MONITORING FOR FATIGUE - EXAMPLES FOR UNEXPECTED COMPONENT LOADING

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ABSTRACT

Continuous as well as short term monitoring for material fatigue serves to identify real component loading. The loading generally comprises temperature transients and inhomogenous temperature distributions.

In designing special instrumentation for data acquisition, design engineers typically rely on the experiences made in similar types of plants as well as on existent design specifications and stress analyses. In short, the layout of the data acquisition systems used for fatigue monitoring are a direct reflection of the know how and experience.

Fortunately, the collected data sometimes also reveal previously unknown loading effects. These can then be examined, backed up by more detailed measurements, analyzed for their fatiguing effects and – if required - incorporated into the regular operating procedures. Thus experience is gained, and subsequent instrumentation layouts will be modified in line with the newly acquired know how.

The present paper elaborates a number of examples of the loading effects that recently have come into focus in Western-type PWRs:

thermal stratification in primary loop induced by pressurizer outsurge
mixing of varying temperature coolant flows in tee branches
temperature loading caused by leaking check valves upon recurrent component functional tests.

The loading is discussed using P&IDs, temperature readings, calculation results of inner wall temperatures and stresses, and finally in terms of usage factors. Such information stimulates amelioration of operating procedures and thus ultimately helps to secure safe and economic component operation. Monitoring for material fatigue is demonstrated to quickly reward for the efforts involved.

1. INTRODUCTION

Components of thermal power plants are loaded mainly by thermal constraints, temperature transients and internal pressure. The design procedure of the components requires definition of the anticipated pressure and temperature histories. These are needed to make enveloping allowance for the stress and fatigue implications of all transients potentially occurring in service. Experience shows, however, that actually the sequence and frequency of load transients vary to a considerable amount. Code regulations, therefore, require relevant loading parameters to be monitored and compared to design margins. Using a purpose designed fatigue monitoring system results are obtained that do not only satisfy such code requirements but also establish the source of information to decide on inspection frequencies, component maintenance, repair, replacement or lifetime extension.

2. THERMAL LOADING PHENOMENA

Two normal types of thermal loading are observed at pipelines:
slug flow causing thermal shock, characterized by an axisymmetrical temperature field (Figure 1a) and
stratified flow, characterized by a temperature field which is symmetric to the vertical (Figure 1b).

Of course there exist many variants of mixes of these types which actually make monitoring and analysis difficult. Additional types of thermal loading like turbulent mixing were investigated in literature /1/ but are not discussed in more detail within this presentation.

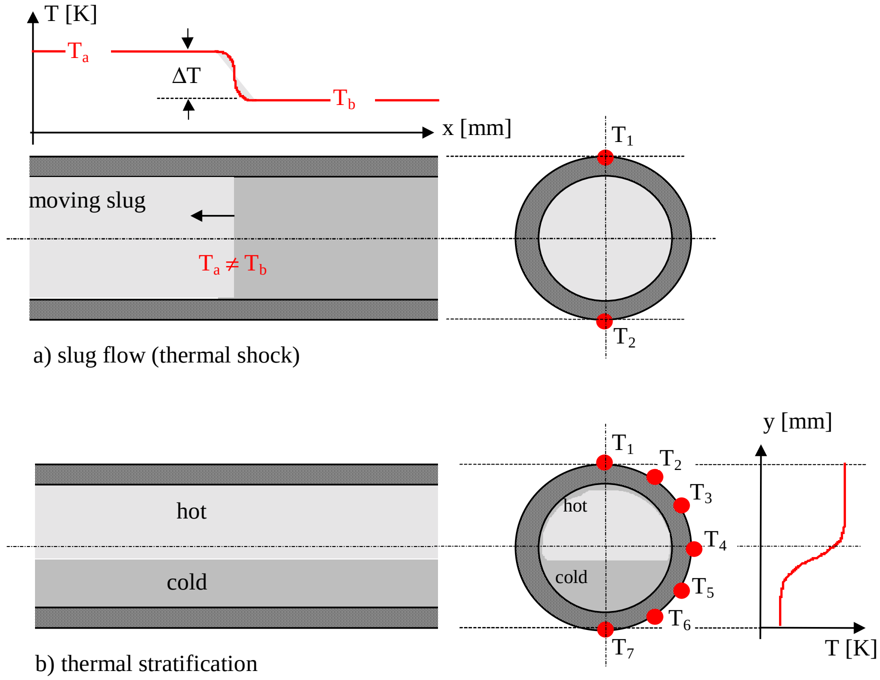

Figure 1 Schemes of idealised thermal loading of a pipeline

In addition the loading specification drawn up for normal operation of a system assumes that every component of the system functions properly; for instance that a valve that is closed is actually flow-tight.

