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# DEVELOPMENT OF TECHNOLOGIES FOR MONITORING THE OPERATING CONDITION OF GUIDANCE DEVICES OF INTERNAL PARTS OF VVER 440 REACTOR PRESSURE VESSELS

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## ABSTRACT

The article describes the requirements and main outputs from R&D project for the development of technologies and prototypes of equipment for dimensional measurements and determination of surface profiles of guidance devices for internal parts of VVER 440 reactor pressure vessels. Determining the state of dimensions or profiles of components in comparison with their design state can confirm their functionality to ensure further safe operation of NPP reactors.

## R&D PROJECT INTRODUCTION

The aim of the R&D project is development and experimental verification of measurement of dimensions and 3D profiles of machine components with accuracy better than 40 μm in places with high radiation up to 20 Gy/h and under water to depth of 12 m. By means of these technologies it will be possible to perform an assessment of the current state or during repeated measurements to assess changes, resp. trends of measured parameters (dimensions and profiles), thereby verify the condition of measured machine components and manage their service lifetime.
The technologies being developed will be applicable to other design sites in NPP primary circuit.

Research and development are carried out in the following areas:

- Research and development of digital video recording processing from a remote-controlled device (radiation-resistant camera and manipulator) for determining the dimensions of machinery components in places with high radiation up to 20 Gy/hour and underwater to a depth of up to 12 m.
- Research and development of equipment for remote sampling of replicas of machine component surfaces in places with high radiation up to 20 Gy/hour and underwater up to 12 m. Replicas will then be scanned, for example, using a mobile 3D laser scanner.
- The above technologies are being developed to measure the dimensions and profiles of the reactor vessel keys and core barrel grooves for NPP of VVER 440 type (see figure 1).
- Verification of the technologies being developed will take place on the mock-ups of the reactor key and the core support barrel groove (see figure 2). The mock-ups will contain predefined defects.

Research and development are carried out under the following conditions:

- The measuring must make it possible to measure the required parameters in the time so that the outage critical downtime is not extended.
- The measuring device must be radiation-resistant (20Gy) and for measuring per reactor resistant to a 12 m water column (approx. 2.22 MPa = 1.5 times the water column).

- The measuring methods must be qualified for the declared accuracy (less than or equal to 40 μm).
- The requirements for measurement accuracy are based on the requirements for a specific application, where the mounting clearance between the key and groove 50 to 170 μm was determined within the Dukovany NPP project. Accuracy of measuring methods must be at least 4 times better than the maximum design (assembly) clearance, ie about 40 μm.
- Developed technologies must allow the measurement of the required parameters at such a time that the critical path of outage is not extended
- Requirements for measurement accuracy of approx. 40 μm have been set for these development technologies.
- To determine the clearances, the profiles of the side walls (with an area of 25 x 5 mm) and the distance between the walls of the keys and grooves (approximately 80 mm) are measured.
- Measurements would take place during outages with the internal parts of the reactor raised.
- The measurement of the grooves would take place with a measuring manipulator located in reactor hall in front of the window of the shielding cylinder, in which the core barrel would be located.
- The measurement of the keys would take place in the reactor pressure vessel with a measuring system located on horizontal arm of the manipulator for non-destructive inspections (see figure 3). This is an MKS manipulator for inspecting reactor pressure vessels from ŠKODA JS a.s. At the time of the inspection, there would be primary circuit water (boric acid solution - up to 16 g / kg) in reactor pressure vessel. The keys are located at a depth of about 8 m.

