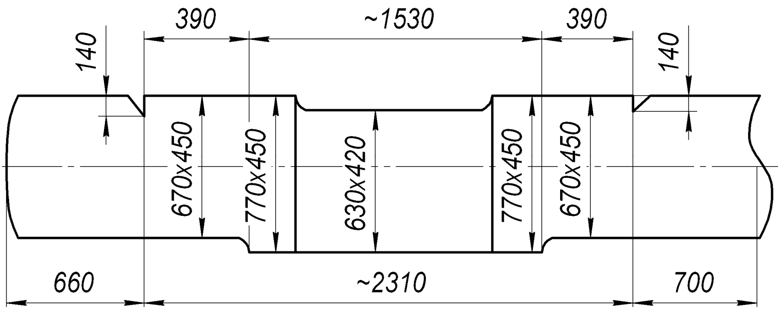


Figure 13.5 – Transitions forging of the six-throw crankshaft



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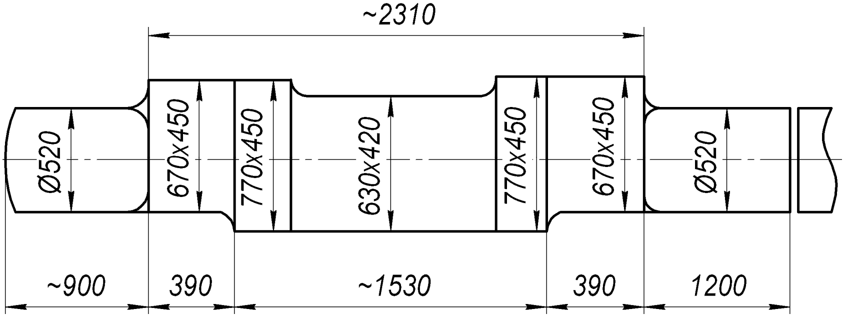

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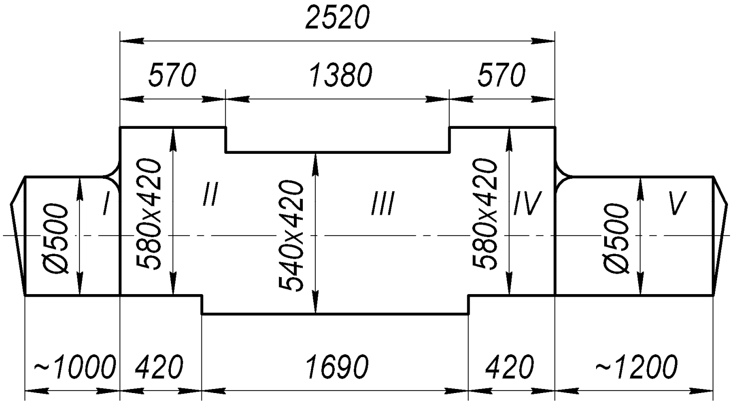

