TEMPERATURE MEASUREMENT ACCURACY AND RELIABILITY INFLUENCE ON VVER - 440 REACTOR OPERATION

V. Petényi, VÚJE Trnava, a.s.
J. Ričány, ÚJD SR

The reactor power in VVER - 440 reactors is controlled by coolant heat-up measurements installed on hot and cold circulation loops (enthalpy rise). For power distribution determination also the thermocouples installed in reactor vessel above the fuel assemblies are mainly utilised.

The paper shortly presents some interesting observations on temperature measurements, which influenced the reactor power operation or revealed changes in reactor core behaviour.

1. Introduction

Electricity generation by nuclear energy on the territory of former Czechoslovak Republic started in the end of year 1972, when the prototype A-1 Nuclear Power Plant with heavy water moderated and gas cooled reactor was connected to the electric network.

The radial power distribution in the reactor core was established on the base of assembly outlet temperature and the gas flow through the fuel assemblies. The complicated nature of the temperature measurement system and on-loaded refuelling obtion lead to lower reliability of the temperature measurements (frequent incorrect temperature readings). The above mentioned fact has its share on the accident in 1977, when fuel assembly melt down happened due to cloasure of the flow area in the fuel assembly.

Due to this reality a great interest was devoted to the accuracy and reliability of the temperature measurements starting with the hot functionality tests of the 1-st VVER-440 unit of Bohunice NPP.

The paper shortly presents some interesting observations on temperature measurements, which influenced the reactor power operation, and revealed not foreseen changes in reactor core behaviour.

2. The measured coolant loop temperature influence on reactor power

The temperature measurements on the 1-st and 2-nd unit of Bohunice NPP were based on the thermocouples (CH-K type). The reactor power in the first stage of power operation was established on the basis of following calorimetric relation

$$P = G.C_p.\Delta T \quad (1)$$

Where:
- P – reactor power (kW)
- G – reactor coolant flow rate (kg/s)
- C_p – specific heat at constant pressure (kJ/Kg/°K)
- ΔT – average coolant heat up (°K)

The reactor coolant flow rate was determined during the reactor hot functionality tests.

From the measured 'G' on the base of (1), ΔT=27,3 °C was determined for reactor power 1375 MW.

From the calibration of thermocouples before the hot functionality tests it was evident that there is systematic deviation between the standard temperature characteristic (according the technical norms) and the measured ones. The mean deviation in the range of 260 °C – 290 °C for 2-nd unit was +1,1 °C [1].

The reactor recording system also revealed unstabilities, which needs frequent adjustation.

Due to these circumstances, there was decided to replace the standard measurement system by new one based on termoresistors and modern digital technology.

The aim was realised in 1979 on the 6-th coolant loop of the 2-nd unit. The gained experience on comparision measured results on both systems showed the priorities of the new system. On the basis of this result there was decided to replace the old system on both units.

The new system of loop temperature measurements was installed on 2-nd unit during the 1-st outage and during the 3-nd outage on the 1-st unit of Bohunice NPP.

Excluding the systematic temperature deviation 0,6°K on 2-nd unit leads to increasing the reactor power by ~ 2 % N_{nom}. Approximately the same result was achieved also on 1-st unit.

The stability and the accuracy of the ΔT measurements system was improved in comparision with previous one.

The new system allowed to better control of the reactor isothermic state when the thermocouples are adjusted.

Further reactor power arrangement was done starting with 1982 when there was approved the new methodology for reactor power determination based on secondary side heat balance.

The above mentioned improvements leads to taking of the conservative margins applied in first period of Bohunice NPP operation and increased the reactor power about 3 – 4 % N_{nom}.

3. The outlet temperature measurements influence on reactors power

The power distribution (assembly power) is limited by two parameters in the reactor core i. e. by:

- k_q^i - power peaking coefficient for "i-th" fuel assembly
- ΔT^i - coolant heat up on "i-th" fuel assembly

The meaning of these parameters is explained in [2].

The maximal values for k_q^i for full core for present are 1.35 for old fuel assemblies and 1.37 for profiled fuel assemblies. The ΔT^i values are determined on the basis of approved methodology [3] taking into account, assembly flow rate peaking factors etc.

The margins in ΔT^i were continuely decreasing due to improvements of reactor power determination methodology.

The reactor power after this improvement was mainly influenced by two events.

The first was the possibility of incorrect adjustation of the thermocouple characteristic in the isothermic state. This was caused mainly that there was not established a well based temperature stabilisation procedure in the reactor and surroundings (different temperature conditions in the period of adjustment and power operation). The consequences of this effect, was ΔT^i limitations on reactor power on beginning of the power operation after the refuelling.

The second event was connected with weakness of the thermocouples cold end compensation effect.