A few examples with thermal stratification measured at some systems are discussed below. The data have been measured and processed using the Fatigue Monitoring System FAMOS developed by Framatome ANP. Since thermal stratification forms under conditions very sensitive to geometric and thermal-hydraulic parameters it is per se a very local phenomenon. This is why existing plant instrumentation is not suitable for observing this loading. Additional instrumentation is required.

1 MEASUREMENT LAYOUT

The stresses induced by thermal stratification vary with local temperature distribution. Especially the location, width and motion of the interface between hot and cold medium determine local stresses at the structure's inner surface. To this purpose extra and specially designed instrumentation is required. The FAMOS special instrumentation features seven temperature transducers around half of the pipe's circumference when stratification is expected and only two thermocouples when slug flow is anticipated (Figure 2).

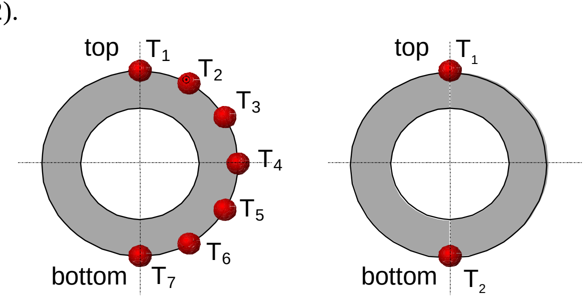

Figure 2 Local instrumentation

The signals represent outside surface temperatures. Inside surface temperatures can be calculated with heat conduction properties of the material and wall thickness being available. Heat transfer properties at the inside surface are not required as long as the inside surface temperature can be assumed to vary negligibly in proximate axial direction.

German nuclear regulations do not allow the thermocouples to be welded on the component's surface. Furthermore, in many instances the thermocouples fixing must be designed as a removable assembly to allow access for in-service inspection. The easy handling of the devices upon removal and refitting avoids radiation exposure of field personnel. Therefore, major objectives of the special layout and procedure developed have been

- measurement accuracy and
- easy and robust handling.

Measurement accuracy has been optimized in a series of laboratory tests. Parameters influencing thermocouple readings have been varied to establish best performance under nuclear power plant environmental conditions /2/.

2 EXAMPLES OF THERMAL LOADING

2.1 Example 1

The PWR surge line (Figure 3) is a system typically experiencing thermal stratification. Two large volume systems - pressurizer and primary loop - are interconnected by the surge line solely for pressure equalization. Variable and often very small flow rates result in complex thermal loading of the surge line in those instances when temperatures of pressurizer and loop differ.

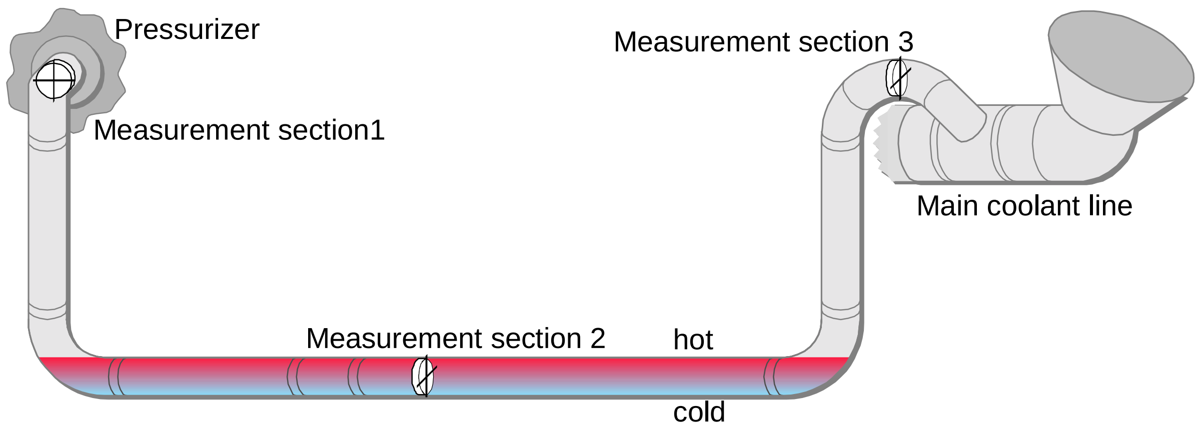

Figure 3 Local instrumentation of a PWR surge line

An example of the complex shock and stratification loading is given in Figure 4. The loading histories were recorded during startup of the plant at the three measurement sections shown in Figure 3. We observe that the loading is