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Figure 13.5, sheet 2

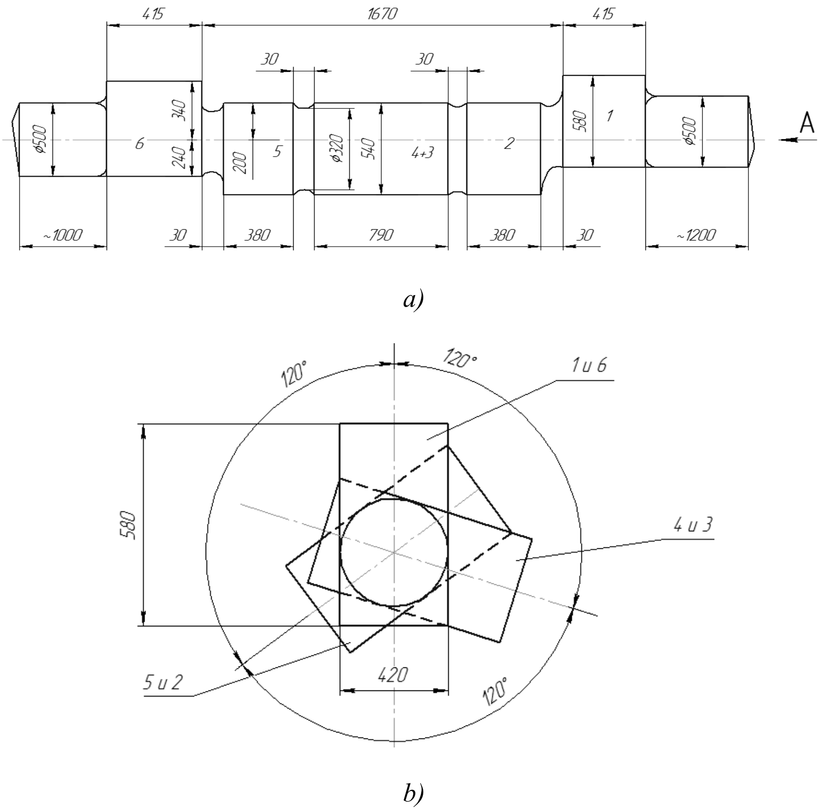
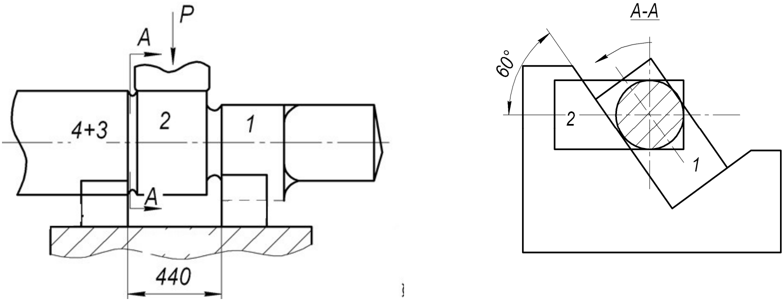


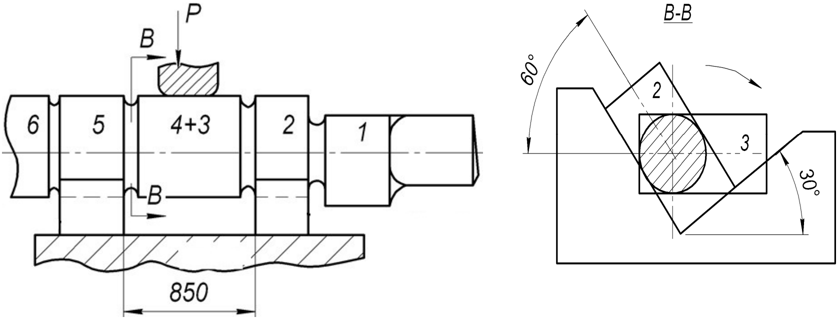
Figure 13.6 – Sketch of the six-throw crankshaft after the necks (a) facing and the throws turning (b)

In the fourth heating, a plate and two die I and II were installed, respectively, under throws 1 and 3 according to the sketch (Fig. 13.7, a). The upper anvil with a reduction value of 20 ... 30 mm during the press stroke turned the throw 2 by the angle of 60º (see section A – A). The manipulator removed the workpiece from the press and performed the change of die. Die II and III were installed on the lower plate, the throws 2 and 5 were put in the die (Fig. 13.8, a). The upper anvil with a reduction value of 20 ... 30 mm in one press stroke turned the throws "4+3" by the 60º angle (see section B–B). The manipulator removed the workpiece from the press and checked the location of the throws 1 and 2, "3+4" and 5 for alignment and a given angle of rotation. After checking, the workpiece was put into a furnace for heating to the temperature of 1000°C. In the fifth heating, the lower flat plate and the upper flat anvil of 400 mm width were installed. The die I and II were installed, respectively, under the throws "4+3" and 6.



