SKI Report 2005:36

Research

Reports within the Area of Nuclear Power Plant Instrumentation

Part 1: Laboratory Test of Analogue and Digital Instrument Components

Part 2: Dynamic Deviations in Reactor Pressure and Water Level Signals Caused by Sensing Lines

Bengt-Göran Bergdahl

November 2004

ISSN 1104–1374
ISRN SKI-R-05/36SE

SKi

SKI Perspective

Background

This is an English version of the report ”Rapporter inom området sensorteknik, SKI Rapport 2003:07”.

Purpose

The purpose of this English version of the report is to spread the results of the report to a wider audience.

Results

The report discusses dynamic behaviour of instrument components and sensing lines in the light of a couple of different experiments performed either at an actual power plant or in laboratory. These experiments have contributed to SKIs supervision concerning instrumentation issues.

The experiments show, for example, that an analogue density converter is faster than a new digital one. It is also shown that signal analysis is a valuable tool when it comes to detecting unwanted filtering of signals.

The conclusion drawn is that to assure that an important measurement signal is reflecting the physical variable in question in a satisfactory way some kind of dynamic tests are needed. The static calibration is not sufficient, since it will not detect unwanted filtering and a prolonged response time.

Project information

SKI reference: 14.05-011184-01279 (the Swedish version)

Responsible at SKI has been: Kristina Johansson (for the English version) and Annelie Bergman (for the Swedish version).

SKI Report 2005:36

Research

Reports within the Area of Nuclear Power Plant Instrumentation

Part 1: Laboratory Test of Analogue and Digital Instrument Components

Bengt-Göran Bergdahl

GSE Power Systems AB
Box 62
611 22 Nyköping

November 2004

Abstract

Reliable measurement signals are of great importance for the safety of a nuclear power plant. The measurement signals are used as input signals to the automatic control systems, they have influence on the reactor protection system and they are the input to the information presented in the control room. Measurement signals are also the basis for analysis of sampled signals after an event. These facts imply that it is important that the measurement data represent physical magnitudes in a correct manner. This holds true both for the static and the dynamic part of the signal.

Mainly depending on the fact that the Swedish BWRs were constructed in the seventies and eighties, the instrument systems were originally designed with analogue technique. This is valid for transmitters as well as density converters, isolation amplifiers and controllers. Right now there is an ongoing modernization of the instrument systems in many plants. Old analogue components are in many cases replaced by new digital ones.

The delay time is the critical dynamic deviation between an analogue and a digital transmitter. A delay time of up to 200 ms has been observed for a digital transmitter (Hartmann & Braun ASK800) in comparison with an analogue one (Fujii). A long delay time is of course undesirable when the transmitter is a part of the reactor protection system. It is therefore important to pay attention to the delay in response when an analogue transmitter is replaced by a digital one. The laboratory tests also included a comparison between an old analogue density converter (Hartmann & Braun TZA2) and a new digital one (Hartmann & Braun TZA4). These results prove that the analogue unit is faster than the digital. The response time from differential pressure to level signal was 50 ms for TZA2 and 250 ms for TZA4. Corresponding times with pressure as input and level as output was 50 ms for TZA2 and 900 ms for TZA4.

The report also includes an investigation of pressure transmitters of the type TDE220. The transmitters exhibited deviating dynamics during ordinary sensor tests. The laboratory test confirms the observed deviation in comparison with transmitters of other types. The construction with Bourdon tube is judged to be the reason for the deviations.

The report also presents results from trouble shooting with steam pressure transmitters at KKM (Kernkraftwerk Mühleberg in Switzerland). It was possible to identify the intermittent sensor error with the aid of controlled pressure changes. Service of the transmitter pointed out a crack on the electronic filter unit. This was judged to be the reason for the intermittent signal interrupts.

Finally, two possibilities used at KKM to investigate the dynamics of temperature sensors are described. Both methods are based on artificial cooling of the sensor. One of them is applied during power operation of the plant and the other during outage.

Table of contents

1 Background

Reliable measurement signals are of great importance for the safety of a nuclear power plant. The measurement signals are used as input signals to the automatic control systems, they have influence on the reactor protection system and they are the input to the information presented in the control room. Measurement signals are also the basis for analysis of sampled signals after an event. These facts imply that it is in important that measurements represent physical magnitudes in a correct manner. This holds true for both the static and the dynamic part of the signal.

The measurement systems consist of many instrument components connected in cascade. For the measurement of e.g. water level in a BWR there are sensing lines, transmitters for differential and reactor pressure, and a density converter. See figure 1.1. Further instrument components like isolation amplifiers can exist in the instrument system in cascade thereafter.

To guarantee good static performance, annular calibration of the transmitters is performed at the plant. Observed static deviation is corrected in connection to these routines. In this way it is secured that the measurement systems have acceptable accuracy in their static presentation.

The dynamic character of the measurement system components is seldom or never tested in BWRs. This implies that transients in the plant may be filtered away in the measurement systems and therefore not be observed. Unwanted filtering of the measurement signals may also give rise to delayed reaction of the protection system during a transient.

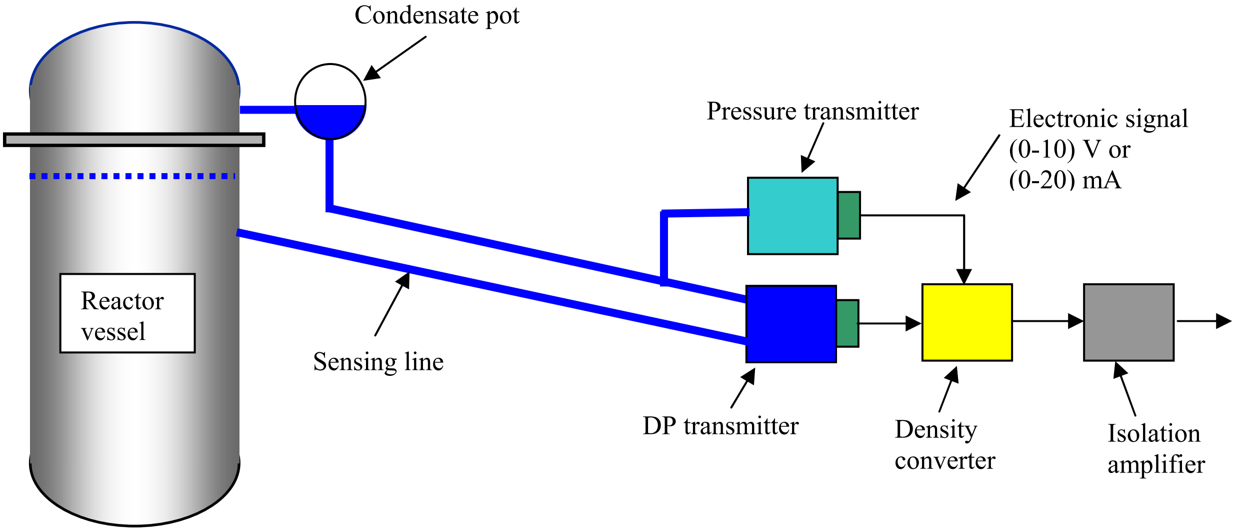


Figure 1.1 Measurement system for the water level in a boiling water reactor.

1.1 Reactor water level measurement in a BWR

Figure 1.1 is a block diagram for a reactor water level measurement system. The differential pressure transmitter (blue) is connected to pressure taps on the reactor vessel with two sensing lines. The electronic output from the transmitter is proportional to the difference between the condensate pot level and reactor water level. This is the DP-signal and at the same time one of the inputs to the density compensation units (yellow). The density compensation unit has the differential pressure, DP, and reactor pressure, P, as inputs and the density compensated water level signal as output. After the density compensation unit isolation amplifiers follows; see Figure 1.1.

1.2 Analogue and digital instrument components

Mainly depending on the fact that the Swedish BWRs were constructed in the seventies and eighties, the instrument systems were originally designed with analogue technique. The components in question are transmitters, density converters, isolation amplifiers and regulators. Now when the instrument systems are modernized in many plants they are replaced by newly developed units. This often implies that old analogue components are replaced by digital ones.

It is important to consider reliability, expected lifetime, capability of resisting temperature and radiation and so on when instrument components are exchanged. It is also, however, important that the response time of the new component is acceptable.

1.3 The content of the report

This report presents results from sensor investigations with instrument components. The thing in common for most of the experiments are that the components have been tested in a laboratory environment or under such operational conditions that accepted experiments. The investigations include:

- A comparison between analogue and digital transmitters and density converters.
- A comparison between analogue pressure transmitters of different designs.
- Operational experience with a not correct working pressure transmitter and the experiment to identify the fault.
- A description of methods for testing temperature sensors when they are already installed in the plant.

2 Exchange of analogue to digital instrument components

There is an interesting development in process industry when we talk about instrumentation and surveillance. The trend is that old analogue instrument components are replaced by new digital ones. This is the case for e.g. digital transmitters and digital controllers. Added to that, the field-bus has been available in process industry for many years. With the aid of a field-bus all transmitters in a plant can be connected in a network, and from a central place in the plant an arbitrary transmitter can be addressed for adjustment of e.g. physical range.

It will take a long time before field-busses are introduced at a grander scale in nuclear power plants. The reason for this is of course the special quality demands in the nuclear industry. On the other hand, digital controllers, transmitters and other digital components are already in use in nuclear power plants. The transfer to digital instrument components happens gradually. Old analogue units, not any longer in storage, are replaced by modern digital components. Typical is that the analogue input-output standard (e.g. 4-20 mA) still is valid. A digital transmitter has for example an analogue output. The same thing holds true when controllers are replaced. There are often analogue inputs and outputs. There are also examples where internal controller signals are D/A-converted to correspond to measurement possibilities that were available in the old analogue controller.

The present chapter compiles some results from different measurement campaigns performed by GSE Power Systems AB. The main focus in the presentation is the dynamic character of the components. The comparison between analogue and digital components presented in this report is performed with the individual parameter adjustment that was valid for the component. The report does not discuss the possible filtering of each component.

2.1 Comparison between an analogue and a digital transmitter at Oskarshamn 2

At a sensor investigation at Oskarshamn 2 in 1997 a comparison was carried out between an analogue and a digital pressure transmitter. The comparison was performed in a laboratory where the transmitters were exposed to a common fast fluctuating pressure at the same time as their output signals were recorded; see Figure 2.1. For practical reasons pneumatic air was used as the pressure source. This fact limited to some extent the rapidity of the pressure changes.

The transmitter signals for the complete experiment from the analogue transmitter Fujii and the digital transmitter ASK800 are displayed in Figure 2.2. In this time scale the figure confirms that there is good agreement between both signals. A closer examination of the signals in an expanded time scale proves the dynamic deviation between the transmitters; see Figure 2.3. The digital transmitter ASK800 reacts with a delay time in relation to the analogue transmitter Fujii during the pressure reduction displayed in Figure 2.3.

Figure 2.4 explains the parameters that will be used to describe the transmitter dynamics. The figure displays a step input signal and corresponding output signal. The output signal reacts with a delay time and a time constant. The delay time (or transport time) is called T_d and the time constant T_c. The time constant is defined as the time it takes for the output to grow to 63.2 % of the final value, not taking the delay time into account; see Figure 2.4. The transport time is a pure delay time; that is the time before the component starts to react at all.

From experience we know that analogue components are characterized by a response with a time constant but without a delay time. The digital components on the other hand have a response characterized by a time constant as well as a delay time.

For the digital transmitter ASK800, the delay time was estimated to T_d = 200 ms; see Figure 2.3. One can also observe that ASK800 has a longer time constant T_c than Fujii. This is obvious since the slope for Fujii is steeper than corresponding slope for ASK800 during pressure reduction. With the aid of process identification a model has been calculated that describes the relation between the two signals. In this case Fujii is treated as input signal and ASK800 as output signal. A step test of the identified model is presented in Figure 2.5. The results indicates that $T_d + T_c$ = 330 ms. Observe that this is the dynamic difference between the two transmitters.

The APSDs (Auto Power Spectral Density) for the signals from the laboratory experiment are presented in Figure 2.6. The figure show that the APSDs agree with each other up to 1 Hz. Thereafter ASK800 is clearly damped in comparison with Fujii. Evidently it is the extra filtering included in ASK800 that causes the observed damping.

According to a note from the experiments at Oskarshamn, ASK800 included a filter with the time constant T_c = 0.125 s. This can explain the deviation in slope for the transmitter signals during pressure reduction as it is shown in Figure 2.3.

2.2 Comparison between two digital and one analogue transmitter at Ringhals 1

An investigation similar to the one described in Chapter 2.1 has been performed at Ringhals 1. This time two digital and one analogue pressure transmitter were studied in laboratory. The transmitters were Hartmann & Braun AVI200, Rosemount 3051C-smart and Hartmann & Braun ASK800. Out of these AVI200 is analogue while the others are digital.

The three transmitters were connected to a common pressure source in a similar way as in the experiments presented in chapter 2.1. Sampling of transmitter signals started during simultaneous variation of pressure. The results of the pressure fluctuations are displayed in Figure 2.8 and 2.9. Qualitatively, this is the same pattern as during the experiments in Oskarshamn. Both of the digital transmitters have a delay time in comparison with the analogue transmitter. The analogue transmitter is therefore faster in the beginning. An estimate of the delay time has been performed and the results are T_d = 95 ms for ASK800 and T_d = 60 ms for Rosemount 3051C. It is also interesting to note that the transmitter Rosemount 3051C lacks internal filter in this test. This is the reason for the edges on the curve in comparison with the other signals. Another observation is that Rosemount 3051C in spite of a delay time reaches the final value before the analogue transmitter AVI200; see Figure 2.8 and 2.9. The reason is that the time constant T_c is shorter for Rosemonut 3051C than for AVI200. It is also obvious that ASK800 has the longest time constant T_c in comparison with the other tested transmitters; see Figure 2.8 and 2.9.

Figure 2.10 shows APSDs for the three transmitter signals. It is clear that the APSDs agree up to 2 Hz, thereafter they disagree. ASK800 has the most damped character above 2 Hz of the three signals. The APSD for AVI200 and Rosemount 3051C agree quite well up to 7-8 Hz. Thereafter the noise content for Rosemount 3051C increases compared to AVI200. This is probably a result of the earlier mentioned edges (high frequency) in the time series data for Rosemount 3051C.

To summarize, it could be said that the critical dynamic deviation between an analogue and a digital transmitter is the delay time. The digital transmitter reacts with a delay time. This can cause trouble when the transmitter is a part of an automatic control system. A delay time in a control loop increases the phase angel and can therefore reduce the stability. A delay time is also annoying when the transmitter is part of the reactor protection system. In this case the triggering of the protection system will be extra delayed with T_d for the transmitter. It is therefore important to pay attention to the delay in response when an analogue transmitter is replaced by a digital one.

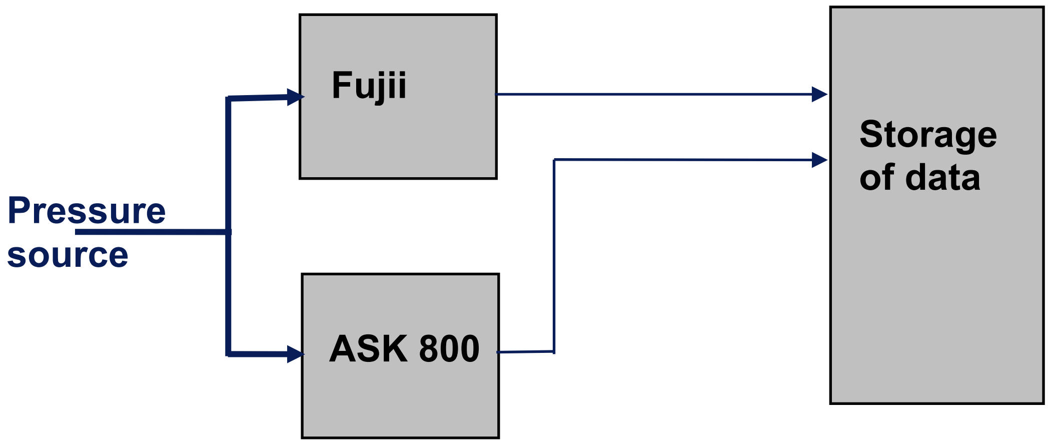


Figure 2.1   Laboratory test of the digital pressure transmitter ASK 800 in comparison with the analogue transmitter Fujii. Oskarshamn 2, 1997.

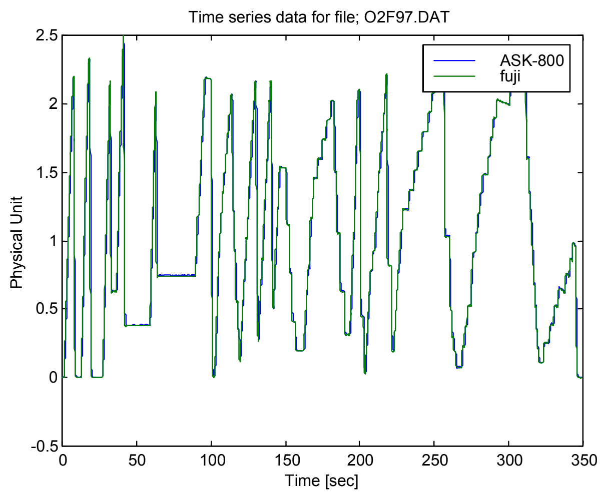


Figure 2.2 Output signals from the transmitters ASK800 and Fujii as a function of time during variation of pressure (P). See also Figure 2.1 above. From Oskarshamn 2, 1997.

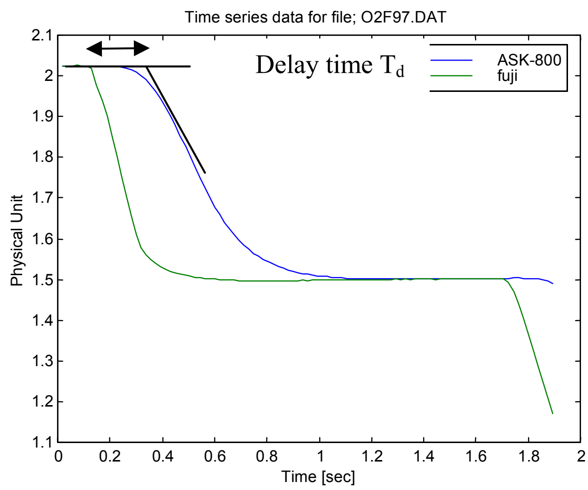


Figure 2.3 A closer look at the difference between the signals from the digital transmitter ASK800 and the analogue transmitter Fujii. The dynamic difference consists of T_d = 200 ms *and a time constant. Oskarshamn 2, 1997.*

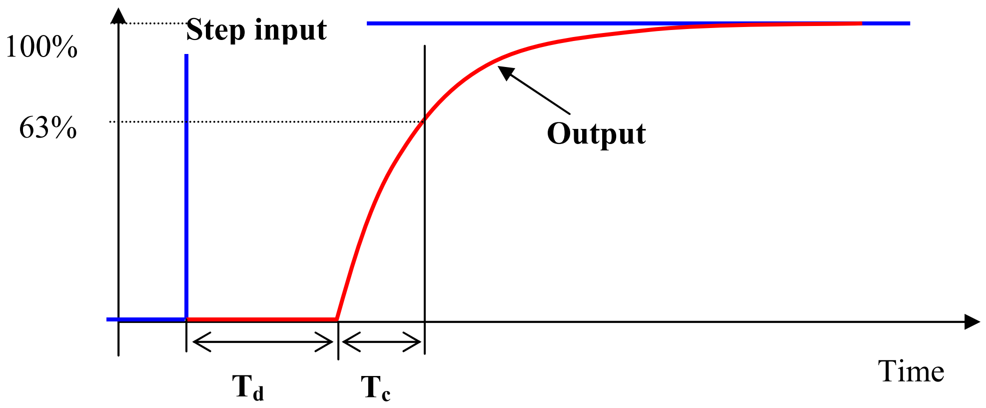


Figure 2.4   Definition of delay time T_d and time constant T_c.

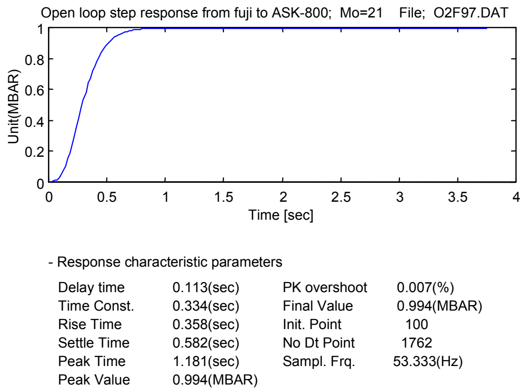


Figure 2.5 Step test with the identified model where the signal from Fujii act as input signal and the signal from ASK800 act as output signal. $T_d + T_c = 0.33$ s. Results from Oskarshamn 2, 1997.

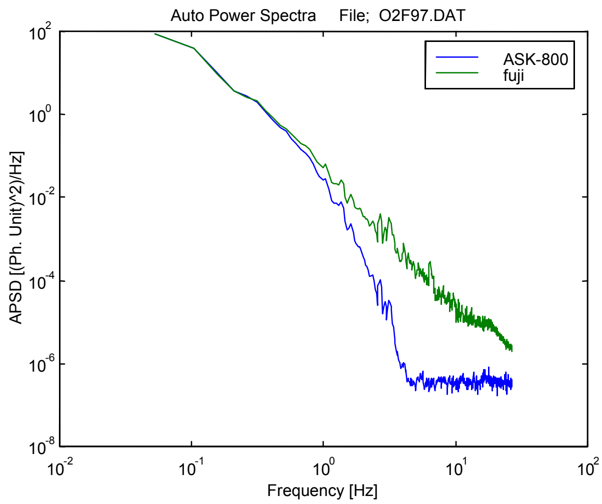


Figure 2.6 APSD for the ASK800 and Fujii signals based on measurement data from the laboratory experiment at Oskarshamn 2, 1997.

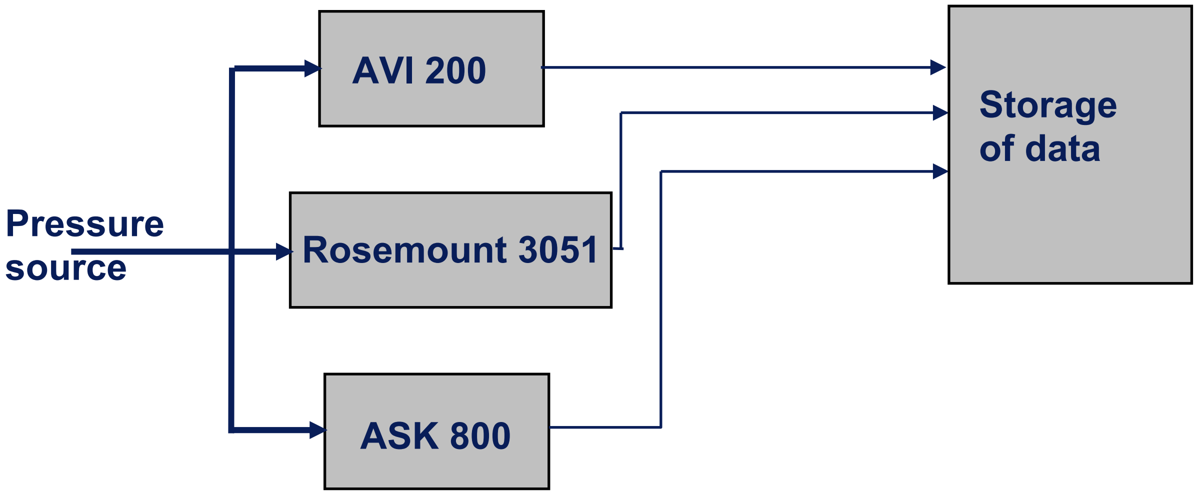


Figure 2.7 Laboratory test of the digital transmitters ASK800 and Rosemount 3051C and the analogue transmitter AVI200. Laboratory investigation performed at Ringhals 1, 2000.

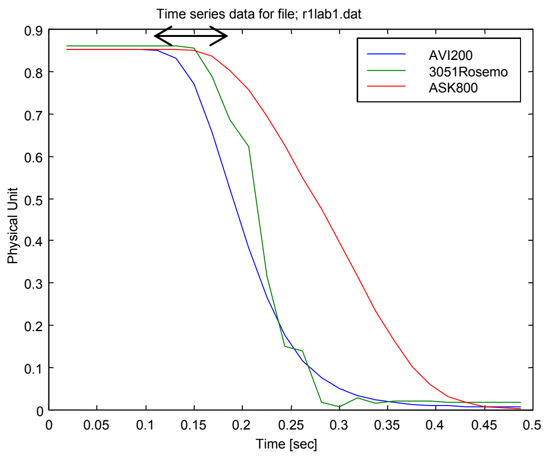


Figure 2.8 Sensor signals from AVI200, Rosemount 3051C and ASK800 during a fast pressure reduction. The digital transmitters displays a delay time. Ringhals 1, 2000.