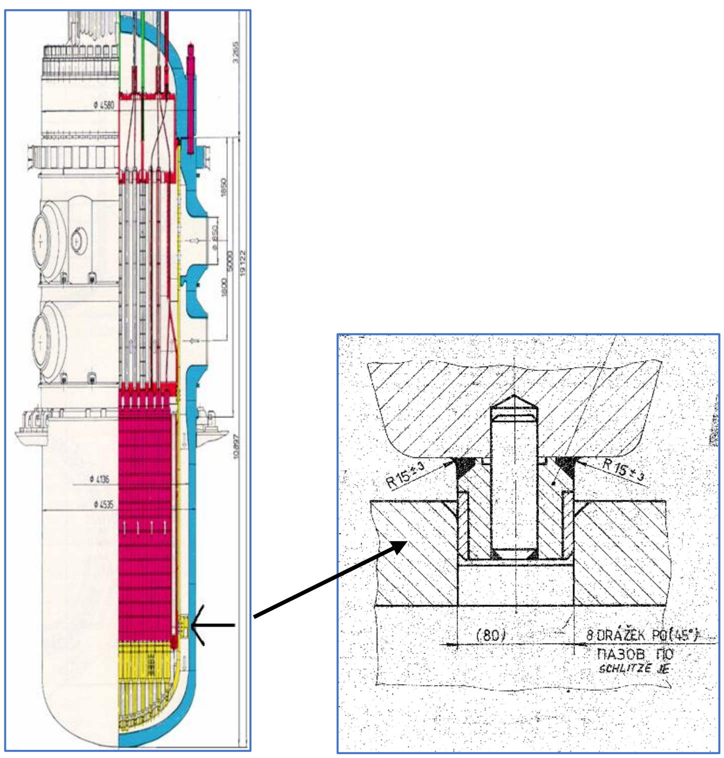


Figure 1. Figure of reactor pressure vessel and the location of key a groove

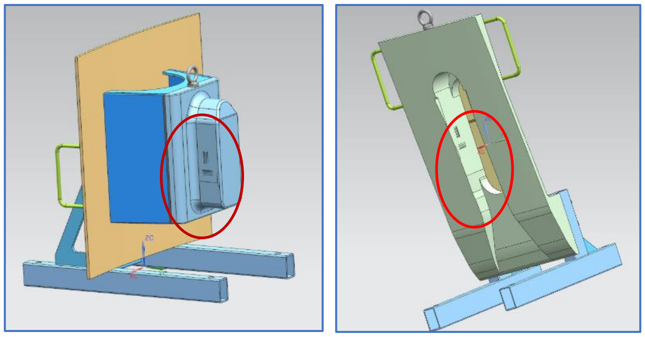

Figure 2. Drawing of key mock-up (left) and groove mock-up (right) with artificial defects (red oval)

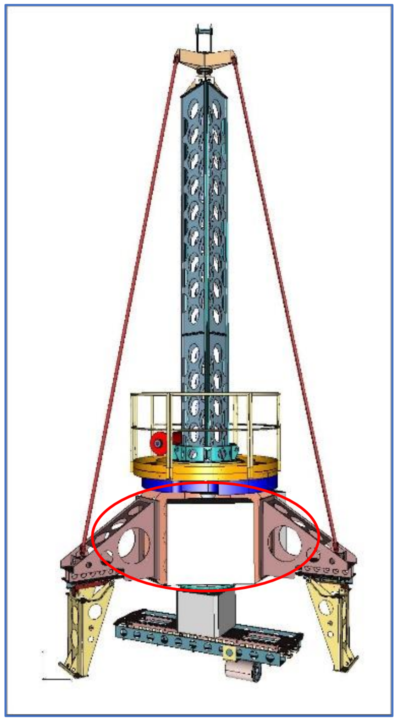

Figure 3. Drawing of MKS manipulator for inspection of reactor pressure vessels from ŠKODA JS a.s. with horizontal arm (red oval)

## TECHNOLOGIES BEING DEVELEPOD

### *Remote replicating technology*

The development of the technology for measuring the surface profiles of machine components using replicators in a dry / underwater radiation environment took place in 2021 – see [1].

The following tests were performed:

1. Leaching tests of replica components
2. Replication mass application tests and replicator jaw sealing
4. Replicator jaw tear tests
5. Tests of radiation resistance of replication mass
6. Measurement of the extrusion force of the replication mass

The outputs of these tests were used in the development of the replicator design.

***3D scanning technology***

Based on the search in 2020, a scheme of qualification of devices suitable for use in the conditions specified by the project was proposed:
- Laser scanning
- Video signal scanning.