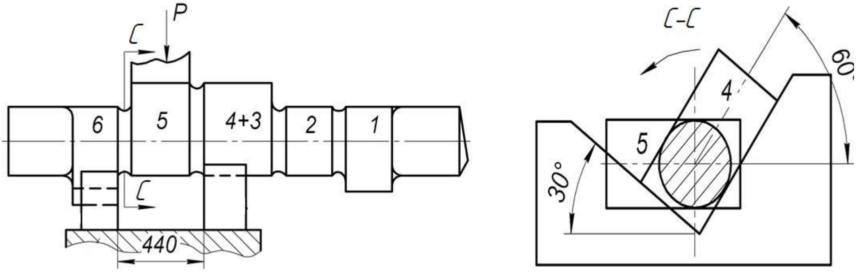
a) b)

Figure 13.7 – Sketch installing of the six-throw crankshaft for turning throw 2 (a), turning the throw 2 by the 60° angle (b)



a) b)

Figure 13.8 – Sketch installing of the six-throw crankshaft for turning the throw 3 (a), turning the throw 3 by the 60° angle (b)



a) b)

Figure 13.9 – Sketch installing of the six-throw crankshaft for turning the throw 5 (a), turning the throw 5 by the 60° angle (b)

After heating, the workpiece was removed from the furnace, and the throws "4+3" and 6 were installed in the die according to Figure 13.9, a. With the upper anvil with a reduction value of 20 ... 30 mm per press stroke, the throw 5 was turned by the 60º angle (see section C–C). Then alternately flattened by flat anvils in pairs the throws 1 and 6, "4+3", 2 and 5 until they were located in the same plane. After flattening, the workpiece was put into a furnace for heating to the temperature of 950°C.

In the sixth heating, the workpiece was taken by the manipulator by the hot-top end, the bottom end was reduced by Ø 420 mm, and the bottom part was cut off. Then the forged piece was taken on a tilting machine and the hot-top end was reduced to Ø 470 mm, flattened along the axis, the hot-top was cut off (see the forged piece sketch), and the forged piece was marked and sent to the thermal department for isothermal annealing. After isothermal annealing, the forged piece was marked according to the part drawing and sent for machining.

Manufacturing crankshafts according to this scheme is a very laborious and time-consuming process. This is caused by both the specific features of the throw turning using a special die, and the duration of production due to the use of isothermal annealing and mechanical preliminary facing of the necks, which in turn reduces the productivity of forging equipment and the capacity of heating furnaces.

To eliminate these disadvantages, a fundamentally new method of forging crankshafts has been developed [45]. This method consists of the fact that the formation of the necks and throws of the shaft is carried out from the section of the intermediate workpiece in the form of an equilateral triangle, and the final formation of the necks and throws of the shaft is carried out by mechanical processing.

Figure 13.10 shows a crankshaft workpiece with a triangular cross-section, and the dashed lines show the contour of throws 1 – 6 (throws 3 and 4 are located in the same plane). The proposed method is carried out as follows. After upsetting, the workpiece is drawn by the diameter, the size of which is calculated taking into account that the ratio of the cross-sectional area of the workpiece to the final area of the forged piece with a triangular cross-section was in the range of 1.65 ... 1.7, which is an important point in the formation of throws of the specified shape.

Then the workpiece is drawn in the lower backing anvil until a triangular section is obtained. As a result of forged pieces according to the proposed method, it was found that when a cylindrical workpiece is deformed in the lower anvil with a triangular shape, a forged piece is also formed of a triangular shape with equal sides and the required radius R of rounding between the corners.

After obtaining a workpiece with a triangular shape, the necks are machined in the throw area, and the positions of the throws 1, 2 (3 – 4), 5, and 6 between each other are obtained in advance at a predetermined 120º angle, which eliminates the need for them to turn the throws in the future.

