AUTOMATED VVER STEAM GENERATOR EDDY CURRENT TESTING AND PLUGGING CONTROL SYSTEM

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ABSTRACT

The inspection of the VVER-440 and VVER-1000 steam generators in nuclear power plant involves eddy current testing of the tubes and plugging if that tube damage is over the required level of damage. The structural architecture of the system contains three main components which are described as follows:

- Manipulator Guidance System
- Eddy Current Acquisition System
- Plug Installation System

The manipulator system has the task to position the end-effectors to the desired tube position. When the final position is reached, the Eddy Current acquisition system performs data acquisition. In case defects are found, the plug installation system performs tube plug instalment. Each system is composed of 3 layers. The first layer is the hardware layer consisting of motors driving the effectors along with sensors needed to obtain the positioning data, pusher motors used to push the test probes into tubes of the VVER steam generator, and plugging hardware tool. The second layer is the control box performing basic monitoring and control routines as an interconnection between first and third layer. The highest layer is the control software, running on the PC, which is used as a human-machine-interface. The reliability of these kind processes has to be on very high level so the procedure for the automation has to be well defined. The article is supported with real data and equipment in the field.

Keywords

WWER steam generator, Eddy Current Testing, plugging, control box, human-machine-interface

1 INTRODUCTION

Steam generator is very important part of the each nuclear power plant's primary water cycle as well in the Russian type of the nuclear power plants with a horizontal steam generator (VVER – rus. *vodo-vodnoj energetičeskij reaktor* or WWER – engl. *Water Cooled Water Moderated Power Reactor*). There are two types of the VVER steam generators depending of the type of the nuclear plant, and that are: VVER-440 and VVER-1000 which have specific power of 440MW and 1000MW. The damages on the steam generators are very hard to repair and the consequence of that damage is mixing of the primary cycle water (the water that is in direct contact with the nuclear fuel cells) with the secondary cycle water which cycles through all motive points of the power plant (steam-turbine). The damage of the steam generator can involve consequences that are very complicated to repair and involves large investment in the reparation and closing of the block where the excess happened.

Unwanted excesses can be avoided by inspecting of the steam generator on the regularly basis and that increases the reliability of the nuclear power plant. Reliability of the nuclear power plant is one of the key parameters depending on which define safety of the nuclear plant. The safety of the nuclear plant is very important for the safe work (preventing of the unwanted excesses) of the plant as well for the environment. The unwanted excesses can produce major damage for the plant but can also generate catastrophic damage for the environment in which a plant is build. The project of VVER-440 nuclear power plant does not involve building of the containment around nuclear reactor so damage of the primary circuit can produce major catastrophe for the environment [1].

Inspection of the VVER steam generator is the obligation of every nuclear power plant and it is performing during remount of the plant. The task of the inspection is to establish the wear of the steam generator and to detect and to remove weaknesses that could cause the problems in the normal operation of the plant.

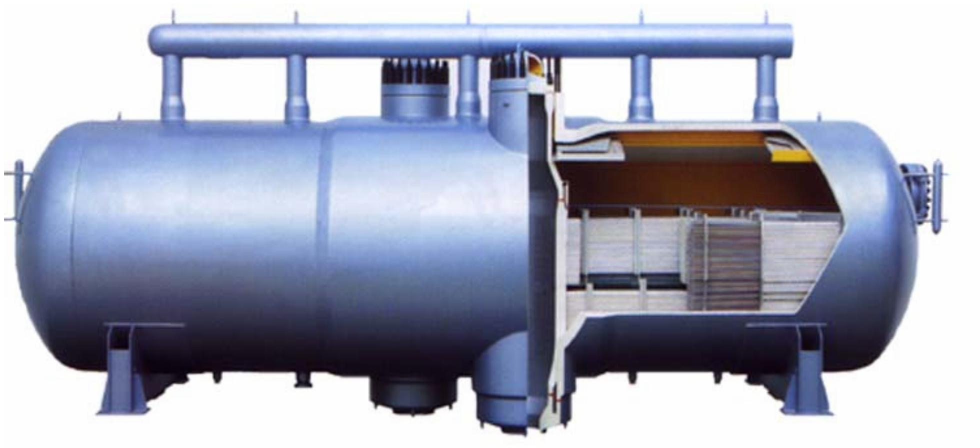

Figure 1. Steam generator in the VVER type nuclear power plant

Steam generator in the VVER nuclear plant is Russian type of horizontal steam generator (in contract with PWR nuclear plant which has vertical steam generator) in two basic types (VVER-440 and VVER-1000). Inlet (hot) leg and outlet (cold) leg of the primary cycle fluid are in the vertical position while between two collectors are collections of the tubes in the horizontal position connecting inlet and outlet collector. These collections of the tubes are week part of the steam generator and they are liable to wearing which can bring to tube cracks and tube cracking. That is the reason why inspection of the steam generator is concentrated on the wear inspection of the tubes which connect inlet and outlet leg. If the inspection of the tubes has found out that some tubes have cracks that are not in the tolerance of the wear these tubes are put through the plugging process. The plugging process on specific tube removes that tube form the normal operation during work of the nuclear power plant. Plugging is the process which decreases the power of the steam generator and by that the power of the nuclear power plant. In case that power of the steam generator is under profitable level the steam generator is replacing with the new one.

