MONITORING OF WATER LEVEL INSIDE REACTOR PRESSURE VESSEL

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1 Introduction

Up to the TMI accident the water level inside the pressurizer was used to monitor the water inventory inside the primary cooling system of pressurized water reactors. The TMI accident showed that this was not a reliable measure for the reactor coolant inventory inside the reactor pressure vessel. For this reason a measurement of the water level inside the reactor pressure vessel (RPV) being independent and diversionary to the measurement of the water level inside the pressurizer was demanded.

For VVER reactors a new level measurement system was developed to monitor the water level inside the reactor pressure vessel by means of the KNITU respectively KITU level assemblies which meet all the mentioned engineered safeguards and geometric and constructive requirements. This system is qualified according to the international classification (IEC 323, RG 1.97, KTA 3502) as part of the Post Accident Monitoring System (PAMS).

The KNITU/KITU level assemblies represent a further development of the KNI assemblies which have been already used in VVER reactors for monitoring of the neutron flux density. Compared to the KNI assemblies the KNITU/KITU level assemblies contain additionally heated and unheated thermocouples as level sensors in the region between the fuel element exit and the RPV closure head. The KITU assemblies are of the same design as the KNITU assemblies with the difference that the neutron part of the assembly is missing.

2 Design Principle

Depending on the redundancy structure of the nuclear power stations of type VVER at least two redundant level probes of type KNITU are recommended as a basic version, each of them comprising of five sensors located axially above each other. As sensors three heated and two unheated thermocouples acting as references are used.

Because of the installation possibilities of the level probe in the reactor pressure vessel of the VVER reactor types and due to the fact that the function of the probe has to withstand a LOSS OF COOLANT ACCIDENT (LOCA), the following criteria for the level probe are the basis for its functional design:

- High structural stability and reliability,
- Use of parts proven by operating experience,
- Observation of VVER specific geometric limiting conditions,
- Fulfillment of specific requirements of VVER reactors as number of measuring positions, spatial resolution, response time, optimal combination with neutron flux detectors,
- High signal voltage to assure reliability for further processing,
- Direct measurement of the water level inside RPV,
- Diversity to the level measurement inside the pressurizer,
- Verification of the operability by tests with LOCA-typical transients
3 Measuring Principle

The level probe KNITU bases on the fundamental design of the already now used neutron measuring assembly with Rh detectors of type KNI. In addition to the neutron detectors in the core region the water level in the region of the upper plenum is monitored by three heated and two unheated thermocouples which are located axially above each other.

The thermocouples have good thermal contact to the inner surface of the common housing tube. Three thermocouples have additionally heating filaments at their exterior, which directly contact these thermocouples; two thermocouples are unheated. As thermocouples NiCr-Ni thermocouples are used; as heating filaments a special wire made of NiCr and Ni is used.

The measuring principle takes credit from the fact that the heat transfer in water is considerably higher than in steam. That means that the heated thermocouple possesses a lower temperature when it is immersed in water then when it is surrounded by steam. In order to become independent of the temperature of the water or steam, the unheated thermocouples are used as reference measuring points. As a measure for the coolant level in the RPV the difference between the signals of the three heated and the related unheated reference thermocouples is formed. The temperature, and thus the voltage of the thermocouples is a measure for whether the thermocouples are immersed in water or steam. When immersed in water the thermovoltage of a heated thermocouple is lower than when it is surrounded with steam.

The coolant level is monitored by thresholds. If the difference of the thermovoltages between heated and unheated thermocouples exceeds a certain threshold, is this an indication that the water level has declined below the heated thermocouple (see fig. 2). The axial resolution of each measuring point is ±50 mm and the response time to reach the threshold ≤ 30 s.

4 Arrangement

The principle design of a KNITU/KITU level probe is shown in fig. 1. The KNITU assembly consists of the neutron measuring part (lower part) and the level probe part (upper part), which are both located in a common housing tube. For KITU assemblies the neutron part is missing.

The level probe part consists of three heated thermocouples by means of a specific filament and two unheated thermocouples. The lower unheated thermocouple is located in the height of the fuel element outlet. This thermocouple can be used not only for monitoring of the fuel element outlet temperature but also to determine the reference temperature of the level measurement. To ensure a good heat transfer, both the heated as well as the unheated thermocouples are attached to the probe’s housing tube. The installation and the removal of the KNITU level probes are carried out in the same way as for the KNI probes used up to now.