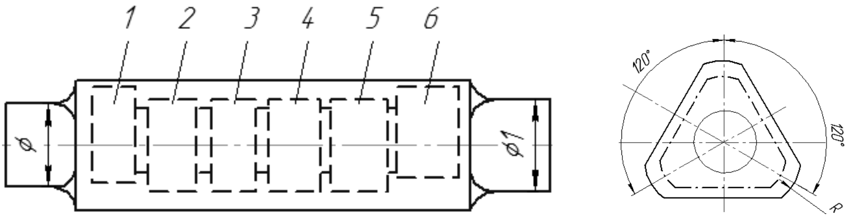


Figure 13.10 – Sketch the workpiece of the six-throw crankshaft with a triangular cross-section

Example 3. The six-throw crankshaft forging has the necks of 420 and 470 mm diameter, 1 000 and 1 150 mm length, respectively, and the area of the given throws by the triangular section with 575 mm height, 2 420 mm total length. Shaft throws are located between each other under the 120º angle, except for throws 4 and 3. The forged piece weight is 7 700 kg. The forging of a six-throw crankshaft was carried out on a press of 30 MN power in two heatings from the ingot weighing 11 200 kg. Material is the 34CrNi3Mo steel. Figure 13.11 shows the sketch forged piece of a six-throw crankshaft, taking into account the given throws in a triangular section. In the first heating after heating to the forging temperature, the ingot was removed from the furnace. The ingot`s hot-top was reduced under the upsetting plate, the excess weld was cut off. The ingot was upset to Ø 1 200, reduced to Ø 700 (Fig. 13.12, a), and put into the furnace.

In the second heating, the workpiece to the forging temperature was fed under the press, having previously installed a special anvil on the lower plate. The workpiece was reduced in parts along the entire length in the lower die to the 650 mm height, the workpiece was turned by the 120° angle. After that, in parts, the workpiece was reduced along the entire length in the lower die to the 580 mm height to the extent (Fig. 13.12, b). Then the die was changed to the lower cut-out anvil. The workpiece was marked according to the sketch (Fig. 13.12, c). The bottom end was reduced to Ø 470 to the notching with a transfer, turned the workpiece, reduced the hot-top end to Ø 370 to the extent with a transfer, flattened it along the axis, cut the forged piece, marked and transferred it to the thermal department for isothermal annealing. After isothermal annealing, the crank-shaft necks and throws were machined and finished to final dimensions, as well as test samples were cut out for mechanical properties. Mechanical tests have shown satisfactory results, while the values obtained correspond to the required specifications of the crankshaft part drawing. Thus, the proposed method can significantly increase the productivity of forging equipment, and heating furnaces capacity, reducing the cost of manufacturing special equipment that in general will reduce labor intensity and simplify the production cycle of crankshafts.

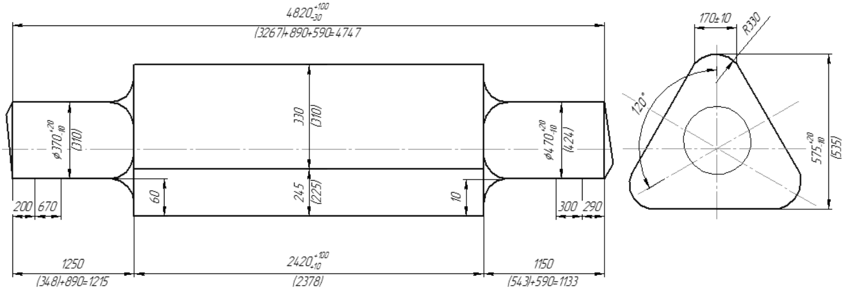
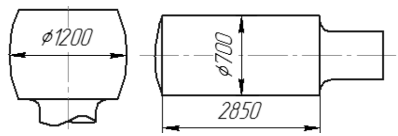


Figure 13.11 – Forging piece sketch of the six-throw crankshaft with a triangular cross-section and cylindrical necks