The pilot project of distance control system will be presented in this article which is completely designed in the company INETEC – Institute for nuclear technology d.o.o. and used for the inspection of the steam generator in Nuclear power plant Paks (VVER-440 model 213 – 4x460MW) located in the southern Hungary. Equivalent system is possible to use for the inspection of the other nuclear power plant of types VVER-440 and VVER-1000.

2 DESCRIPTION OF THE SYSTEM AND CARRYING OUT OF THE INSPECTION

System for the inspection of the VVER steam generator in the nuclear power plant designed for the complete distance control and it includes: tools for the inspection, equipment for the distance control and software for the control and supervision. The need for the distance control system is justified with the fact that the inspection of the steam generator is performing inside of a nuclear plant's containment which includes an area of increased ionizing radiation (radiation zone) and exposing of the personal to the radiation should be maximally avoided.

Distance control system has a distinction that the tools in the radiation zone are controlled from the far distance where the ionization radiation is on the normal level. Design and planning of the distance controlled system is more complex especially for the reason that work in the nuclear plant required increased reliability of the control over that system.

System for the control and supervision of the inspection of the VVER steam generator is composed from two subsystems which are composed form some subsystem inside them as shown on figure 2.

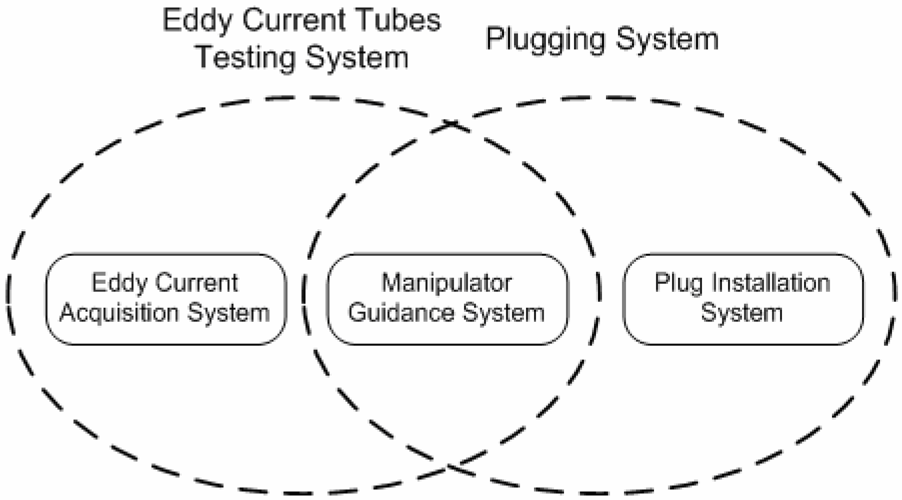

Figure 2. System for the inspection of the VVER steam generator

Eddy Current testing system and Plugging system are not performing their actions in the same time so they are time independent systems. Concerning that we can divide the process of the inspection into two time phases:

- testing of the tube wear using Eddy Current tubes testing system
- plugging of the specific tubes which do not satisfy certain criteria using Plugging system

A distance controlled system requires a local unit (one or more of them) which task is to receive commands from the distanced unit, reinterpret it and perform specific action on the tool, as well software on the distance unit that will communicate with local unit(s).

Three local units were used in the previous designs (one for the acquisition system, one for manipulator guidance system and one for plug installation system). The experience with that kind designed system has shown that the system has large number of interconnections between the tool and local units, as well between local units themselves, which are unstable and usually produce stoppage in the process. Those stoppages are big problem because inspection is time critical and should be completed in defined period. Two local units do not have any sense because the manipulator guidance system is used for both phases of the testing and sometimes one contractor is working on only one phase (tube testing or tube plugging). In two local units design both local units are needed for each phase and that is not practical. This kind of thinking leads us to the design with only one local unit what is practically realized in this pilot project. That local unit is called EC-PLG control unit and its functionality will be described in next chapter.

Plug installation system has one additional local unit – Platform box which location is on the platform next to the collector opening of a steam generator and it is cable connected to an EC-PLG control unit. Basic task of this unit is to enable manual setting of the air pressure and transferring some measurement parameters to an EC-PLG control unit. This unit is only an EC-PLG external module because EC-PLG controls and supplies Platform box. The reason for this kind of design is the fact that platform is usually dirty and the units on the platform are usually lot more contaminated than the units in upper level from the platform. In this way EC-PLG control unit can be located on the upper level where the contamination is lower.

The next component that is very important for the distance controlled system is the software which is executing on the distance units (PC computers with the Windows platform) outside from the containment area. The major importance of this software is to increase safety of the process because enables semiautomatic and automatic working mode what drastically decreases human errors during operating on this system. The software enable us to document every state of the system in the time and by doing that it eases the fault detections or disables unwanted states. The software packet is composed of three main parts (product of the INETEC) which are required for each system segment: *EddyCurrent Acquisition* (controlling the acquisition system), *Steve Manipulator* (controlling manipulator guidance system) and *Plugging Control System* (controlling plug installation system).