CVŘ decided to explore 3 possible ways to solve the problem of measuring reactor internals with an accuracy of 40 μm:
1. Measurement using digital image processing using a radiation-resistant camera.
2. Measurement using digital image processing using a commercial UHD or 4-5K camera.
3. Measurement using laser scanning of components with a set of scanners.

Based on the performed SWOT analysis, it was chosen to continue the development of digital image processing from 4-5K camcorders.

Due to the fact that a patent application for 3D scanning technology was filed at the time of writing, a description of this technology will be presented at the time of the conference.

## MEASURING SYSTEM BEING DEVELOPED

The developed measuring system consists of a manipulator (see figure 4) for precise positioning.

The manipulator is either connected to:

- a replicator (see figure 5) which contains jaws for remote sampling of replicas and measurements for accurate determination of jaw opening via linear encoder.
  or
- a camera system.

In the case of keys measurements, the manipulator is connected to a horizontal arm of the manipulator for non-destructive inspections (see figure 3). In the case of grooves measurements, the manipulator is connected to the developed fixing frame (see figure 6).

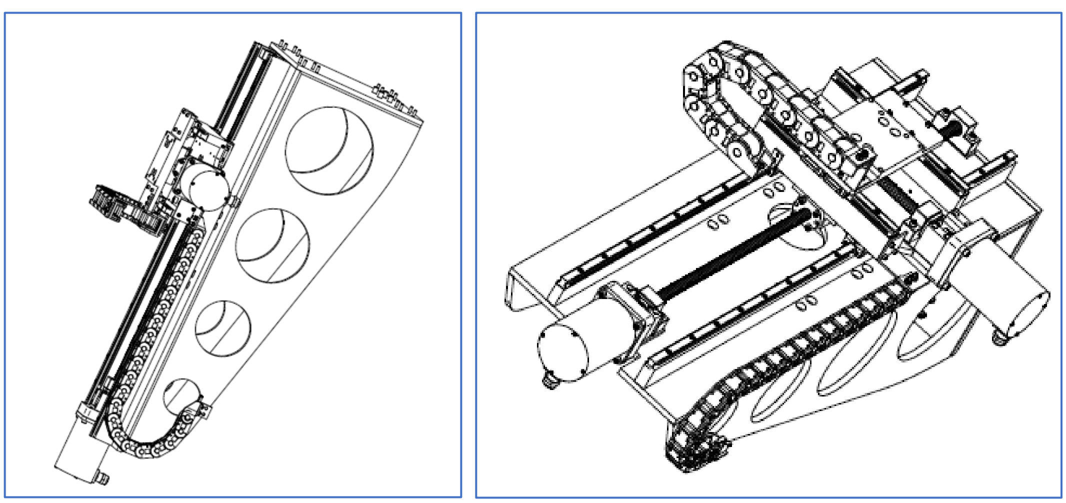

Figure 4. Drawings of the measuring system - manipulator

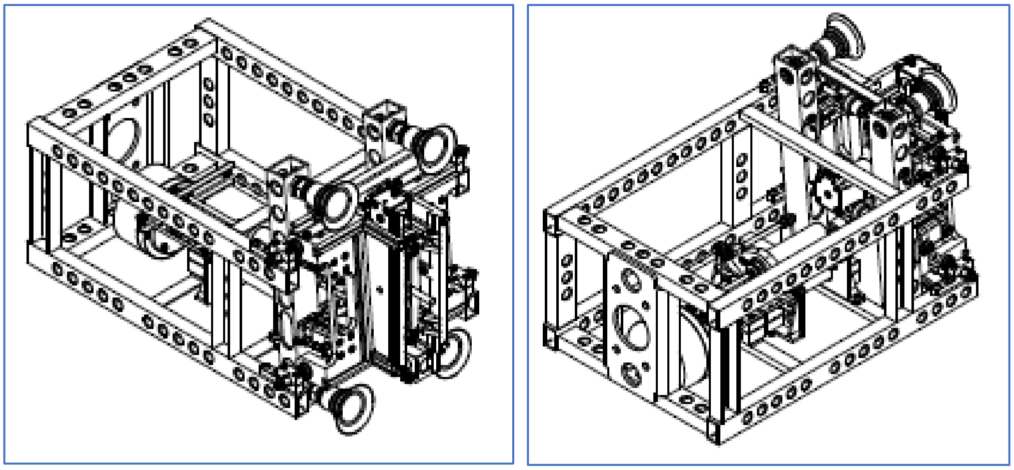

