Increase of Effectiveness of Service Activities during Outages of Nuclear Power Plant Units

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Abstract
The article deals with the ŠKODAJJS solutions to streamline service activities in nuclear power plants with VVER reactors, and this in regards to graphite gaskets for reactor flange gaskets and tightening EZ Class reactor units for flanged joints of the upper reactor block. Both solutions have been proposed and developed by the company and contribute significantly to the reduction of time for individual operations during reactor shutdown.

Introduction

1. Gaskets of Expanded Graphite for Flanged Joints of VVER Type Reactors

The company ŠKODA JS a.s., with its current staff of over 1000 employees, can boast of rich, today more than half-century-long experience in manufacture of components for nuclear facilities and in other nuclear energy oriented activities, including but not limited to engineering, designing and construction of new sources and further manufacture, testing and supplies of equipment of nuclear power plants. And last but not least in complex maintenance of the primary circuits of the operated nuclear power plants at Dukovany and Temelin and implementation of servicing, reconstructions and repairs of nuclear power plants (NPP) in Slovakia, the Ukraine, Hungary and Finland. In the past ŠKODA JS manufactured 21 complete reactors of the VVER 440/V-213 type and three complete reactors of the VVER1000/V-320 type.

Experience in maintenance and immediate contact with operators of nuclear power plants help ŠKODA JS company in development and manufacture of new devices supporting shortening of the periodic outages of NPP units, reducing exposure of the maintenance staff to ionising radiation, assuring the required comfort of the operators and minimising the effects of the human factor, thus contributing to reduced probability of error occurrence. This also fully applies to the manufacturing programme of the EZ series tightening units and the related use of expanded graphite gaskets for flanged joints of the VVER type reactors.

Reliability and stability of the sealed joints of the nuclear power plant reactor flanges is a ne-cressary prerequisite for safe and continuous operation of the equipment in the course of the circa one-year campaigns between fuel exchanges and significantly affect the life-span of the device across the planned period of operation. Even though the parameters inside the primary circuit of the VVER nuclear power plants do not represent any peak in the energy field (temperature circa 320 °C, operation pressure up to 16 MPa) but regarding the possible consequences of leaks (economic loss in the case of a failure of a unit of this output) the requirements for the function of the sealing joint are by far the highest nevertheless. Assurance of reliable sealing, whose properties and functions together with the process of the joint tightening support the above requirements, represent one of the necessary preconditions of long-term reliable operation of nuclear units. The combination of nickel rings and asbestos ropes together with the classical method of the joint tightening with spanners used in the past for reactor flanged joints did not sufficiently support this intention.

Therefore in the 1990s ŠKODA JS in cooperation with the power plant staffs prepared both for the operated and for the newly commissioned nuclear units a complex programme of replacement of the originally used nickel and asbestos gaskets with new seals made of expanded graphite. The main reason for the replacement was the advantages of expanded graphite used as seals of flanged joints, such as reliability of the sealed joint, reduction of the tightening torque with a positive impact on the life of the exposed parts of the sealed joint and reduction of the risk of damage to the sealing surfaces. Another assets was represented by reduction of use of materials such as asbestos with their negative effect on the operators and on the environment. This programme has resulted in a broad offer of graphite gaskets for flanged joints of VVER 440 and VVER 1000 reactors, manufactured and supplied by ŠKODA JS for Czech, Slovak, Hungarian and Ukrainian nuclear power plants. The design and size of the gaskets can be adapted individually pursuant to the original manufacturing tolerances of the sealing surfaces of the flanged joints. This is an important aspect with regard to the actual condition of the sealing surfaces caused by the previously used sealing materials.

The graphite gasket replacement programme, the "resealing programme", include construction preparation and design of the gaskets, preparation of design and manufacturing documentation and construction of a new manufacturing space for the gasket manufacture. One of the most important stages was implementation of a complex programme of verification of behaviour of the gaskets including above all a predefined series of tests on experimental devices. These tests were performed on the full-scale experimental loops at ŠKODA JS, capable of modelling of design and supra-design conditions of the nuclear unit operation. The results of these tests greatly expanded the deep knowledge of our engineers in the area of behaviour of graphite gaskets both under routine operation conditions and in situations which cannot realistically be expected even in emergency situations.

This knowledge and experience has become the basis of the subsequent development programme of the new, electronically controlled tightening units of the EX series for tightening of flanged joints of VVER reactors.

2. Theory of Controlled Tightening of Graphite Gaskets

As mentioned above, the expanded graphite gaskets bring many advantages for flanged joint sealing. For the optimum condition of the sealed joint it is necessary, though, to keep during the tightening process even distribution of the pressure and the process of forming of the gasket between the sealing surface of the flange and the counter-piece. Unlike the tradition tightening procedure, when a manual spanner is used for separate tightening of every bolt by transfer of the tightening torque onto the bolt nut, the tightening unit tightens all bolts along the flange perimeter at once.
That eliminates the possibility of unbalanced acting of the flange on the surface of the gasket as a consequence of uneven distribution of forces in the course of the classical tightening procedure (the so-called "floating") and achieves optimum relaxation of the gaskets in the course of the tightening process.

