INNOVATED FEED WATER DISTRIBUTING SYSTEM OF VVER STEAM GENERATORS

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Defects in feed water distributing system due to corrosion – erosion effects have been observed at many VVER 440 steam generators (SG). Therefore analysis of defects origin and consequently design development and testing of a new feed water distributing system were performed.

System tests in-situ supported by calculations and comparison of measured and calculated data were focused on demonstration of long term reliable operation, definition of water flow and water chemical characteristics at the SG secondary side and their measurements and study of dynamic characteristics needed for the innovated feed water distributing system seismic features approval.

The innovated feed water distributing system was installed in the SGs of two VVER 440 units already.

1. Introduction

Defects in feed water distributing system of primary Russian design due to corrosion – erosion effects have been observed at many VVER440 steam generators (SG) after approximately of ten years of operation. This defects have been observed in SGs of NPP Jaslovské Bohunice too. Therefore analysis of defects origin and consequently design development and testing of a new (innovated) feed water distributing system (co called SE-EBO design) were performed.

2. Brief description of the SE-EBO feed water distributing system design

The feed water pipeline inside the SG is subdivided into left- and right- hand chambers both located above the tube bundle. A number of feed water boxes with ejectors is inserted into the tube bundle using vertical gaps shaped by the tube bundle support system. The feed water is distributed from both chambers into feed water boxes by distributing pipelines.

Outlets of ejectors are oriented horizontally and located approximately in the half of the tube bundle height. All elements of the system are manufactured from an austenitic stainless steel.

3. Verification of features

Features of the new feed water distributing system have been verified theoretically, experimentally and on prototype in-situ.

3.1 Theoretical analysis

Theoretical analysis were performed with following aims especially:

- To clarify hydrodynamics of feed water flows in pipelines and elements of the innovated distributing system.
- To analyse field of medium flow velocities at the SG secondary side for different box with ejectors configurations.
- To analyse field of impurities concentrations (sodium etc.) in the water at the SG secondary side for different box with ejectors configurations and selected blow down flow rates.
- To study mode and frequency of feed water distributing system self vibration.
- To provide understanding of requirements on and verification of technical and safety characteristic of the innovated feed water distributing system.

Examples of analysis results are in Fig.1 and Fig.2.

Computed distribution of feed water flow rates in the SG length for the case of one of distributing system design variants is in Fig.1. The mean water flow velocity in the left- or right- hand chamber decreases with the distance from the inlet as a result of the feed water flow into distributing pipelines. The water dynamics pressure decreases and the water static pressure increases with distance from the chamber inlet at the same time. Therefore the local water flow rate from the chamber into distributing pipelines is lower at the inlet of the chamber and higher to the end of the chamber.

If an exchange of water among individual tube bundle sections is considered, in fact such sections are formed by the tube bundle support and tube distance systems, then a medium velocity field like shown in Fig.2 can be expected in the SG. The length of arrows is proportional to the medium mean velocity among sections. To this velocity field corresponds a field of impurity in water concentrations, Fig.3. More or less uniform distribution of impurities in water along the tube bundle is archived in this studied situation at the SG thermal power level of 100 %.

3.2 Experimental assessment

Features of selected parts of the innovated feed water distributing system were analysed experimentally. Experiments were focused mainly on:

- Study of characteristics of ejectors and investigation of the feed water jet range in a water volume.
- Study of tube wall temperatures if the outer target tube surface is submitted to a cold water jet (expected situation for same probable reactor accidents).

One of the positive features of ejectors with feed water boxes is the colder feed water is mixed with more hot water from the SG secondary side and warmed up before injected into the water/steam volume at the secondary side consequently. This is also a positive SG safety improvement for many NPP operational and accidental transients.

