ANALYSIS OF NEW TECHNOLOGY FORGING MONOLITHIC FORGED BOTTOMS

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Abstract

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 from the viewpoint of local judgment and assessment of individual parts of the pressure vessel mutually different levels. 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 energetic. 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, bottom pressure vessels

1. INTRODUCTION

Primary power engineering sector uses at present fossil fuels for generation of power – coal, oil, natural gas, as well as uranium and recoverable sources, such as water biomass, solar energy, etc. These sources are consumed for generation of electric power and heat, but also by transport, industry, households and services. World production of electrical power is ensured in power plants using coal (39%), gas (18%), nuclear fuel (17%), water (17%), burning of liquid fuels (8%) and in other types of power plants (1%). Due to limited sources of fossil fuel their burning is arguable and it is accompanied by creation of noxious emissions. Nuclear power plant does not generate undesirable emissions, that's why it is possible to consider this method of generation of electric power as ecological.

At present all over the world altogether 435 nuclear power units (NPU) in 31 countries, see Fig. 1. It is, however, necessary to deduct from this number the units that are serving out and which will be put out of operation due to their unsatisfactory condition, but on the other hand service life of some units may be extended after technical revision. Another 31 units are being built in 13 countries, and long-term plans calculate with erection of another 250-300 reactors in 21 countries (China and India will built 24 units each, Russia intends to increase capacity of its nuclear power plants from the existing 20.8 GWe to 49.3 GWe by the year 2020).
2. PRESSURE VESSELS FOR NUCLEAR POWER PLANTS

Pressure vessels for nuclear power plants (reactor, steam generator, pressurizer) are assembled from individual forged components. Fig. 2 shows construction of the pressure vessel for reactor [1].
From the viewpoint of function the pressure vessel for nuclear reactor presents an enclosed space, in which nuclear power is being transformed to heat, and its transfer into coolant at high temperatures and pressures with simultaneous impact of radiation and corrosive effects. Nuclear reactor is characterised by high thermal output and in its active zone also by higher parameters of neutron flux. Indispensability of high technical level of reactor design concept is here quite obvious. Progressiveness of structural design depends wholly on possibilities of new metallurgical-technological processes, differing from the existing production methods.

3. MANUFACTURE OF PRESSURE VESSELS BOTTOMS BY OPPRESSING FROM ROUND PLATES

It is possible to manufacture bottoms of pressure vessels for nuclear power plants from the pressed pieces or from forged pieces. Pressure vessel cover and bottom are connected to other parts of the reactor by welding to the forged rings. Inner surface of the bottoms forms a shape of ellipsoid of rotation, their outer surface is an equi-distant area at the distance, corresponding to the wall thickness. These bottoms are pressed from round plates. Thickness of the plate for the cover cap varies around 350 mm, the plate diameter is approx. 4 450 mm [2]. Mass of the plate is up to 41 000 kg. Thickness of the plate for the bottom is 250 mm, its diameter is 5 650 mm and mass is 48 000 kg [3]. Individual world manufacturers of large round plates use different production methods. The plates are manufactured most often by electro-slag welding of rolled heavy plates. Fig. 3 shows photo of welded and machined round plate made of two heavy plates.

Fig. 3 Machined round plate

Forging ingot serves as input semi-product. First slab is forged from it and it is afterwards rolled to a heavy plate. Disadvantage of this approach consists in unfavourable concentration of internal heterogeneities from the ingot's central part and deteriorated mechanical properties (mainly plastic ones) ensuing from this in central areas of the plate. Another disadvantage consist in the fact that round plate is cut out from the rolled rectangular plate. Angle parts, containing high quality material are thus wasted. Experience shows that manufacture of round plates by electro-slag welding of the plates is advantageous for the thicknesses of max. 120 to 150 mm. At the place of welding and at transition zone into the basic material plastic properties of steel are deteriorated, and at pressing of round plate cracks are formed at these places on external surface of the pressed piece. It is necessary to perform regularly during exploitation of the pressure vessels very demanding inspection of the weld joints of their bottoms.