Except their task of guiding the level probes in the desired position and to protect them from flow forces out of the upper plenum, the guide tubes also have an important task for the measurement: During many accidents, as well as during small leakages, by means of the steam which is rising out of the core a heavily moving two phase mixture is formed in the upper plenum without well defined surface. The enclosed splash water could fake the signal „water level above sensor“ by cooling effects at the sensors. The guide tube causes that nevertheless the equivalent water level is measured. The guide tube is closed over its entire length and merely at its upper and lower end connected to the upper plenum by equalizing bores. In that way in its interior (as in the conventional hydrostatic glass water level indicator of a steam boiler) a water level is formed which corresponds to the level (the collapsed or equivalent water level) inside the upper plenum. To this water level the sensors can react unambiguously.
4.1 Recommended Positions of the Sensors

The assemblies shall be installed into the guiding tubes of former KNI assemblies. For choosing of the azimuthal positions of the KNITU assemblies the principles of redundancy (e.g. local distribution) have to be taken into account.

The axial arrangement of the heated and unheated thermocouples are defined as follows:

One heated thermocouple and the corresponding unheated thermocouple are located below the RPV closure head. The difference signal of these sensors indicates the evolution of bubbles respectively its growth in the upper plenum.

The measuring positions of the other two heated thermocouples are located in the height of the inlet and outlet of the reactor coolant lines and their corresponding unheated thermocouple is located in the height of the fuel outlet.

The axial positioning of the sensors is justified in the typical behaviour of the coolant level as it shows during small and medium leakages: On decreasing pressure the steam will accumulate in the space below the closure head. It will displace the water there (in the upper plenum in the region above the reactor coolant line nozzles). Hence in this phase the water level will drop relatively quickly, while the total water inventory will decrease only very little.

If the level has decreased so far that the steam forces its way into the reactor coolant lines, the reactor coolant lines and the steam generators will start to empty. Due to the large water inventory available there the water level of the upper plenum declines only slowly while the water inventory decreases strongly. As soon as the steam generators and the reactor coolant lines will have been drained extensively, the water level in the upper plenum starts again to decrease faster. In this case the remaining water inventory will certainly be very low.

For this reason the sensors should be positioned at such a position that there will be enough time to undertake countermeasures until the decline will reach the top of the core, the corresponding thresholds will be exceeded before the steep decrease of the water inventory will start.

Assigned to the measuring point 1 (upper measuring point) is the reference point 1 (upper reference point) and to the measuring points 2 and 3 the reference point 2 (lower reference point). The positioning of the measuring points and the assignment of the reference point is justified as follows:

1. Measuring Point 1 with Reference Point 1

Measuring point 1 is used to detect the development of steam bubbles below the closure head. Assigned to the measuring point 1 is a separate reference measurement point 1. This reference point is located closely below the measurement point 1 in order to receive an unambiguous measuring signal even in case of a reactor scram. At a scram a temperature decrease at the fuel element outlet is observed.

2. Measuring Point 2 with Reference Point 2

This measuring point is used to indicate whether the outlet line of the loop is sufficiently filled with water and thus natural convection for reactor cooling is possible. Reference point 2 at the fuel element outlet is for the formation of the measuring signal an unambiguous reference value.

3. Measuring Point 3 with Reference Point 2

This measuring point is used to supervise the monitoring of the water of the core in case of a leakage in the loop inlet line. It is recommended to position this measuring just below the lower edge of the loop inlet line. The fuel element outlet temperature (reference point 2) is also for this measuring point an unambiguous reference value.
5  **Manufacturing Principles**

The design of the level assemblies KNITU bases on the KNI assemblies which have been used successfully in VVERs. Therefore the same closure plug for the RPV nozzle as well as the same fastening of assembly and cable in this plug can be used with its proven materials.

For product assurance reasons only materials and electrical parts are used which are proven under normal and accident conditions by tests or operational experience or whose use is suitability on the basis of available manufacturer’s technical data.

5.1  **Testing of Probe Head, Plug and Cable**

For the electrical parts inside the head of the level assembly (Pt 100 element) as well as for their electrical connections to the junction boxes theoretical and practical proofs of the LOCA resistance were performed.