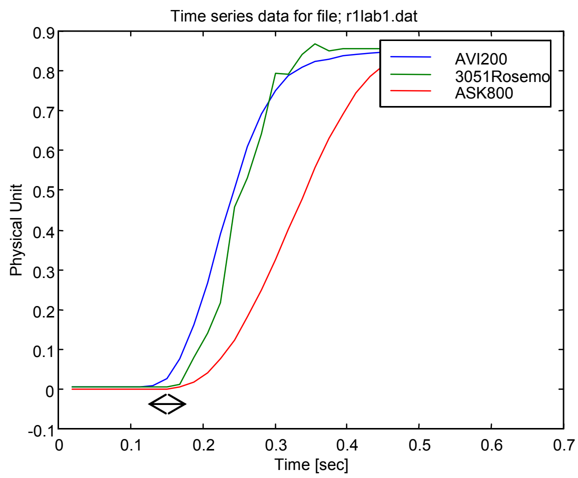


Figure 2.9 Sensor signals from AVI200, Rosemount 3051C and ASK800 during a fast increase in pressure. The signals from the digital transmitters are clearly delayed. Ringhals 1, 2000.

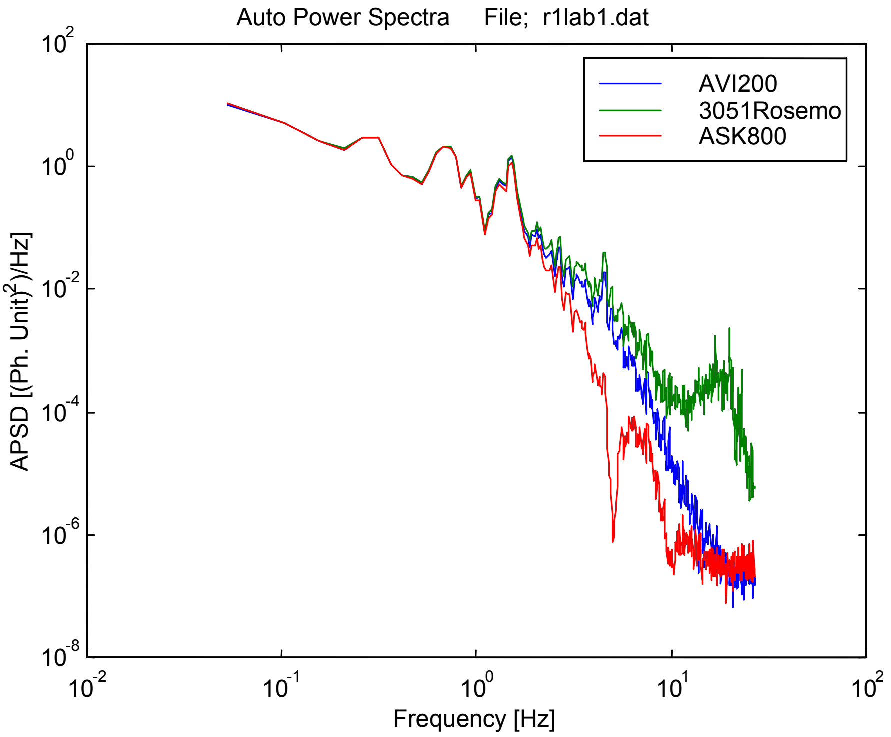


Figure 2.10 *APSD for the sensor signals from AVI200, Rosemount 3051C and ASK800 during experiments with pressure fluctuations. Observe that the APSD functions agree very well up to 2 Hz. Above this frequency there is deviation between the transmitters. Ringhals 1, 2000.*

2.3 A comparison between an analogue and a digital density converter

Measurement of the water level in a BWR is performed with differential pressure via the pressure taps on the reactor vessel. As seen in Figure 1.1 the pressure taps are followed by an electronic unit, a so-called density converter. This unit compensates for density. The output signal from the density converter is proportional to the reactor water level. A density converter can have different applications, but it is common in older reactors that the water level is a function of the differential pressure and reactor pressure. This is the case in Figure 1.1. The electronic density converter has differential pressure- and pressure transmitter outputs as inputs and the output from the converter is the reactor water level signal. The density converter is an analogue electronic unit.

As was the case with the transmitters, it is now common to replace old analogue converters with digital ones. Such an exchange has been performed at Barsebäck 2 and it is also under way in other plants. Experiments have been performed in laboratory at Barsebäck 2 to investigate the difference in character between an analogue and a digital density converter; see Figure 2.11.

The investigated units are Hartmann & Braun TZA2 (old-analogue) and Hartmann & Braun TZA4 (new-digital). The setup presented in Figure 2.11 will be used, since the converters operate with current signals (0-20 mA). One of the current generators corresponds to DP (Differential Pressure) and the other one to P (Pressure). Observe that the units are connected in such a way that the current signal for DP is equal for both units. The same holds true for signal P. Finally there is a resistance R in all current loops to get voltage to the sampling unit; see Figure 2.11. The current outputs from the converters are equipped with resistors for the same reason.

Figure 2.12 shows the input signal DP and the corresponding level signal TZA2-level from the analogue unit TZA2. The dynamic relation between input and output can be evaluated by identifying the model where DP is input and TZA2-level output. Step test of the model is presented in Figure 2.13. The step test gives that $T_c = 50$ ms.

The results for the digital density converter TZA4 are displayed in Figure 2.14 and 2.15. The time series data show that the digital density converter has different dynamics. The output signal is clearly delayed compared to the input signal; see Figure 2.14. A model was identified and step tested. The result for the step test in Figure 2.15 is $T_d + T_c = 250$ ms. The time constant and delay time is consequently 5 times longer for TZA4 in comparison with TZA2 regarding the dynamic relation from DP to Level.

Figure 2.16 shows the output signals from the density converters TZA2 and TZA4 during variation of the pressure signal P. DP is constant during this experiment. It is obvious that the TZA4-level signal is delayed compared with the TZA2-level signal. Step test of the identified model for the relation between P and TZA4-level is shown in Figure 2.17. The result is that $T_d + T_c = 934$ ms. Corresponding dynamics for the relation between P and TZA2-level is displayed through a step test in Figure 2.18. The figure gives that $T_c = 53$ ms.

The old analogue unit TZA2 has fast dynamics considering the relation between DP and Level. The same conclusion holds true for the relation between P and Level. Both relations are characterized with $T_c = 50$ ms. The new digital unit TZA4 is on the other hand clearly slower. The relation between DP and Level is described with

$T_d + T_c$ = 250 ms, while the dynamics with P as input and Level as output is described with $T_d + T_c$ = 934 ms. The results from the experiments are displayed in Table 2.1.

Table 2.1 Results for the dynamic relation between DP, P and Level for the analogue and digital density converters.

Density converter	**DP ⟶ Level**	**P ⟶ Level**
	$T_d + T_c$ (ms)	$T_d + T_c$ (ms)
TZA2 (old – analogue)	50	53
TZA4 (new - digital)	250	934

2.4 Replacement of all instrument components in the water level measurement

Figure 2.19 displays a block diagram for the reactor water level instrumentation. The figure also shows a complete exchange of transmitters and density converters from analogue units to digital ones. This implies that the delay times will be added. This is obvious since the transmitter and density converter are connected in cascade. There is therefore a reason to warn about that the total delay time can be too long if all instrument components are replaced.

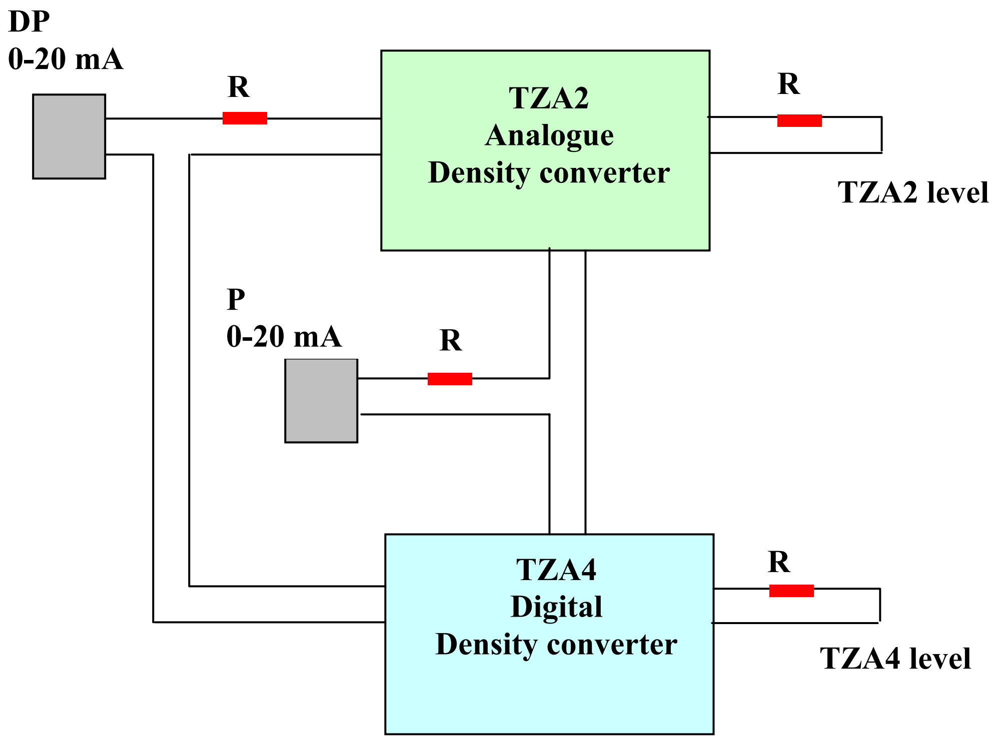


Figure 2.11 Laboratory experiment with the aim to compare the analogue density converter TZA2 with the digital TZA4. Measurements at Barsebäck 2

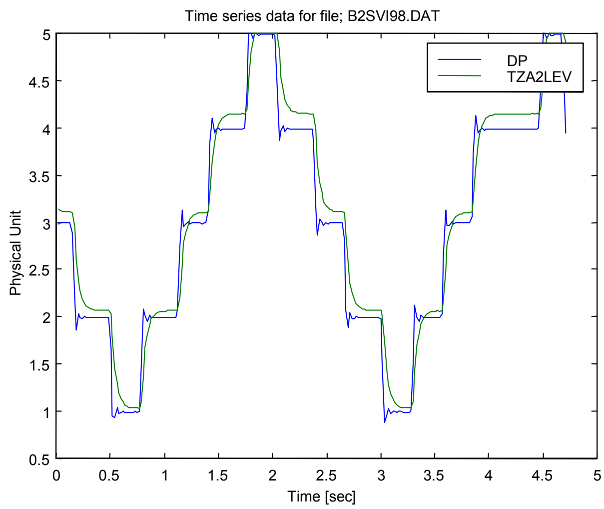
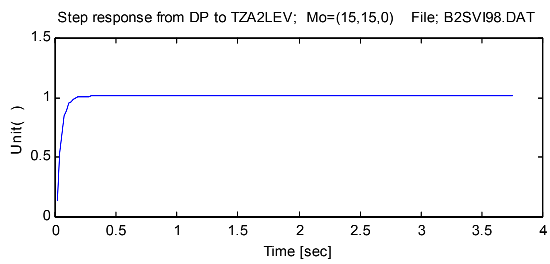


Figure 2.12 Input signal DP and output signal Level for the analogue density converter TZA2. Experiment at Barsebäck 2, 1998.



- Response characteristic parameters

Time const	; 0.050233 (sec)	PK overshoot	; 0 (%)
Rise time	; 0.10206	Final value	; 1.0207
Peak time	; Inf	Init data	; 6500
Settle time	; 0.15	No data	; 3501
Peak value	; 1.0216	Sampl Frq.	; 53.3333 (Hz)

Figure 2.13 Step test with DP as input signal and Level as output signal for the density converter TZA2. Experiment at Barsebäck 2, 1998.

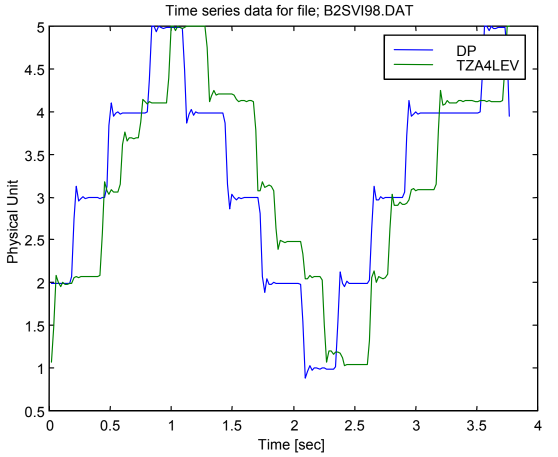
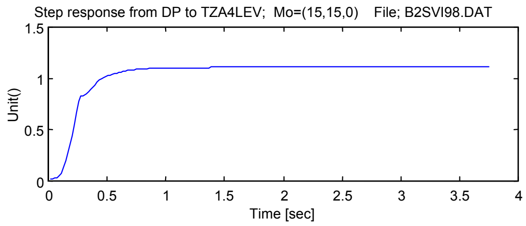


Figure 2.14 Input signal DP and TZA4-Level as a function of time. Barsebäck 2, 1998.



- Response characteristic parameters

Time const	;	0.24932 (sec)	PK overshoot	;	0 (%)
Rise time	;	0.45282	Final value	;	1.1072
Peak time	;	Inf	Init data	;	5000
Settle time	;	0.58125	No data	;	5001
Peak value	;	1.1072	Sampl Frq.	;	53.3333 (Hz)

Figure 2.15 Step test of the model with DP as input signal and TZA4-Level as output signal. ($T_d + T_c$) = 250 ms. Barsebäck 2, 1998.

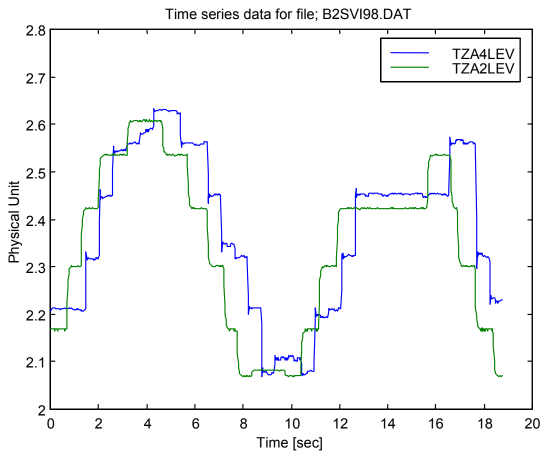
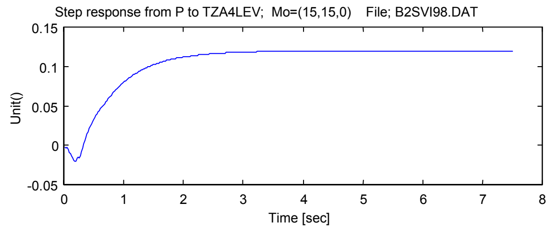


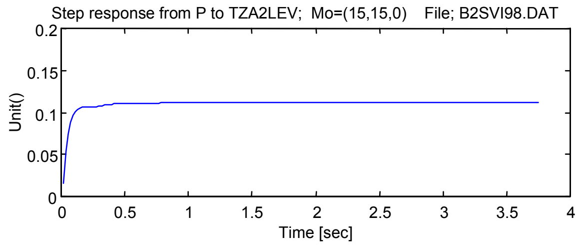
Figure 2.16 Output signals TZA2-Level and TZA4-Level as a function of time during fluctuation of P. Barsebäck 2, 1998.



- Response characteristic parameters

Time const	;	0.9341 (sec)	PK overshoot	;	0 (%)
Rise time	;	1.7424	Final value	;	0.11965
Peak time	;	Inf	Init data	;	25000
Settle time	;	2.175	No data	;	4687
Peak value	;	0.11965	Sampl Frq.	;	53.3333 (Hz)

Figure 2.17 Step test of the model with P as input signal and TZA4-Level as output signal. ($T_d + T_c$) = 934 ms.



- Response characteristic parameters

Time const	;	0.053046 (sec)	PK overshoot	;	0 (%)
Rise time	;	0.11363	Final value	;	0.1123
Peak time	;	Inf	Init data	;	25000
Settle time	;	0.1875	No data	;	4687
Peak value	;	0.1123	Sampl Frq.	;	53.3333 (Hz)

Figure 2.18 Step test of a model with P as input signal and TZA2-Level as output signal. T_c = 53 ms. Barsebäck 2, 1998.

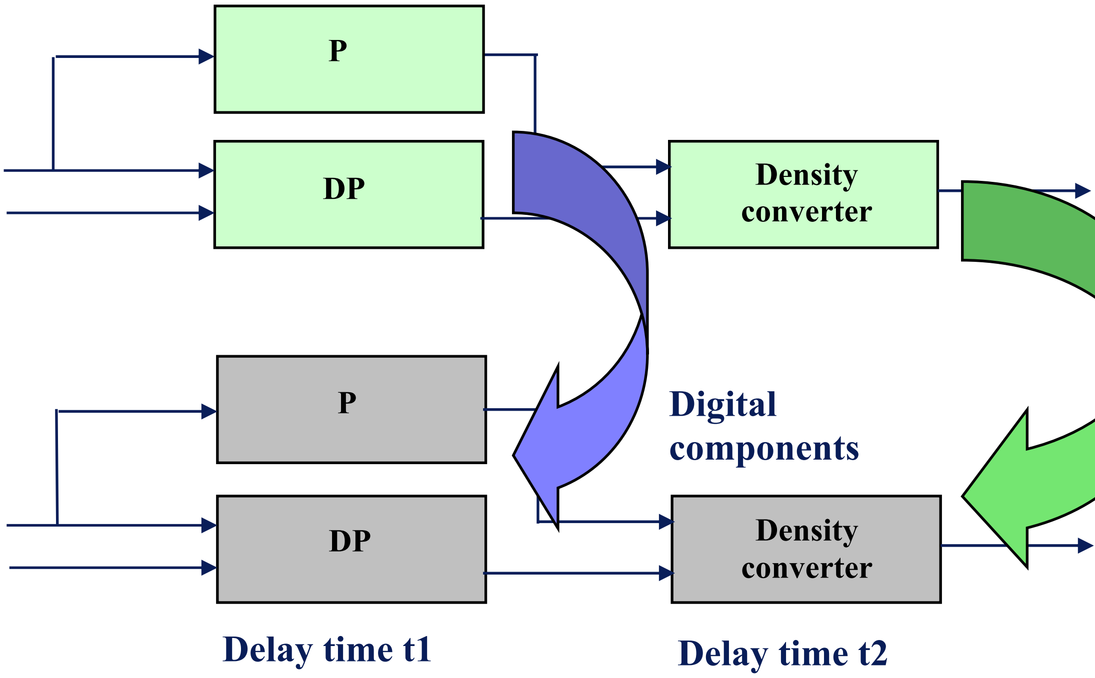


Figure 2.19 The delay times for the digital components will add together when the complete reactor water level instrumentation with analogue transmitters and density converters are replaced by digital components.

3 Laboratory investigation of pressure transmitters with Bourdon tube design

During sensor tests performed by GSE Power Systems at Swedish power plants it was shown that one type of transmitter exhibit dynamic deviations. The type of transmitter is Hartmann & Braun Shoppe & Faeser TDE220.

When performing an investigation at Oskarshamn 2, two pressure signals were recorded from multiple transmitters connected to the same pressure taps on the reactor vessel. Both transmitters were of the mentioned type. The signals deviated from each other in spite of the agreeing technical assumptions for the measurements. Figure 3.2 presents the pressure signals 211K116 and 211K101 as a function of time. It is obvious that the signals deviate from each other. The low frequency components in the time series for 211K116 is not observed with 211K101, see Figure 3.2. APSDs for both signals confirms the dynamic deviation. The signal 211K101 has noticeably higher noise content than 211K116; see Figure 3.3.

A closer investigation of this type of transmitter was performed in a laboratory test at Barsebäck 2 in 1998. Four transmitters in total were examined during this investigation; see Figure 3.1. Out of these, two were of the type TDE220 and the remaining two were Hartmann & Braun AED280. A reference transmitter manufactured by Alvetec was used as well.

The pressure was increased by water in the sensing lines until it reached 74.5 bar. Then the pressure was released stepwise; see Figure 3.4. Interestingly enough, the signals show different behavior during the experiment. The signals from the transmitters TDE220 contain high frequency noise that is clearly triggered by the step changes in pressure; see Figure 3.4. The signals from AED280 and Alvetec have a more filtered behavior in comparison with TDE220. It is also evident that AED280 has longer response time than the other transmitters.

The reason for the high frequency fluctuations when using TDE220 can be understood by examining the design of the transmitter; see Figure 3.5. The transmitter is designed with a Bourdon tube with a movable tip influenced by the pressure in the tube. The tip in its turn influences a differential transformer that generates the transmitter signal. This construction is defective. An independent vibration in the Bourdon tube influences the transmitter signal. What happens during the experiment is that a disturbance of the Bourdon tube starts and continues in connection to the step test. The recorded transmitter noise arose in the transmitter mechanics and was not caused by the pressure in the sensing line. The TDE220 transmitter signals also show that this independent noise occur between 2 and 3 seconds before the step changes in pressure, see Figure 3.4.

As a comparison, the design of AED280 is presented in Figure 3.6. This construction works with small movements of the transmitter membrane position, which is transferred to the transmitter signal. This is a modern transmitter example.

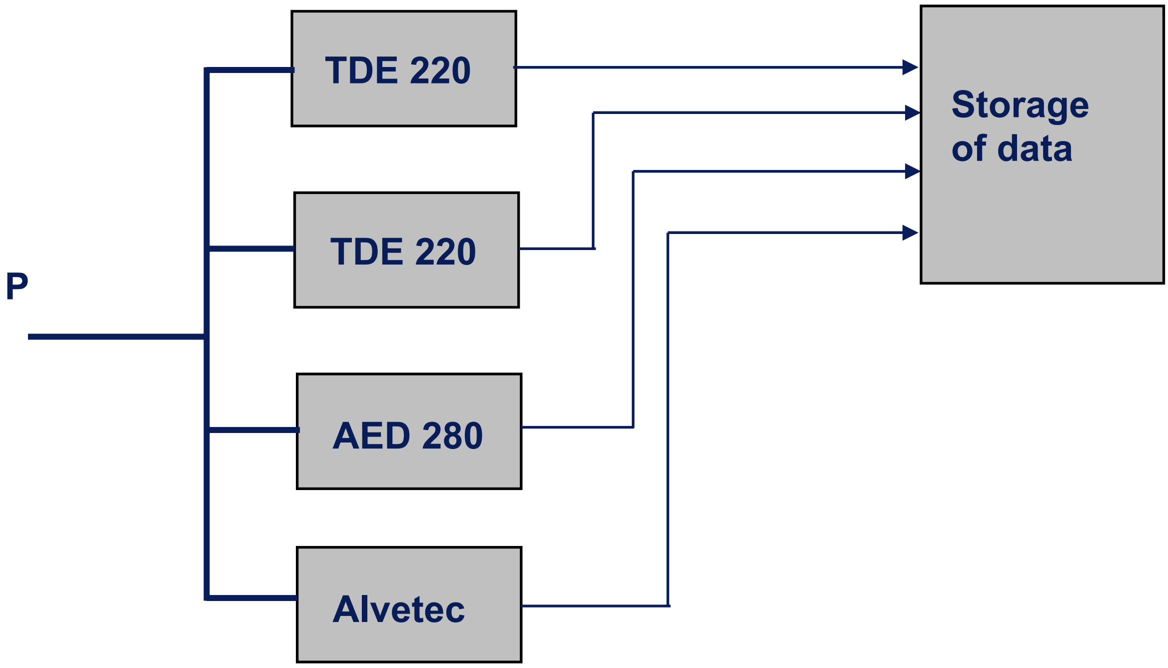


Figure 3.1 Investigation of pressure transmitters in laboratory, Barsebäck 2, 1998.