Figure 5. Drawings of the measuring system – replicator for groove's measurement

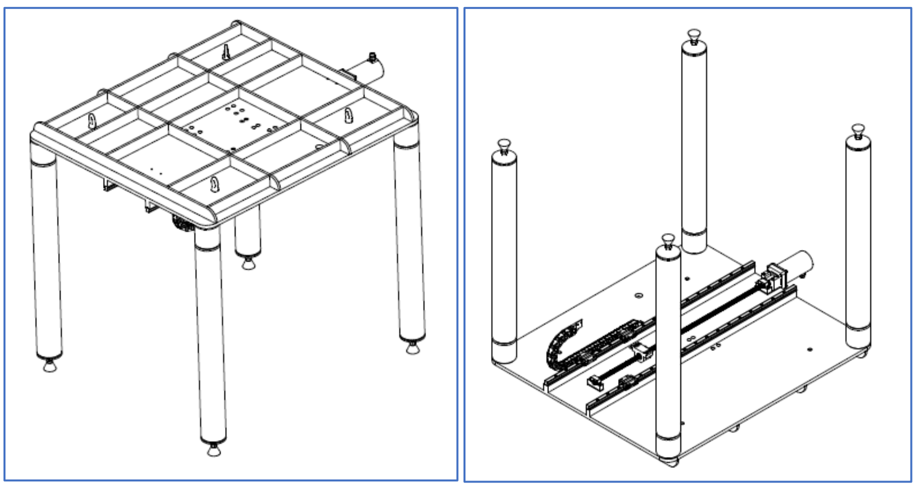

Figure 6. Drawing of the fixing frame

***Measuring assembly for the case of the groove's measurement***

Basic components of the assembly (see figure 7):

1. Fixing frame, which forms the base of the manipulator.
2. Manipulator ensuring movements in individual axes:
   Y-axis – It secures the zoomed device to the measuring position.
   Z Axis – It allows the measurement height to be set correctly. In the case of a camera system, it allows the 3D scanner to be moved in the axis of the groove.
   X Axis – It centres the device in the groove axis.
3. Replicator or Camera system

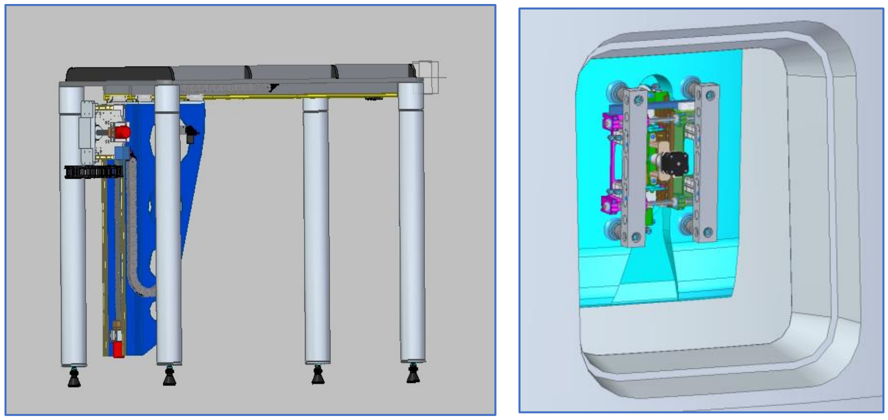

Figure 7. Figure of measuring assembly for the case of the groove's measurement with the window of the shielding cylinder

### *Measuring assembly for the case of the key's measurement*

Basic components of the assembly (see figure 8):

1. Manipulator for non-destructive inspections, which horizontal arm forms the base of the manipulator.
2. Manipulator ensuring movements in individual axes:
   Y-axis – It secures the zoomed device to the measuring position.
   Z Axis – It allows the measurement height to be set correctly. In the case of a camera system, it allows the 3D scanner to be moved in the axis of the key.
   X Axis – It centres the device in the key axis.
3. Replicator or Camera system