In SGs of VVER 440 units of the type V230 is the feed water distributed by one feed water distributing system as during normal operation as in accidental situations. Therefore in some low probable but specific accidental situations a very cold (less than 50°C) feed water is pump into hot water /steam mixture or only steam (approx. 260°C) at the secondary side via the feed water distributing system generating individual cold water jets. One of possible cold water jet targets is the hot outer surface of some tubes in the tube bundle. Local non steady cooling of the tube wall generates temperature shocks and transients and stress transients in the tube material and can initiate cracks at the tube surface.

These phenomena were studied also experimentally. A tube of 16 mm O.D. and of 1,4 mm wall thickness manufactured from the OCH18N10T steel was connected to a test loop. The water flow rate as well as pressure inside the tube were the same as in the SG and water temperature at the inlet (T_3) of the tested tube was kept at a level of 280°C , Fig.4.

The hot tube outer surface was a local target for a water jet with the temperature of 20°C and flow velocity of 5 m/s. The response of a local surface temperature (T_4) of the tube to the jet is in Fig.4. In this diagram are also plotted calculated temperatures of tube inner surface (t_{vni}) and tube outer surface (t_{vne}) for very extreme conditions of cooling in the real SG: So in much more extreme temperature conditions than really expected. After some time period the cold water jet was stopped and so covered one load cycle. No crack initiation was observed at the tube surface after approximately 100 load cycles.

3.3 In – situ testing

A prototype feed water distributing system of the SE-EBO design was manufactured and installed into a one SG in Jaslovské Bohunice in 1994.

In – situ long term tests were performed and focused on safety related verifications especially:

- Response in the rate and distribution of impurities (Na, Cl^-, Fe) in the water at the SG secondary side on innovated feed water distribution system operation also in dependence on SG thermal power level.
- Local temperatures of the system structure and surrounding medium
- Spectra of vibrations emitted by SG operation
- Characteristics of waves emitted in high frequency ranges by SG operation

An example of obtained responses is in Fig.5. RMS vibration values for two accelerometer locations are plotted in time at the full thermal power of the SG.

4. Conclusions

Expected technical and safety features of the innovated feed water distributing system of the SE-EBO design have been verified by theoretical and experimental analysis as well as by long term in-situ testing. Based on this verification results the SR Nuclear Regulatory Authority made out a permition to install this system into steam generators in Jaslovské Bohunice. So now in all steam generators of two VVER440 units are installed and operating innovated feed water distributing systems of the SE-EBO design.

