DEVELOPMENT OF TECHNOLOGY FOR FORGING OF BOTTOMS OF PRESSURE VESSELS FOR NUCLEAR POWER PLANTS

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Abstract

Pressure vessel of nuclear reactor represents very wide complex of designing, scientific, material, technological-operational and diagnostic problems, level of solution of which predestines and influences both operational reliability and safety and efficiency of production of this equipment. The pressure vessel itself consists of several characteristic components, the working stress of which in its complex determines unequivocally the state of stress of the reactor on the whole, although this stress achieves mutually different levels from the viewpoint of local judgment and assessment of individual parts of the pressure vessel. Development of new technology for manufacture of bottoms of pressure vessel for nuclear power engineering is oriented on future demands of market with respect to ecology and power engineering. It is necessary to propose new technology for production of forged bottom with flange for power engineering, namely by forging from one ingot without use of welding of the bottom to the flange. The objective is to verify for this forging technology an optimum shape of tools, which will make it possible to forge the bottom with a minimum loss of metal at forging and final processing. High degree of forging and also the required quality of products, characterised by high values of mechanical properties, will be achieved by minimum extra metal allowances for forging. After implementation of the new technology for forging of bottoms with flange the manufacturer will be able to offer on the world market a peak technology and sophisticated completely new products – monolithic forged bottom with flange for high quality pressure vessels for nuclear power plants.

Keywords: open die forging, forging design, pressure vessels

1. INTRODUCTION

Primary power sector in the world uses nowadays fossil fuels, such as coal, oil, natural gas, uranium, and also renewable sources, such as water, bio-mass and others. These sources are then consumed in electric power engineering, heating industry, transport, industry, households and services. World production of electric power is ensured in coal power plants (39%), gas power plants (18%), nuclear power plants (17%), water (17%), oil (8%) and other power plants (1%) [1]. Due to limited reserves of oil, coal and natural gas, it is possible to describe burning of these natural resources, which could have been used for the mankind in a much more efficient manner for example in chemistry and medicine, as wastage, not to mention harmful emissions created by their combustion, which are polluting the atmosphere. Nuclear power plant does not produce noxious substances, such as sulphur dioxide, nitrogen oxides and other carcinogens, and it is possible to consider this method of generation of electric power, in relation to creation of greenhouse effect and warming of atmosphere, as the most ecological. In comparison with other power sources the nuclear power engineering has an indisputable advantage, since character of radioactive decays and effect of ionising radiation makes it possible to measure the wastes with high precision and to evaluate their direct and indirect influence on human beings and their environment. Without nuclear power engineering any hope for reduction of emissions of CO₂ and other noxious substances in the atmosphere is just an illusion and utopia. At present altogether 435 power units of nuclear power plants are operated in 31 countries [2-4]. It is necessary to deduct from this number the plants that are serving out and will be put out of operation due to their unsatisfactory condition, while service life of some other plants will be extended after technical revision
and revamping. Another 31 units in 13 countries are currently under construction, and construction of some 250-300 units in 21 countries is planned or foreseen (maximum in China and India – 24 units each, Russia intends to increase its nuclear capacity from the existing 20.8 GWe to 49.3 GWe by the year 2020). From the viewpoint of functionality the pressure vessel of nuclear reactor forms an enclosed space, in which nuclear energy is transformed to heat, which is transferred to a coolant at high temperatures and pressures with simultaneous effect of radiation and corrosion influences. Nuclear reactor is at the same time characterised by high overall output per unit and high specific volumetric capacity of the active zone, higher parameters of neutron flow and removal of heat by coolant. Necessity of the highest technical level of structural design is here absolutely obvious. Progressivism of structural design depends wholly on possibilities and feasibility of application of new metallurgical-technological processes, dissimilar to the existing manufacturing methods.

2. PRESSURE VESSELS OF NUCLEAR REACTORS

Pressure vessel of nuclear reactor is composed of individual forged components, Fig. 1

![Fig. 1. Shape and dimensions of the pressure vessel of nuclear reactor [5]](image)

3. MANUFACTURE OF THE BOTTOM OF PRESSURE VESSEL FOR REACTOR BY PRESSING FROM CIRCULAR PLATES

Bottoms of pressure vessels for nuclear reactors can be manufactured also from pressed pieces. Manner of structural design is shown in Fig. 2. The cover and bottoms are connected to other parts of reactor by welding to the forged rings [6]. Interior surface of bottoms has a shape of ellipsoid of rotation, and exterior surface is an equidistant surface at the distance of the pertinent wall thickness.
Fig. 2. Pressed piece of the pressure vessel bottom for reactor

Semi-products for pressed pieces for bottoms are circular plates machined on both front faces and flame-cut along the perimeter. Thickness of the plates for the cover cap varies around 350 mm, diameter of the plate varies around 4 450 mm [7-8]. Mass is 41 000 kg. Thickness of the plate for the bottom is 250 mm, its diameter is 5 650 mm, mass 48 000 kg. The machined circular plate is ultrasonically tested and it is equipped on its perimeter with hooks for handling (Fig. 3).