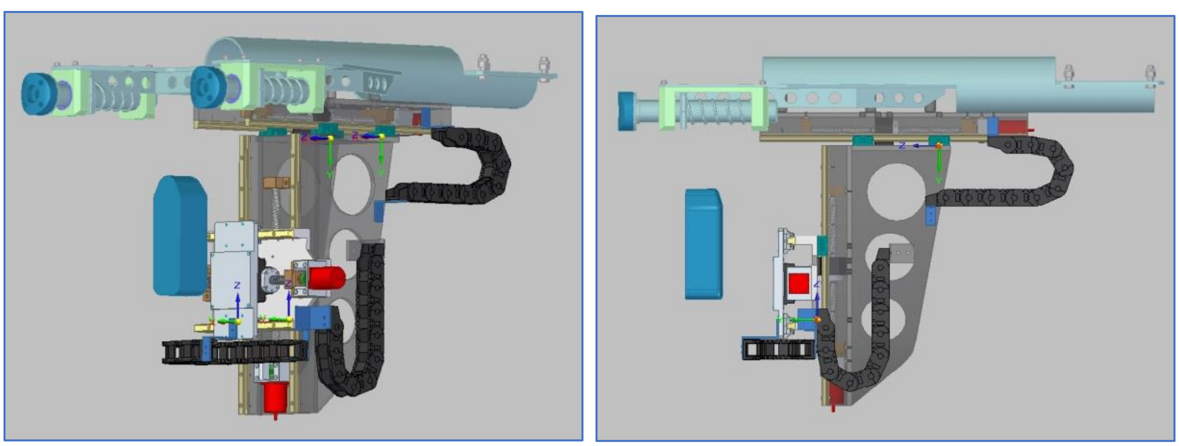

Figure 8. Figure of measuring assembly for the case of the key's measurement

## VERIFICATION TESTS

### *Irradiation tests*

Both developed technologies have been subjected to radiation tests – see [2], [3] and [4].

By comparing the 3D profiles of the replicas before and after irradiation with a dose of 40 kGy, it was found that no differences greater than the permitted ones were found. The success criteria for the radiation replication test were met.

At an exposure of 20 Gy / hour (target exposure according to the R&D project), it has been shown that 3 to 4 pixels of the image will be lost in the area of interest of an individual image. However, the position of pixels with image loss changes over time. Then, using a larger number of images to process a single profile during component scanning can eliminate the problem of bad pixels. Therefore, despite the higher SW complexity of image processing, the gamma effect on the resulting measurement will be eliminated. The camera radiation test success criteria were met.

***Pressure and boric acid resistance tests***

Pressure and boric acid resistance tests will be performed in the CVR infrastructure used for LOCA test. The tests will be performed with a measuring device placed in a LOCA vessel with boric acid 16 g/kg and a pressure simulating a water column of 12 m.

***Tests of the measuring and supporting manipulator connection***

Tests of the connection of the measuring and supporting manipulator will be performed in the experimental laboratory of ŠKODA JS, a.s. Pilsen. The following tests will be performed for both technologies:
- possibility of remote manipulation by the measuring system to the location of the models with an accuracy of ± 2 mm
- simulation of measurements with electrical cables resp. pneumatic hoses at a distance of 60 m.

***Measurement accuracy tests***

For both technologies, the difference between the scan measured by the technology being developed and the scan measured by the device allowing an accuracy of ± 4 μm must be less than ± 48 μm.

## CONCLUSION

The R&D project are developing measuring technologies that achieve high dimensional accuracy under very specific measurement conditions such as underwater and in radiation. For this, it was necessary to develop special manipulators and measuring techniques.
The developed techniques of measurement using replicas and 3D scanning, with an accuracy of 40 μm, will make it possible to evaluate the condition of the reactor pressure vessel keys and the core barrel grooves and to determine the degree of wear due to operation.
The developed technologies will be very promising and can be used with minor modifications on other components of the primary circuit in NPPs as well as in other industrial technologies, where standard measurement methods cannot be used.

## ACKNOWLEDGMENT

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