The inspection of the VVER steam generator can be separated into two time phases (testing of the tube wear and plugging of the specific tubes) as previously mentioned. The task of the first part is to check if the collection of tubes between inlet (hot) and outlet (cold) collector are damaged (have the cracks inside the tube). The NDT (non-destructive technology) testing method which is used for detection of the cracks inside the tube is Eddy Current method. The sensitivity of the Eddy Current method satisfies the ability to detect very small cracks inside the tube. Manipulator guidance system is being used for the positioning of the guide tube of the pushing tool (DPS – double pusher system) in front of required tube. DPS is used for pull/push to EC probes into the tube which are sensing the tube cracks during tube pull operation. EC probes are connected to the Eddy Current Tester MIZ-70 (property of Zetec, Inc.) which is stimulating probe coils so the probe coils can generate info about the surface inside the tube. We will discuss only motive parts of the system and not the Eddy Current method and different types of probes in this article.

If the analysis of the acquired data shows that specific tubes have cracks on some part of the tube over the limited tolerance the process of plugging should be performed. Manipulator guidance system is used for the positioning on the required tube that is mark for plugging (in the same matter as when performing testing process). Controlling the plugging tool we need to perform plug instalment. Identical process is required on the opposite end (the same process from the opposite collector).

Figure 3 shows us the schema of interconnection between system parts during inspection in Nuclear power plant Paks. Schema does not notify that workstation is outside the containment (radiation zone) and it is connected to the EC-PLG control unit using fibber-optic cable (the distance is around 250m)

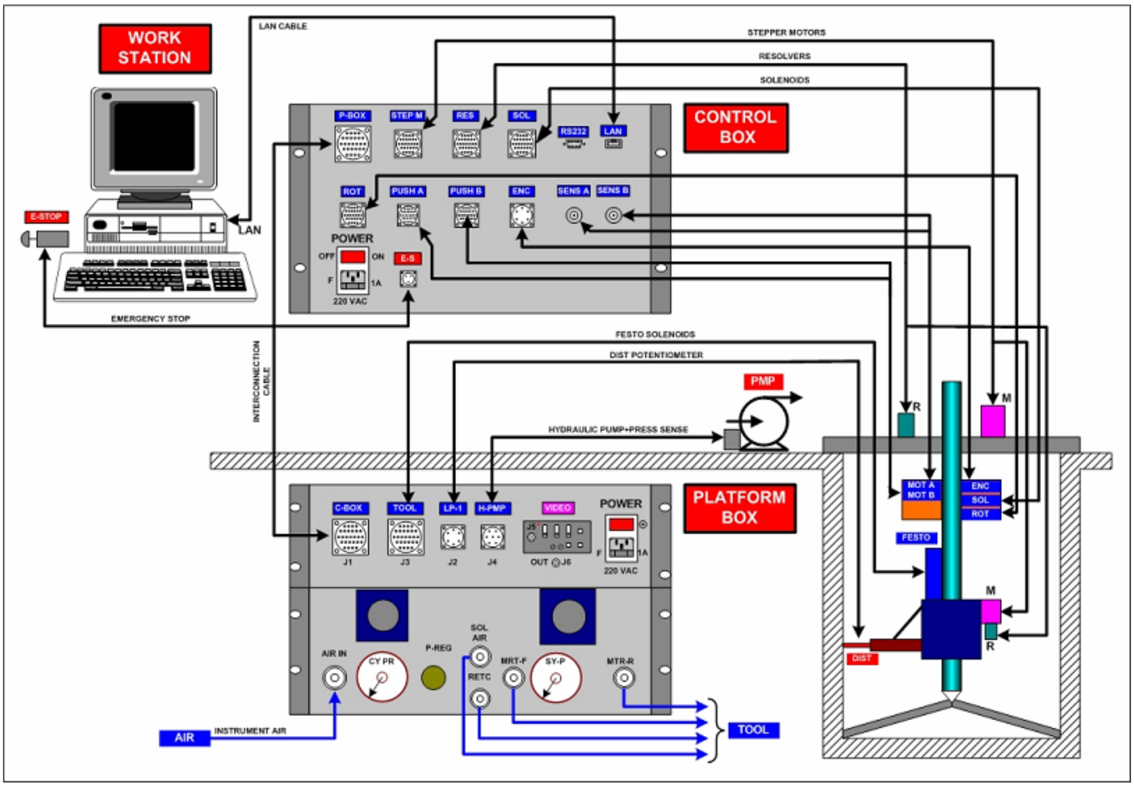

Figure 3. Interconnection schema of the inspection system in a Paks Nuclear power plant

3 EC-PLG CONTROL UNIT

EC-PLG controller unit was developed as a local unit which was to be placed close to the operating tools (5-10 meters), and by connecting it to local area network to be able to monitor and control the tool operations from a distant control room, central processing unit also connected to the local area network. The base of this unit is an embedded microprocessor control module with basic characteristics such as:

- remote control from distant central processing unit
- programming capabilities, that is ability to write independent control routines which can be executed remotely
- interface to step and DC PWM power amplifier with position and velocity feedback
- additional digital inputs/outputs for general purposes

Control modul of EC-PLG controller unit is responsible for execution of controls given by distant remote control unit, tool's state verification and continuous check of remote connection. Modul is programmed in such way that any alarm state (for example remote connection failure) cause a certain response, such as halting all current tool activities.

As stated earlier, EC-PLG control unit is responsible for operation and control of all tools that are a part of inspection system for VVER steam generator, so it is placed in the same mounting unit as a power section (power supply and power amplifiers). In the next articles, all the relevant subsystems will be descried aswell as the operations they perform combined with the apropriate tools.