The first important aspect is the moment when the graphite gasket is installed on the flange without prior compression. The flange seating may unevenly load and deform the soft sealing ring. That is why even compression of the gaskets by a predefined value of the torque is very important in this first stage (see figures 2 and 3), which provides for even moulding of the gasket in the sealing groove and correct initial position for the final tightening.

In the second stage of the tightening process the needed time for the gasket moulding need to be assured. A too quick procedure can mean achievement of very short times of the joint tightening but this is not an ideal solution with regard to further function of the sealed joint under operation conditions. For that reason the tightening units produced by ŠKODA JS controlled with a sophisticated software, which takes into consideration relaxation of the graphite gaskets in the process of their compression and adapts to the given conditions the value and progress of the torque applied on the joint.

Fig. 2 shows a typical simplified tightening process, divided into several stages. Stage 1 comprises connection of the torsion bar head of the tightening unit with the served nut or bolt head. Stage 2 is the moment when free turning of the nut results in the first contact of the nut surface and the flange. When EZ 650 is used this stage is usually also sued for diagnosing the condition of the thread when on the basis of increased torque the thread damage or insufficient lubrication is detected. Stage 3 shows the beginning of the first contact between the nut and the flange and commencement of the first pre-stressing of the gasket. This stage ends by achievement of the given value of the threshold torque. The final stage 4 then shows the final tightening where the control SW of the tightening unit monitors achievement of the target ("green") window of tightening framed by the values of the target torque and the nut tilt angle.

3. Electronically Controlled Tightening
Unit EZ for VVER 440 Units

The first manufactured and supplied units produced by ŠKODA JS was tightening unit EZ 650 for flanged joints of the upper unit of Lovisa NPP in Finland in 2003, where successful completion of all operations met the customer expectations. The work with the tightening unit was much more effective than the procedure used previously and the total process time of the tightening of all 37 positions with two flanged joints each was significantly reduced.

On the basis of this reference and excellent continuing co-operation between the engineers of Lovisa NPP and ŠKODA JS another type of the tightening unit, EZ 650 TK&KNI, was supplied including a storage and calibration stand. This unit was designed for tightening and release of the flanged joints of the measuring thermocouples and neutron flow sensors in the reactor pressure vessel. The supplied stand allows for periodic calibrations and tuning of the tightening units before the actual use on the reactor flange. The first set EZ 650TK&KNI was used in the course of the 2006 outage of the Lovisa NPP.

Use of these tightening units in Lovisa NPP significantly contributed to achievement of the total outage time shortening to less than 20 days, which is the shortest time achieved by this type of NPP at all.

Both units EZ 650 and EZ 650 TK&KNI assure joint tightening under permanent control of the torque with the accuracy of up to 5 % as well as control of the nut tilt angle, which is an important measured value for complex assessment of the process of the joint tightening. The combination of the torque control and the nut tilt angle and the considered real behaviour of the joint assure achievement of the correct and long-term reliable functioning of the sealed joint.
The option of parallel control of the joint tightening with the help of the original measurement of elongation of the bolts may be preserved if so requested by the customer or by the approved procedures of joint tightening in the NPP in question. In this case this measurement is performed manually on the VVER 440 on the central control rod of the bolt with the help of a measure with a deflection meter. Achievement of the required value of the bolt elongation is also assured by this tightening method (to the prescribed torque), which has also been proved under real conditions on an actually operated device.

4. Electronically Controlled Tightening Unit EZ 250 for VVER 1000 Units

The last type of the electronically controlled tightening unit of the EZ series is unit EZ 250 for flanged joints of reactor VVER 1000. When developing this unit ŠKODA JS applied experience in construction of a longer with electronic torque control of EZ 650 series, successfully used by VVER 440 reactors. Unlike in the case of VVER 440 the work on tightening of the flanged joints of VVER 1000 is significantly complicated by the different dislocations of the flanges of the upper reactor unit, or inaccessibility of part of these flanges. Therefore neither a visual inspection of the seating of the flange nor the manual control measurements of the bolt elongation by the deflection meter can be applied.

All the different requirements had to be considered for construction of the advanced tightening unit EZ 250. Solutions of all the related issues were a hard piece of work even for the experienced constructors.

The unit EZ 250 is universally designed for operation of all flanged joints of the lid mouthpieces including flanged joints of the case of the linear stepped drive (LKP), flanged joints of the measuring thermocouples (TK) and sensors of neutron flow (KNI). For the purpose of the flanged KNI joints the EZ 250 unit was designed to be able to serve both types of these flanges – the flanges of the original variant with six bolts M27 as well as the modernised version of the flange with six main bolts M27 and six push-away screws. The modernised version of the KNI flange has been designed by ŠKODA JS for the purpose of facilitation of work with the sensors measuring the neutron flow and especially for the purpose of elimination of their mechanical damage by the reactor disassembly and reassembly in the course of the unit outage.