References

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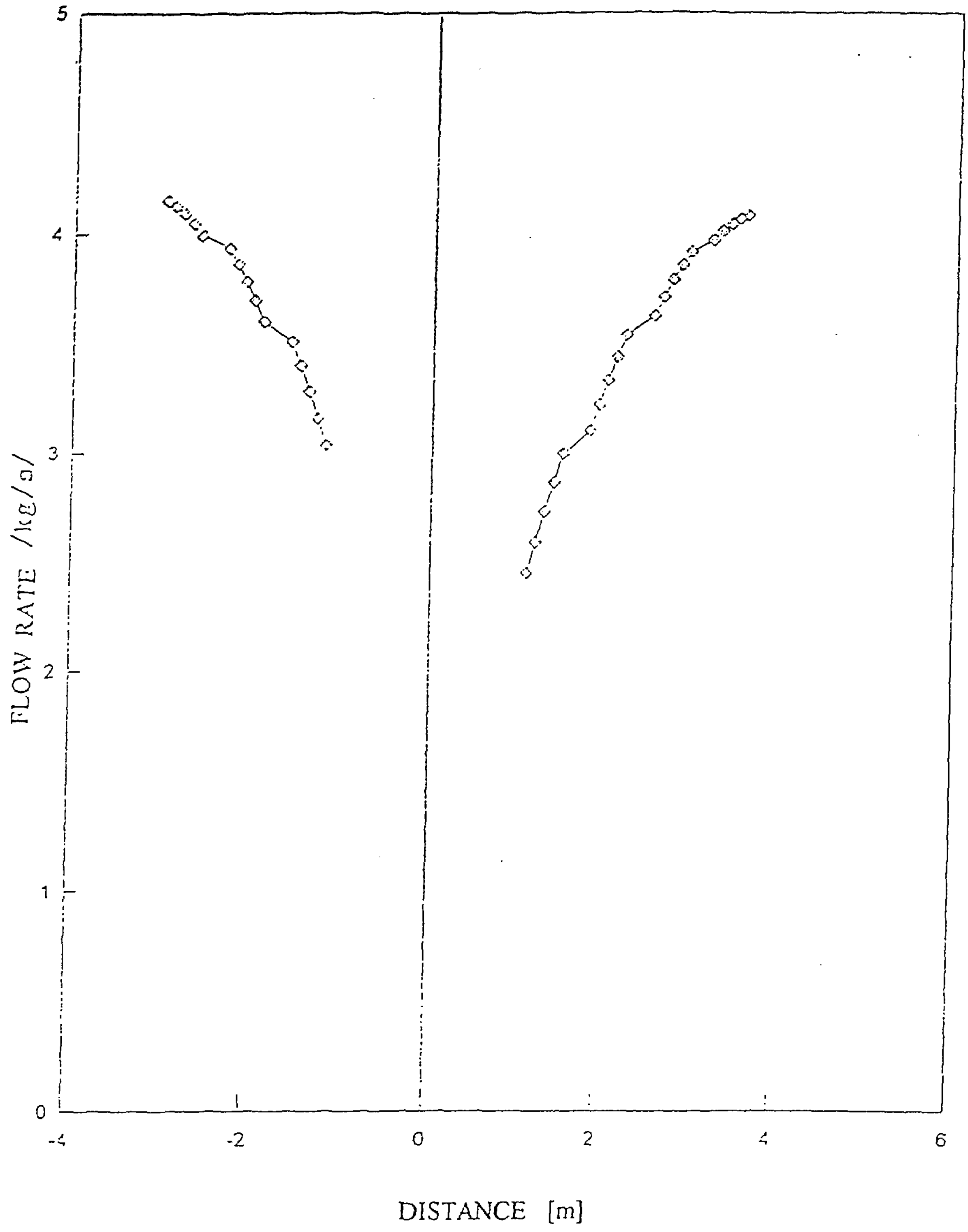

Fig 1: Computed distribution of feed water flow rates in the length of the steam generator

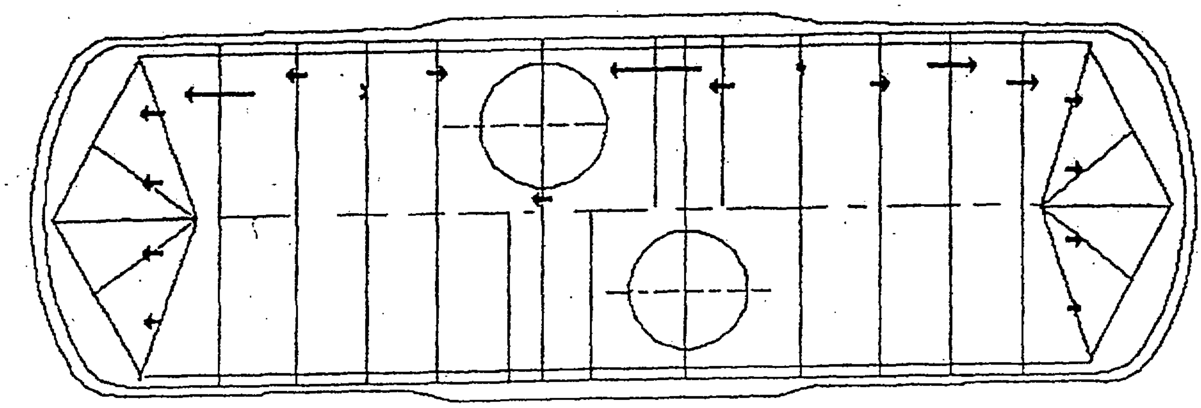

Fig 2: Velocity field of medium in a longitudinal cross section of the steam generator