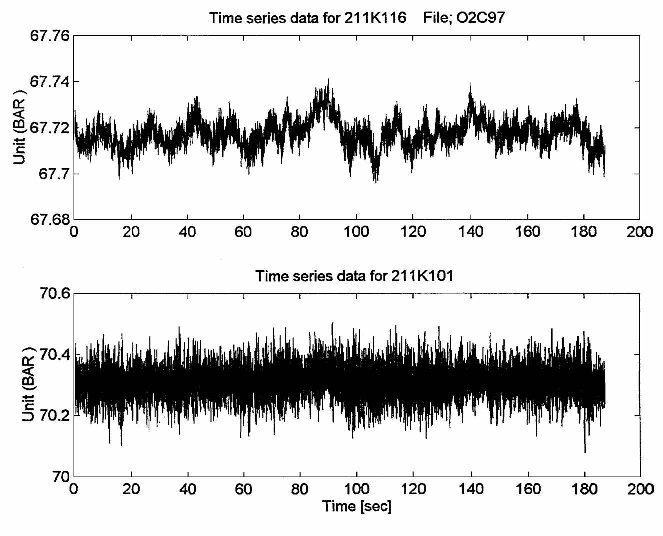


Figure 3.2 Recording of pressure signals 211K116 and 211K101 at Oskarshamn 2, 1997.

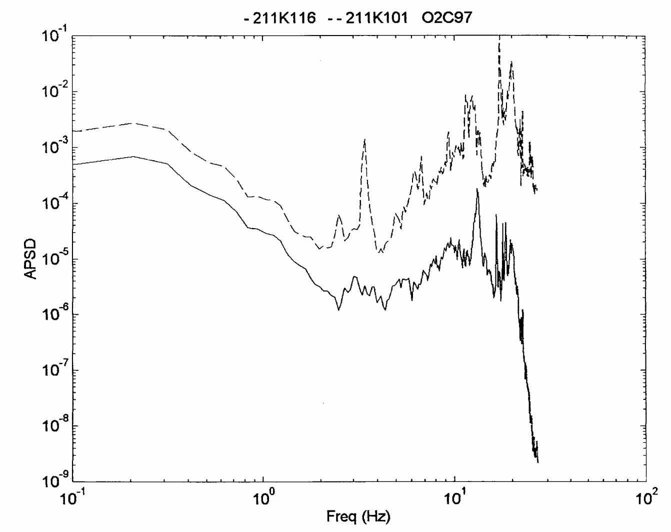


Figure 3.3 APSD for the pressure signals 211K116 and 211K101 at Oskarshamn 2, 1997.

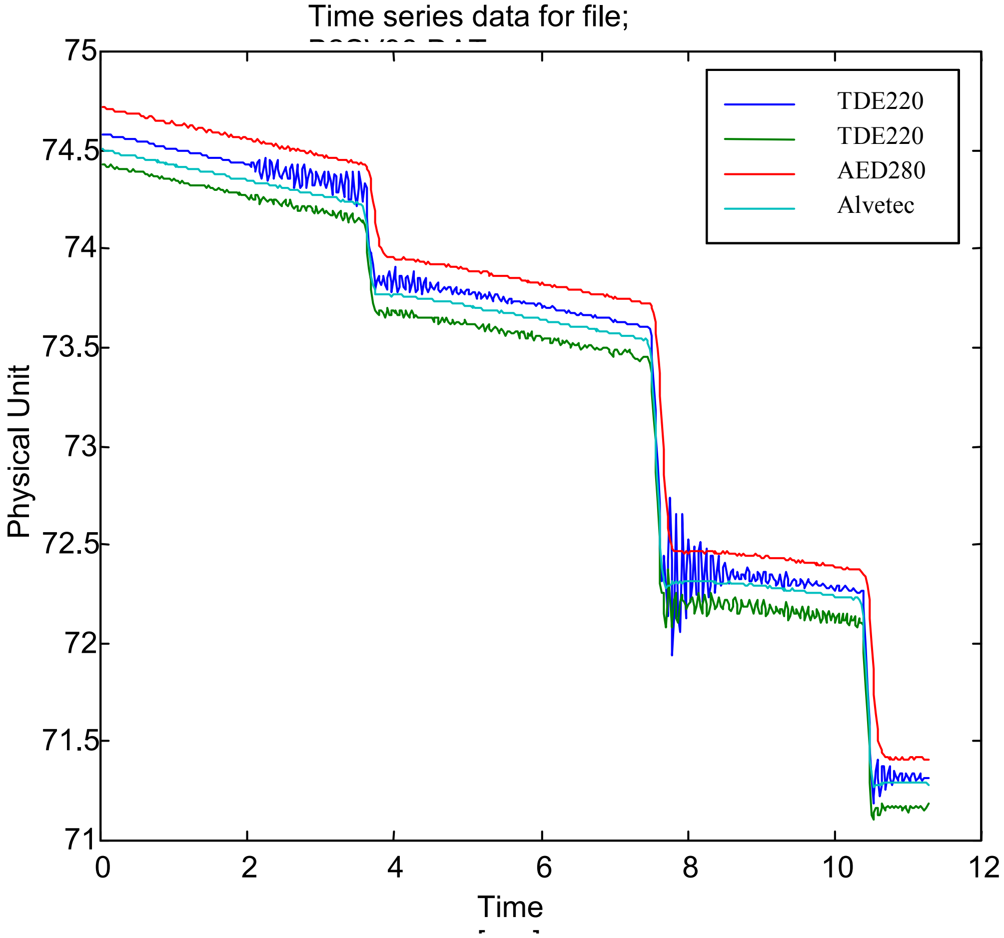


Figure 3.4 Results during the laboratory investigation of pressure transmitters. Barsebäck 2, 1998.

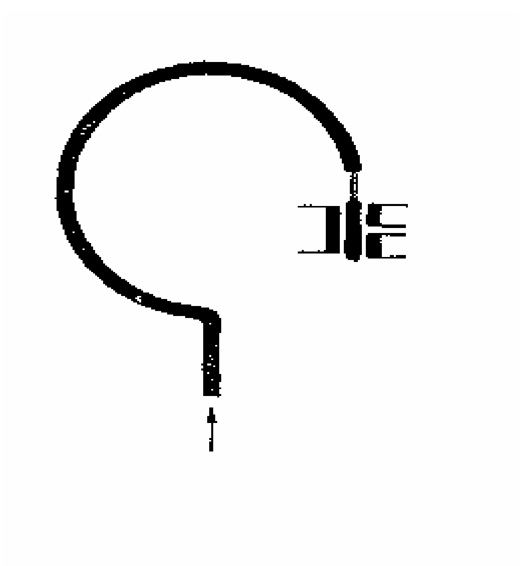


Figure 3.5 Hartmann & Braun Shoppe & Faeser TDE220.

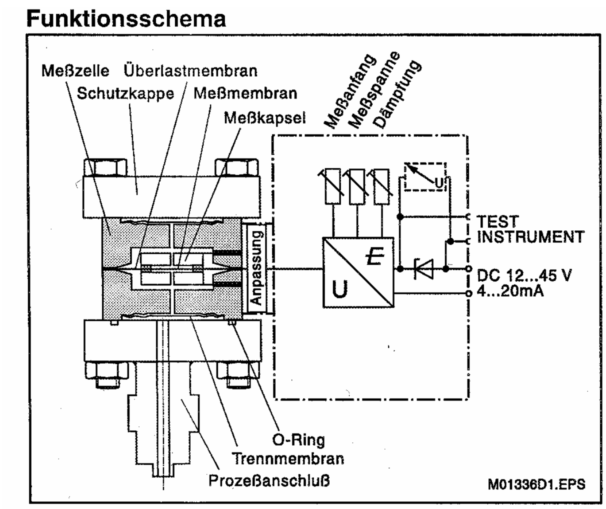


Figure 3.6 Hartmann & Braun AED280.

4 Experiments with an error indicated steam pressure sensor

Since 1994, GSE Power Systems AB has performed annual investigations of sensors at KKM. 300 sensors are investigated every year. Many of these are part of the reactor protection system. A number of sensor test reports have been delivered to KKM over the years. These are now stored in a database called SensBase™ developed by GSE. The following list contains examples of parameters stored with SensBase™ for each sensor or multiple sensor pair: short time series (30 s), APSD, histogram with mean value, standard deviation, skewness, kurtosis, time constant, multiple sensor information in time domain with gain, offset and amplitude ratio.

Sensor errors can be observed with SensBase™ by means of comparing for example APSDs for redundant transmitters. Errors can also be observed via multiple sensor comparison in time domain with gain, offset and amplitude ratio. Time constants can be evaluated for density converters that are part of the reactor water level instrumentation. These time constants can be compared with multiple measurement channels to observe deviations. All parameters in SensBase™ can also be compared with history to observe trends for example caused by ageing.

SensBase™ uses a GUI (Graphic User Interface) where transmitters with sensing lines and connections to the process are presented in graphic windows; see the window presented in Figure 4.1. This GUI is called “high pressure instrumentation for turbine”. The transmitters work like push buttons in the window in question. The graphic presentation of stored data is available for the user by pushing one or more transmitter buttons. There are in total 23 different GUI and these are used to cover the instrumentation at KKM. Every GUI covers a part of the instrumentation.

The turbine instrumentation in Figure 4.1 is valid for both turbine A and B at KKM. Letter A in the transmitter name refers to turbine A and letter B refers to turbine B. A transmitter with the name MP05B2 is a steam high-pressure transmitter for turbine B; see Figure 4.1. The GUI in SensBase™ shows that MP05B1 and MP05B2 are multiple with a common sensing line. The same holds true for the pair MP05B3 and MP05B4. It is also reasonable to expect that there is an agreement between the steam pressure pairs (MP05B1, MP05B3) and (MP05B2, MP05B4), since they record the steam pressure in the same stage of the process; see Figure 4.1.

4.1 Steam pressure transmitter MP05B2

In 1999, a deviating behavior was observed for the steam pressure transmitter MP05B2. Temporary changes in the signal mean value was observed. The deviations occurred intermittent. In Figure 4.2 an example from 2001 is shown. The signals MP05B2 and MP05B4 are recorded as a function of time in the figure and after 150 seconds there is a temporary reduction in pressure for MP05B2 that is not the case for MP05B4. MP05B2 and MP05B4 are connected to different pressure taps on the turbine according to the instrument system in Figure 4.1. Therefore it could not be excluded that the process caused the dip in pressure. Because of redundancy reasons it was unfortunately not possible to record MP05B1 and MP05B2 during full power operation. Such a recording could have shown if the transmitter MP05B2 was deviating.

An investigation of the sensors was made based on measurement data collected during normal tests of the turbines A & B, when the reactor was no longer in power operation mode. A separate sensor recording was this time performed with the signals MP05A1 – MP05A4 and MP05B1 – MP05B4. During the measurement the steam pressure reference value was changed as the pattern shown in Figure 4.3 (turbine A) and Figure 4.4 (turbine B). Notice the good agreement between the steam pressure signals MP05A1 – MP05A4 for turbine A when the reference value is changed. The only deviation between the signals is a minor offset; see Figure 4.3.

The result for turbine B is shown in Figure 4.4. This figure displays that the pressure signals agree in the same way as for turbine A. Here, however, there is an interesting deviation. A sudden step shaped change occurs for MP05B2 after 120 s; see Figure 4.4. This shift is unique for the transmitter MP05B2. The interpretation is obvious. The transmitter MP05B2 has deviating dynamics.

The experiment has also been evaluated with the measures used in SensBase™. Gain, Offset and Amplitude ratio are used in SensBase™ for the comparison between time series. These measures can easily be explained with a graph where time series for the two signals are represented with the x- and y-axis. When two multiple signals are identical they form a straight line in the coordinate system with the slope = 1 and the extrapolation of the line passes origin. The relation between MP05B4 and MP05B3 are presented in Figure 4.5. The agreement between the signals is almost ideal. Gain is equal to the slope, deviation from origin the same as Offset and the deviation from the straight line is an Amplitude ratio measure.

These measures of comparison have been calculated for the signal pairs in Table 4.1 and 4.2. Gain is close to 1 for all comparisons while Offset is highest for the signal pair MP05B1 and MP05B2 in the tables. The Amplitude ratio valid for the different signal pairs is highest for MP05B1, MP05B2 where the figure 37.5 % is noted. The explanation for the high Amplitude ratio is evident from Figure 4.6, that presents MP05B2 as a function of MP05B1. The problem with MP05B2 causes the deviation from the straight line in the diagram.

Table 4.1 Gain, offset and amplitude ratio for the steam pressure signals in turbine B.

Parameters	031MP005B1/ 031MP005B2	031MP005B3/ 031MP005B4
Gain	0.9761	1.0010
Offset	1.5891	0.3709
Amplitude ratio	37.3	0.8176

Table 4.2 Gain, offset and amplitude ratio for the steam pressure signals in turbine A.

Parameters	031MP005A1/ 031MP005A2	031MP005A3/ 031MP005A4
Gain	0.9809	1.0182
Offset	1.0758	-1.3822
Amplitude ratio	3.2830	0.3476

4.2 Exchange of the transmitter MP05B2

The transmitter MP05B2 was sent for service during the regular outage 2001. The report from service proves that there were interrupts in the electrical output from the transmitter. There was a crack on the electronic filter unit in the transmitter that could explain the sudden reductions in signal mean value; see figure 4.2. The exchanged filter unit is presented in Figure 4.7, observe the crack in the picture. Service documentation shows that it was necessary to replace certain mechanical and electronic parts of the transmitter.

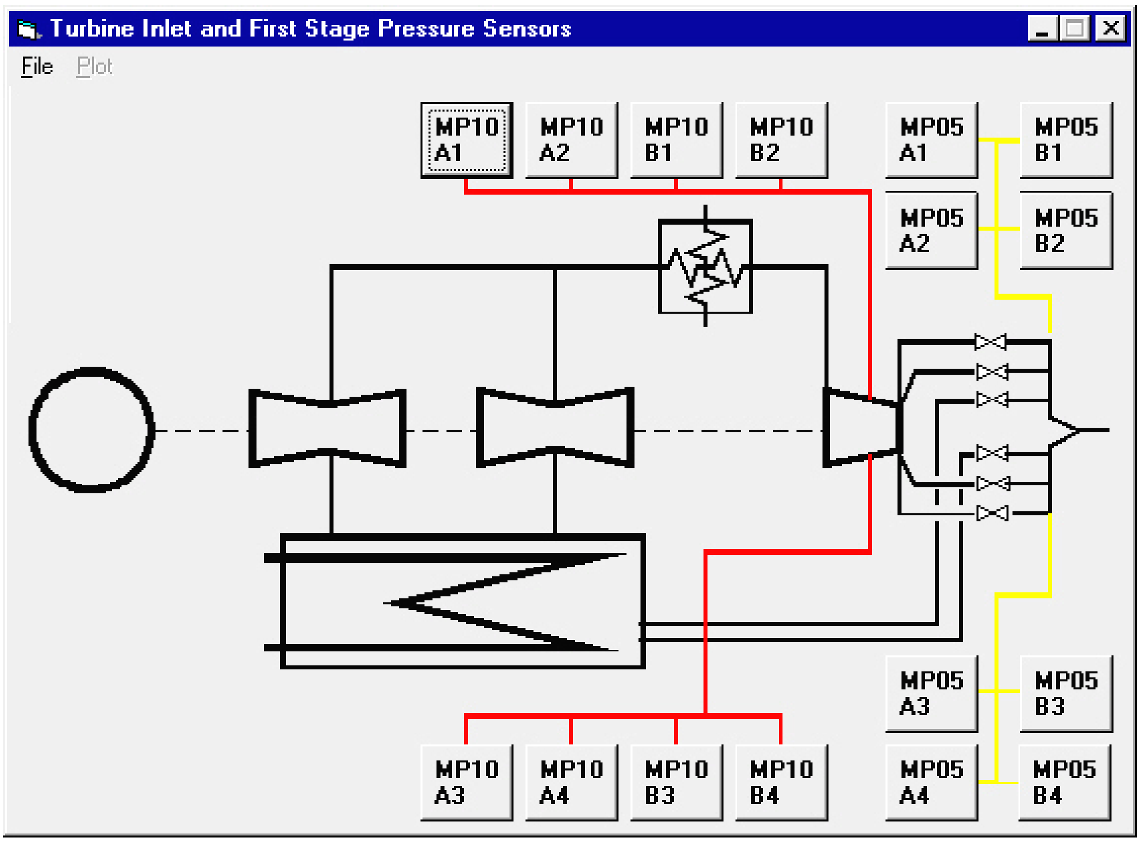


Figure 4.1 The instrumentation for steam pressure measurements in turbine A and B at KKM.

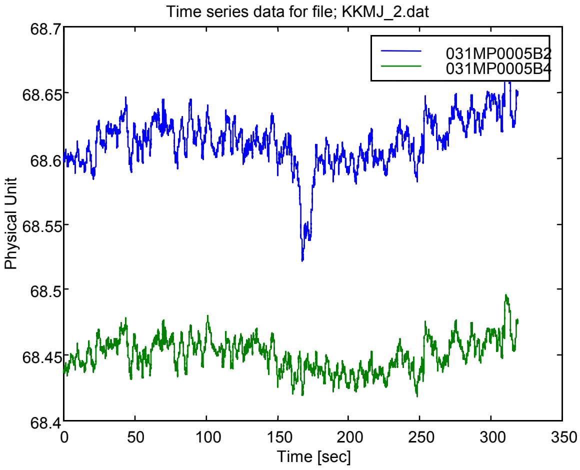


Figure 4.2 MP05B2 and MP05B4 as a function of time. KKM, 2001.

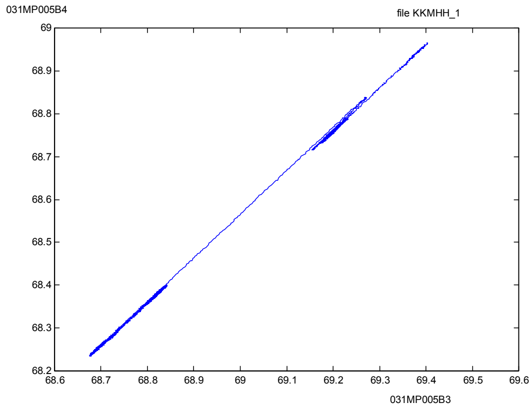


Figure 4.5 MP05B4 as a function of MP05B3 during the experiment. KKM, 2001.

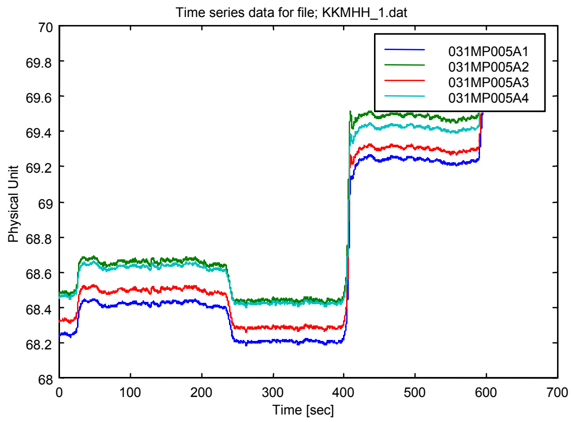


Figure 4.3 MP05A1-MP05A4 as a function of time during the experiment. KKM, 2001

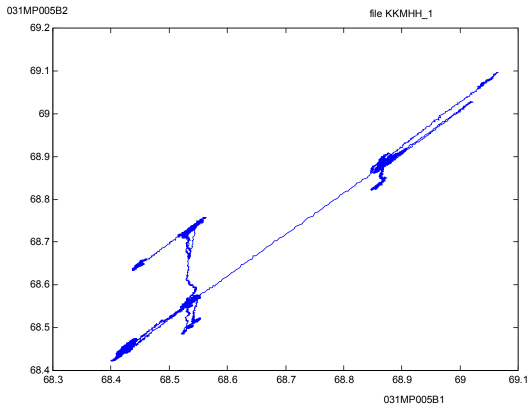


Figure 4.6 MP05B2 as a function of MP05B1 during the experiment. KKM, 2001.

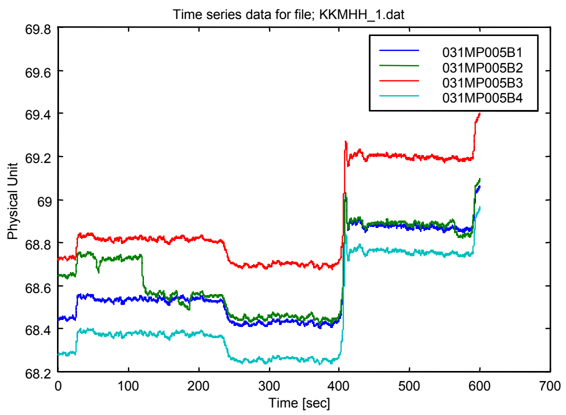


Figure 4.4 MP05B1-MP05B4 as a function of time during the experiment. KKM, 2001

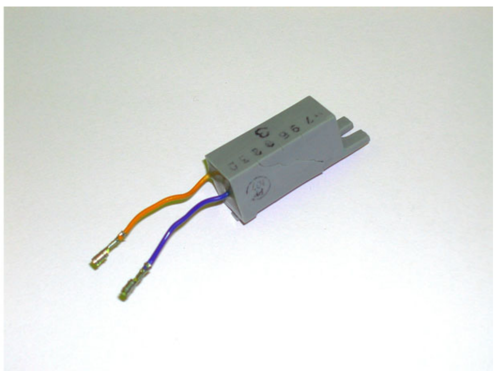


Figure 4.7 The electronic filter unit from the transmitter MP05B2.

5 Methods of investigating temperature sensors

Temperature signals normally include very little noise. There are many reasons for this. One explanation can be that the process is regulated in such a way that it only accepts very small fluctuations in temperature. Another reason can be that the measurement is filtered. An air temperature sensor that is constructed with a lot of metal will not react on small fast temperature fluctuations, for example. The real temperature is filtered by the construction of the sensor in such a way that only the mean value and the low frequency changes in temperature influence the measurement signal. The filtering also implies that a fast change in air temperature will be recorded by the measurement system with a time delay.

This chapter describes methods of investigating temperature sensors used at KKM. The first type of sensor measures air temperature while the other records water temperature in an emergency cooling system in the plant.

5.1 Investigation of air temperature

Steam lines at KKM are surrounded by temperature sensors in the so-called steam tunnel; see Figure 5.1. In this part of the reactor construction, where the external main steam line valves are installed, the aim with temperature measurement system is surveillance of leakage. They are in total 16 sensors of the RTD (Resistance Temperature Detector) type; see Figure 5.1.

These temperature sensors are tested in connection to the regular outage by being manually exposed to cooling spray. The cooling spray wets the temperature sensors and vaporizes. This process gives a fast reduction in temperature; see Figure 5.2. The reduction in temperature stops when the sensor is dry and all liquid has evaporated. Thereafter the temperature rises to the original temperature. The air temperature is the driving source of the increasing sensor temperature; therefore it is clearly slower than the cooling process. Figure 5.3 displays the temperature as a function of time during the cooling and natural heating of the sensor.

Used response times during cooling and reheating are defined in Figure 5.2 and 5.3. Cooling corresponds to the total temperature reduction that is 100 % and the cooling time is calculated to be between 10 % and 90 %; see Figure 5.2. Time for reheating is calculated to be from the point where the temperature starts to increase, just above 0 % in the Figure 5.3, until it reaches 63 % of the final value. The investigation is repeated every year and the results are stored.

5.2 Investigation of the temperature sensors in torus

Below the reactor at KKM there is a water filled torus shaped suppression pool, which is used in connection with emergency cooling. Steam can be transferred down into the torus to be condensed during an emergency. To supervise the torus, 12 temperature sensors, so-called RTD:s (Resistance Temperature Detectors), are mounted in thermo-wells in the torus; see Figure 5.4.

The temperature in the torus is always about 22 degrees. It does not contain any natural fluctuations, because the water volume is so large. Therefore one experiment with each temperature sensor is carried out every year to investigate the dynamics. The individual temperature sensor is dismounted from its thermo-well and entered into a bucket with ice and water. When the temperature is stabilized at zero degrees the temperature sensor is dried and remounted into the thermo-well. This is performed during full power operation of the reactor. Sampling of the measurement signals is performed continuously during the experiment. The experiment is repeated for all 12 temperature sensors.

The temperature during the experiment is presented in Figure 5.5. The cooling is a fast process. According to the diagram, temperature reduces from 24 degrees down to almost zero in between 700 to 800 seconds. The time constant for the temperature reduction is calculated as the time it takes for the temperature to lose 63 % of the total temperature reduction. This is the most common definition of the time constant. The horizontal arrow during the temperature reduction in Figure 5.5 represents the 63 % level. This is from a physical point of view the time constant for the RTD-element with belonging electronics. The numerical values prove that the time constant for the temperature reduction is about 10 s.