- local, that it is
- complex in magnitude (ΔT) and frequency (dT/dt) and
- that it is specific to the mode of operation.

Stress and fatigue analysis with the FAMOS stage 3 allowed to calculate the stress histories on the basis of the monitored loading histories. The stress response is composed of instationary (thermal shock) and stationary fractions (stationary thermal stratification, internal pressure, member forces). Automatic fatigue analysis allows all of these to be superimposed in a chronologically correct manner. The ascertained results for the fatigue usage factor are given in Table 1

Table 1 Design life fatigue usage U

Location	Item	U
Measurement section 1	Nozzle to pressurizer	0.17
Measurement section 2	60 degree pipe bend	0.00
Measurement section 3	Nozzle to main coolant line	0.13

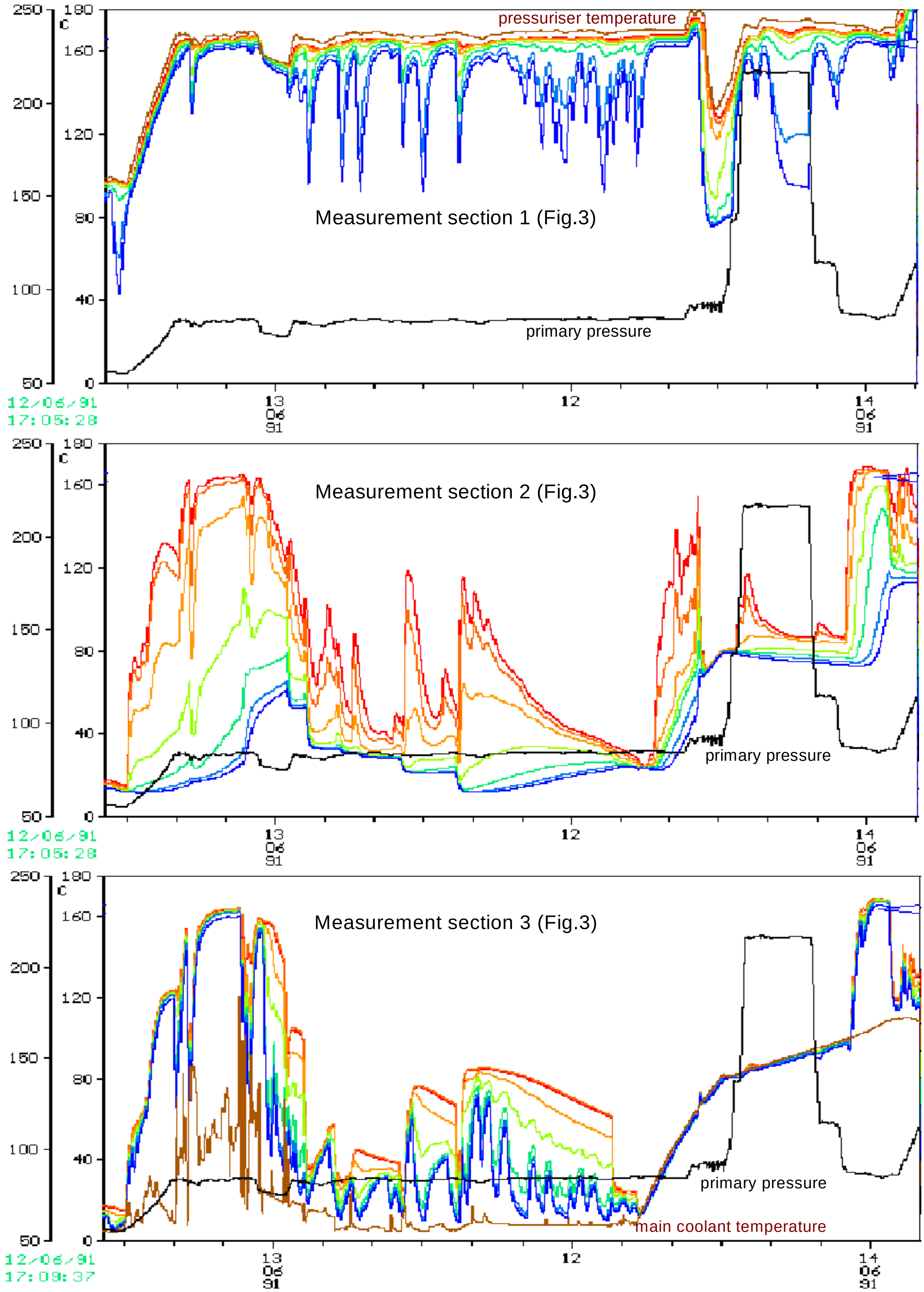

Figure 4 Loading of a PWR surge line – 32 hours of thermal stratification and shock

2.2 Example 2

The joint of water streams of different temperature in a tee may lead to a variation in stress within the structure that can cause fatigue damage /3/. The complex thermo-hydraulic boundary conditions of such turbulent mixing processes are very difficult to simulate by calculation. Therefore temperature