Apart from this technology the pressed bottoms for pressure vessels for nuclear power plants are manufactured also from monoblocks, i.e. from solid forged round plates. Special procedure is used for removal of central heterogeneity of round plates, which were carried forward from the ingot onto the plate. Manufactured of bottom by this technology consists of the following operations:
• forging of manipulation spigot from the ingot crop end;
• re-forging of the ingot body into round blank;
• cutting off of ingot metallurgical croppings;
• upsetting of the blank;
• re-forging of the upset blank to a prism with longitudinal axis perpendicular to the ingot original axis;
• cutting off of the manipulation spigot and metallurgical croppings from the ingot crop end;
• re-forging of the prism to a round block;
• upsetting of the block;
• gradual flattening – enlarging of the round plate diameter to the final dimensions.

Diameter of the forged round plate for the bottom is 5800 mm, thickness of the forged plate is 360 mm, its mass is 81 000 kg. Forged round plates are further machined on both faces to the required thickness of approx. 350 mm. Round plates are for die forging reheated to the temperature of 1100°C. Final forging must take place at the temperatures of 950 to 850°C and the pressed piece is removed from the die at the surface temperature of at least 800°C.

4. FORGING OF BOTTOMS WITH FLANGE

Advantage of the procedure of forging of bottoms with flange consists in reduction of number of welds on the pressure vessel. Fig. 4 shows drawing of the bottom with flange. Fig. 5 show photo of the machined bottom with flange. Parameters of the machined bottom: diameter 4015 mm, bottom height 1705 mm, mass 38 000 kg, material according to ASME SA508,CL.3EQ.

![Fig. 4 Forging piece of the bottom with flange](image-url)
4.1. Experimental verification of technology for forging of bottoms

The basic prerequisite for construction of nuclear power plants is availability of heavy forgings and high level of heavy engineering. The forging shops supply pressed pieces both for primary and secondary circuit of nuclear power plants, particularly forgings for reactor vessel, steam generators, pressurizers, turbine rotors and generators.

Manufacture of forged pieces for nuclear power plants of the generation 3+ requires that forging shops are equipped with presses using the force of 140 to 150 MN, which are able to process ingots with the mass of 500 to 600 tons [4]. Construction of reactors of the 2nd generation required 2000 tons of pressed pieces, while reactors of the generation 3+ require twice this quantity. The biggest components (forged pieces for nuclear engineering) are manufactured by technology of hammer forging. By assembling individual parts we obtain the required construction, such as reactor pressure vessel.

The design of the existing nuclear power plant (NPP) of the 3rd generation, type EPR supplied by the French manufacturer from the AREVA group, requires steel ingots with mass between 500 to 600 tons. These ingots are used for forging of the most complex parts of the reactor pressure vessel: top cover (head seal), central ring and ring with branch extrusion (Fig. 2). Production of individual parts of the nuclear power plant consumes more than 4000 tons of steel pressed pieces, such as containment, parts of the reactor vessel, steam generator and pressurizer, turbine and generator rotors. Nuclear power plant EPR uses altogether 4 generators, each weighing up to 500 tons. Mass of the generator rotor exceeds 200 tons. Nuclear power plant has 3 to 4 turbine rotors. Top cover for the pressure vessel is one of the most complex pressed pieces for the reactor pressure vessel.

Prior to its implementation into common practice the technology for forging of the top cover was first simulated mathematically (MKP) and then verified experimentally in laboratory with use of models on a scale of 1:20 [5]. Photo of the model form is shown in Fig. 6 and that of the model forged piece in Fig. 7.
Fig. 6 Forging blank for the reactor top cover

Fig. 7 Forging piece of the reactor top cover

Contribution of the new technology consists in manufacture of the cover from one piece of ingot without any welding of the cover and flange. This new manufacturing technology brings significant ecological-economic effects on production and at the same time it increases safety of the reactor pressure vessel.

5. CONCLUSIONS

Bottoms with flange can be manufactured in a shape of monoblock, or as welded bottoms consisting of the pressed round plate and pressed round ring. Pressed round plate and pressed round ring are connected by welding. Advantage of the first manufacturing procedure consists in lower number of welds on the pressure vessel and thus in lower operational costs connected with inspection of quality of the reactor bottom. Another advantage is higher quality and better assertion on the world markets. Predominant part of manufacturers of pressure vessel for nuclear power plants requires this type of products. Advantages of the second procedure
consist in lower requirements to the mass of forging ingots. This method is simpler from the viewpoint of handling of the semi-product during production

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