5.2  **LOCA Test**

Basis for the LOCA test have been test curves valid for the LOCA scenario of VVER440. Furthermore only components are used which were qualified under the conditions of a LOCA (e.g. LOCA qualification of components inside containment of pressurized water reactors).

6  **Structure of the Measuring Channels**

6.1  **Description of the Electronics**

6.1.1  **Measuring Electronics**

The block diagrams and the functional diagrams are shown in fig. 3.

The electronic modules are accommodated in three separate electronic cabinets which are located in the PAMS rooms. Essential components of the measuring electronics are:

- Power supply for electronic modules
- Power supply for the heating filament of the thermocouples
- Measuring amplifier module with
- Input modules for temperature measurements with thermocouple characteristics
- Input modules for temperature measurements with resistance thermometer characteristics (Pt 100 in 4 lead wiring)
- Signal processing module
- Limit value/interface module

6.1.3  **Power supply of the Probe Heating Filament**

The power supply of the heating filament is a special FRAMATOME ANP GmbH development. The current is automatically controlled by a closed loop control following a preselected function due to the temperature change of the heater circuit resistance. Therefore a sufficiently constant signal over the entire operating range of the level probe is ensured which assures a constant sensitivity of the system over the whole operating range from start up to full power respectively LOCA.
6.1.4 Signal Conversion

Inside the KNITU probe head there is a material transition from the thermocouple material (NiCr-Ni) to the loop cable wire (Cu). This material transition creates a further thermoelectric voltage. To correct for this signal distortion the temperature inside the assembly head is measured by means of a Pt 100 resistance thermometer. The Pt 100 resistor signal is transmitted to the input module for temperature measurements with resistance thermometer characteristics according to DIN 43760. The Pt 100 resistor signal is then transmitted to the measuring amplifier module to correct the signals from the thermocouples.

The corrected thermocouple signals are converted into current signals 0/4 to 20 mA. In doing this the characteristics of the NiCr-Ni thermocouples are corrected. These analogue signals as well as the difference signals from the heated and unheated thermocouples are transmitted by current converters as 0/4 to 20 mA signals to the main part of PAMS. Furthermore the threshold alarms "WATER LEVEL LOW" are transmitted as binary signals to the main part of PAMS.

The a.m. signals can be additionally transferred via the RS 485 interface to the plant computer system (PCS). A fibre optic link can be used. The communication is classified in category C according to IEC 1226.

6.1.6 Cable Routing

The signals are picked up from the assembly head by connectors and transmitted by a loop cable to the penetration at the postament. All components inside confinement have to fulfil the LOCA requirements.

Within the loop cable the signals from level monitoring part and from the neutron monitoring part are split into two separate cables (see fig. 5). The signals from

1. the neutron monitoring part are led to the before used penetrations. From outside the penetrations the signals of the neutron monitoring part are led via the existing cables to the existing neutron monitoring processing units.

2. whereas the signals from the level monitoring part (temperature signals and heating current signal) are led to new defined penetrations and from the penetrations to the electronic cabinet in the PAMS rooms via new installed cables.

6.2 LOCA Instrumentation

The signals of the level probe channels are used for the accident and post accident instrumentation and connected to the main part of PAMS.

All components of the level monitoring part (cable, penetrations, connectors) have to fulfil the seismic and LOCA requirements of the relevant installation locations. Additionally the criteria of redundancy has to be taken into account for the cable paths and physical separation of the electronic cabinets.

6.7 MMI Design

All information necessary to operate and observe the signals of the level measurement are presented on the PAMS screen and on the Plant computer system.
8 References

NPP Bohunice VI, Unit 2
2 KNITU
1998

NPP Kola, Unit 1&2
1999

NPP Novovoronezh, Unit 4
2 KITU
1999

NPP Bohunice V1, Unit 1
2 KNITU
2000

9. Pictures and Diagrams
Fig. 1: Design of KNITU assembly and axial arrangement in reactor pressure vessel
Fig. 2: Settings of limit value and time resolution of the difference measuring points
Fig. 3: Principle design of the electronic channels for the level monitoring system
Fig. 4: Distribution of the signals of the level monitoring system