Tube Sheet Runner
Sergio Galošić, Matija Vavrouš, Marko Budimir
INETEC Institute for Nuclear Technology
Dolenica 28, 10250 Zagreb, Croatia
sergio.galosic@inetec.hr, matija.vavrous@inetec.hr, marko.budimir@inetec.hr

ABSTRACT

Tube Sheet Runner (TSR) is a polyvalent device designed to perform different tasks in steam generators with the aim of positioning, movement and working with a variety of tools, primarily with eddy current probes for NDT (non-destructive testing). Movement is achieved by translating the main axis and sticking fingers (grippers) in the tubes of the steam generator tube sheet. The device speciality is moving like a spider in all working positions: horizontal, ceiling, vertical and rounded, and easy adaptation to different parameters of heat exchangers. The main advantage is the high speed inspection because TSR principal axes remain idle while the auxiliary axes can inspect up to 72 tubes before the next TSR movement.

Functional parameters:
- Each module is detected and reported to the system with a "plug and play" feature
- Extremely high inspection speed in relation to the existing systems
- Machine Vision integrated to the system to assure an independent position verification
- Safety lock grippers with sensor detection
- Automatic levelling through the three axis inclinometer/accelerometer
- Suitable for individual inspection strategy, as well as the complete inspection strategy of a heat exchanger

Principal axes guidance has been specifically designed (in comparison to others) in order to allow angular and linear oscillations and to assure the correct levelling of the entire device.

Grippers are equipped with many safety features that prevent the falling of the TSR in the event of power or air pressure failure.

The integration of a second auxiliary axis combination on the upper linear axis is assured to obtain the possibility of simultaneous work with two modules.

1 INTRODUCTION

The purpose of the steam generators tube inspection is a determination of the tube material condition and corrective measures eventually required (tube plugging etc.). Since the steam generator (SG) tube’s wall is a heat transfer surface and practically only boundary between primary and secondary circuit of the reactor coolant, continuous monitoring of SG tube’s wall condition and preservation of its integrity, greatly affects to the safe operation of the SG and consequently the safety of the power plant.

In order to improve inspection quality as well as maintaining SG integrity, INTEC has developed a new system for SG inspection, whose role is not only increasing inspection quality, but also to facilitate the process of inspection conducting.
This article presents system for inspection of the SG tubes with focuses on the inspection manipulator, system control and machine vision.

2 MANIPULATOR

Tube Sheet Runner (TSR) is a polyvalent device designed to perform different tasks in steam generators with the aim of positioning, movement and working with a variety of tools, primarily with probes for NDT testing. Movement is achieved by translating the main axis and sticking fingers (grippers) in the tubes of the steam generator tube sheet. The device specificity is moving like a spider in all working positions: horizontal, ceiling, vertical and rounded, and easy adaptation to different parameters of heat exchangers. The main advantage is the high speed inspection because TSR principal axes remain idle while the auxiliary axes can inspect up to 72 tubes before the next TSR movement.

![Figure 1: Tube Sheet Runner](image)

Functional parameters:
- The entire device is modular with "snap on" connectors (single gripper, the main axis, the control box, pneumatics) and each module is detected and reported to the system with "plug and play" feature
- Extremely high inspection speed in relation to the existing systems
- Machine Vision integrated to the system to assure independent position verification
- Safety lock grippers with sensor detection (pre-calibrated to the posture working force of 1700N)
- Automatic leveling through the three axis inclinometer/accelerometer
- Suitable for individual inspection strategy, as well as the complete inspection strategy of a heat exchanger

Principal axes guidance has been specifically designed (in comparison to others) in order to allow angular and linear oscillations, without jeopardizing system integrity and to assure the correct leveling of the entire device.

2.1 Grippers

Grippers function with obligatory safety locking that is pre-calibrated to the working holding force of 1700N for each gripper.
In the case of a need for more holding force, the pressure in the chamber for locking can be raised up during the working progress, without any changes in the system, to 8 bar and thus obtain maximum holding force of over 2000 N. If at any time, while the grippers are locked, loss of the air pressure in the system occurs, grippers always remains locked in their security key to the 1700N.

All faults that may be happen are detected by the sensors and gripper can be unlocked independently from the system by one pneumatic method (remotely) and two mechanical methods (remotely and directly) and removed from the device for replacement.

Prototype testing derived from the 45,000 cycles of the locking without forced stopping. Free estimated duration is about 200,000 locking before the first signs of wearing.

2.2 Stiffness and system levelling

TSR with its system for stiffness, tolerates twisting and bending of the main axis, and uses them as an advantage in moving and positioning on the tube sheet.

Guiding over the main axis is specifically done to allow small angular and linear oscillations without compromising the integrity of the system. This facilitates the installation of the device with an installation tool.

Each main axis movement leads to gripper locking in the new tube hole. Before the locking of the free grippers of the moved axis locked couple grippers on the fixed axis do the function of tamping the entire device. This assures the contact of the both grippers to the tube sheet in the phase of locking.