measurements at the component are the appropriate means to provide the necessary information about the thermal load distribution. German authorities requested the investigation of such tees in several German plants. Figure 5 shows the flow diagram of the residual heat removal system and the geometry of the affected tee.

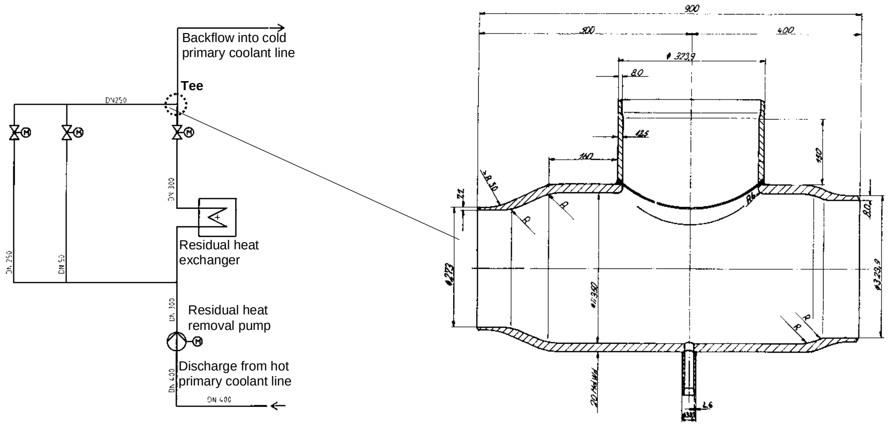

Figure 5 Flow diagram and tee geometry

Around the tee 4 measurement sections were placed as given in Figure 6. In deviation to our standard FAMOS instrumentation with two or seven thermocouples, the measurement sections 3 and 4 were arranged with eight thermocouples around the circumference of the pipe. The reason was that the pipe with the mixed cooling medium stream is arranged vertically and therefore no preferred temperature distribution was expected.

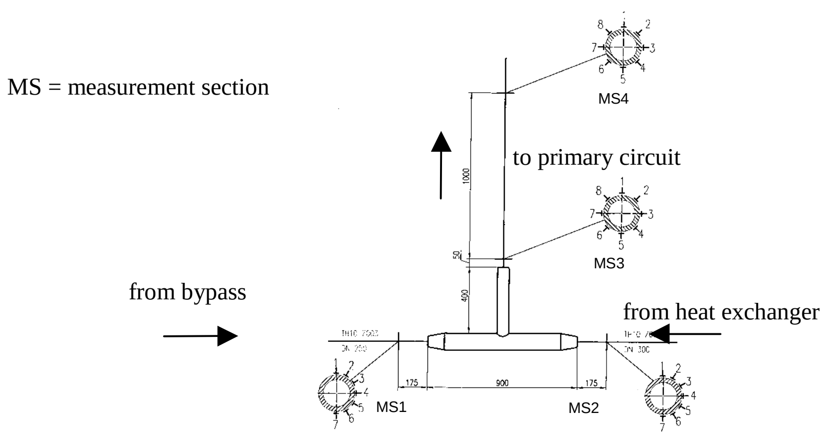

Figure 6 Arrangement of measurement sections

As a result of the measurement program there were only small temperature fluctuations recognised in measurement section 1 and 4. On the other hand there were temperature fluctuations on measurement sections 2 and 3 (see Figure 7 for measurement section 2) which were not negligible and so the harmlessness regarding to fatigue had to be shown.