3.1 Controlling the Manipulator Guidance System

For positioning to the coordinates of specific steam generator tube within steam generator collector, the two axis manipulator is used. Manipulator has polar system configuration with one axis name Rotation, and the other Elevation. The control system powers two step drives, each of nominal 12W power, while position verification is based on two resolvers, one for each axis. They are connected to step motor shafts through gearboxes.

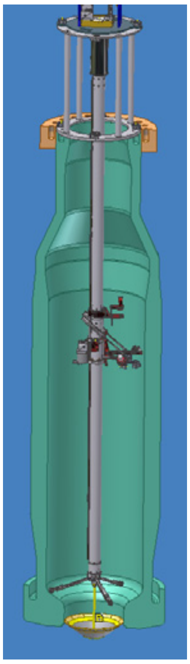

Figure 4. VVER Manipulator

Step motors normally operate in open-loop, because their construction is such that number of step pulses brought to the motor windings is linearly proportional to the shaft turn angle φ. In this case, resolver's duty is to verify the motor's shaft angle to make the positioning more reliable. There are various things that can cause positioning errors due to motor shaft slip, such as weight overload, collision with some obstacle, or similar. As a position feedback component the resolvers are used. Resolver as a feedback component has many advantages: robustness, small dimensions, they are absolute positioning elements. They are powered by a sine wave of a certain amplitude and frequency specified by manufacturer. Due to precise and steady measures, the sine wave signal purity is of most importance. Distorted signal cause noisy position measures. Output signals from resolvers are two sine waves with 90^o phase lag between them (usually denoted as *sin* and *cos*), from which is possible to tell the angle of resolver shaft φ .

Manipulator guidance with EC-PLG controller is very simple due to fact that the control modul itself has step and DC motor power amplifiers interface. But control module doesn't support resolver-type feedback, but only encoder feedback in form of quadrature or pulse-direction. That's why an additional subsystem was developed. The developed resolver-to-encoder converter subsystem is presented on the figure below. This subsystem enables the manipulator to use resolver and get feedback signals in form like encoders are used.

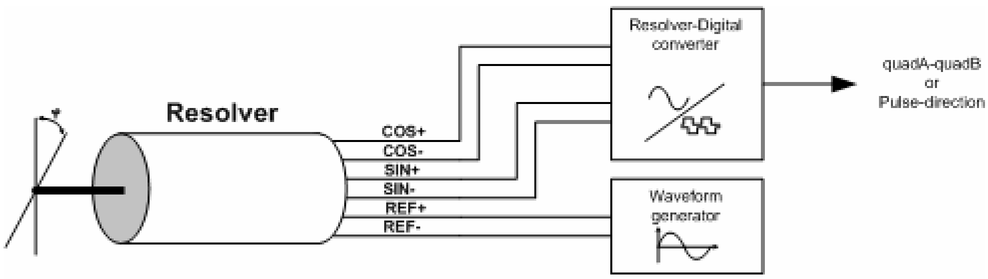

Figure 5. Resolver-to-digital converter

The resolver-to-digital converter subsystem consists of two basic items: sine waveform generator and a 16bit signal converter. The subsystem is designed as a PCB, and therefore main components are integrated circuits. Waveform generator is manufactured by EXAR, while signal converter comes from Analog Devices. Output signals from resolver-to-digital subsystem come in form of quadrature or pulse-direction encoder. Quadrature encoder signals can be decoded by using a scheme presented on the figure below. Pulse-direction type of signal can be achieved by using only channel A and direction output from the converter IC.

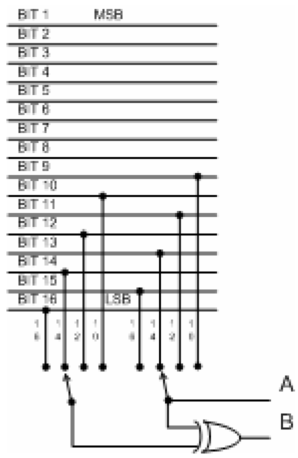

Figure 6. Selecting the resolution

It is possible to adjust these parameters: reference signal amplitude adjustment, total harmonic distortion, and converter resolution. During NPP Paks steam generator inspection, 14bit resolution was used.

3.2 Controlling the Eddy Current Acquisition System

In Eddy-Current acquisition systems the double probe pusher tool is used. Double probe pusher (DPS) is used because it enables two probes to work simultaneously, which shortens the total inspection time. The tool consists of two DC brushed motors, two incremental encoders and seven pneumatic solenoid driven valves. Encoders are used to measure how far the probe penetrated. Solenoid valves control these tool functions:

- up/down of the upper guide tube
- up/down of the upper front wheels
- up/down of the upper back wheels
- up/down of the lower guide tube
- up/down of the lower front wheels
- up/down of the lower back wheels

- service/work position mode

Rising (up) the guide tube is necessary because the entry part of the collector has smaller diameter that the other part of the collector (figure 4) and a tool with guide tube in working position (down) is not able to pass through that part. The Eddy Current probe is passing trough the centre of the manipulator and it is tighten between two wheel pairs (front and back) on the DPS which are pushing/pulling the probe.