For instant this effect was measured on 1-st and 2-n unit of Bohunice NPP about ~0,1°K in ΔT^i for 1°K change of cold end temperature.

This effect mainly limited the reactor power (through ΔT^i) in winter time operation.

After recognising these effects remendies were implemented in operational manuals for establishing isothermic reactor conditions and also for minimising the coold end compensation effect.

4. The fuel assembly modification influence on outlet temperatures

In 1985 the Russian fuel vendor started to supplay a modified fuel assemblies compared with previous ones. The design change concerned implementation additional so called, upper flow mixing grid in upper header of assembly. Not correct accounting this design changes in the side of reactor operator leads to miss – interpretation of the in core temperature measurements. The consequence of this effect was power limitation due to reaching the assembly limiting ΔT, and also there was observed disagreement between the ΔT and kq values.

The problem was published in former VMK Symposium in 1986 [4]. The root cause of the discrepancy was found in the change of the hydraulic top grid design explained by IVO Company [5]. They analysed the outlet temperatures of the mixed cores where the old an new type fuel assemblies were used in the symmetrical positions.

The measurements revealed that the $\Delta T^i - s$ in the new design are higher in comparison with the older design for the same assembly power.

5. Influence of Reactor internals change on assembly outlet temperatures

On the first period of reactor operation in Bohunice NPP there was a meaning that the lower assembly outlet temperatures compared with the mean temperature values on the same symmetric position are on the safety side.

The operation of the 2-nd unit of Kozloduj NPP [6] revealed there is a possibility of higher flow rate through the fuel assemblies for example caused by wearing out of the reactor core basket consistors. This effect leads to lower ΔT readings due to higher coolant flow rate through the affected fuel assemblies. The consequences of this effect were fuel failures in position of defective consistors due to higher hydraulical loads.

Takin into account the above mentioned reality the UJD SR requested the Bohunice NPP on 1996 to check all the consistors, and implement a diagnostic procedure for consistor survailance based on thermocouple readings.

6. Remendies implemented to the operational manuals and other relevant documentation

In connection of about mentioned realities the ÚJD SR requested the NPP operators in 1994 for reassessing the operational manuals concerning the reactor start up procedures.

There were elaborated also UJD SR guids for implementation modified type fuel assemblies [7], for evaluation core reload design [8], for evaluation start-up test results [9] and for elaboration limiting ΔT and outlet temperature values for reactor operation.

The present operational manuals for reactor start up procedures contain remendies, which may be followed in the case of non-consistency between the measured and expected test results. The above mentioned procedures and UJD SR guids are successfully applied in the phase of core design, test performance and for handling non – consistency cases in the course of reactor start – up.

By implementation of this methodology, and improvement of the accuracy and reliability of the temperature measurements leads to practical excluding reactor power limitation due to ΔT^i or k_q^i limitation.

7. Conclusions

The reliability and accuracy of the temperature measurements on VVER-440 reactors were successfully upgraded in comparision with first stage of 1-st and 2-nd units operation in Bohunice NPP.

The operational manuals for reactor start-up tests were also improved and there is estabilished a well determined fead-back procedure for solving non-consistency cases.

Due to these improvements the power limitation caused by temperature measurements are very rear at present.

References

[1] S. Štanc, J. Tomík, J. Mádel: Influence of Improved Nuclear Reactor Temperature Measurement on Reactor Power, Proccedings of the „Conference on Temperature Metrology – 82“ Praha, 1982

[2] Ovčinikov et al: Operational Modes of the VVER Reactors, Atomizdat, Moskva 1977 (in Russian)

[3] Ričány J.: Slovak Nuclear Regulatory Authority Requirements for Elaboration of Tables of Reactor Operational Modes, UJD SR guid (under review)

[4] Petényi V.: Core Design Problems in VVER-440 Reactors with Low Leakage Core, 15-th Symposium of VMK, Rostok, Germany, 26 – 31 October 1986 (in Russian)

[5] Siltanen P.: The Influence of Fuel Assembly Design Changes on Measured Coolant Enthalpy Rise Observed in Loviisa Reactors, XVI Symposium of VMK, Moscow, 21 – 25 September 1987

[6] Simov R.: Nuclear Fuel Failures in Kozloduj NPP in the Period of 1992 – 1998, 15-th IWG FPT plenary meeting, Vienna, 27 –29 April 1999

[7] Petényi V.: Requirements for Issue UJD SR Approval for Fuel Utilization in WWER-440 type Reactors, UJD SR Safety Guide, Bratislava, 2000

[8] Petényi V.: Requirements for Safety Evaluation of Core Reload Design, UJD SR Safety Guid, 2000, Bratislava, 2000

[9] Petényi V.: Slovak Nuclear Regulatory Authority Requirements for Start-Up Physics Tests valuation, UJD SR Safety Guid, Bratislava, 2001