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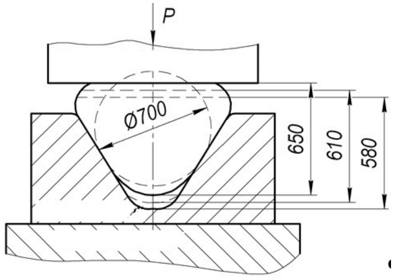
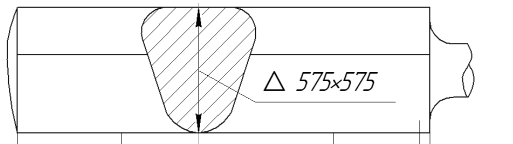


b)



c)

a – ingot upsetting and preliminary drawing;
b – forming a workpiece with a triangular cross-section; c – cutting for end necks forging into a cylindrical section
Figure 13.12 – Forging scheme of the six-throw crankshaft

SECTION 14
FORGING OF SMOOTH LONG SHAFTS

Smooth round section forged pieces with an elongated axis include such parts as rods, shafts, columns, tailshafts, etc. Forging of long forged pieces, due to their large length, is carried out mainly by drawing from ingots of a conventional shape in combined or cut-out anvils. The specified details refer to products of responsible use and are subjected to ultrasonic testing by the SEP 1921 requirements, D / d, and C / s class, according to which the level of permissible defects is $Ø_{equ}$ = 2 ... 5 mm. This group produces long billets such as propeller shafts with 20 ... 25 m length and 700 ... 850 mm diameter from high-alloy steel grades of ingots weighing 120 ... 132 tons. Forging of long billets was developed with the existing dimensions of heating furnaces and is carried out in three heatings under the press with 100 MN power. The drawing of the billet in the last heating is one of the laborious operations, due to the significant elongation of the metal, at which the drawing ratio reaches K_e = 2.0…2.5, based on the ratio (L_f / L_w). In the third heating, the forging of long forged pieces should begin first at the ends of the billet and finish at its middle part, thereby providing a uniform temperature field for forging. In this case, the forging of the billet should be carried out with maximal feeds equal to the width of the anvil, and uniform reductions along its whole length with the same turning at the same angle to avoid displacement of the ingot liquation zone.

In some cases, the production of long forged pieces with a relatively large length of hard-to-deform metals and alloys is carried out for several heating with the use of intermediate annealing before the last heating. After annealing, only a part of the unforged piece is heated in the furnace.

A typical technical process for forging shafts up to 8 m long includes the operations of heating and drawing the billet in several passes to the forged piece dimensions, flattening along the axis, cut of the bottom, and forged piece. The disadvantage of the described technology is that the heating of ingots (billets) is accompanied by the formation of a heavy layer of scale, a significant part of which is pressed into the metal during forging and forms depressions and pimples on the forged pieces. This deteriorates the surface quality of the manufactured forged pieces and reduces their accuracy. Eliminating the noted shortcomings is allowed by a technical solution [46], which consists of the fact that the billets reduction is carried out in the following sequence: first, the ingot reduction is performed in the direction from the bottom to the top on flat anvils with the 35 ... 40 % degree of deformation, then the billet is reduced in combined anvils with the 8 ... 12 % allowance relative to the given forged piece dimensions, after which the billet with the maximum length is cut out (Fig. 14.1). Heating before the last reduction is performed in a furnace at a forging temperature during 5 ... 10 minutes or, if necessary, at the temperature up to 900°C for 1 hour, and the billet is drawn to forged piece dimensions in cut-out anvils in two passes. Thus, due to the use of various forging anvils in the process of metal deformation and short-term heating of the billet before the final stage of its forging, the following advantages of this method were determined:

- the surface quality of the billet was improved due to the variation of the forging anvil and its final heating without the formation of scale;

- the length of the original forged pieces increased by 300 ... 500 mm (depending on its section) due to the reduction of metal loss for scale and the dimensional accuracy of forged pieces in diameters increased due to their forging in cut-out anvils.