2.3 Additional tools

Auxiliary axis (or two auxiliary axes) is used to work with tools and Machine Vision and gives absolute freedom to work while the TSR with the main axes is closely attached to the tube sheet. Certain activities require independent verification by the Machine Vision system, which is present along with basic video surveillance.

Interchangeable tools are attached to the rotational segment of the auxiliary axis. Each tool has been detected and reported in the system with "plug and play” setup. TSR provides the ability to change tools while standing attached to the tube sheet.

3 MACHINE VISION

During steam generator (SG) inspection it is of crucial importance to know exact position where manipulator is located to correctly correlate acquired inspection data to a specific tube. Secondly, during plugging operation, it is vital that the tube is again correctly identified. SG tube sheet consists of a large number of tubes that operator should navigate inspection manipulator to, identify the tube and perform data acquisition with an eddy current probe. A camera usually mounted near the guide tubes used to align guide tube and tube hole center prior to probe deployment has a small field of view (FOV) to aid in finding manipulator location. Furthermore, tube sheet lacks visual cues to aid such process. Thus, there usually exists a positioning system (often called primary) that takes input from encoders mounted on the manipulator axes and after proper calibration software can calculate current manipulator position by applying movement deltas, thus correctly identifying the tube.

As manipulator ages and its parts are getting worn out, it can happen that such positioning system starts to introduce errors. Thus a secondary positioning system, totally independent from primary, is needed to catch those errors and it should get its motion movements from some other source to aid in reliability, redundancy and independence of the
two. Lastly, those two systems should be seamlessly cross-checked without introducing additional operator burden or heavy training requirement due to potential system complexity.

With those real field requirements, needs and INETEC ever enhancing quality-driven culture, INETEC developed a secondary positioning system where source of movement detection are high-speed machine vision cameras. Inetec SGMV system is a direct plug-in to the TSR, operates independently in the background in a transparent fashion and position mismatches are visually and unambiguously communicated to the operator, requiring his/her negligible additional training.

![Machine Vision](image)

**Figure 2: Machine Vision**

## 4 TSR CONTROL SYSTEM

TSR control system is a closed module with a multipin connector ("Snap On") and as such, provides easy system assembling as well as compatibility with improved versions in the future. It is absolutely "cable free” and connected to the main driving axis Junction box.

The system is controlled through the advanced spatial algorithms (matrix field motion) and controlled via sensors which provides the monitoring of the load of each axis ("safety monitoring"- every action has a feedback sensory information).

Black Box concept has been applied for the registering of all sensors’ information:

- For any "error" message, it is necessary to pass through this "Event Viewer" to perceive the problem
- TSR online monitoring (over the “Event Viewer” monitoring of the system operation and troubleshooting are performed)
- Black Box is untouchable and provides accurate information of all sensor’s records

---

4.1 TSR Manipulator control software

TSR Manipulator Control Software provides a rich graphic and intuitive user interface to monitor and control the TSR manipulator during the inspection process. TSR Manipulator Control Software enables the operator to:

- Monitor manipulator state – the manipulator operation and state are displayed using both easily comprehensible symbols and textual representation; the operator can easily see the state of motion axes, motors and pneumatic grippers
- Real time location – the central part of the software is a steam generator tube sheet, which represents the actual state and configuration of the physical tube sheet of the steam generator manipulator is currently inspecting. The manipulator gripper locations and manipulator axes configuration geometry is overlaid over the same tube sheet. The manipulator location and its geometry are always updated during in real time
- Exclusion zones – the operator can assign an exclusion zone containing one or more tubes, which are also shown on the tube sheet graphics. If a tube is inside the exclusion zone the gripper cannot enter it. Exclusion zones are valid both in manual and automatic drive mode
- Manual operation – the operator can manually drive the manipulator from tube to tube. The operator can manually start an inspection of a tube where a guidetube for inspection probes is located
- Automatic inspection – inspection is performed in a fully automatic mode, where the operator assigns a region of tubes to be inspected and software finds an optimum path for inspecting them with the goal of reducing inspection time. The tube region to be inspected can be imported from the EddyOne data management software or it can be manually assigned inside the manipulator control software
- Logging – all major actions and events are logged and time stamped.

Figure 3: TSR Manipulator control software
5 CONCLUSION

TSR is a new generation inspection system, fully modular, multifunctional and compatible with all versions in the future, as well as software and hardware. Conceptually it includes:

- Recognizes all modules that are connected ("plug and play" setup)
- Cable free with multipin connectors ("Snap On")
- Enables module interchangeability and adaptability to all kinds of heat exchangers
- The exceptional power and gripper reliability with feedback of the sensor’s information
- Ability to upgrade with additional modules
- "Suitcase type machine" (a simple device transfer in the single suitcase)

TSR is currently in final-testing phase, through which INETEC want to prove that the TSR meets and performs all the tasks and demands being placed in front of it.

REFERENCES