A temperature increase with longer time constant (about 60 s) than during cooling is observed when the temperature sensor is reinstalled in the thermo-well; see Figure 5.5. The horizontal arrow during temperature increase defines the 63 % level. The water in the torus tank heats the RTD-element via the thermal resistance between the RTD and the thermo-well.This results in a clearly slower response time.

It is interesting that both time constants can be used for diagnosis. Deviations in the RTD-element and the sensor electronics are correlated with the cooling time constant. The time constant during heating indicates if there is rubbish or oxide between the RTD-element and the thermo-well. The experiment is also partly a calibration of the temperature sensor in the range 24 – 0 degrees.

Figure 5.6 displays results from the experiments with SensBase™. The two bar graphs in the bottom display the initial temperatures (Highest temperature) and the cooled temperature (Lowest temperature) in the torus tank for a temperature sensor from the years 1997-2000. It is evident from the bar graph that the torus temperature is between 21 and 25 degrees while the cooled temperature fluctuates between zero and 1.1 degree. The two top bar graphs in Figure 5.6 display the time constants during heating (Time constant + thermo-well) and the time constants during cooling (Time constant RTD). The results for the time constants for heating are very smooth during the years (between 50-55 s), while corresponding time constants for cooling varies between 9 and 15 s.

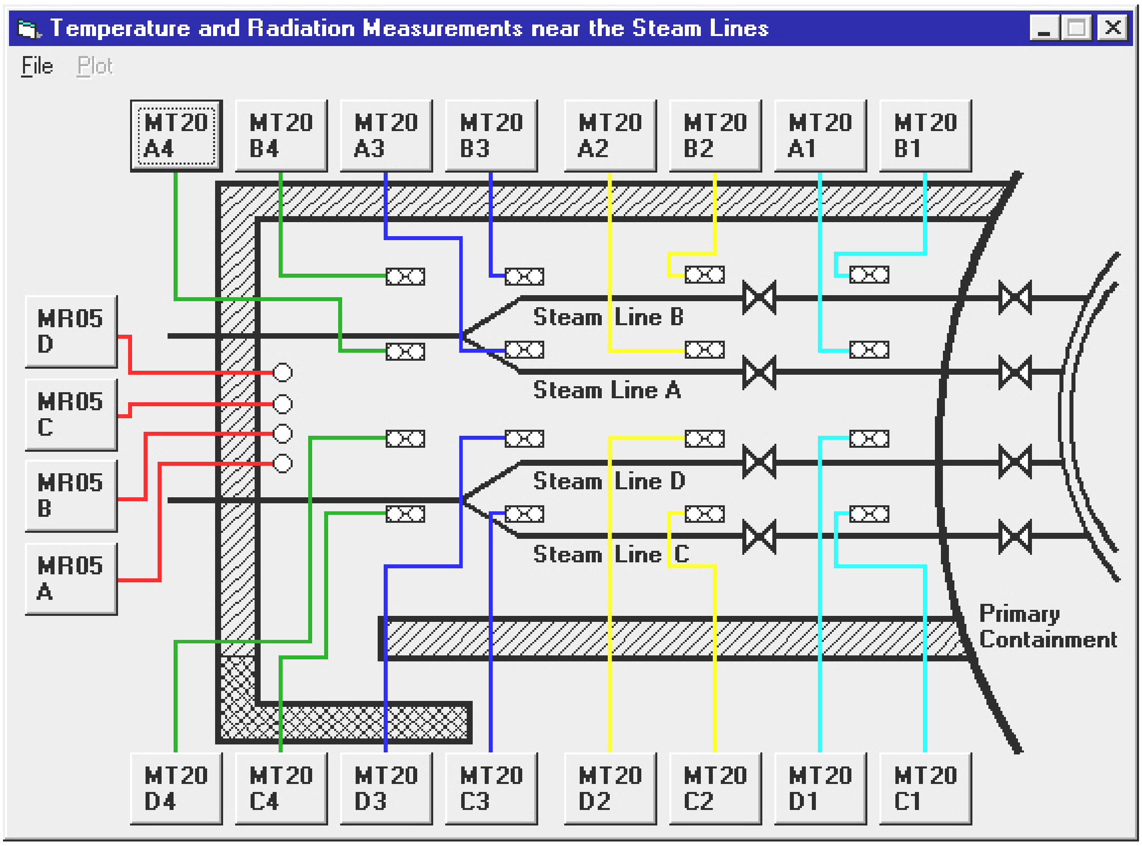


Figure 5.1 Temperature measurement system at the steam lines. Figure from SensBase™ at KKM.

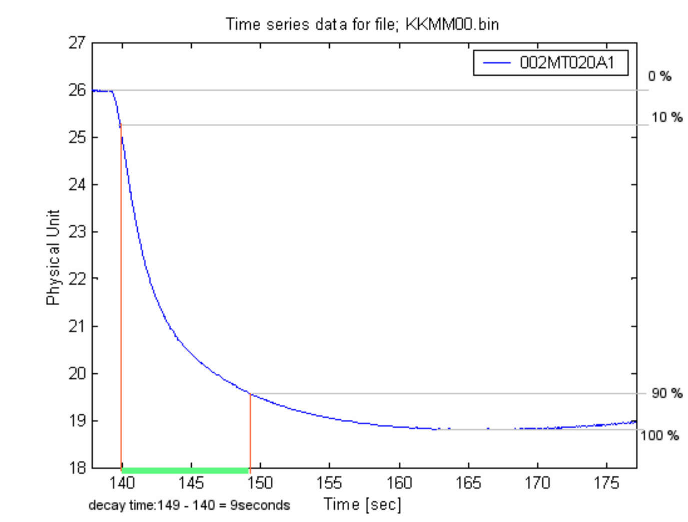


Figure 5.2 Graphic presentation of the temperature during cooling with spray. KKM, 2001.

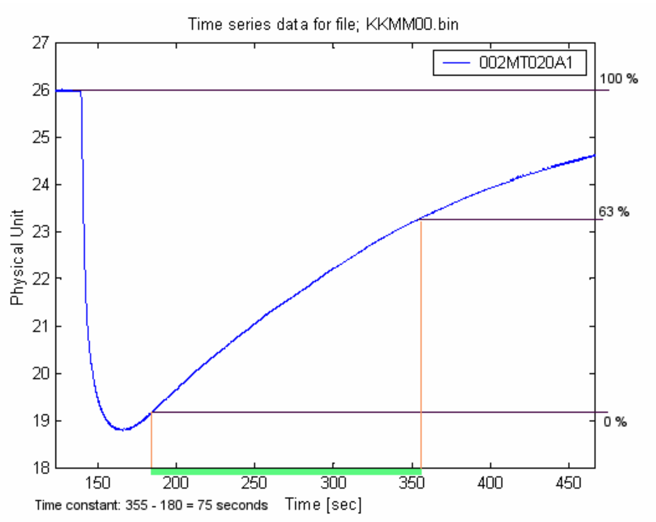


Figure 5.3 Graphic presentation of the time constant estimate during reheating. KKM, 2001.

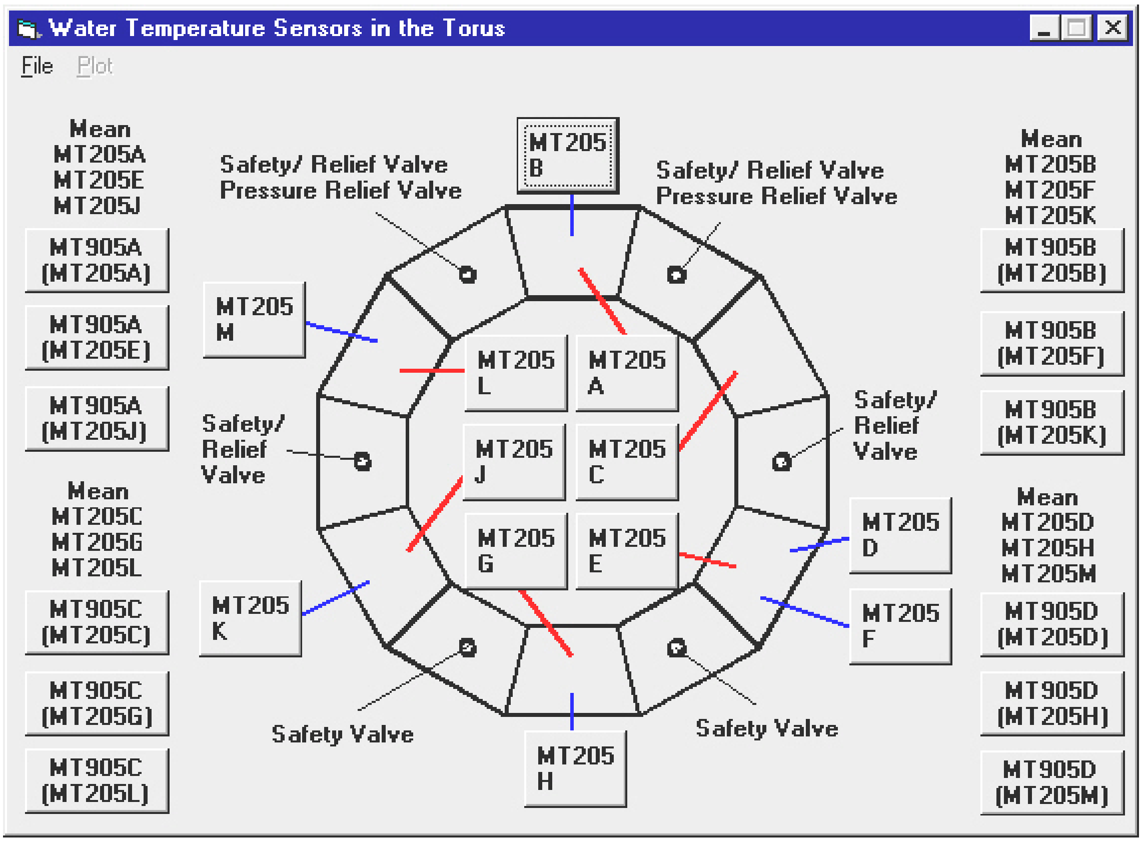


Figure 5.4 The position of the temperature sensors in torus at KKM. The twelve sensors are installed in thermo-wells.

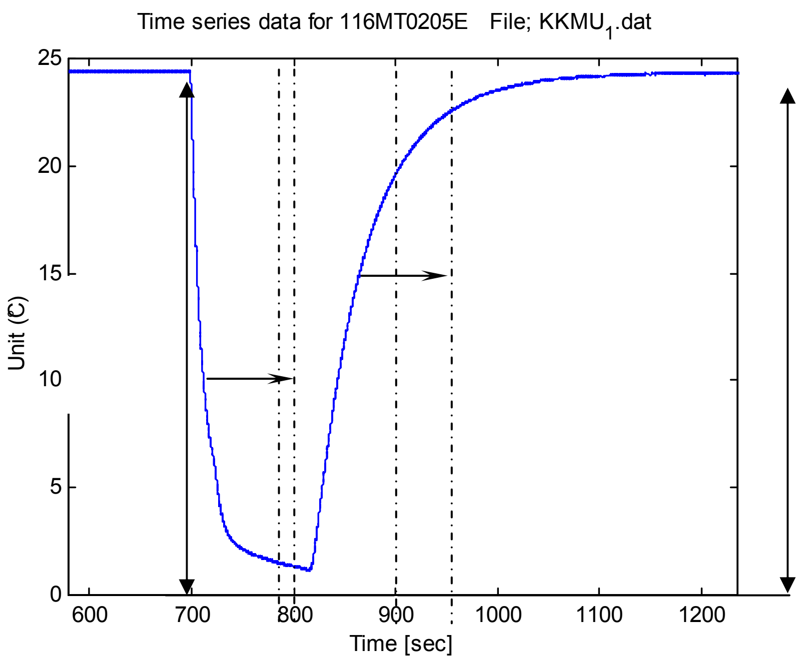


Figure 5.5 Calculation of the time constants during cooling and reheating after installation of the sensor in the thermo-well.

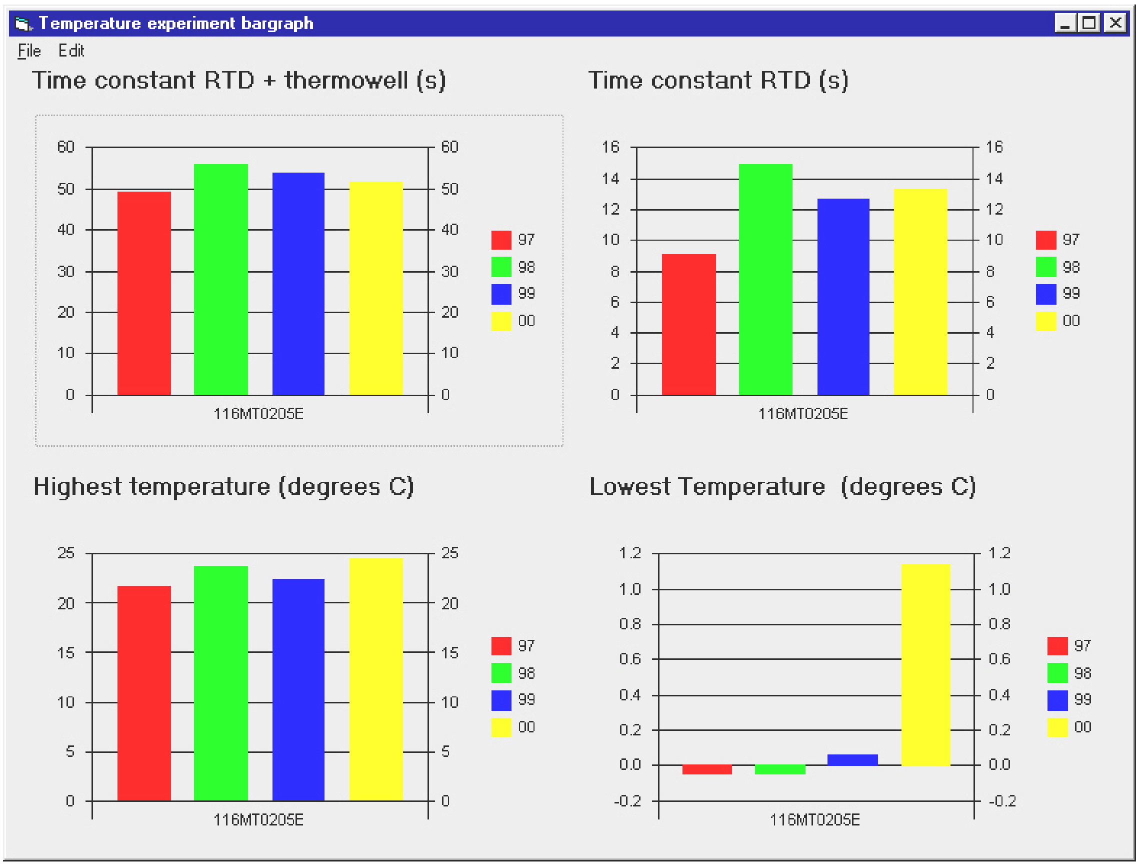


Figure 5.6 Time constants during cooling and reheating and the temperature in the thermo-well in torus and ice-water. Results from the years 1997-2000 with temperature sensor MT205E. Data from SensBase™ at KKM.

6 Conclusions

Mainly depending on the fact that the Swedish BWRs were constructed in the seventies and eighties, the instrument systems were originally designed with analogue technique. This is valid for transmitters as well as density converters, isolation amplifiers and regulators. Right now there is an ongoing modernization of the instrument systems in many plants and components are replaced by newly developed ones. This implies in many cases that analogue components are replaced by digital ones.

The delay time is the critical dynamic deviation between an analogue and a digital transmitter. A delay time of up to 200 ms has been observed for a digital transmitter (Hartmann & Braun ASK800) in comparison with an analogue one (Fujii). A long delay time is of course undesirable when the transmitter is part of the reactor protection system. It is therefore important to pay attention to the delay in respons when an analogue transmitter is replaced by a digital one. The laboratory tests also included a comparison between an old analogue density converter (Hartmann & Braun TZA2) and a new digital one (Hartmann & Braun TZA4). These results prove that the analogue unit is clearly faster than the digital. The response time from differential pressure to level signal was 50 ms for TZA2 and 250 ms for TZA4. Corresponding times with pressure as input and level as output was 50 ms for TZA2 and 900 ms for TZA4.

The report also includes an investigation of pressure transmitters of the type TDE220. The transmitters exhibited deviating dynamics during ordinary sensor tests. The laboratory test confirms the observed deviation in comparison with transmitters of other types. The construction with Bourdon tube is judged to be the reason for the deviations.

The report also presents results from trouble shooting with steam pressure transmitters at KKM. It was possible to identify the intermittent sensor error with the aid of controlled pressure changes. Service of the transmitter pointed out a crack on the electronic filter unit. This was judged to be the reason for the intermittent signal interrupts.

Finally two possibilities used at KKM to investigate the dynamics of temperature sensors are described. Both methods are based on artificial cooling of the sensor. One of them is applied during power operation of the plant and the other during outage.

7 References

1 Bergdahl B.G. Investigation of sensors and instrument components in boiling water reactors. Results from Oskarshamn 2, Barsebäck 2 in Sweden and Kernkraftwerk Mühleberg in Switzerland. May 1998, SKI Report 98:22.

2 Bengt-Göran Bergdahl, Joakim K.-H. Karlsson, Ritsuo Oguma and Herbert Schwaninger. Experiences from sensor tests and the evaluation of long-term sensor performance using SensBase™. Paper presented at the NPIC & HMIT 2000 meeting, Washington, DC, November, 2000.

3 B.G. Bergdahl, M. Morén and R. Oguma. Experiences from sensor tests and evaluation of sensor performance. Paper presented at SMORN VIII, Symposium On Nuclear Reactor Surveillance And Diagnostics, May 27 – 31, 2002, Göteborg, Sweden.

4 IAEA-rapport. Management of ageing of I & C equipment in nuclear power plants. Report prepared within the framework of the International Working Group on Nuclear Power Plant Control and Instrumentation. June 2000. IAEA-TECDOC-1147.

5 Bergdahl BG, Liao B, Oguma R, Schwaninger H. Sensor diagnostics in a BWR based on noise analysis. An invited paper presented at the NPIC & HMIT'96 meeting May 6 - 9, 1996, The Pennsylvania State University, USA.

6 Hashemian HM et al. Effect of Aging on Response Time of Nuclear Plant Pressure Sensors. Analysis and Measurement Services Corporation. NUREG/CR-5383.

7 Hashemian HM et al. Long Term Performance and Ageing Characteristics of Nuclear Plant Pressure Transmitters. Analysis and Measurement Services Corporation. NUREG/CR-5851.

Färgat mellanblad (framsida)

Färgat mellanblad (baksida)

SKI Report 2005:36

Research

Reports within the Area of Nuclear Power Plant Instrumentation

Part 2: Dynamic Deviations in Reactor Pressure and Water Level Signals Caused by Sensing Lines

Bengt-Göran Bergdahl

GSE Power Systems AB
Box 62
611 22 Nyköping

November 2004

Abstract

Sensors are a part of the safety system in a reactor. They are the first link in a chain of components that influence the protection system. It is therefore of great importance that the sensors fulfill the requirements on reliability and response time. The dynamic character of sensors is in practice seldom or never tested in BWRs. The static performance is on the other hand tested every year during the calibration of the transmitters. This is performed during the regular outage of the reactor.

It is quite common that many transmitters are connected to the same sensing line. This is especially valid in old reactors where only a few number of pressure taps are available on the reactor vessel. This is a shortcoming in the construction since one fault in the sensing line influences all connected components; a so-called CCF (Common Cause Failure).

The present report was sponsored by SKI (Swedish Nuclear Reactor Inspectorate). The report focuses on possible deviations in the sensing lines. The deviations are presented with practical examples from Swedish and foreign BWRs.

The sensing line and its belonging mechanical passive components can reduce the response time for a measurement system without influencing the static presentation. The report describes cases in a power plant where the response time was extended from 0.1 s to 5 s. The reason was gradual blockage in the sensing line. There is only one technique available today with which it is possible to investigate sensor dynamics, and that is signal analysis. Appropriate analysis of the transmitter signals can reveal filtering whether it takes place in the sensing line, the transmitter or in the electronic instruments.

As an example a practical case is presented where pulsation dampers with so-called needles were used at Ringhals 1 in Sweden. Their influence on the response time for the measurement signal corresponded to a time constant of 0.55 seconds. By eliminating the needles the requirements on the response time was fulfilled.

Results from KKM (Kernkraftwerk Mühleberg in Switzerland) show a way to supervise blockage in sensing lines based on the transmitter signal. One example is presented with a transmitter for flow measurement equipped with pulsation dampers. Results from SensBase™, a database system for sensor tests, is used in this work. SensBase™ stores new sensor test results every year. The nuclear power inspectorate in Switzerland has approved that KKM reduced their comprehensive transmitter calibration after introduction of the annular use of sensor tests and SensBase™.

The report also describes pressure oscillations that take place in the sensing line and not in the real measured process. The water in the sensing line together with the transmitter membrane form a dynamic system with water as mass, elasticity in the transmitter membrane as spring constant and reactor pressure fluctuations as driving force. The problem with oscillations in the measurement system is illustrated with examples from Ringhals 1 and KKM.

One example is also presented from KKM where the oscillation in a level transmitter – a Barton Cell – influenced eight transmitters connected to a common sensing line. It was possible to identify the deviating transmitter during operation of the reactor via

experiment with isolation valve closing. The oscillations ceased after replacing the transmitter with one with less volume and displacement.

The report finally proves that mechanical vibrations in the sensing lines contribute to signal noise around 10 Hz. This is shown with the aid of laboratory tests performed at KKM. Transmitters have also been exchanged because of deviating noise in the frequency range 2-20 Hz. After replacing the transmitter the mentioned noise disappeared. The results from KKM indicate that it cannot be excluded that ageing increase the transmitter sensitivity for sensing line vibrations.

Table of contents

1 Background

Sensors are part of the protection system in a reactor. They are the first link in the chain that influences the protection system. It is therefore of importance that the sensors fulfill the demands of reliability and response time. In practice, the dynamic characteristics of sensor systems are seldom or never tested in Swedish and foreign BWRs. The static character however, is tested by sensor calibration during the regular outage of the plant.

Transmitters and other instrument components will be replaced by different models of components in an ageing nuclear power plant. This implies that different sensor types and models are in operation. Furthermore it is not unusual that complete systems with sensing lines are exchanged or rebuilt and newly-developed condensate pots are installed. This implies that the dynamic character during the test operation of the plant has changed.

The measurement systems for reactor pressure and water level in a BWR consists of transmitters connected to the pressure taps on the reactor vessel through water filled sensing lines. The transmitters are installed outside the containment where temperature and radiation is lower. Figure 2.1 shows such an installation at Barsebäck in Sweden. It is obvious from the figure that the sensing line from the pressure tap to the transmitter can be many tens of meters.

It is quite common that many sensors are connected to the same sensing line. This is especially the case in old reactors where only a few number of pressure taps are available on the reactor vessel. This is an inconvenient drawback in the construction since an error in the sensing line influences all connected components; a typical CCF. The high positioned taps on the reactor have condensate pots installed. This is to separate steam in the reactor from water in the sensing line. It is evident from the Figure 2.1 that the high positioned pressure taps in Barsebäck have up to 3 condensate pots connected to one pressure tap. This construction was made to improve the redundancy and reduce the described CCF.

The report is focused on deviations in the measurement system in connection to the sensing lines. The deviations are demonstrated with practical examples from Swedish and foreign power plants. The report was sponsored by SKI, the Swedish Nuclear Power Inspectorate.

The deviations treated in the report are:

- Changes in the condensate pot water level caused by gas in the reference sensing line.
- Increasing degree of blockage, influence by gas or freezing in the sensing line.
- Not wanted oscillations that can take place in pressure and level measurements caused by the mass of water in the sensing line and the spring constant in the transmitter.

- How can one oscillating transmitter have influence on the others connected to the same sensing line and at the same time filter fast pressure changes on multiple transmitters?

- The influence from pulsation dampers (snubbers) and other mechanical components in the sensing line on the signal response time.

The author of the report wants to express his thanks to Mr. Hashemian at AMS in the USA for stimulating discussions and exchange of experiences within the sensor test area. References with high importance on Chapter 2 and 3 in the report are Reference 6 and 7 (NUREG/CR-5383 and NUREG/5851).

Thanks also to Mr. Marcus Andersson who gave us the permission to publish the results from the GSE investigation at Ringhals 1. Thanks also to Mr. Herbert Schwaninger who gave us the permission to publish the results from KKM and also inspired the research with fruitful discussions. Thanks also to Jan-Ove Andersson for the permission to publish material from Barsebäck 2 and his contribution with valuable comments on the report.