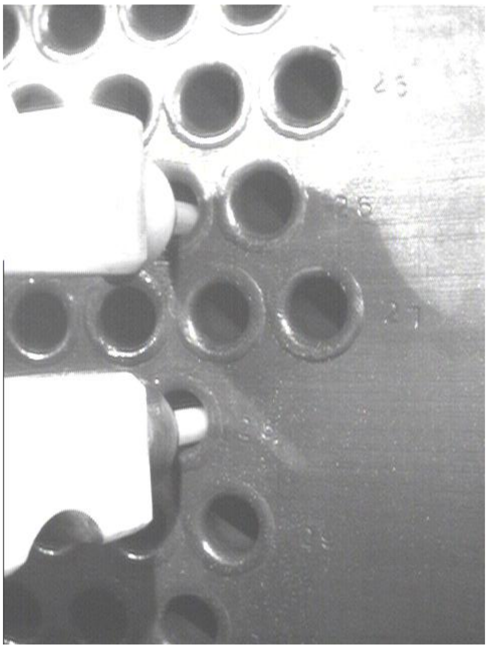

Figure 7. Natural DPS environment

DC servo motors work in velocity servo closed-loop, with tachometers as velocity measuring component. They are powered by PWM (Pulse Width Modulation) power amplifiers placed in EC-PLG controller mounting unit. The basic connection scheme is presented in the figure below. Few parameters should be adjusted prior to inspection, such as tach gain and loop gain, so that adequate *control voltage/motor speed* ratio is achieved. These parameters are adjusted on trim pots situated on the amplifiers.

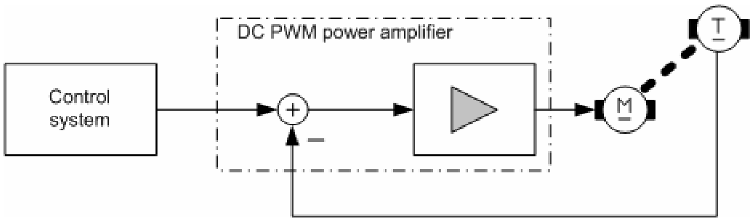

Figure 8. Pusher motors servo loop

When the probes are pulled out from the steam generator tubes, they could be damaged if they are not stopped before they reach pusher guiding wheels. That's why the sense coil subsystem was developed, which reacts when the probes passes through the coil by shutting down the amplifiers and therefor stopping the motors.

The set of seven pneumatic solenoid driven valves are controller through relay outputs. They are placed on relay control module, and they provide opto isolation and signal amplifying of standard TTL outputs provided by control system. It's necessary to have opto isolation because various things such as overload, short circuit or similar could cause damage to the control system. On the tool there's also a CCD camera that alows the operator to monitor the manipulator behavior, verify manipulator position, and check for any possible obstacles.

3.3 Controlling the Plug Installation System

The lower lever of the plug installation system consists of two subsystems: plug installation tool (figure 9) which is attached on the two axis manipulator mentioned earlier, and Platform control box which is placed on the platform floor just above the steam generator collector and is connected to the EC-PLG controller unit. Platform control box contains pressure regulators, pressure gauges, linear potentiometers gauges and adequate connectors for the tool interface.

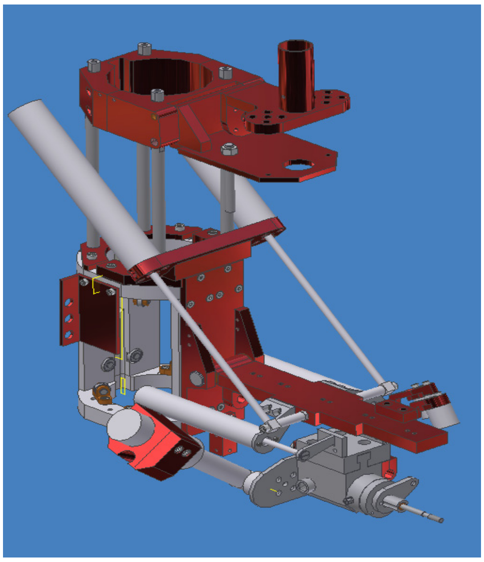

Figure 9. Plugging tool

Plug installation tool consists of 5 24V pneumatic solenoid driven valves and 2 relays. There are 4 5/3 valves (on, off, undefined state) and 2 3/2 valves (on, off), and the relays are all DPCO configuration (Double Pole Changeover). They are all controlled from EC-PLG controller unit through relay control module.

Controlled parts of the plugging tool are:

- Tool up/down (similar to the DPS) – 5/3 valves
- Column up/down – 5/3 valves
- Lock Pin in/out – 5/3 valves
- Plug grip/release – 5/3 valves
- Head forward/retract – 3/2 valves
- Roller motor forward/reverse - relay
- Hydraulic pump on/off – solid state relay

4 AUTOMATION OF THE VVER STEAM GENERATOR INSPECTION

Automation of the VVER steam generator inspection, as well as entire system, can be separated into two major parts:

- Eddy Current tube testing system automation
- Plugging system automation

These two parts are time independent so we can analyze them separately. The task of the Eddy Current tube testing system is to perform the acquisition of all required tubes safely and reliable as fast as possible. The reliability of the acquired data is very important because errors are impermissible (some errors can be tolerated but they should be lowered to the minimum). A first component of this system is Manipulator guidance system which task is to position guide tube, through which Eddy Current probe is passing, exactly in front of a required tube. Steve Manipulator is the software which task is to control the manipulator and take care that guide tube is directly in front of the required tube. Steve Manipulator signals the EddyOne Acquisition software when it reaches the required position and EddyOne Acquisition can start the process of acquiring the data from the tube. EddyOne Acquisition controls pusher motors (DPS) to push the probe in to a tube to the defined depth. When defined depth has been reached, motors are automatically starting to run reverse (pulling of the probe) and activates data acquisition using Eddy Current tester. When the probe passes through sensing coil DPS motors are signalled to stop and Steve Manipulator is signalled that it can move to the next tube.