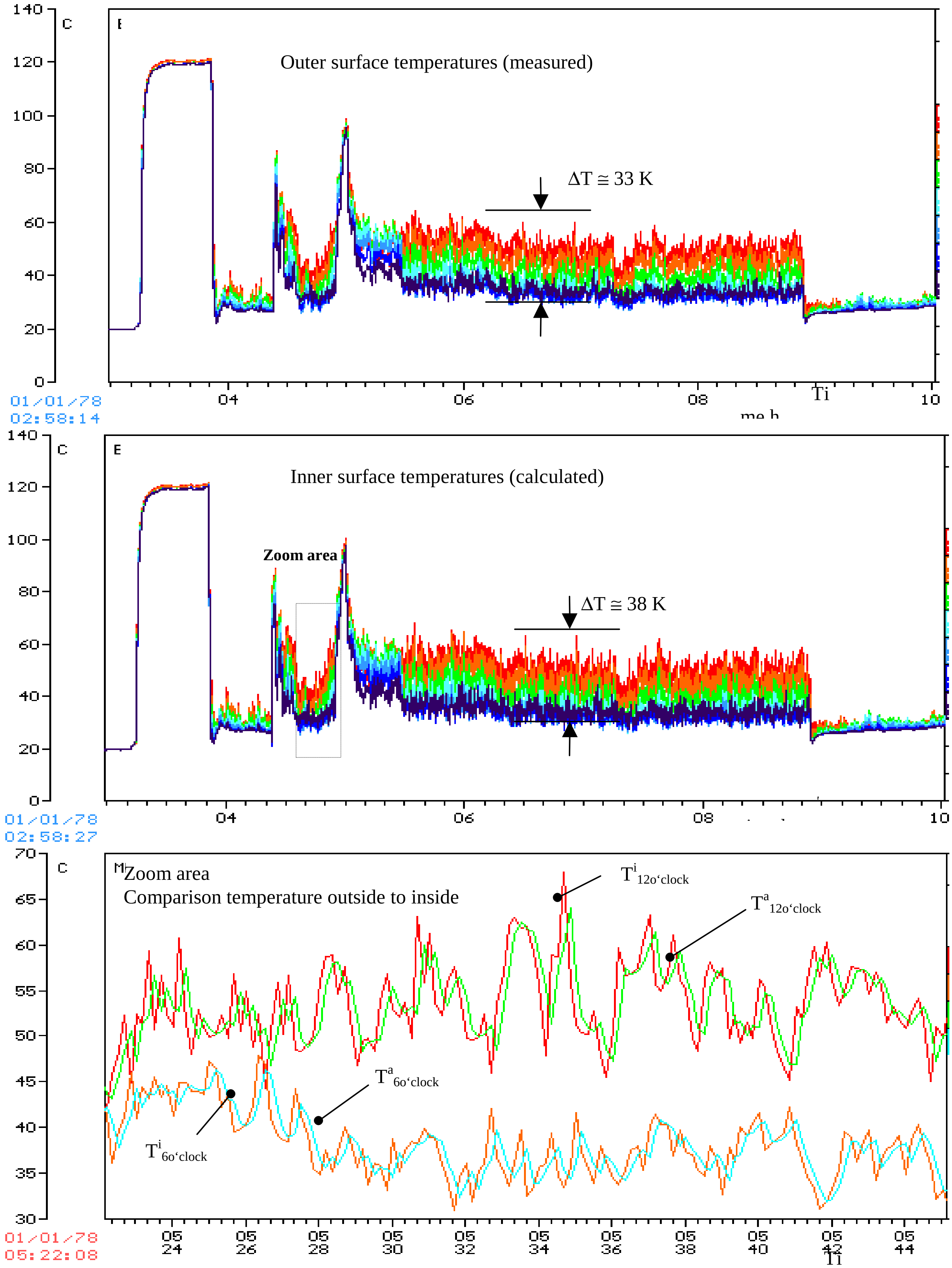

Figure 7 Temperature load in measurement section 2

The fatigue calculation according to KTA 3211.2, section 7.8 /4/ showed that with a conservative assumption for the amplitude and frequency of the temperature fluctuations the allowable limits will not be reached within the assumed lifetime of 40 years (see Table 2). Also a second tee in a different plant showed equivalent results. But this does not mean that the results can be overtaken to other tees without approval, as there were special conditions which may not be given in other plants or systems.