2 Water level changes in the condensate pot

A principal picture for the transmitter and other components that can be connected to a sensing line for measurement of reactor pressure is presented in the Figure 2.3. Close to the pressure tap on the reactor vessel a condensate pot is connected. In this unit the water in the sensing line is separated from the steam in the reactor that exist on the level where the pressure tap is placed. Steam communicates via the pressure tap between the reactor and the condensate pot – where condensation is performed. Overflow of water in the pot will run back to the reactor. This is the way the water level in the pot is controlled.

Gas bubbles can arise in the sensing line, for example during pressure transients. They are transported to the condensate pot since the sensing line normally is constructed without horizontal slopes. An increasing gas content in the sensing line water increases the volume, so called swelling. As a result there will be overflow of water to the reactor from the condensate pot. When the formation of gas has ceased and the gas has been transported away there will be a clearly reduced water level in the condensate pot. This is especially a problem for the water level measurement in the reactor. These transmitters use dp measurement with the level in the condensate pot as a reference. The level measurement will deviate in the same way as the reference level changes. This type of error is well known. Some reactors have the possibility to refill the water level in the condensate pot during operation after such an event. This is done manually in this case.

Gas is transported together with steam to the condensate pot during normal operation. This gas is diluted in the sensing line water and as far as the gas is diluted there is no negative influence on the level measurement. But a pressure transient is enough to release the diluted gas to bubbles in the sensing line water.

Another thing is that non-condensable gas for example oxyhydrogen can be collected in the condensate pot. Such a gas can explode and influence all components connected to the pot. The result can be not wanted scram of the reactor. New types of pots have been developed to avoid collection of non-condensable gas. One type is more flat and without the sphere shape seen in Figure 2.3. The result is that the complete volume will be ventilated by steam. Such a construction has been chosen at KKM. There are also other solutions, for example the one used at Barsebäck 2. There the top of the condensate pot has been connected to the steam line with a pipe; see Figure 2.2. This is one way to evacuate steam as well as non-condensable gas and gas that can be diluted in the sensing line water. The result is reduced amount of diluted gas (or no gas at all) in the sensing line water. This is a way to reduce the risk for swelling during a reactor pressure transient.

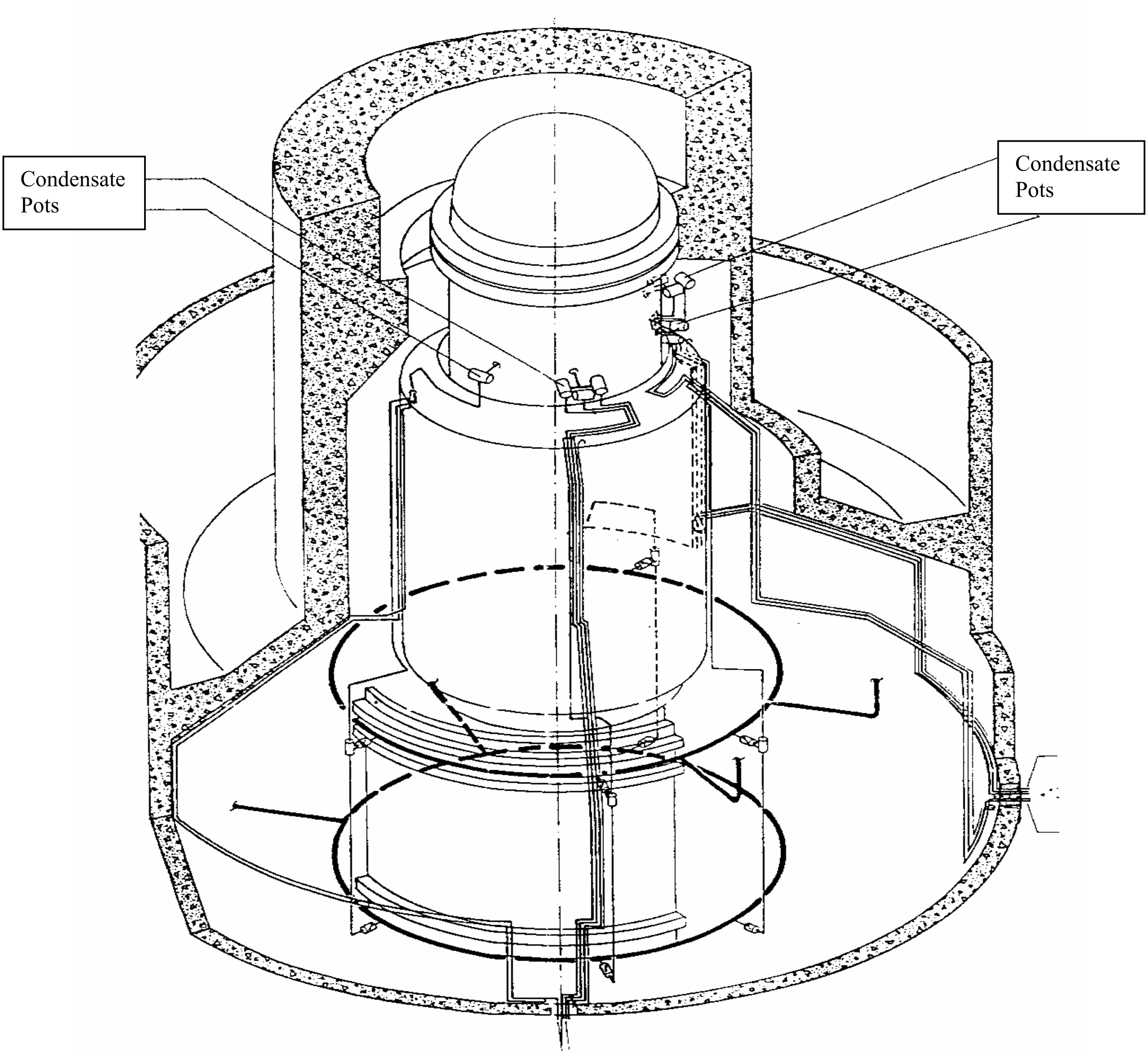


Figure 2.1 Pressure taps, condensate pots and sensing lines for pressure and level measurement system in Barsebäck 2 in Sweden.

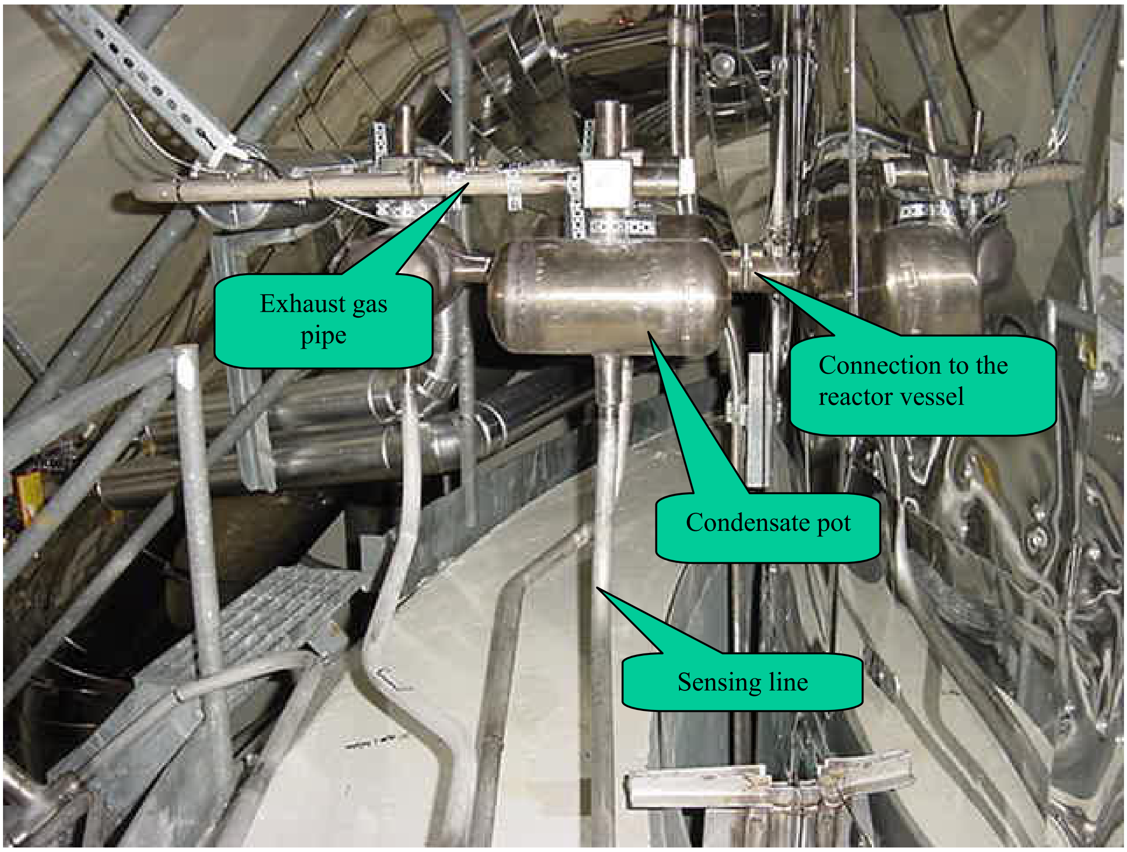


Figure 2.2 Condensate pots, sensing lines, pressure tap to the reactor vessel and exhaust gas pipe to the steam line at Barsebäck 2.

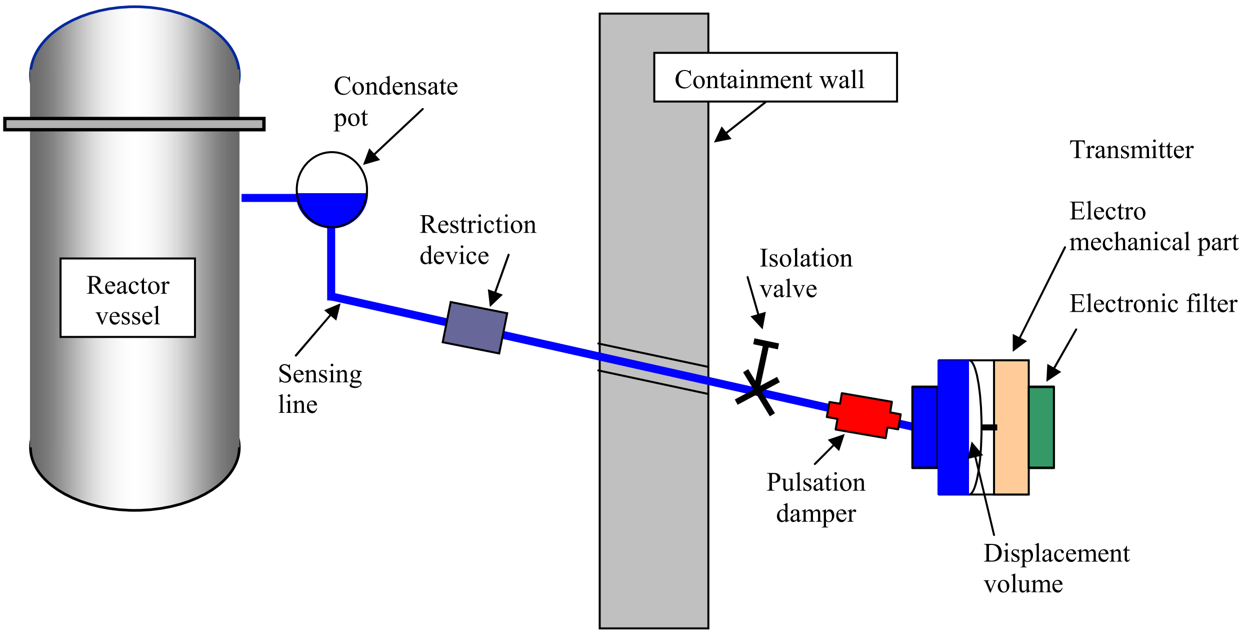


Figure 2.3 Reactor pressure instruments. The figure displays sensing line, pressure tap, condensate pot, restriction device, containment wall, manual isolation valve, pulsation damper (snubber) and transmitter.

3 Gradual blockage, gas or freezing in a sensing line

The aim with the sensing line is to transfer the pressure at the pressure tap to the transmitter membrane without inconvenient filtering; see Figure 2.2. This is not always successful. The components that are part of the measurement system can filter the pressure fluctuations by gradual blockage of the water in the sensing line. Some times the gradual blockage can also increase caused by crud – a chemical process in the sensing line water.

Gradual freezing of the sensing line water has a filtering influence similar to the description of gradual blockage.

Gas bubble in sensing lines also have dynamic influence on the pressure signal that will be transferred to the transmitter membrane. The pressure transmitter signal will be presented with time delay during a real pressure transient as a result of the filtering.

This chapter will present these types of problems and suggest actions to be taken to reduce their influence on the response time.

3.1 The sensing line and its components

The sensing line and its components for pressure measurements are displayed in Figure 2.2. Besides pressure tap and condensate pot that already has been discussed in the report there are also further components. To them belong the units called restriction device, isolation valve, pulsation damper and transmitter.

The restriction device is a mechanical unit with the task to stop the leakage of reactor water if a sensing line ruptures. The restriction device will not filter the transmitter signal during normal operation. International reports recommend that restriction devices should be avoided in measurement systems that demands short response times; see Reference 7. The same thing holds true for the isolation valve installed on the sensing line. This unit is also not meant to influence the measurement signal. The valve in question is meant to be used for closing of the sensing line e.g. during exchange of transmitter.

Pulsation dampers may also be installed in the sensing line. Such a unit is displayed in Figure 2.2. The pulsation damper works like a mechanical restriction in the sensing line. The constructions can differ. One design is an axial pipe installed in the sensing line where so-called needles can be inserted. It is possible to achieve different restrictions by choosing the size of the needle. The task for this unit is mechanical filtering of the pressure to the transmitter. This was a common way to filter signals in the seventies and eighties but the method has obvious drawbacks. These will be described later in the report. NRC (Nuclear Regulatory Commission) in USA recommends the utilities not to use pulsation dampers for filtering.

The transmitter is installed in the end of the sensing line. This unit consists of a water filled volume that influences the transmitter membrane. The response from the membrane is a movement that increases the volume. This increase in volume is called transmitter displacement. An increased pressure results in increasing volume achieved by movement of the membrane; see Figure 2.2. The movement of the membrane in its turn influences the electro mechanical system, which transfer the membrane position to an electric signal. Finally there is often a possibility to filter the transmitter signal electronically. This is also presented the Figure 2.2. This unit enables electronic low-pass filtering of for example measurement noise in the transmitter signal.

3.2 Air or gas in sensing line

Air or gas can exist in a sensing line; see Figure 3.1. An air bubble can for example be introduced in connection with outage of the reactor when components are exchanged. Air in the sensing line influences the static and the dynamic character of the transmitter signal. Static since the mass of the water pillar is changed when a part of it no longer is water. This is of cause most important for the differential pressure measurement. When we come to measurement systems for reactor pressure and water level it should be stressed that pressure is so high that an existing air bubble will be reduced in volume when pressure increases to 70 Bar.

A gas bubble in a sensing line also influences signal response time. Laboratory experiment performed abroad shows that a gas bubble in the sensing line water filter the pressure signal; see Reference 6. APSD (Auto Power Spectral Density) for the signal after introduction of a gas bubble is clearly damped for high frequencies. Gas is compressible and therefore different than the remaining water in the sensing line. The gas bubble works like a low-pass filter. Fast movements will not be transferred. Mentioned laboratory tests showed also a low frequency oscillation in the pressure signal. The gas bubble - equal to a spring constant – together with the mass of the sensing line water forms an oscillating system with a clear resonance frequency. The oscillation frequency is a clear peak in APSD for the signals; see Reference 6.

3.3 Freezing or gradual blockage in the sensing line

The problem with freezing and blockage in the sensing line are similar. Freezing can of course occur in situations with low temperature when the sensing lines are not insulated. Gradual freezing or blockage will not have influence on the signal mean value, especially not during steady state conditions. The reactor pressure in a BWR will continue to display 70 Bar even if the sensing line is in gradual blockage.

The signal fluctuation is on the other hand influenced by the gradual blockage and as a result APSD is influenced. Blockage works like a low-pass filtering. This implies that the signal response time is extended. A transient will therefore be time delayed.

The phenomenon is explained in Figure 3.2. A sudden reactor pressure increase causes a flow in the sensing line to expand the transmitter volume by moving the membrane and present the new increased pressure. Gradual blockage in any of the involved mechanical components will reduce the flow speed in the sensing line. Longer time will be needed for the transmitter membrane to change to the new position when there is gradual blockage in the sensing line. Sensor response time is consequently influenced by the gradual blockage. The static value will not be influenced. This is the problem from maintenance point of view. The static value is correct during calibration and hides the fact that the response time for the measurement system has been extended.

Reference 7 presents results from an investigation of 40 000 LER (Licensee Event Report) during the time from 1980 until 1992. The reports are from 100 nuclear power plants in total. Out of these reports 551 were problems with the sensing line and out of these 165 were caused by ageing problems. 67% of these, that is 111 LER, were problems with the sensing lines like blockage, freezing and so on. It is stressed in the report that blockage and freezing are especially inconvenient as it has influence on the response time. Isolation of the transmitter from the process can be the final result if blockage continues.

3.4 Pulsation damper compared with electronic filtering

Pulsation dampers as well as electronic filtering can be used for filtering of the transmitter signal. This fact has already been mentioned. The result is independent of the method used, but the different methods have important advantages and disadvantages. These will be described in this chapter.

The pulsation damper reduces the flow speed in the sensing line with a mechanical restriction. The only advantage with this method is that the mechanical part of the transmitter is not stressed so much since the pressure at the transmitter membrane fluctuates with reduced amplitude.

The drawback with the pulsation damper is that filtering is dependent of the mechanical character of the transmitter. The cut-off frequency may be different depending on the transmitter in question, even if the pulsation damper used is the same. The reason is the displacement of the transmitter. The larger displacement the more will the signal be filtered. This implies that exchange of a transmitter with kept pulsation damper can cause another response time for the signal. It is also important to indicate that there is an increased risk for blockage in the pulsation damper.

Electronic filtering is introduced in modern transmitters. This means that the transmitter signal can be filtered with a chosen cut-off frequency. There is a system with buttons on the transmitter that admit choice of electronic filter in some cases. Often there is a passive network of resistors/capacitors behind each button with different combination of components that corresponds to the filtering. Unfortunately there is not one standard for definition of the electronic filtering. To be sure laboratory experiments should be performed with step tests of the investigated transmitter together with a reference transmitter. One positive thing with electronic filtering is that both noise in the sensing line pressure and electronic noise are filtered. The only drawback with electronic filtering is that the mechanical stress caused by pressure fluctuations will have influence on the mechanic part of the transmitter.

All filtering should therefore be done with electronic filtering.

3.5 Conclusions for the dynamics in sensing line

The sensing lines are mechanical passive components that can prolong the response time for a measurement signal without deviation on the static presentation of the measurement. For examples of practical cases from nuclear power plants where sensing line dynamics has changed from a time constant equal to 0.1 s (normal response time) until 5 s; see Reference 4. This happened in a power plant in the USA because of gradual blockage. This is not uncommon.

Another example is a French PWR that met with scram during load-follow operation. Scram was caused by blockage in a sensing line to a differential transmitter. Signal analysis of measurements and comparison with earlier collected signals was the way to find the cause for the problem; see Reference 8.

In Reference 7 there is a letter from NRC to the power companies in the USA with a warning that use of pulsation dampers can extend the response time for the measurement signals outside acceptable limits. There is also a warning that particles in the sensing line water can more or less cause blockage in sensing line water flow and give further extension of the response time.

There is also a warning that maintenance experiments with the transmitter to measure the response time can exclude the pulsation damper that is installed in the sensing line. This mistake gives rise to shorter response time than the correct value for the measurement system.

Signal analysis is the only method today to investigate sensing line dynamics. Measurement of the transmitter signals and appropriate analysis can reveal filtering independent of where it occurs in the sensing line, transmitter or cascaded instrument components.

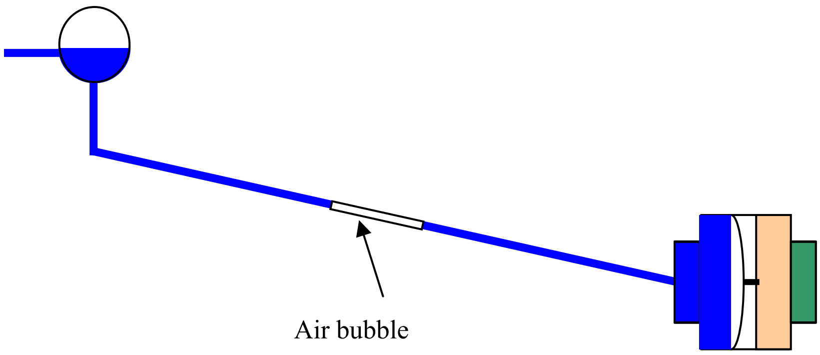


Figure 3.1 Air bubble in the sensing line. The result is low-pass filtering of the pressure signal and a resonance where the compressibility of the air works like a spring connected to the mass of the water in the sensing line.

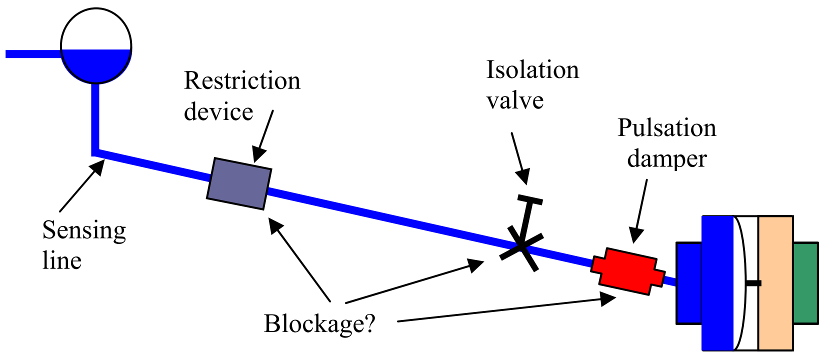


Figure 3.2 Risk for blockage in the sensing line components: restriction device, isolation valve and pulsation damper. Particles in the sensing line water can make the situation worse.

4 Oscillations in reactor pressure signals at Ringhals 1

GSE Power Systems AB has performed an investigation of reactor pressure signals at Ringhals 1 in Sweden. Among the pressure signals that were involved in the measurement are four with the designation 211K112, 211K113, 211K124 and 211K114. All of them are installed on different sensing lines and pressure taps on the reactor vessel. Transmitter manufacturer and physical range are shown in Table 4.1.

To become familiar with the dynamics the APSDs for the pressure signals are shown in the same plot; see Figure 4.1. The result is very interesting. Three clear peaks at different frequencies are seen for the different APSDs. The peaks are visible at 1.8 Hz, 2.5 Hz and 3 Hz for the transmitters 211K124, 211K112 and 211K114. The transmitter 211K113 does not show any peak at all.

The pressure in the reactor is global. This implies that the dynamics for the signals should be the same independent of the sensing line used. It is not that easy here. The results display oscillations at different frequencies or no oscillation at all.

The background to the observed oscillations is not reactor pressure fluctuations in the frequency range 1.8 – 3 Hz. The interpretation is that resonance peaks are formed by the transmitters in interaction with the water in the sensing line. The water pillar in the sensing line and the spring constant in the transmitter membrane causes the oscillation; see Figure 4.2. The frequency is decided by the mass of the water (the length of the sensing line) and the transmitter spring constant. Therefore there are different oscillation frequencies for the different sensing lines. The energy supply for the oscillation comes from the reactor pressure noise. The consequence of this problem is that all sensors connected to the sensing line will observe the not wanted oscillation. The transmitters influence each other. This is a CCF for the dynamic character of the sensors. APSD for the pressure sensors 211K101, 211K112, 211K119 and the level sensor 211K401, where all components are connected to the same sensing line, are displayed in Figure 4.4 as an example. See also Figure 4.3. Observe that all APSD have a common resonance at 2.5 Hz.

Many transmitters for pressure and level are installed to each sensing line. Furthermore there are also a number of pressure switches installed; see Figure 4.3. Therefore it is not easy to identify the components that are driving the oscillations in this case. In Figure 4.3 all installed components are displayed. The pressure switches include a relay function and do not allow measurement of continuous signals. To be able to analyze which component that is the reason to the observed oscillations, there is a need for a more detailed measurement combined with experiments.

Another phenomenon that is evident from Figure 4.1 is that APSD for the pressure signals are damped for frequencies above the oscillation frequency. The fast pressure changes between 5 and 10 Hz are damped by the elasticity. APSD for 211K114 and 211K112 are clearly lower than for 211K113 for the mentioned frequencies.