Plugging system also uses Manipulator guidance system for the positioning of the plugging tool in front of the required tube. When the manipulator is on the required position (using Steve Manipulator), the Plugging Control System software is signalized that the plugging process can begin. Plugging of the specific tube is complex process and requires huge reliability in tool operations (wrong plug installation is a huge problem) so semiautomatic mode is implemented is this process (a operator is operating the plugging process while some unwanted states are controlled automatically).

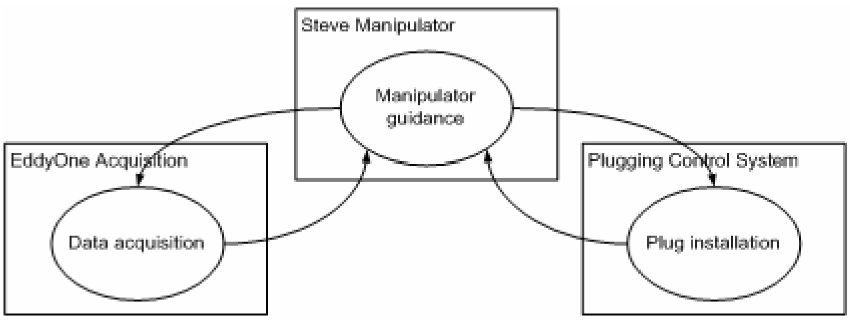

Figure 10. Interaction between software components during automatic process

The process of the automation of each component, as well as problems in implementation, of the system will be presented in the next few chapters. The goals of the system automation are:

- to speed up the testing process
- to increase reliability by avoiding the operators mistakes
- to increase level of process logging and documenting

4.1 Manipulator Guidance System

VVER steam generator collector is in cylindrical shape and the collection of the tubes are welded between inlet (hot) leg and outlet (cold) leg and symmetrically separated in cylindrical coordinate system. The planar model of the collector (*Tube sheet model*) is used for the enumeration of each tube with coordinates row and column (figure 11).

Inlet and outlet collector (leg) have identical tube sheet model, but with the difference in numerations – the column coordinates are mirrored column coordinates in opposite leg what is obvious from the figure 11 (a top tubes plan). TEH is inlet (hot) leg, while TEC states for the outlet (cold) leg. On the same plan we can see that length and shape of the tube depends on the column coordinate.

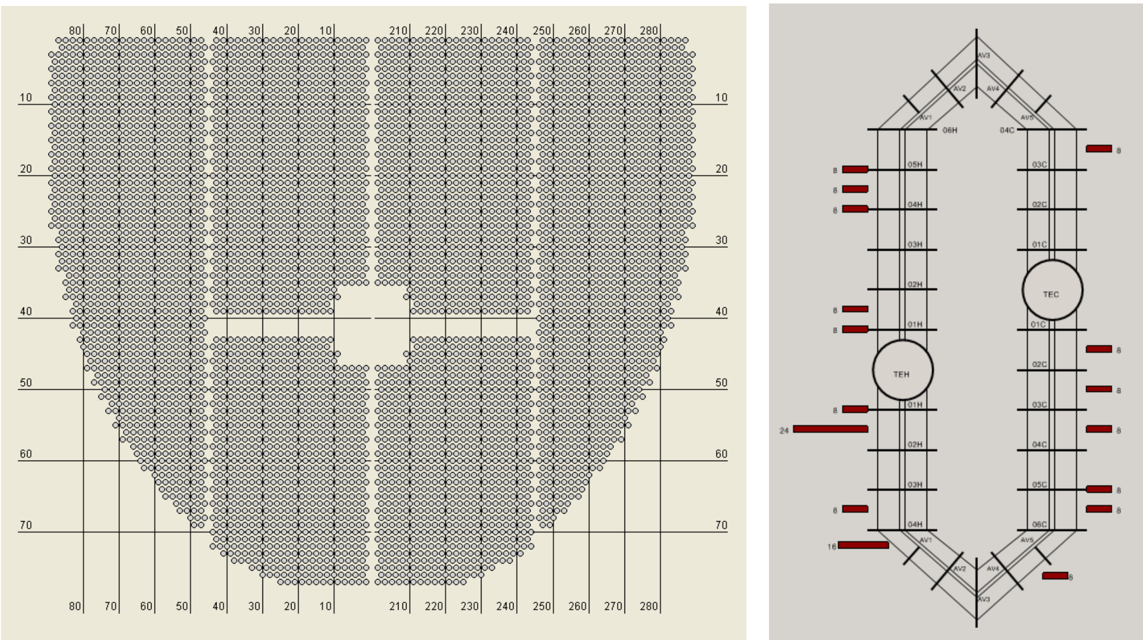

Figure 11. Tube sheet model and top tubes plan

The main task of this system is to position a guide tube exactly in front of the tube (tube diameter is around 13mm for VVER-440, while the distance between tubes is around 10mm). This system is used to position DPS on the required tube as well as plugging tool. The manipulator is graded mainly on its precision and, less importantly, on its speed because of the small distance between the tubes and small tube diameter.

