ANALYSIS OF TECHNOLOGICAL PROCEDURES FOR FORGING OF STROKE ON LARGE CRANKSHAFTS

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Abstract
Technology of forging of (strokes) central parts of large crankshafts by bending and die forging was verified on a scale model 1:15. The analyses were focused on the shape of forging, filling of die and surface defects. On the basis of obtained results new shape of the preform was proposed in such a way that the forging shape corresponds to dimensions on the drawing. Results of simulation have proved that the above mentioned defects could be eliminated by the new shape of the preform. Apart from that the required deformation force at bending was reduced only to 72 %, and at the same time mass of the preform was reduced by 15 %. Optimal shape of the preform may be applied to the existing technological procedure of forging. The obtained findings may be used for an optimisation of forging procedure also of other types of central parts of crankshafts.

Keywords: forging, crankshafts, technology

1. INTRODUCTION
Due to dynamic load of crankshafts the required mechanical properties (tensile strength Rm, yield strength Rp0.2, ductility A, notch toughness KCU) depend on the used steel, shape of arms and their transition to pins, course of state of stress, surface quality, structural design and other factors [1,2]. Due to uneven load of central pieces (Fig. 1) it is necessary to achieve the required degree of reduction (PK) and corresponding course of fibres, which significantly influences the crankshaft fatigue properties. Areas I to IV in Fig. 1 describe in qualitative manner the stress level at load of the central piece (IV—the lowest stress, I – the highest stress).

![Stress distribution at load of the crankshaft central piece](image)

Mechanical properties of steel must correspond to these loads. With respect to the required strength and fatigue properties the following steels are used: noble carbon steels (Rm = 450 to 550 MPa), low-alloyed chromium-vanadium steels (Rm = 590 to 740 MPa), low-alloyed steels CrNiMoV (Rm = 690 to 835 MPa). European manufacturers of engines use apart from the above grades also the following modified steels: S20Mo, S44S, S19Mo, or M56, M60 and 6KW.
2. PRODUCTION OF CRANKSHAFTS

Crankshafts may be produced compact, i.e. made from one forging (monoblocs), or they may be assembled from several parts, i.e. greater number of forging (semi-built-up, built-up), when individual parts of the crankshaft are forged as individual forgings [3].

2.1 Semi-built-up crankshafts

Individual central pieces for semi-built-up crankshafts (arms with crank pins are in one piece), main pins and shaft are forged as information forgings (Fig. 2a). Main pins are made with an oversize and they are assembled with individual central pieces, which are reheated to the temperature of 200°C [4]. Apart from this method also welded crankshafts are used, with welding of strokes (central pieces + halves of the main pins) by TAW method or by electro-slag welding. Individual parts may be welded in main pins or crank pins (Fig. 2b). In the first case the forgings are forged in the shape of cranking (crankshaft with two arms and adjoining halves of main pins). This reduces number of weld joints to half and reduces also dimensions of the crankshaft and thus of the engine.

![Fig. 2. Crankshafts built-up from individual parts: a) welded crankshaft, b) semi-built-up crankshaft](image)

2.1.1 Forgings of central pieces

Characteristic feature of all technological procedures for forging of forgings for semi-built-up crankshafts is the fact that the main attention at forging is concentrated on the parts with the most complicated shape, i.e. on forgings of central pieces (cranking, strokes), which may be forged by some of the following methods.

2.1.2 Forging crankthrow from rings

It represents the method of manufacture of central pieces for semi-built-up crankshafts, which is characteristic by the fact that first a hollow ingot is made with body height between 1.5 to 2,5 multiple of the wall thickness. After re-heating of the ingot a spacer is inserted into its hollowness and it is swaged to the required dimension with use of the swaging plate with a hole. The preform (ring) manufactured in this manner is then used for usual forging of two central pieces.

2. 1.3 Forging of block and creation of the gap between the arms

From the perspective of technology this manner represents the simplest method for production of central pieces. After forging of the basic block the gap between the arms is obtained by machining.
2. 1.4 Free forging and die bending
Freely forged pieces are used, which are bent and calibrated in special die. With respect to the fact that the preform if forged by free forging, the allowances for machining are in this case too quite big and consumption of metal is rather high. This method was verified by modelling [5] on the forgings of strokes for crankshafts of the type L60MC (Fig. 3), but they have not yet been implemented into industrial practice.

![Fig. 3. Diagram of bending (a) and calibration of stroke in a die (b)](image)

2.1.5 Swaging of castings
Method of manufacture of central pieces for crankshaft L60MC is shown in Fig. 4. Shape of the casting has been designed in such a way that the required shape of the forging is achieved after its swaging to the half height [6]. Its advantage consists in small allowances for machining and thus small consumption of steel. Certain disadvantage consists in small degree of reduction (PK = 2). Nevertheless, due to the fact that maximal deformation at swaging is concentrated into the areas with disadvantageous cast structure, mechanical properties of forgings should be equivalent to the properties of forgings that were forged with a higher degree of reduction.