Another possible interpretation is that the observed oscillations are caused by gas in the sensing line. A gas bubble can cause oscillations, since gas is compressible.

Table 4.1 Transmitter type, physical range and so on for the signals analyzed in Chapter 4. Ringhals 1.

Sensor name	Physical range	Sub	Transmitter type	Signal range	Sensor task
211K112	5 - 76 Bar	A	Rosemount 1151GP	0-10 V	Reactor pressure
211K113	5 - 76 Bar	B	Rosemount 1151GP	0-10 V	Reactor pressure
211K114	5 - 76 Bar	C	Rosemount 1151GP	0-10 V	Reactor pressure
211K124	0 - 100 Bar	B	H&B AZC200 15720	0-10 V	Reactor pressure
211K101	0 - 100 Bar	A	H&B AZC200	0-5 V	Reactor pressure
211K119	64-79 Bar	A	Rosemount 3051C smart	0-5 V	Reactor pressure
211K401	-5.4 - +11.6 m	C	H&B AZI200-15780	5-0 V	Water level

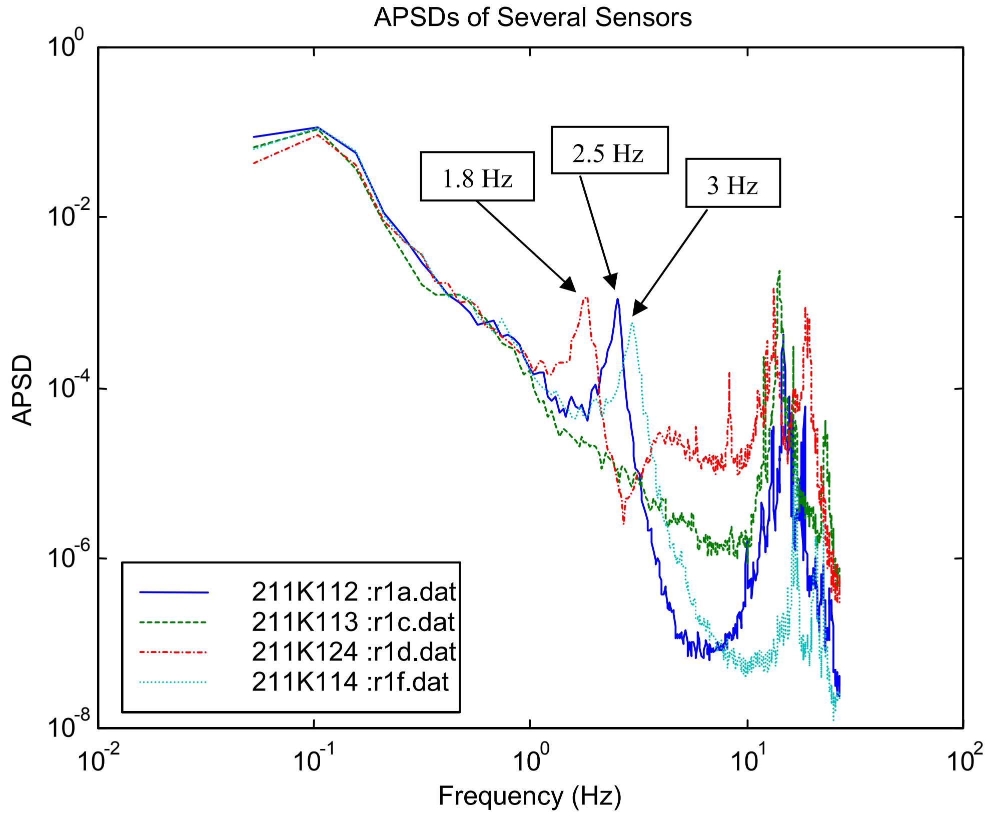


Figure 4.1 APSD for the pressure signals 211K112, 211K113, 211K124 and 211K114 at Ringhals 1. Observe that the transmitters are connected to different pressure taps on the reactor vessel. Measurement data from Ringhals 1, February 2000.

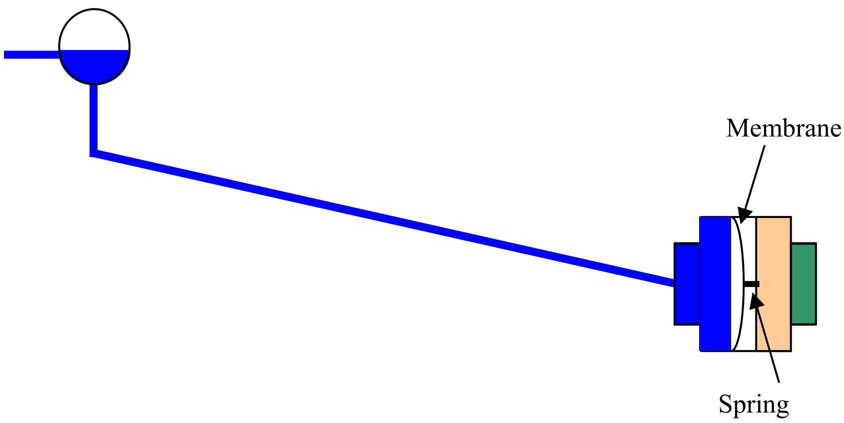


Figure 4.2 Water in the sensing line in combination with the elasticity in the transmitter membrane forms the oscillating system.

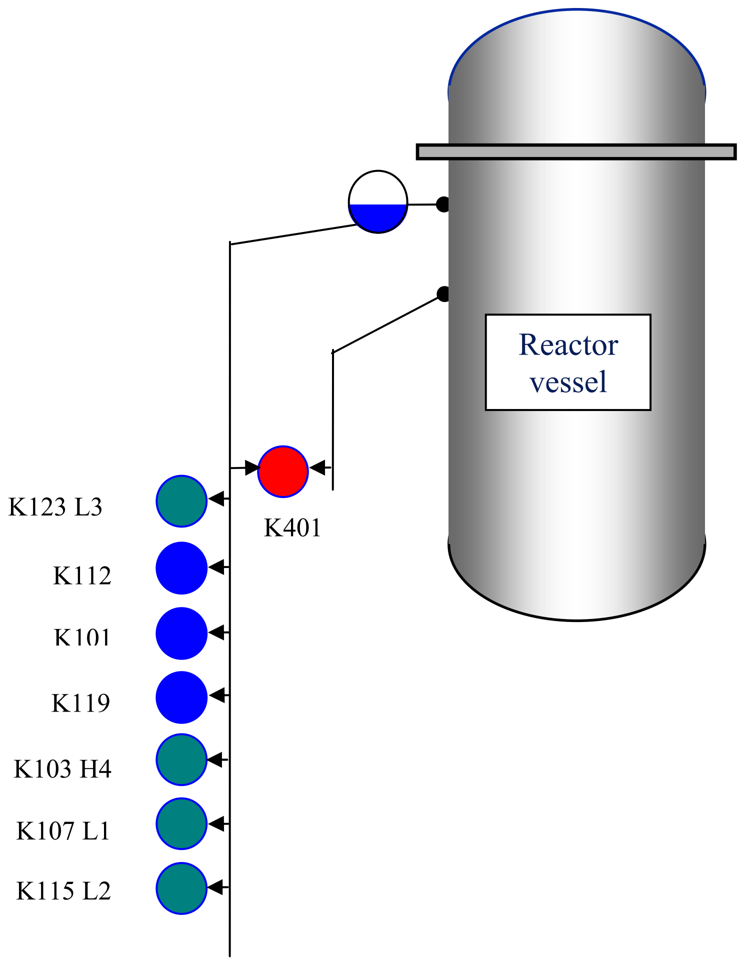


Figure 4.3   Pressure transmitters (blue), pressure switches (green) and level transmitters (red) connected to the sensing line with the resonance-frequency 2.5 Hz at Ringhals 1.

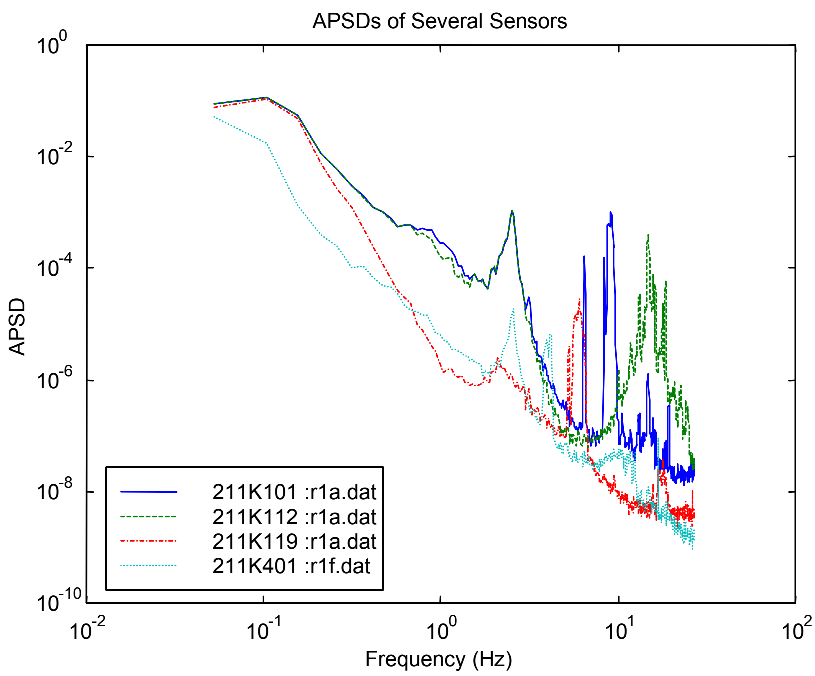


Figure 4.4   Observe that the resonance frequency is the same 2.5 Hz for all transmitters connected to this sensing line. Ringhals 1, 2000.

5 Differential pressure sensors with and without needles in the pulsation dampers in Ringhals 1

The reactor vessel in Ringhals 1 is equiped with so called swelling sensors; see Figure 5.1. The swelling sensor signals have influence on the reactor protection and when the level is too high, there will be scram of the reactor. The sensors measure the differential pressure between two vertically placed pressure taps on the reactor vessel; see Figure 5.1. Both pressure taps are on the level where steam exists and therefore they are equipped with condensate pots. The instrumentation includes for safety reasons four multiple transmitters: 211K416, 211K417, 211K418 and 211K419. Out of these four 211K419 is a spare sensor. The transmitter manufacture and physical range is presented in Table 5.1. The instrumentation is split in two different pairs of pressure taps on opposite side of the reactor vessel; see Figure 5.1. It is also clear from the drawing that all transmitters have sensing lines of their own. As a result of the instrumentation the sensor pair 211K416 and 211K417 have the same pressure taps and should therefore agree. The same fact holds true for the sensor pair 211K418 and 211K419

In connection to a sensor investigation in February 2000 GSE Power Systems AB performed measurements of the swelling sensor signals. During this measurement 211K418 and 211K419 were recorded at the same time. The analysis of the signals showed a clear deviation between the signals. The interpretation made by GSE was that the spare signal 211K419 was incorrect; see Figure 5.2. The APSDs for the different swelling sensors are shown in Figure 5.3. It is also clear from this figure that 211K419 deviates. The APSD is clearly higher with 211K419 at 1 Hz than the APSD :s for the other signals. The figure also displays to some extent that APSD for 211K417 is between 211K419 and the others.

During the regular outage 2000 an inspection was performed of all sensing lines to the swelling transmitters. It was found that all of them were equipped with pulsation dampers. The inspection also proved that the pulsation dampers included damping needles, except for 211K419. It was also found that 211K417 missed a needle in one of the sensing lines; see Figure 5.1. All the other swelling sensors included needles in both sensing lines.

The discovery of the damping needles in the pulsation dampers showed that the initial hypothesis where 211K419 was estimated to be incorrect did not agree with the observations. Instead all the other swelling sensors were filtered in an improper way with the needles while the spare sensor 211K419 works with acceptable response time; see Figure 5.1.

The time series displayed in Figure 5.2 are very interesting. Two transmitters of the same type are connected to the same pressure taps on the reactor and are therefore expected to give the same output. The output is however different, which depends on the fact that 211K418 includes needles that are missing in 211K419; see Figure 5.1. The pulsation damper clearly filters the differential pressure fluctuations; see Figure 5.2. The observed difference is also displayed in the APSDs for the signals; see Figure 5.3. The sensor signals with needles 211K416 and 211K418 are most filtered between 0.2 and 5 Hz. The APSD for the sensor signal 211K417 with needles in one sensing line but not in the other is between the sensor without needles and the one with needles in both sensing lines.

The results for the identification of the pulsation damper dynamics with needles in both sensing lines are displayed in Figure 5.4. The dynamics is identified with a model with 211K419 (no needles) as input and 211K418 (with needles) as output. This can be done since both transmitters have the same pressure inputs. The top diagram in Figure 5.4 shows the input signal 211K419 as a function of time while the bottom diagram in Figure 5.4 shows the output signal 211K418 – blue curve, and the estimated signal from the model – red curve. The model is good since the real output signal and the model output signal agrees with each other. Step test of the model displays that the filtering of the needles are equal to a time constant of 0.55 s.

The surprising discovery of the needles in the pulsation dampers started a careful investigation at Ringhals. It was clear that the response time was longer than the required response time with respect to the sensors task in the safety system. The deviation led to a report to the Swedish Nuclear Power Inspectorate (equivalent to a Licensee Event Report) with INES level 1. The title of the report is "Too long response time caused by not correct installed pulsation dampers in swelling transmitters."

All needles were dismounted from the pulsation dampers during the regular outage 2000 to shorten the response time for the measurement signals. The swelling sensor signals 211K418 and 211K419 from a repeated measurement in March 2001 are displayed in Figure 5.6. The recording proves that there is good agreement between the signals. It is therefore obvious that the measure to eliminate the needles gave a good result.

A comparison between APSDs calculated before and after the dismount of the needles is displayed in Figure 5.7. The result is clear. All APSDs are not filtered in the measurements in March 2001. This deviates from the APSD with needles taken in February 2000. And between these spectra is the APSD for 211K417 with only one needle from the measurement in February 2000.

Table 5.1 Transmitter type, physical range and so on for the signals analyzed in Chapter 5. Ringhals 1.

Sensor name	Physical range	Sub	Transmitter	Signal range	Sensor task
211K416	0 - 950 mmvp	A	S&F TDE250	0-20 mA	Swelling sensor
211K417	0 - 950 mmvp	C	S&F TDE250	0-20 mA	Swelling sensor
211K418	0 - 950 mmvp	B	S&F TDE250	0-20 mA	Swelling sensor
211K419	0 - 950 mmvp	D	S&F TDE250	0-20 mA	Swelling sensor Spare

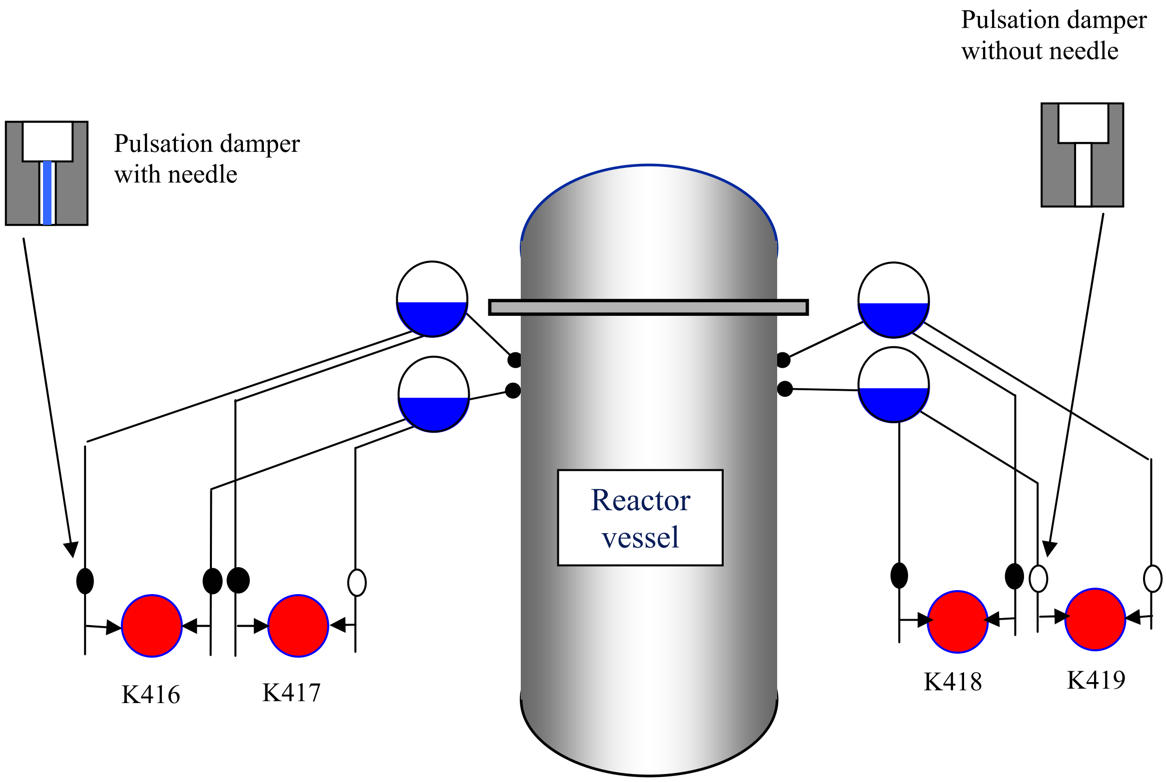


Figure 5.1 The measurement system with swelling sensors at Ringhals 1.

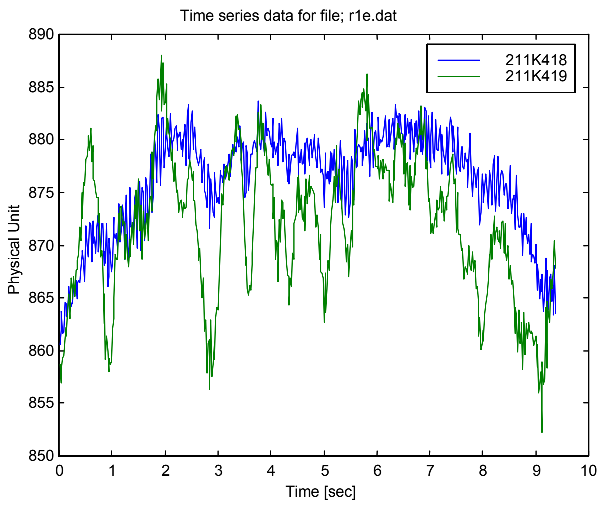


Figure 5.2 The swelling sensor signals 211K418 and 211K419 as a function of time. Ringhals 1, February 2000.

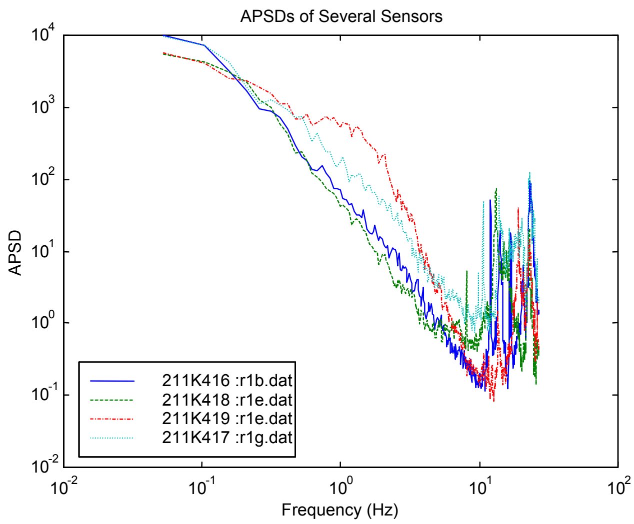


Figure 5.3 APSDs for the swelling sensor signals. Ringhals 1, February 2000.

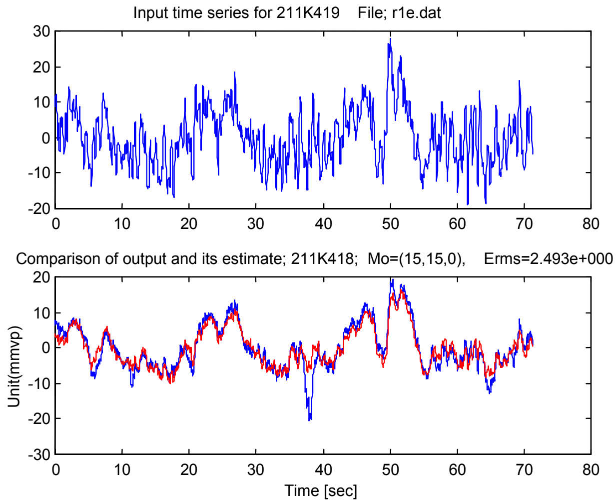


Figure 5.4 Process identification with 211K419 as input signal and 211K418 as output signal. Ringhals 1, February 2000.

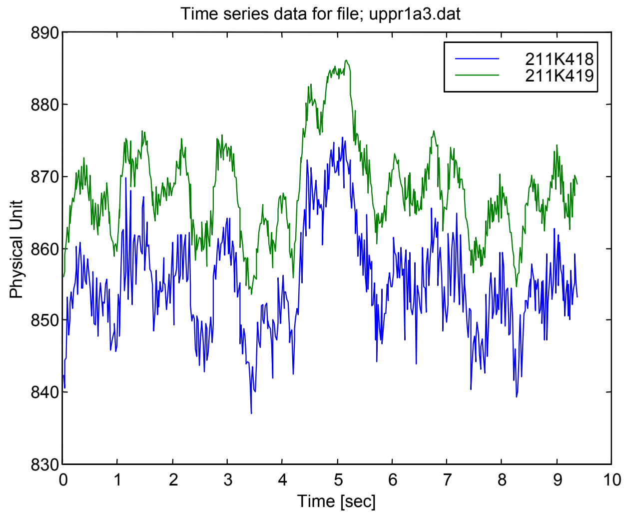


Figure 5.6 The swelling sensor signals 211K418 and 211K419 without needles. Ringhals 1, March 2001.

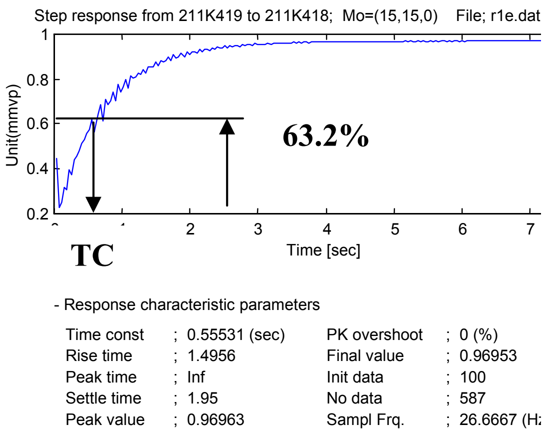


Figure 5.5 Step test of the identified model. Time constant = 0.55 second.

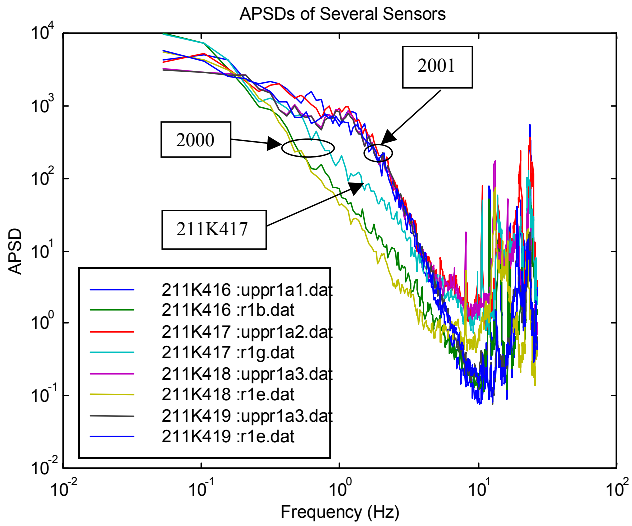


Figure 5.7 APSDs for the swelling sensor signals before and after dismount of the needles. Results from Ringhals 1 from year 2000 and 2001.

6 Pulsation dampers in sensing lines in jet pump flow measurement system at KKM

Every year a great number of sensors and instrument components are investigated at KKM. These annual investigations have been performed since 1994 and the last years the number of involved sensors has been over 350.

12 internal jet pumps distributed in the periphery of the core force the reactor core flow. Figure 6.1 shows a simplified picture of the jet pumps in the reactor. The picture is a part of SensBase™ – the database with GUI's (Graphical User Interface) developed by GSE for storage of sensor test results and used at KKM. SensBase™ includes 23 graphical pictures of the sensor system, each one with an own display for related sensors; see Figure 6.1. The transmitter symbol is a button in SensBase™ and the user get access to stored sensor test results by pressing the button.