Steve Manipulator is used for distance control of this system and can operate in two operating modes:

1. Free-Run Mode
2. Automatic Mode

In Free-Run mode an operator can freely control a manipulator to guide it to specific tube. This mode of operating is mainly used during manipulator calibration process and during tool or probe replacement when the tool should be in top position (outside the collector). During the calibration process operator is locating three different tubes (e.g. grey tubes on figure 12) and based on the position feedback on that coordinates the interval between tubes can be calculated.

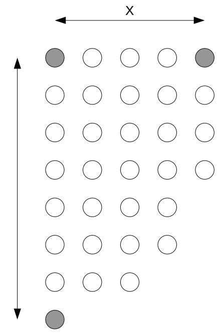

Figure 12. Calibration example

The process of calibration is used to create planar tube sheet model in the software and use that model for the positioning of manipulator. The coordinates can be transferred from planar tube sheet model (column and row) into manipulators cylindrical coordinates (rotation and elevation), and vice verse, according to the following equations [3]:

$$\vec{t} = A\vec{m}, \quad \vec{m} = \begin{bmatrix} \varphi_m \\ y_m \\ 1 \end{bmatrix}, \quad \vec{t} = \begin{bmatrix} col_t \\ row_t \\ 1 \end{bmatrix}, \tag{1}$$

where $\vec{m}$ is the input consisting of manipulator sensor readouts (rotation and elevation), while $\vec{t}$ is the vector consisting of coordinates in tube sheet model (column and row). The calculation of the transformation matrix A according to three points is calculated as follows:

$$\begin{aligned} & A = \vec{t} \times \vec{m}^{-1} \\ & \Rightarrow \\ & A = \begin{bmatrix} col_{t1} & col_{t2} & col_{t3} \\ row_{t1} & row_{t2} & row_{t3} \\ 1 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} \varphi_{m1} & \varphi_{m2} & \varphi_{m3} \\ y_{m1} & y_{m2} & y_{m3} \\ 1 & 1 & 1 \end{bmatrix}^{-1} \end{aligned} \tag{2}$$

where col_{ti}, row_{ti} are coordinates in tube sheet model, and φ_{mi}, y_{mi} are coordinates in cylindrical system according to the manipulator feedback.

The basic assumption made with this mapping is that the manipulator vertical axis, that is also the center of rotation for the horizontal motion axis, runs through the axis of the cylinder of tube sheet. This is reasonable because the manipulator hardware can be mounted very precisely on the steam generator. Since the planar tube sheet model is only a representative model of the actual tube arrangements where scales and angles are not always proportional, separate calibrations have to be made for each section on the tube sheet or correct errors on some area using *spot calibration* which recalculates transformation matrix A according to the current position of the manipulator.

The automatic manipulator guidance system involves Test Plan (or Plugging Plan) list which defines tubes that are requested for testing (or plugging). That plan defines in which order we want to do the testing (plugging). When Steve Manipulator gets the signal that current tube has been tested (plugged) it automatically guides the manipulator to the next tube in the plan.

4.2 Eddy Current Acquisition System

Eddy Current Acquisition System has a primary function to push two probes in tubes on specific depth and to record the state of the tube by pulling the probes from the tube monotonously. The system involves following parts:

- DPS (double pusher system)
- Eddy Current probe
- Eddy Current tester
- EC-PLG control unit modules
- EddyOne Acquisition software

Tubes that should be tested are different length and shape depending of the column coordinates in the tube sheet mode according to the figure 11.

The task of the EddyOne Acquisition software is distance control of the acquisition process – pushing/pulling the probes and recording of the tube state. Software supports double pusher system (DPS) which enables to synchronously acquire two tubes (in the same column, distanced for two rows) and to decrease testing time. The acquisition is possible to do in manual mode (an operator is responsible for the starting/stopping of the pusher motors and acquisition process) or in automatic mode where software controls the process of acquiring data and pusher motors automatically which will be described in the following text.

Eddy Current probe is very delicate and can be easily damage (destroy). On the other side the testing should be performed as quick as possible and the biggest problem are tube curves through which delicate probe should pass in much lower speed than through straight part of the tube. To perform this operation software should have the information about probe position in the tube. That information is provided to the software through encoder feedback so software can reduce speed in front of the curve.

Each tube has a number of supports which is used to detect specific places (specific depth) in a tube. Distance between supports is well defines and provided to the software in Landmark table. All tube curves have a specific support and by knowing the depth from the Landmark table and from encoder feedback we can enable easy tube pushing to specific support (specific depth) and lower the speed before entering tube curve (also support).

A friction between probe and tube is increasing with the probe depth in a tube, and the number and the shape of passed tube curves. The AV3 support (curve) is the sharpest and too deep so the friction is too high so the acquisition is performing for half tube from each collector side (half from inlet and half from outlet leg). The depth criteria is AV3 so pushing of the probes is activated until probes do not pass AV3 support and then EddyOne Acquisition automatically starts acquisition process.

The acquisition process involves starting of the recording of the tube using Eddy Current tester instrument and starting the DPS motors in reverse (pull) direction and defined speed. The motor speed is unique (defined in the testing procedure) because during the probe pulling there is no problem with tube curves. When the probe exits the tube and enters guide tube sensing coil will automatically stop the motors and the recording is finished. EddyOne Acquisition sends a signal to the Steve Manipulator that recording is finished and it can move to the next tube in test plan. The automatic acquisition process is presented on figure 13.