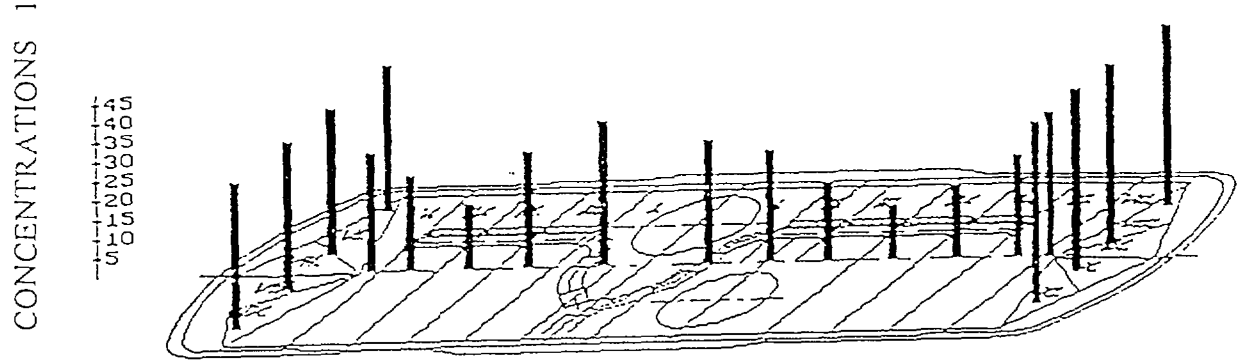

Fig 3: Field of impurity in water concentrations

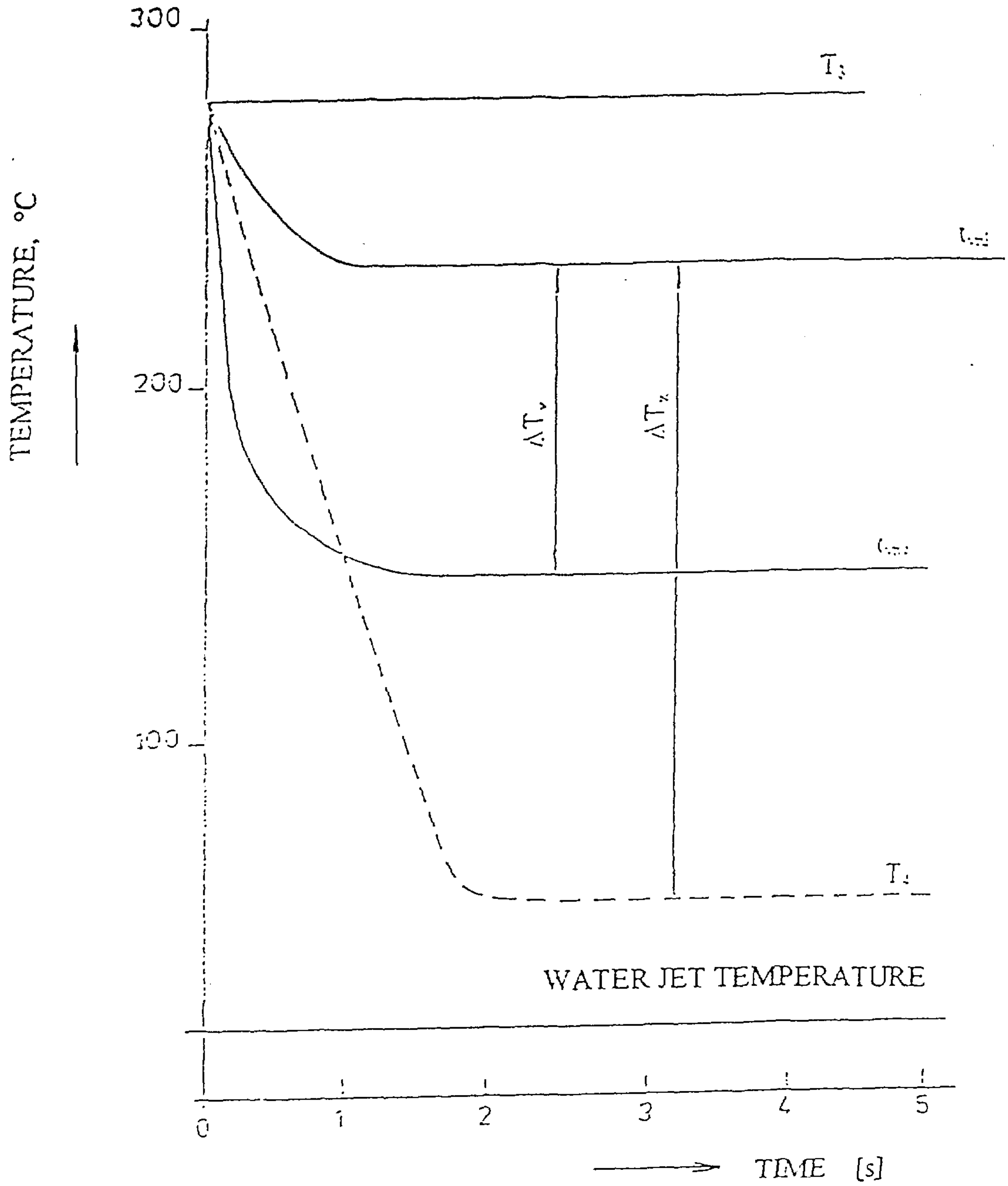

Fig 4: Tube wall and water temperatures

T_3 – measured temperature at the inlet in the tested tube
T_4 – measured local temperature at the tube outer surface
t_{vne} – calculate local inner tube surface temperature