![Fig. 4. Diagram of swaging of the casting of stroke (a) and evolution of deformation in modelled stroke (b)](image)

2.7 Forging by TR method
Technology of forging and the equipment is a modification of forging of monobloc crankshafts. Individual strokes are made of roughed preforms, which are swaged after re-heating in a simple die and then they are shaped in special instrument (Fig. 5). Advantage of this method consists in precise dimensions of the forgings and in small allowances for machining. Due to force possibilities of the largest presses for free
forging it may be used for forging of strokes for semi-built-up crankshafts up to the size RTA 76 and L70MC, as well as for welded execution up to RTA 84 and L 80MC. Disadvantage of this procedure is the necessity to use an expensive and heavy equipment.

![Diagram of technological procedure of forging of central pieces by TR method](image)

**Fig. 5.** Diagram of technological procedure of forging of central pieces by TR method  
 a) preform, b) pre-pressed shape, c) swaged preform, d) forging of stroke

### 2.1.7 Forging of central pieces by bending of the shaped preform

This is the most wide-spread method of manufacture of central pieces.Forging procedure is based on the use of shaped preforms, which are then bent to the required shape (Fig. 6). This technology does not have big requirements to equipment of the forging shop and it may be applied at forging of central pieces even for the biggest engines. For example the biggest engine L90MC has the height of the central piece of 2 950 mm, and the biggest engine of the type RTA 84 has the height of the central piece of 2 400 mm. Due to considerable length of the largest pieces this method remains the only possible method of their manufacture. It is, however, impossible to neglect its disadvantage consisting in big consumption of steel. Procedure of forging of stroke by bending was verified on a model scale. Fig. 7 shows shape and dimensions of the model forging.

![Shape of preform and of tools for model forging of central pieces by bending](image)

**Fig. 6.** Shape of preform and of tools for model forging of central pieces by bending:  
a) shape of preform, b) tools and diagram of location of the preform in tools
2.1.6 Die forging of central pieces

It partly eliminated the disadvantages of free forging, such as low formability due to unfavourable state of stress, difficult repeatability of technological procedure, which depends on human factor. Technological procedure of forging was developed and is currently used by the company JSW. Fig. 8 shows diagram of forging procedure Fig. 8.

![Diagram of forging procedure](image)

**Fig. 8** Technological procedure of forging of central pieces in closed die

In comparison with other, older, forging technologies, such as forging from rings, blocks or forging by free bending on a stand, this technology ensures high quality of product and low machining costs. Manufacture of the preform is made by classical free forging, only final forging operations are performed in closed die, and it consists of two stages:

a) first stage - preform is inserted into the lower part of the die, it is closed by the upper part and then compressed in press. This operation closes the inner non-integrities in the preform and at the same time it shapes the outer contour of the forging;
b) second stage – separating tool is pressed into the preform in order to create a gap between arms and to shape the crank pin.

The data summarised in Table 2 give an idea about influence of some methods of forging of central pieces on the forgings’ mass.

**Table 2. Mass of forgings in dependence on the on technical procedure of forging**

<table>
<thead>
<tr>
<th>Technological procedure of manufacture of stroke</th>
<th>Mass of forged piece [kg]</th>
<th>Change of stroke mass [kg]</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free bending on stands</td>
<td>17 600</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Creation of a gap between arms by machining</td>
<td>18 700</td>
<td>+ 1 100</td>
<td>+ 6.5</td>
</tr>
<tr>
<td>Forging in closed die</td>
<td>14 800</td>
<td>- 2 800</td>
<td>- 16</td>
</tr>
<tr>
<td>Swaging of cast piece</td>
<td>14 000</td>
<td>- 3 600</td>
<td>- 20</td>
</tr>
<tr>
<td>Die bending and shaping</td>
<td>13 700</td>
<td>- 3 900</td>
<td>- 22</td>
</tr>
<tr>
<td>Method TR, semi-built-up execution</td>
<td>13 000</td>
<td>- 4 600</td>
<td>- 26</td>
</tr>
<tr>
<td>Method TR, welded execution</td>
<td>10 200</td>
<td>- 7 400</td>
<td>- 42</td>
</tr>
<tr>
<td>Pressing in closed die</td>
<td>10 300</td>
<td>- 7 300</td>
<td>- 42</td>
</tr>
</tbody>
</table>

### 3. CONCLUSIONS

It is evident from the above characteristics and analysis of selected methods of manufacture of forgings for crankshafts of ship engines, that the TR method, which may be used for monobloc crankshafts up to the stroke length of 1 200 mm, has the lowest consumption of steel. Modification shown schematically in Fig. 7 appears to be suitable for crankshafts with longer stroke. Technological procedure of forging illustrated schematically appears to be feasible for forging of individual strokes for the types of crankshafts up to RTA 84 and L80MC.

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### LITERATURE