The smooth round forged pieces mainly up to 8 m long are manufactured in this way, and the process is simple.

The specified technology is implemented in the press-forging production for the manufacture of shaft-type forged pieces (Fig. 14.1).

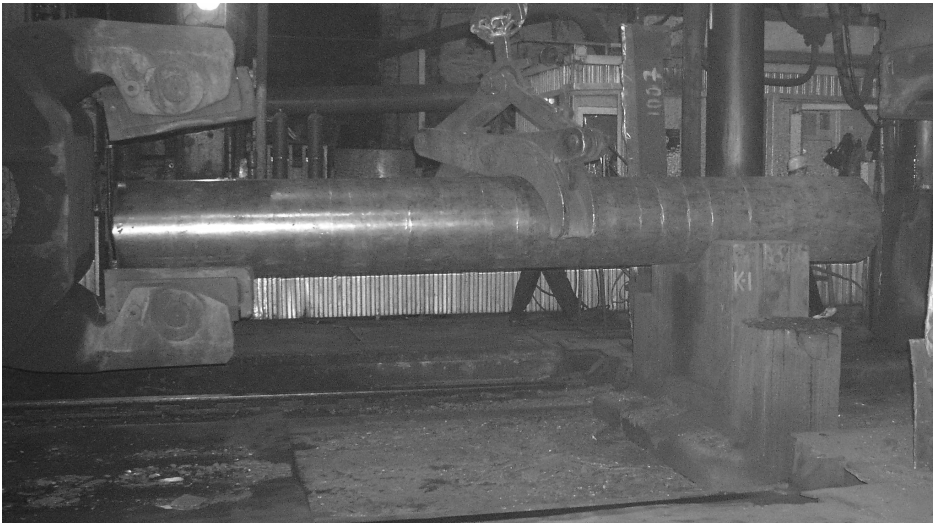


Figure 14.1 – Forged piece after flattening by combined anvils

SECTION 15
SELF-GUIDING DIE FOR PIERCING PUNCH OF HOLES IN SHAFTS

At present, in the press-forging production, for carrying out heating and heat treatment processes (normalization or volume quenching and tempering) of parts such as shafts in a vertical position at the end section of the forged piece, a special allowance is provided, in which a hole is drilled for assembly into anvil arrangement "axis - rod". Holes for pickup are obtained at the large time expenditures of machining equipment, using in most cases critical facilities – boring machines.

To reduce labor costs during machining of holes for parts subjected to heat treatment (hardening or normalization with tempering), as well as expanding the technological capabilities of forging and pressing equipment, a design of self-guiding stamp for piercing punch holes in round section forged pieces has been developed.

Figure 15.1 shows a general view of a die for piercing punch forged pieces on a press in two projections. The top projection shows the stamp in the initial period (left side) and the end of the piercing punch (right side). The stamp for piercing punch forged pieces consists of the following main parts and assemblies: shoe 1, upper plate 4, connected using double-acting power cylinders 2, guide columns 5 and bushes 6, piercing punch 8 and piece put 9, intermediate bushes 12. The die is controlled by the machinist from the press control panel through the distribution valve from the air or hydraulic circuits.

The stamp design and operation are the following. The stamp working surface gives the known shape of cut anvils [47] to extend the size range of the processed forged pieces. In this case, the working surface is made with a notch width that is larger than the working surface of the upper plate notch width to reduce the amount of tightening on the forged piece when the piercing punch comes out. To complete the working stroke of the piercing punch with an extension, a cylindrical hole is made in the axial part of the upper plate taking into account the location of the intermediate replaceable bush 12 in it to center the piercing punch of the required diameter. Besides, to ensure ease of the proposed stamp maintenance, the working cylinders are located on one of the holder base diagonals. Before the last transition of the forging, for example, a support roll, the assembled stamp with the holder base 1 is placed on the press table under the upper anvil. Then pressure is supplied to the pressure side of the cylinders 2.