t_{vni} – calculated local outer tube surface temperature
ΔT_v - computed temperature difference governing additional stresses in the tube wall
ΔT_2 – generated temperature difference by a cold water jet governing additional stresses in the tube wall

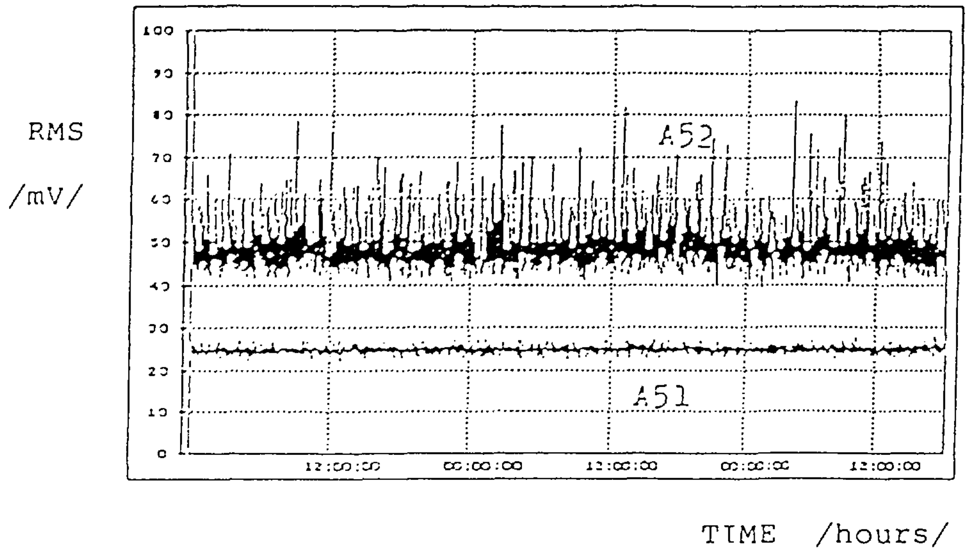

Fig 5: RMS vibration values for two accelerometer locations at the full thermal power of the steam generator