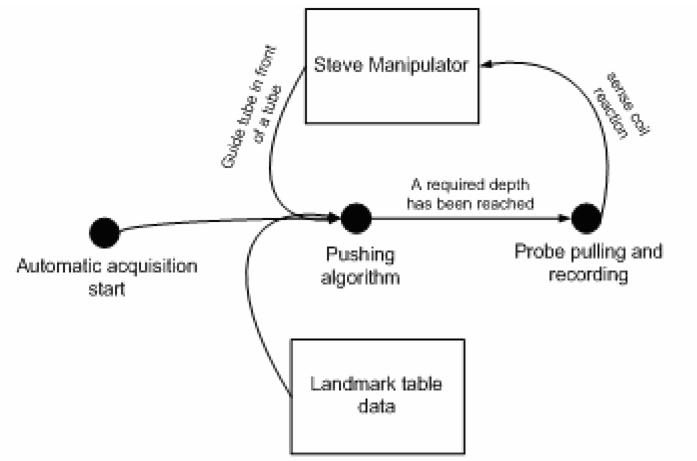

Figure 13. The automatic acquisition process

4.3 Plug installation system

Plug installation system is responsible for reliable plug installation as specified in procedure [4]. According to mechanical plug installation procedure [4] consists of two basic operations:

1. Tube end rolling
2. Plug installation

Tube end rolling is performed with roller tool placed on the plugging manipulator. It is a pneumatic drive which is CW/CCW controllable, and has rotating speed proportional to input pressure. The purpose of rolling is to make the inner tube surface smoother so that mechanical plug can fit the tube and by that seal the tube.

After the rolling has completed on all required tubes, the more demanding part comes – plug installation. Roller tool is replaced by plugging tool. Mechanical plug is a qualified unit which has a characteristic to expand while it's being placed into the tube and exposed to high pressures (around 6000 psi) and by that it merges with the tube. During plug installation hydraulic pump pressure (during plug expansion) and plug expander distance are monitored. Based on these two measurements the operator can conclude whether plug installation has been performed successfully. Measurements of these two parameters are performed locally on the EC-PLG unit (which is connected directly with the tool) and the plug expansion is stopped automatically when measured values are within required limits.

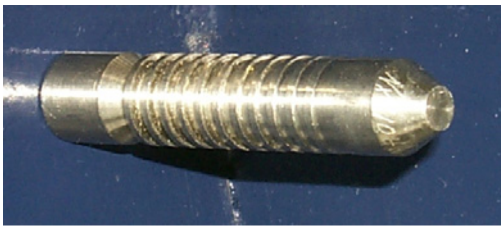

Figure 14. Plug

The tool can carry up to 10 mechanical plugs in a loading tube. This ensures that the manipulator should not drive to the collector entrance every time after the plug has been installed. The control unit must simply assure taking the next plug in the loading tube and continuing the plug installation task.

Control and monitoring of the entire process is performed remotely through Plugging Control System software. Because of the potential hazardous events (such as plug dropping to the bottom of the steam generator) tool operations are performed by operator while the software monitors various parameters and assures that the whole procedure is performed according to the procedure [4]. Software monitors the number of installed plugs, a component wear calibration time and parameters and assures that all tool operations, positions and actions are according to the procedure [4]. By that, all the activities are recorded and force the operator to perform all the activities as specified in the procedure [4] and assure that installed plug is reliable.

The diagram 15 shows the plug installation process.

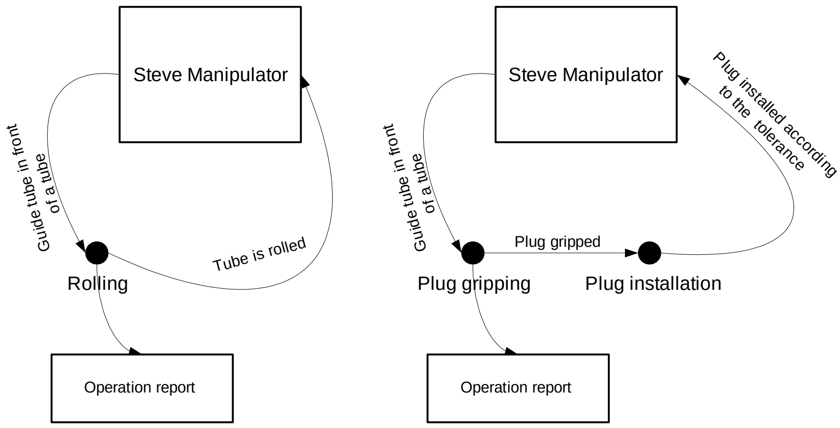

Figure 15. Plugging process

5 CONCLUSION

Automation of the VVER steam generator is possible to accomplish only if the system is very well defined and very well know. The system is very specific and should be very reliable and that is the main reason why previous experience with this system in manual mode is necessary. This system has one big specific tag: tools for the inspection are operating in the high radiation zone of the nuclear power plant. That kind of environment is difficult for testing and to correct possible errors. Despite all potential problems, this system can be run in automatic mode as we presented in this article.

Inspection in the Paks Nuclear power plant has been accomplished successfully using the introduced system and were not reported some major defect. The task of that inspection was to test designed control system in automatic mode and to increase the level of operator's control over the system to a higher level.

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