The jet pumps have flow meters of differential pressure type equipped with pulsation dampers. Therefore it is interesting to investigate if there is increasing flow resistance in the pulsation dampers over the years, a typical ageing problem. The mechanical filtering in a pulsation damper reduces the signal amplitude. A statistical measure for the amplitude is standard deviation. An increased damping reduces the standard deviation.

Changes in filtering can in this case in a simple way be studied with SensBase™. The window with the flow mean values for the chosen transmitter MF040F is presented in Figure 6.2. The result is presented with a bar graph for the mean value of the jet pump flow from the years 1998, 1999, 2000 and 2001. The flow has been relatively constant at about 1000 kg/s at the different measurement occasions. Standard deviation for corresponding years is presented for the sensor MF040F in Figure 6.3. This measure is also relatively constant from year to year, namely 3 –3.5 kg/s.

An increasing blockage in the pulsation damper to the flow meter, e.g. by particles in the sensing line water, would reduce the standard deviation from year to year when it is clear that the flow mean value has been constant. The measurement system is therefore judged to be intact from this question, since the standard deviation is constant.

SensBase™ includes many statistical parameters, see the following list for examples:

- Short time series (30 second) of the measurement
- APSD
- Histogram with mean value, standard deviation, skewness and kurtosis
- Time constants
- Multiple sensor information in time domain with gain, offset and amplitude ratio.

With the aid of these statistical measures comparisons may be performed for multiple sensors in frequency domain with APSD and in time domain with gain, offset and amplitude ratio. Time constants can also be compared for the different components in the instrumentation system and for identifying extended response times. Comparison of SensBase™ parameters over the years for a sensor system can reveal ageing problems.

The volume of work with calibration of transmitters at KKM has been reduced as a benefit of the use of SensBase™.

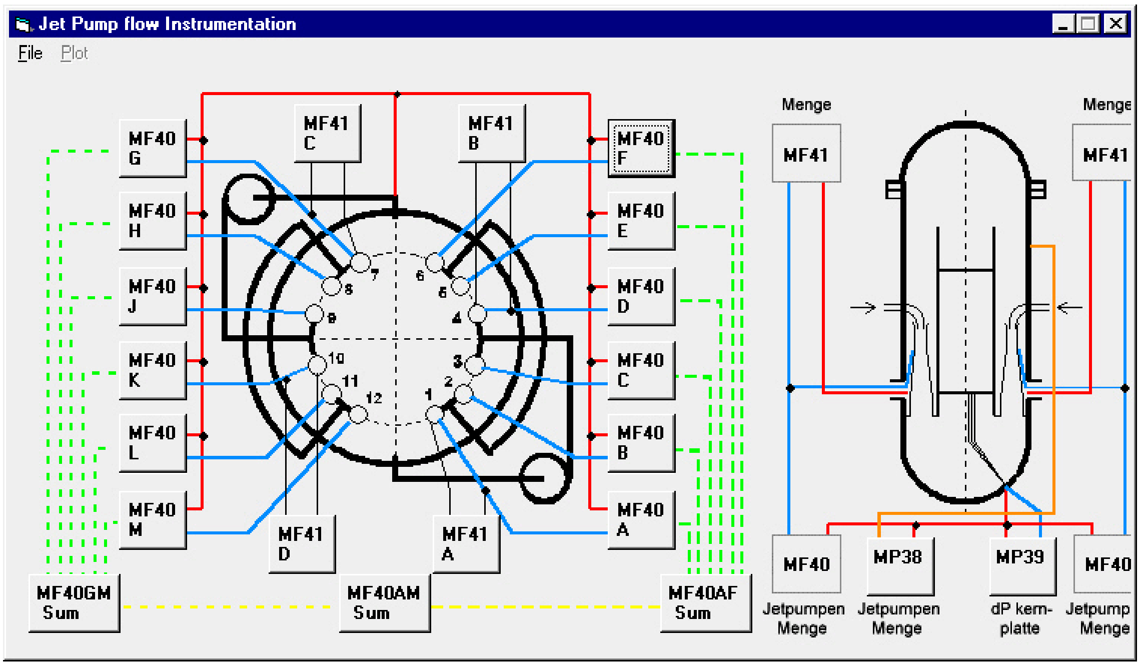


Figure 6.1 Instrumentation for the Jet pump flow measurement at KKM. The picture is a part of the GUI in SensBase™ – the GSE database for sensor test results.

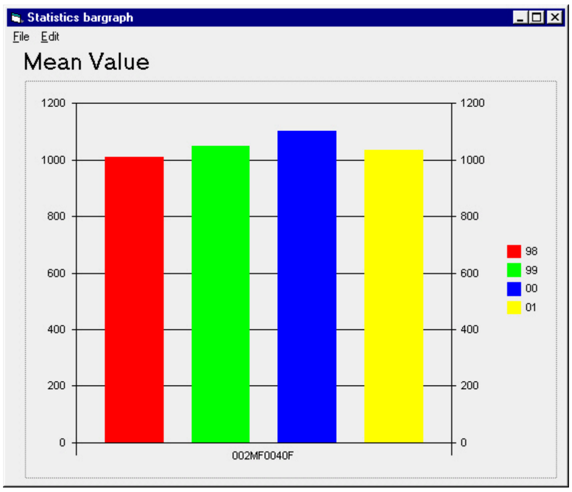


Figure 6.2 Bar graph for jet pump flow mean value MF040F from measurements at KKM 1998, 1999, 2000 and 2001.

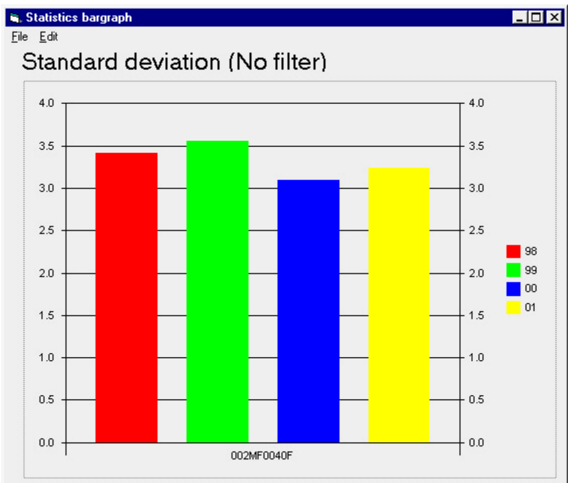


Figure 6.3 Bar graph for the standard deviation for jet pump flow MF040F from measurements at KKM 1998, 1999, 2000 and 2001.

7 Oscillation in a water level transmitter with influence on others

Chapter 4 presented results from Ringhals 1 where oscillations occurred in the pressure signals. The interpretation is that the oscillations arise because of resonances. The water pillar in the sensing line acts as the mass and the elasticity in the transmitter acts as a spring. The interpretation is that the three resonance peaks found in Ringhals 1 is a result of the different lengths of the individual sensing lines.

This chapter presents results from KKM where a very clear oscillation in reactor water level and reactor pressure was identified and corrected.

The central part of the reactor pressure and water level instrumentation is shown in Figure 7.1. The figure is a part of the graphic presentation in SensBase™. There are four pressure taps on each side of the reactor vessel and one on top of the reactor. Five of the pressure taps are connected with condensate pots. KKM has been in operation since the early seventies and this generation of reactors was designed with few pressure taps. This implies that many instruments are connected to the same sensing lines; see Figure 7.1. The sensing lines are drawn with colored lines in Figure 7.1 and the transmitters are buttons with sensor name information.

During sensor tests performed by GSE in 1994-1995 it was found that many transmitter signals were oscillating with 2 Hz. These are marked with red dots in the Figure 7.1. As seen in the figure most of the influenced transmitters are on the left hand side of the reactor. Signal analysis indicated the highest oscillation amplitudes for the level transmitters ML93 and ML94A. The investigation showed that the pressure signals MP92 and MP30A were coherent and out-of-phase at the frequency 2 Hz. There was also high coherence between pressure and level signals and this is un-normal since the water level signal records the differential pressure.

The diagram for the reactor instrumentation in Figure 7.1 displays that ML93 and ML94A are connected to the same sensing line (blue and yellow). It is also clear that all transmitters that record the 2 Hz oscillations are connected to either the blue or the yellow sensing line.

The conclusion was that the 2 Hz peak was caused by membrane oscillations either in transmitter ML93 or ML94A; mainly depending on their high amplitude. Both signals are shown as a function of time in Figure 7.2, after reduction of the signals mean values. The figure displays that the amplitudes agree well between the both signals.

7.1 The decision to close valves on the sensing lines to ML93 and ML94A

During spring 1996 it was decided that experiments were to be performed to find the reason for the 2 Hz oscillations. It was decided that the isolation valves that are installed near the suspected transmitters ML93 (valve A) and ML94A (valve B) were to be manually closed during normal power operation of the plant; see Figure 2.3 and 7.1. The valves should be closed and opened again for a short period one at the time during simultaneous recording of ML93, ML94A, MP30A and MP92.

The results from the valve closing are shown in Figure 7.3 with the signals ML93 and ML94A as a function of time. The top curve displays ML93. When valve A is closed the level signal is essentially constant without fluctuations. There is, however, a minor increase in the mean value in comparison with the period before and after the valve closing; see Figure 7.3. Both time series are displayed with expanded time scale in Figure 7.4. It is interesting to note that the closing of valve A influences ML94A. Figure 7.4 displays clearly that the signal ML94A is changed from oscillation with 2 Hz to high frequency noise after the closing of valve A.

Valve B is closed 300 s after beginning the measurement in Figure 7.3. This is clear from the signal ML94A that essentially reduces in noise amplitude and at the same time increases in mean value as long as the valve is closed. The closing of valve B is presented in expanded time scale in Figure 7.5. It is clear that the closing of valve B does not influence ML93. ML93 continues to oscillate without hindrance.

To evaluate the experiment the ASPDs for the signals are used. The APSD has been calculated for ML94A with fixed short time series length shifted from the beginning of the measurement until it comes into the period with closing of valve A. The result is clear. In the beginning of the time series when valve A and B are open the APSD includes a sharp peak at 2 Hz and damping for frequencies between 2 and 10 Hz; see Figure 7.6. When valve A is closed the 2 Hz peak is cancelled and the frequency content between 2 and 10 Hz increases at the same time. Observe that the transmitter ML94A does not have anything to do with the closing of valve A; see Figure 7.1. The result is clear. Closing of valve A isolates the transmitter ML93 from one of the sensing lines and at that time the 2 Hz oscillations ceases and the noise at high frequencies increases in the sensing line. So far everything points to ML93 to be the cause to the observed 2 Hz oscillations.

A corresponding sequence of APSD calculations for ML93 is shown in Figure 7.7 for time series before and during closing of valve B. The result in the frequency domain is obvious. The valve closing does not influence ML93. This implies that ML94A is not the cause to the observed oscillations.

Figure 7.10 displays a three-dimensional figure of APSD for ML94A during the experiment with the closing of valve A. Spectra have been calculated with the time as one of the third dimensions. The x-axis = the frequency, y-axis = the time and z-axis = APSD in the three-dimensional figure. Also this figure supports the interpretation that when the valve A is open in the beginning and end of the measurement, there is a clear 2 Hz oscillation in APSD. The figure also displays the damping in APSD between 2 and 10 Hz when valve A is open. When the valve is closed, at 200 s in the three-dimensional figure, the 2 Hz peak is cancelled and at the same time APSD has increased clearly between 2 and 10 Hz.

The interpretation is that the transmitter ML93 causes the observed oscillations and damps the high frequency noise coming from the reactor pressure via the sensing line. It is interesting to note that one transmitter generates the oscillations and 8 transmitters receive the oscillations via the common sensing lines; see Figure 7.1 where the 2 Hz influenced transmitters are marked with a red dot. All of them except ML94B and MP92 have in common that they are connected to the blue sensing line and therefore possible to be influenced by ML93. ML94B and MP92 are influenced by ML93 via the yellow sensing line; see Figure 7.1.

7.2 Exchange of transmitter ML93

The transmitter ML93 was a Hartmann & Braun Barton Cell construction of the type TDHZ224 with a large volume and displacement. Figure 7.8 shows a section of the mechanical part of the transmitter. Observe especially the bellows with springs in center of the construction. The transmitter ML94A was a Hartmann & Braun Membran-Zelle 050 with a smaller volume than the Barton Cell and a modern construction. A section of the mechanical part of the transmitter is displayed in Figure 7.9.

ML93 was replaced by a new transmitter during the regular outage 1996. The new transmitter was a Hartmann & Braun Membran-Zelle 080 and the construction is similar in design to Membran-Zelle 050; see Figure 7.9. The exchange of transmitter solved the problem with the 2 Hz oscillations.

The result of the exchange of transmitter is presented with the aid of SensBase™. The APSD for the water level ML93 is displayed in Figure 7.11 for the years 1996 – 2001. There is a clear peak at 2 Hz in the year 1996 with ML93 but for all the other years the resonance peak is extinguished. APSD for ML94A in Figure 7.12 displays in the same way that the measure was successful. The resonance peak disappears after the year 1996. It is finally proved that ML33B1 has an influence on the APSD at 2 Hz that disappears after the replacement of the transmitter ML93; see Figure 7.13. The position of the transmitter ML33B1 in the instrument system is shown in Figure 7.1. The influence is performed via the blue sensing line.

It is worth to mention that the damping of ML94A in the frequency range 3 – 10 Hz disappears after the replacement of the transmitter ML93. The damping is caused by the elasticity in ML93 and the replacement of the transmitter ML93 makes ML94A slightly faster in response time.

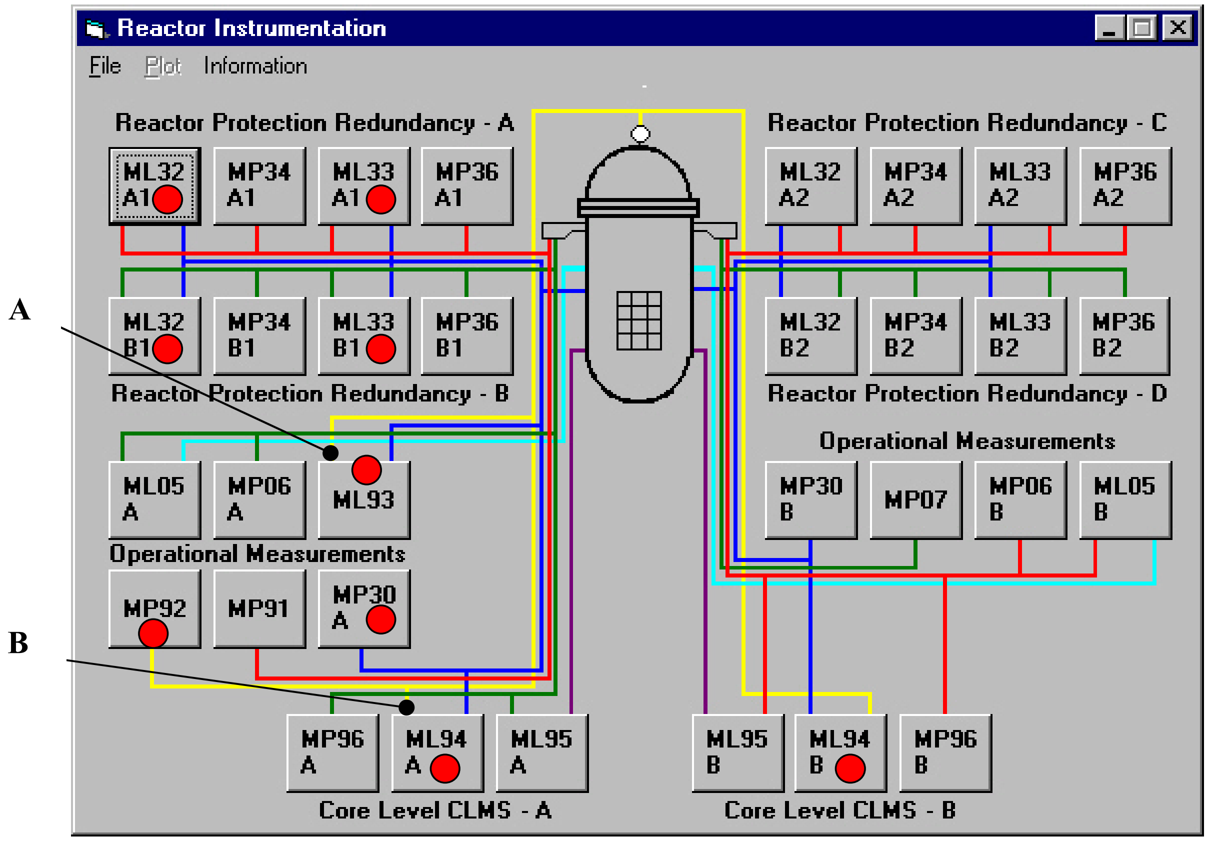


Figure 7.1 Reactor pressure and water level instrumentation at KKM – a GUI from SensBase™. Transmitters are represented by buttons. The sensor test results are displayed by activating one or more buttons. Buttons with a red dot are influenced by the 2 Hz oscillations.

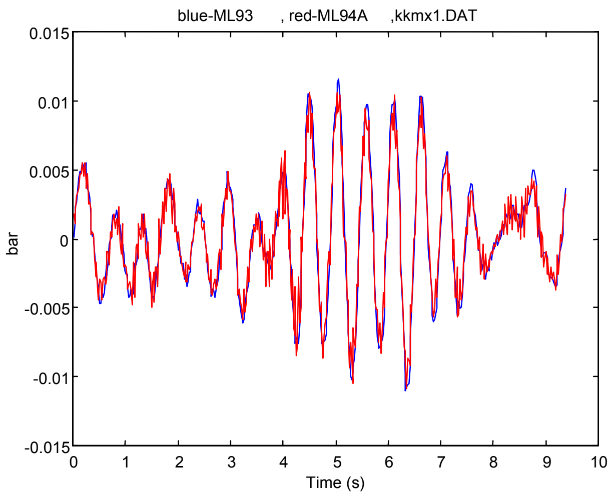


Figure 7.2 ML93 and ML94A as function of time at KKM.

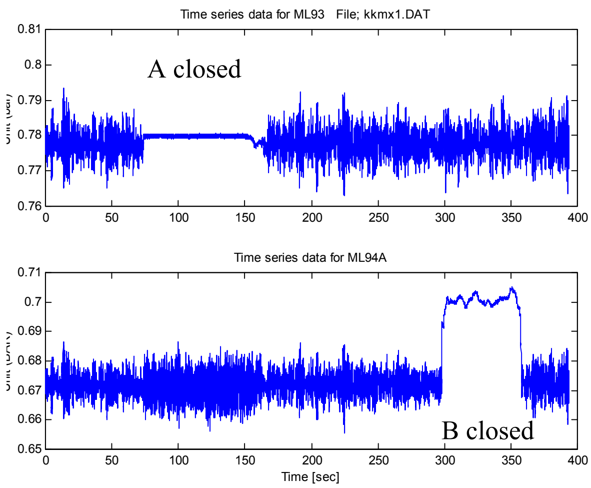


Figure 7.3 Experiment at KKM during closing of the valves A and B.

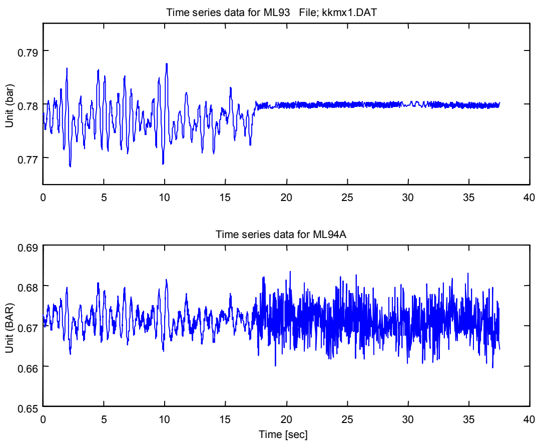


Figure 7.4 ML93 and ML94A as function of time during closing of valve A at KKM.

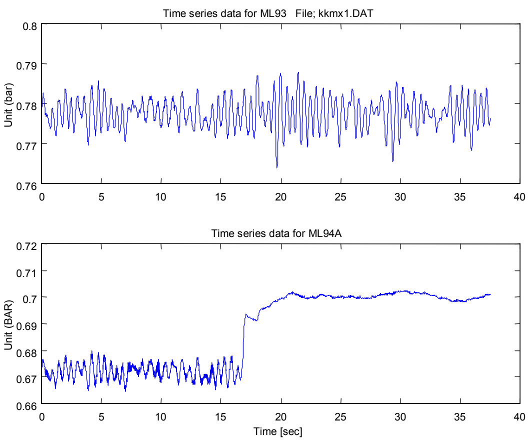


Figure 7.5 ML93 and ML94A as function of time during closing of valve B at KKM.

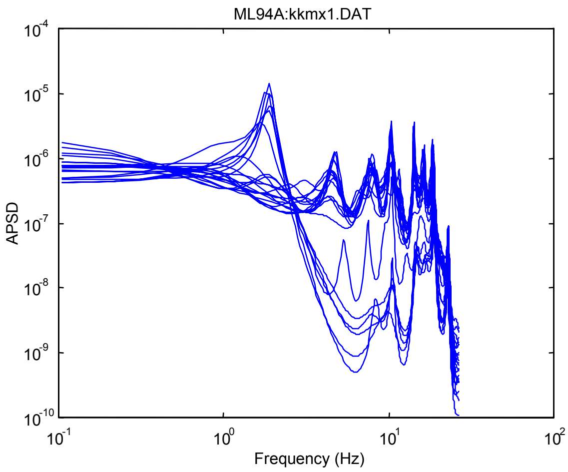


Figure 7.6 APSD for ML94A during closing of valve A at KKM.

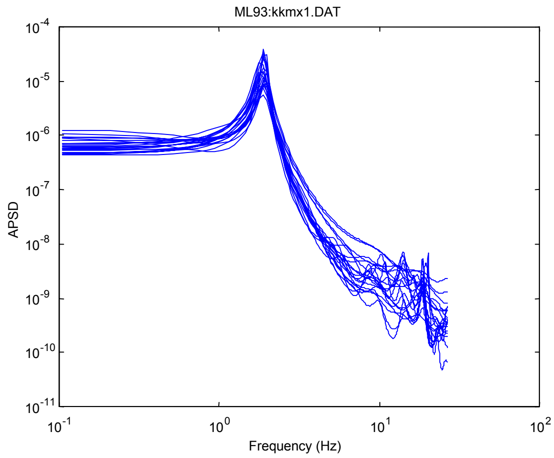


Figure 7.7 APSD for ML93 during closing of valve B at KKM.

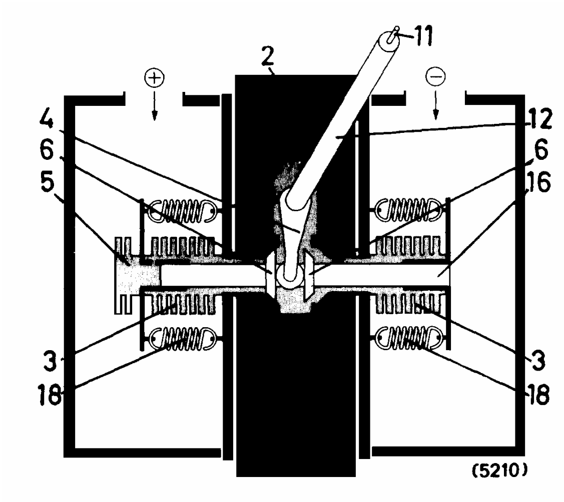


Figure 7.8 The transmitter ML93 that caused the oscillations at 2 Hz. Barton Cell TDHZ 224.

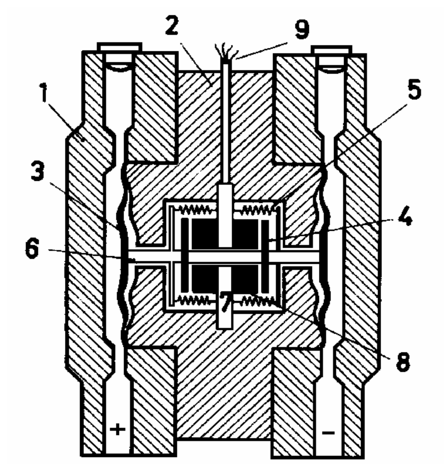


Figure 7.9 Transmitter ML94A Membran-Zelle 050.