The EZ 250 unit comprises a control box with a hinge for handling, a touch screen, control buttons for communication with the operator and a USB port for data transmission. Under the control box there is the transmission unit with six power mechanisms. The transmission optionally distributes the torque among the six main tightening rods for the bolts or the six tightening rods for the push-away screws. The distribution of the torque transfer is controlled manually by two control elements.

On the bottom of the transmission box there is a centring tube for correct guiding of the unit to position if seated by a crane. This tube further assures stability of the unit in the vertical position when it is seated over the flanged joint and is used for catching the reaction force resulting from the tightening process. The reaction force is transferred from the centring tube by means of the reaction catchers to the openings in the upper distance plate of the upper reactor unit. The reaction force catching is absolutely necessary for tightening of the joint with the criterion for the bolt elongation, as this part assures the required stability of the unit and the corresponding accuracy of the measured data on the bolt elongation.

On the output shafts under the transmission box there are six tightening rods with sensors for the bolt elongation measurement. These rods are designed for transfer of the torque onto the six bolts of the main flange. Under the transmission box there are also another six tightening rods without the measuring equipment for tightening of the push-away flange.

The unit can further be equipped with a 2D key reader. The reader in connection with the 2D key of a particular flange, fixed by the relevant opening for the flange in the upper distance plate of the reactor unit, is able to uniquely identify the position of the tightening unit during work on the flange in the tightening/releasing process. Thus elimination of human error of repeated operation on an already tightened/released flange is achieved. The option of identification of a flange with the 2D key at the same time simplifies the identification of the correct tightening protocol for the correct tightening. The software of the unit is connected with the data of these flanges and is used to control the tightening process. The software allows for remote online control of the unit to the required stability and the corresponding accuracy of the measured data on the bolt elongation.

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The EZ 250 unit is supplied with a storage box for the unit storage and transport between the storage space and the reactor hall in the nuclear power plant. The box is also equipped with a calibration stand in its bottom part on which the unit sits. This design allows for advance calibration of the unit before application to an actual joint. The calibration system is part of the supply.

Software (SW) of EZ 250 is based on the SW used for unit EZ 650 and is extended with further functions specific for use for VVER 1000 project. The control system guides the operator in the course of the tightening process and helps eliminate human error. The software also checks quality of tightening of all the required coor-dinates and at the same time completeness of the operation and tightening of all positions. The data produced by the tightening process are stored and eventually transferred to the joint tigh-tening protocol.

Software of all units of the EZ series allows for remote online control of the unit by the operator via a cable or WiFi connection. In this case the operator stand can be located anywhere in the reactor hall.

5. Advantages and Benefits of Use

Experience in actual deployments of the different tightening units of the EZ series confirms the assumption on which construction of these devices was originally based. Use of a tightening unit significantly reduces the time of the operation of tightening/releasing.

As well the number of operators needed for running the device is reduced to the total number of two one for the unit operation and the other for the crane operation. The quality of the joint tightening will also improve considerably, as the gaskets will be evenly (opti- mally) moulded between the sealing surfaces. The combination of the above will reduce the collective exposure of the maintenance staff to radiation and the times of the individual operations in the course of the unit outage.

When the EZ 250 unit was first used in the Temelín NPP the tigh-tening of he 30 flanges of the measuring thermocouples (TK) and neutron flow sensors (KNI) was completed in circa 6 hours. The time of the same operation performed with a hydraulic tighter ranged between 16 and 20 hours.

6. Conclusion

ŠKODA JS as a reliable supplier for nuclear industry offers not only variant types of gaskets in the “nuclear” quality but also a device assuring corresponding quality of the joint tightening and a significant benefit for the operator of the nuclear power plant represen-ted by the significant reduction of the outage times. The objective and strategy of ŠKODA JS is to offer complex sophisticated solutions not only for tightening of flanged joints. This is ŠKODA strategy for all main areas of its activity including engineering, service and manufacture for nuclear energy industry.

The units of series EZ 650 and EZ 650 TK&KNI for VVER 440 reactors are now successfully used wherever requirements of the operators for functionality and reliability of major equipments have been interconnected with the art and experience of constructors, i.e. in Loviisa, Mochovec, Bohunice and Pács NPPs. The first “live” application of EZ 250 for VVER 1000 was implemented in Temelín NPP in 2010.

By inclusion of the tightening units of the EZ series in the manufacturing portfolio together with the hydraulic tighteners of the VVER 440 and 1000 lid nuts constructed and manufactured in cooperation with Siempelkamp Tensioning Systems GmbH, the ŠKODA JS company is now able to offer a complex set of devices for servicing the sealing joints of reactors, which makes it one of the leading world producers of this type of equipment.