Fig. 3. Forged plate for bottom reactor pressure vessel

Fig. 4. Machined circular plate

Individual world manufacturers use different methods for manufacture of large circular plates. They are most frequently produced by electro-slag welding of rolled heavy plates. Fig. 4 shows a photo of welded and machined circular plate made of two heavy plates. The input is a forging ingot, from which a slab is forged [9]. This slab is then rolled to heavy plate. Disadvantage consists in unfavourable concentration of internal heterogeneities from the central part of the ingot and related lower mechanical properties (mainly plastic properties) in central parts of the plate. Another disadvantage is the fact that rolling produces a square plate, from which it is necessary to cut the circular plate. Corner parts containing high quality material are cut off as waste. The existing experience shows that from the viewpoint of material consumption the manufacture of circular plates form electro-slag welded plates is advantageous for the thicknesses up to max. 120 to 150 mm. Big disadvantage is the fact that plastic properties of steel at the place of weld and in transition area into basic material are degraded and at pressing of circular plate into the die at these places on exterior surface of the pressed piece cracks occur due to big tensile stress. The cracks must be mechanically removed and welded up. It is necessary to perform during exploitation of the pressure vessel demanding periodical inspections of the bottoms at the place of welds [10-14]. Apart from this technology the pressed pieces for bottoms of pressure vessel for nuclear reactors are made from mono-blocks, i.e. from solid forged circular plates [15]. This procedure removes from the circular plates central heterogeneities transferred to the plate from the ingot.
Manufacture of bottoms by this technology consists of the following operations:

- re-forging of the ingot body to a round semi-product,
- forging of trunnion for handling from the ingot head,
- cutting-off of head and heel metallurgical waste;
- upsetting of circular semi-product;
- re-forging of the upset semi-product to a prism with longitudinal axis perpendicular to the original ingot axis;
- cutting off of trunnion for handling and metallurgical waste from the ingot head;
- re-forging of the prism to a circular block;
- upsetting of the block;
- gradual flattening – enlarging of diameter of circular plate to the final dimensions.

Diameter of the forged piece of circular plate for the bottom is 5800 mm, thickness of the forged piece is 360 mm, mass of the forged piece is 81000 kg. Forged pieces of circular plates are then mechanically machined on both front faces to the required thickness of approx. 350 mm. Circular plates are for die pressing reheated to a forging temperature. Top forging temperature is 1100° C, lower forging temperature is 850° C. Circular plates are die pressed. The matrix is situated on the moving table of the press, matrix is fixed on the moving traverse of the press. Final pressing must be made at the temperatures from 950 to 850° C and the pressed piece is taken out from the matrix at the surface temperature min. 800° C. Fig. 5. shows the shape of the pressed piece for the bottom [16].

Fig. 5. Pressed piece for the bottom of the reactor vessel

4. FORGING OF BOTTOMS WITH FLANGES

Procedure of forging of bottoms with flanges is in comparison with production of bottoms by pressing very advantageous by reduction of number of welds on the pressure vessel. Fig. 6 shows the shape and dimensions of the forged piece of the bottom with flange. Size of extra allowances for machining can be seen in the Fig. 7.

Fig. 6. Forged piece of the bottom with flange (mass of the forged piece is approx. 83000 kg)  
Fig. 7. Size of extra allowances for machining
Extra allowances are removed by machining and thus the bottom of the pressure vessel is obtained – see Fig. 8.

![Fig. 8. Shape and dimensions of the machined bottom (mass of the machined bottom is 39 000 kg)](image)

Comparison of mass of the forged piece and machined bottom shows very small usage of metal and large extra allowances for machining, which increases costs of production of solid forged bottoms. This disadvantage is in comparison with the assembled bottoms outweighed by economies related to checking of welds quality at exploitation of the pressure vessel. Photo of the machined bottom with flange is shown in Fig. 9. Parameters of the machined bottom: diameter 4015 mm, height of the bottom 1705 mm, mass 38 000 kg, material according to ASME SA508,CL.3EQ [17-20].

![Fig. 9. Photo of the forged piece of bottom with flange](image)

5. CONCLUSIONS

Bottoms with flange can be manufactured in the form of mono-block, or as welded bottoms consisting of the pressed piece of circular plate and from the forged piece of circular ring. The pressed piece and the ring are joined together by welding:

a) **Forged pieces of bottoms with flanges.** Advantage of the first production sequence consists in lower number of welds on the pressure vessel and therefore in lower operational costs related to inspection of quality of the bottoms at exploitation of reactor pressure vessel. Another advantage consists in higher quality and better applicability on world markets. Predominant part of manufacturers of pressure vessels for nuclear reactors requires this type of products.
b) **Bottoms composed of pressed pieces and forged rings.** Advantage of this procedure consists in lower requirements to mass of forging ingots. This procedure is simpler from the viewpoint of handling the semi-product. This production technology was verified in conditions of forging shops in Czech Republic and rich experience was gained at manufacture of pressure vessels for power plants VVER 440 and VVER 1000.

**ACKNOWLEDGEMENT**

*The paper was prepared within the frame of solution of the projects MPO FR-TI1/224 and FR-TI1/226*

**REFERENCES**