Table 2 Existing and allowable Temperature differences with given frequencies

Frequencies within 40 years	existing ΔT	allowable ΔT
400	100 K	160 K
800	60 K	125 K
$2 \cdot 10^5$	25 K	36 K

2.3 Example 3

Framatome ANP has collected a huge amount of reports about failures in nuclear power plants world-wide. Damage according to thermal fatigue with cracks or even leaks were investigated in 19 cases. In seven of these cases a leaking valve was the root case of the damage. Figure 8 shows the loading history taken at an instrumentation plane located downstream of the feedwater valve close to the steam generator. The power plant is in hot standby condition, i.e. the feedwater valve is closed. But since the valve is not flow-tight, complex convective secondary flow develops in the horizontal pipe section downstream of the valve. The nearby steam generator supplies heat to the more or less pronounced feedwater leakage flow. Again a highly localised temperature field deriving from a moderate stratified flow can be discerned.

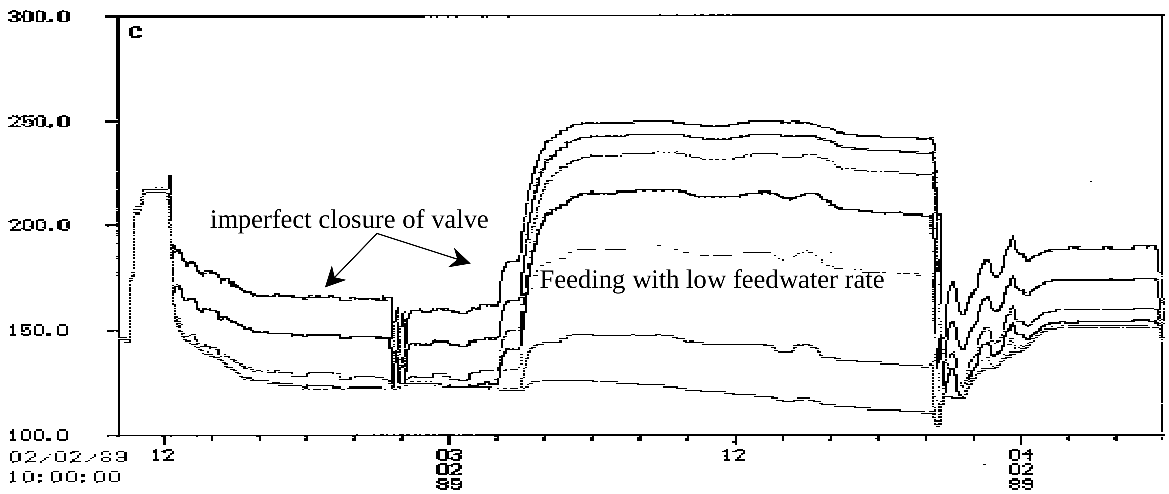

Figure 8 Leaking Feedwater valve causes additional loading

3 CONCLUSION

With the FAMOS system installed at correctly selected locations of the components, the plant staff get the information about the loading behaviour of the component which he would not get in such deep insight without such a system. Without doing any calculations he can use the temperature diagrams to improve the operating procedures. With the data recorded he is able to verify the design calculation and with the special FAMOS tools he can make stress and fatigue analyses on the basis of the real operational loads. The continuous monitoring of the fatigue usage factors enables the staff to run the plant at low fatigue operating modes, to plan non-destructive examinations or even to prepare repairs and replacements of components.

During the last 10 years a lot of experience was collected with so far unknown loading conditions. Now these thermal loads are under observation but still new cases arise which have to be analysed. The Fatigue Monitoring System FAMOS can serve as a basic tool to observe and also analyse known as well as up to now unknown fatigue relevant loads.

4 REFERENCES

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