Rods 3 affect the upper plate 4 and move it to a predetermined height along the guide columns 5 and bushes 6. After that, billet 7 is introduced into the stamp working cavity for piercing punch and pressed by the upper plate 4 using the reverse stroke of the rods 3. Then the piercing punch 8 together with the extension 9 are installed into the hole of the upper plate 4 with the tool manipulator or the crane and the piercing punch is carried out by the working stroke of the anvil 10, attached to the movable traverse of the hydraulic press 11, onto the piercing punch 8 through the extension 9. After that, the billet is released from the stamp using the upward stroke of the rods and installed in the lower anvil to finish the last forging transition: cutting off the bottom or hot-top part of the ingot. The stamp change-over to the required hole size is carried out outside the press by replacing the intermediate service bush 12, piercing punch 8, and extension 9. The use of this stamp allows to obtain holes in round section forged pieces during the forging process and contributes to a significant reduction in their labor intensity during machining.

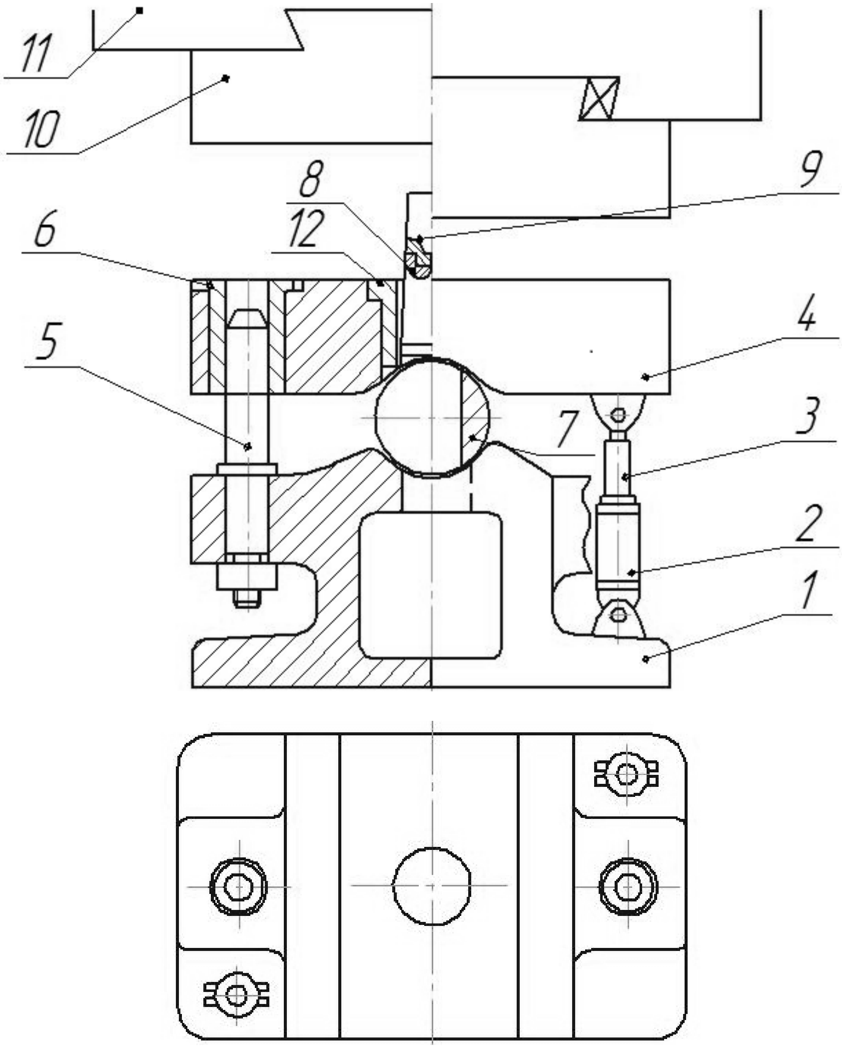


Figure 15.1 – Self-guiding stamp for round section piercing punch of the forged pieces

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