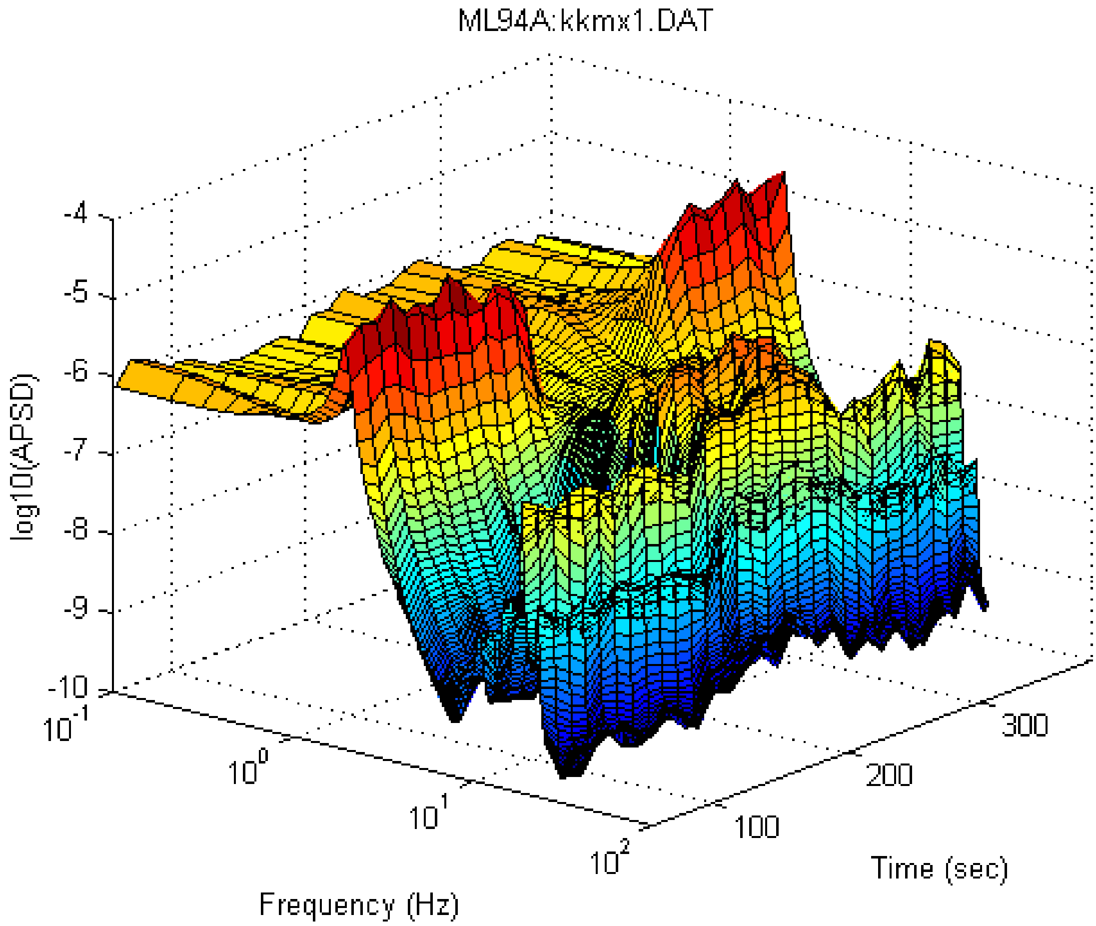


Figure 7.10 *APSD for ML94A during the closing of valve A. The APSD has been calculated for a short time series and then shifted stepwise to the end of the measurement. The 2 Hz resonance is visible as a red mountain in the beginning and the end of the measurement. The 2 Hz peak is cancelled when the valve is closed and at the same time the APSD increases between 3 and 10 Hz.*

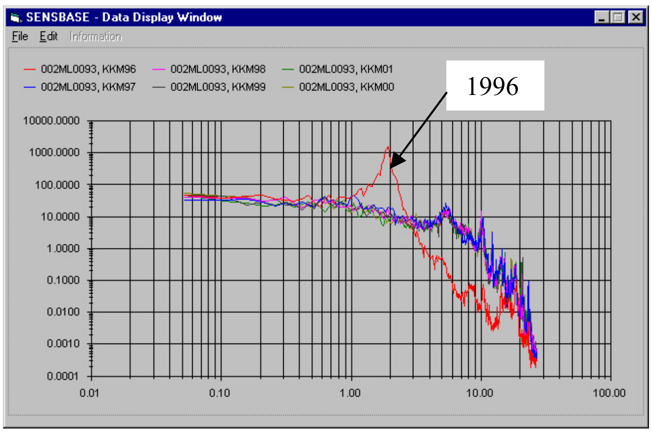


Figure 7.11 APSDs for ML93 during the years 1996-2001. Results with SensBase™ at KKM.

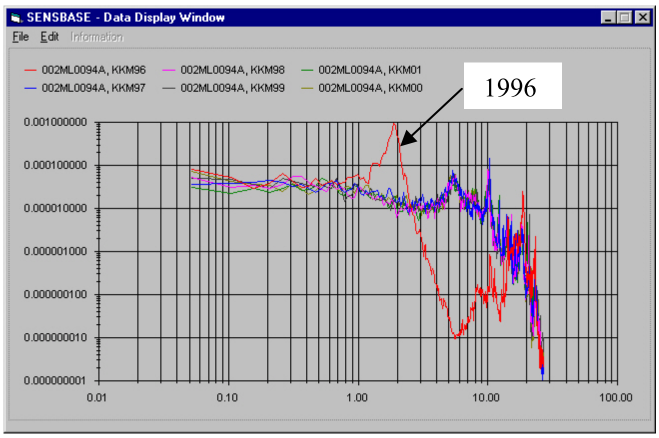


Figure 7.12 APSDs for ML94A during the years 1996-2001. Results with SensBase™ at KKM.

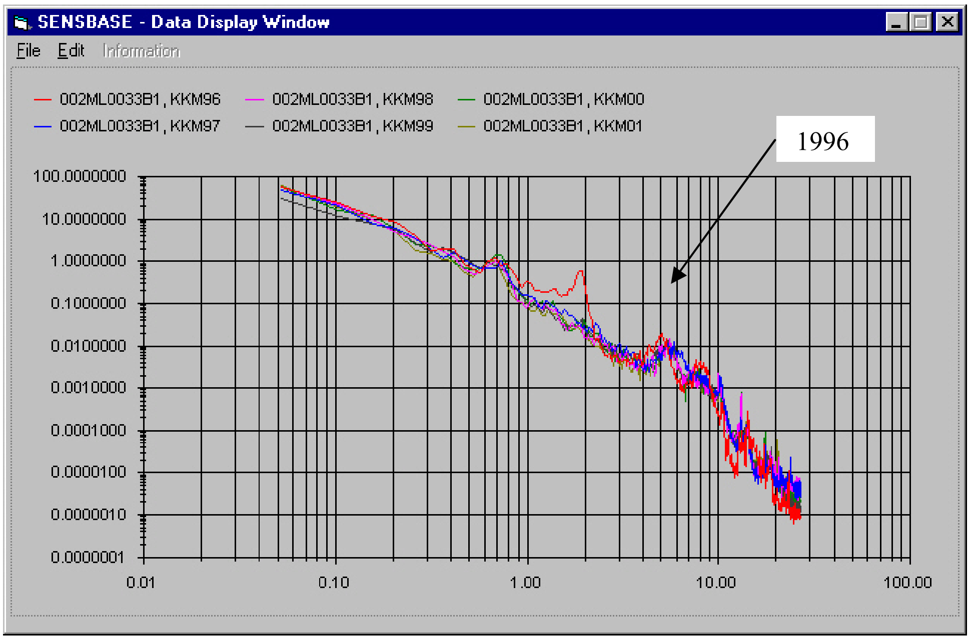


Figure 7.13 APSDs for ML33B1 during the years 1996-2001. Results with SensBase™ at KKM.

8 Reactor pressure and reactor water level with 10 Hz noise

It is not un-common that reactor pressure and water level signals include 10 Hz noise. The origin of the noise can be the process, the measurement system or vibration in the sensing lines. Sometimes it comes from a combination of many different sources.

In Figure 8.6 the APSDs for two multiple reactor pressure signals, MP34A2 and MP36A2, are shown. They were recorded at KKM. The pressure transmitters are installed on the same sensing line; see Figure 7.1. They are displayed on the right hand side of the reactor in the figure and they are connected to the red sensing line. The transmitters have therefore the same input pressure signal. The result is a very good agreement between the two signals. Even the noise content between 10-20 Hz agrees. The transmitters reproduce noise even if vibrations in the common sensing line are the cause. It does not exist any unique measurement or transmitter noise when using these transmitters.

In other words two transmitters by the same manufacturer have the possibility to reproduce APSD up to 20 Hz when they have common pressure via the same sensing line.

Figure 8.2 show APSDs for the swelling (reactor water level) sensors 211K418 and 211K419 at Ringhals 1 in 2001. The signals agree completely up to 5 Hz. In the frequency range 5-15 Hz the APSD for 211K418 is clearly higher than the ASPD for 211K419. Above this frequency, that is between 15 and 20 Hz, the APSDs agree again. The construction of the measurement system is shown in Figure 5.1. The transmitters have different sensing lines but they are connected to the same pressure taps on the reactor vessel. They are also of the same type, that is S & F TDE 250. A reasonable interpretation is that there are different vibrations on the sensing lines to 211K418 and 211K419 that cause the deviating noise between 5 and 15 Hz.

Figure 8.1 displays APSDs for three pressure sensors connected to the same sensing line. See also Figure 4.3 where the instrumentation is presented. The transmitters are from different manufacturers: 211K112 of the type Rosemount 1151, 211K101 of the type AZC200 and 211K119 of the type Rosemount 3051 smart. All these APSDs have different patterns between 5 and 20 Hz although they have a common sensing line. The interpretation is that the deviation is caused by different transmitter character and therefore the vibrations on the sensing lines have different influences.

8.1 Experiments with sensing line vibrations at KKM

An experiment with the aim of getting to know more about the noise at 10 Hz has been performed at KKM. The reason was that two transmitters had been replaced because of increased noise between 5 and 10 Hz in comparison with multiple transmitter signals. Their measurement points were MP34B2 and MP211A. These two transmitters and a reference transmitter were connected to a common sensing line in a laboratory. The equipment is presented in Figure 8.3. The water filled sensing line influences the transmitters with 68 Bar. The result of the measurement is shown in Figure 8.4. To create vibrations on the sensing line knocking was performed on the sensing line several times during the measurement. It is clear from the measurement in Figure 8.4 that vibrations are recorded differently with the three transmitters.

APSDs for the signals displayed in Figure 8.5 show that the vibrations give strong resonance peaks just above 10 Hz. It is interesting to note that these results agree very well with the observations in the plant; see Figure 8.1, 8.2 and 8.6. The experiment at KKM supports the hypothesis that sensing line vibrations is the source to the peaks just above 10 Hz.

The experiment at KKM indicates also that the transmitters, in this case from different manufacturers, have different sensitivity for vibrations. The highest APSD was observed with MP211A - of the type AVC200, thereafter MP34B2 – of the type AVC200 and then the reference transmitter – of the type Rosemount 1151.

It is worth to stress that the transmitters were replaced because of increased noise in the frequency range 5 – 15 Hz. Therefore it could not be excluded that the vibration sensitivity increases with age. And increased APSD in the range 5-15 Hz can be an ageing sign for the transmitter. Further systematic investigations should be performed in this area.

8.2 MP34B2 before and after the exchange of transmitter observed with SensBase™

Finally the result for the reactor pressure MP34B2 is presented with the aid of SensBase™ before and after the replacement of the transmitter that was tested in Chapter 8.1. MP34B2 is connected to the same sensing line as transmitter MP36B2; see Figure 7.1. The APSDs for these transmitter signals are therefore expected to agree. This is not the case in the annular sensor investigation performed during spring 2000. The APSDs for the signals deviate especially for the frequencies between 2 and 20 Hz; see Figure 8.7.

As a result of the observation the transmitter was exchanged during the regular outage in the summer 2000. The result of the measure is available in SensBase™. APSDs for the measurement signals MP34B2 and MP36B2 for 2001 are shown in Figure 8.8. It is clear that agreement is recovered between the two spectra. They are identical even at high frequencies.

The exchanged transmitter MP34B2 was finally sent to service. It was made clear that the mechanical part of the transmitter was faulty and needed to be replaced.

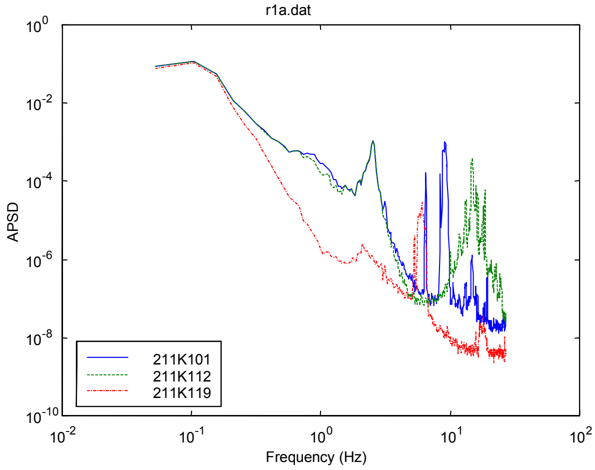


Figure 8.1 APSDs for reactor pressure with 3 sensors at Ringhals 1

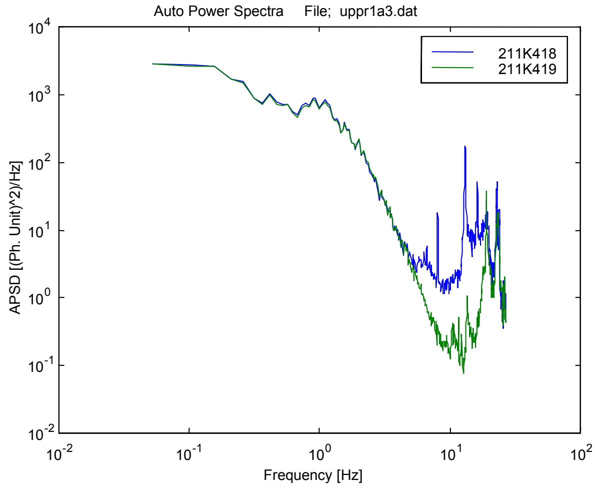


Figure 8.2 APSDs for two swelling-signals at Ringhals 1, 2001.

Figure 8.3 Laboratory test of three pressure transmitters at KKM.

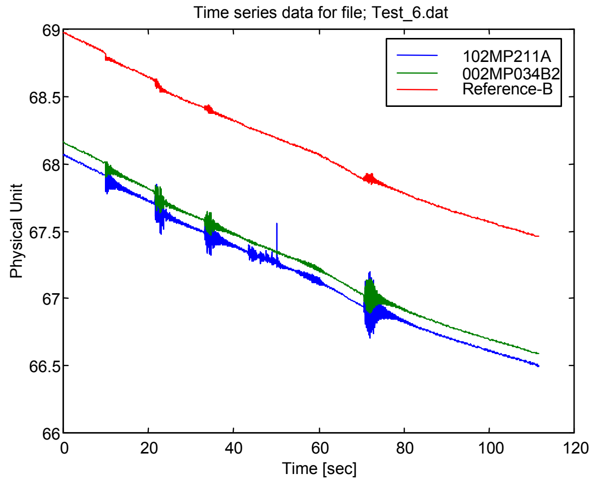


Figure 8.4 Repeated knocking on the common sensing line during experiment at KKM.

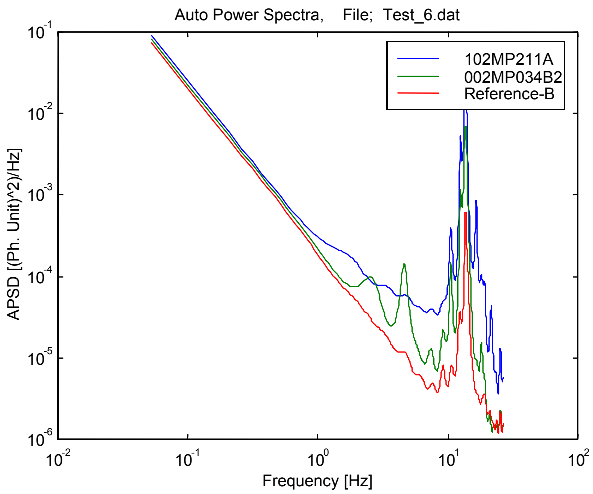


Figure 8.5 APSDs for the pressure signals during the experiment at KKM.

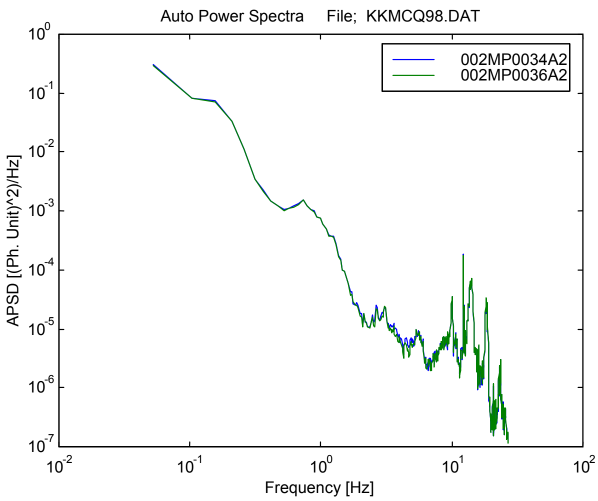


Figure 8.6 APSDs for the multiple pressure signals recorded at KKM.

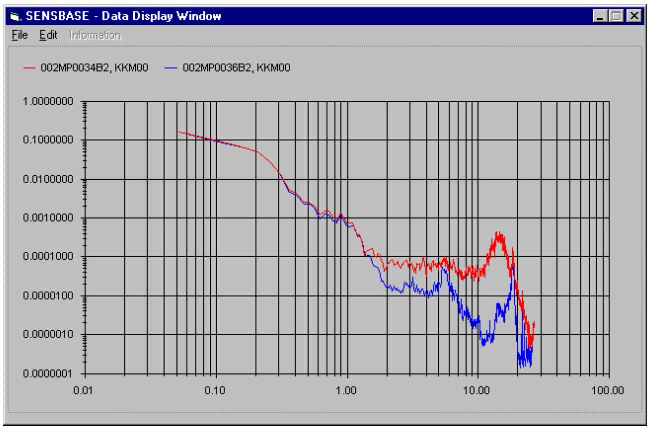


Figure 8.7 APSDs for MP34B2 (red) and MP36B2 (blue) year 2000. Before the replacement of the transmitter MP34B2

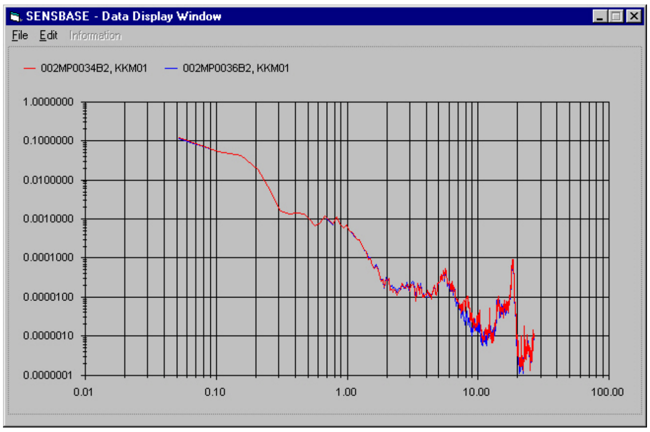


Figure 8.8 APSD.s for MP34B2 (red) and MP36B2 (blue) year 2001. After the replacement of the transmitter MP34B2.

9 Conclusions

Sensors are a part of the safety system in a reactor. They are the first link in a chain of components that influence the protection system. It is therefore of great importance that the sensors fulfill the requirements on reliability and response time. The dynamic character of sensors is in practice seldom or never tested in BWRs. The static performance is on the other hand tested every year during the calibration of the transmitters. This is performed during the regular outage of the reactor.

It is quite common that many transmitters are connected to the same sensing line. This is especially valid in old reactors where only a few number of pressure taps are available on the reactor vessel. This is a shortcoming in the construction since one fault in the sensing line influences all connected components; a so-called CCF (Common Cause Failure).

The present report was sponsored by SKI, Swedish Nuclear Power Inspectorate. The report focuses on possible deviations in the sensing lines. The deviations are presented with practical examples from Swedish and foreign BWRs.

The sensing line and its belonging mechanical passive components can reduce the response time for a measurement system without influencing the static presentation. The report describes cases in a power plant where the response time was extended from 0.1 s to 5 s. The reason was gradual blockage in the sensing line. There is only one technique available today with which it is possible to investigate sensor dynamics, and that is signal analysis. Appropriate analysis of the transmitter signals can reveal filtering whether it takes place in the sensing line, the transmitter or in the electronic instruments.

As an example a practical case is presented where pulsation dampers with so-called needles were used at Ringhals 1 in Sweden. Their influence on the response time for the measurement signal corresponded to a time constant of 0.55 seconds. By eliminating the needles the requirements on the response time was fulfilled.

Results from KKM (Kernkraftwerk Mühleberg in Switzerland) show a way to supervise blockage in sensing lines based on the transmitter signal. One example is presented with a transmitter for flow measurement equipped with pulsation dampers. Results from SensBase™, a database system for sensor tests, is used in this work. SensBase™ stores new sensor test results every year. The nuclear power inspectorate in Switzerland has approved that KKM reduced their comprehensive transmitter calibration after introduction of the annular use of sensor tests and SensBase™.

The report also describes pressure oscillations that take place in the sensing line and not in the real measured process. The water in the sensing line together with the transmitter membrane form a dynamic system with water as mass, elasticity in the transmitter membrane as spring constant and reactor pressure fluctuations as driving force. The problem with oscillations in the measurement system is illustrated with examples from Ringhals 1 and KKM.

One example is also presented from KKM where the oscillation in a level transmitter – a Barton Cell – influenced eight transmitters connected to a common sensing line. It was possible to identify the deviating transmitter during operation of the reactor via experiment with isolation valve closing. The oscillations ceased after replacing the transmitter with one with less volume and displacement.

The report finally proves that mechanical vibrations in the sensing lines contribute to signal noise around 10 Hz. This is shown with the aid of laboratory tests performed at KKM. Transmitters have also been exchanged because of deviating noise in the frequency range 2-20 Hz. After replacing the transmitter the mentioned noise disappeared. The results from KKM indicate that it cannot be excluded that ageing increase the transmitter sensitivity for sensing line vibrations.

10 References

1. Bergdahl B.G. Investigation of sensors and instrument components in boiling water reactors. Results from Oskarshamn 2, Barsebäck 2 in Sweden and Kernkraftwerk Mühleberg in Switzerland. May 1998, SKI Report 98:22.

2. Bengt-Göran Bergdahl, Joakim K.-H. Karlsson, Ritsuo Oguma and Herbert Schwaninger. Experiences from sensor tests and the evaluation of long-term sensor performance using SensBase™. Paper presented at the NPIC & HMIT 2000 meeting, Washington, DC, November, 2000.

3. B.G. Bergdahl, M. Morén and R. Oguma. Experiences from sensor tests and evaluation of sensor performance. Paper presented at SMORN VIII, Symposium On Nuclear Reactor Surveillance And Diagnostics, May 27 – 31, 2002, Göteborg, Sweden

4. IAEA-rapport. Management of ageing of I & C equipment in nuclear power plants. Report prepared within the framework of the International Working Group on Nuclear Power Plant Control and Instrumentation. June 2000. IAEA-TECDOC-1147.

5. Bergdahl BG, Liao B, Oguma R, Schwaninger H. Sensor diagnostics in a BWR based on noise analysis. An invited paper presented at the NPIC & HMIT'96 meeting May 6 - 9, 1996, The Pennsylvania State University, USA.

6. Hashemian HM et al. Effect of Aging on Response Time of Nuclear Plant Pressure Sensors. Analysis and Measurement Services Corporation. NUREG/CR-5383.

7. Hashemian HM et al. Long Term Performance and Ageing Characteristics of Nuclear Plant Pressure Transmitters. Analysis and Measurement Services Corporation. NUREG/CR-5851.

8. Hashemian HM. Private communication.

www.ski.se

STATENS KÄRNKRAFTINSPEKTION
Swedish Nuclear Power Inspectorate

POST/POSTAL ADDRESS SE-106 58 Stockholm
BESÖK/OFFICE Klarabergsviadukten 90
TELEFON/TELEPHONE +46 (0)8 698 84 00
TELEFAX +46 (0)8 661 90 86
E-POST/E-MAIL ski@ski.se
WEBBPLATS/WEB SITE www.ski.se