ON-LINE IDENTIFICATION OF THE NUCLEAR POWER PLANT PHYSICAL PARAMETERS AT POWER OPERATION

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ABSTRACT

After the upgrade of Borssele NPP in 1997, core cycle 24, power plant operated three years more with the 91% availability. Authority of the power plant decided to enhance and upgrade the reactor trend monitoring and plant information recording system as well as the plant information system. This paper will introduce on-line core barrel motion (CBM) monitoring, plant physical parameters and vibration of the primary coolant pumps trend analyses.

I. INTRODUCTION

Borssele Nuclear Power Plant own and operated by NV - EPZ Nederland, and located near to the Westerschelde estuary. The single unit plant was build over the years 1968 to 1973 by Siemens/KWU and achieved a lifetime load factor above 80% over the first 24 years. In the first half of the 1997 world's most ambitious nuclear back-fitting project successfully finished and the power plant of core cycles from 1998 to 2002 achieved to average load factor above 91% (e.g., H.H. Gruhl and C. Kalverboer [1]). The new plant data collection and processing system were introduced by E. Türkcan et.al. [2]. The system consist of two sub-systems which includes 96 DC signals of the plant with 10 samples/s used for operational history recording with the aid of plant transient analysis. In the reactor noise diagnostic system selected 32 AC/DC conditioned signals with higher sampling rates. Both systems build in National Instruments hardware and software. Paper will present the diagnostic system as well as the monitoring system results of the new core cycle in operation.

II. MEASURING SYSTEM

A new measuring system, based on NI-System equipment's [2] shown in Fig.1. The first system (MR) is used as data recording with the purpose of detection and replay. In case of any transients may occur this system can display the transient data. Also this system can be used for on-line follow-up of operation by means of ANN software to identify the deviations from the normal behaviour [3]. The second system MS is used with special purpose for the monitoring of spectral changes of selected signals from reactor safety channels; in-core and ex-core neutron detector signals, pressures of primary system, generated electric power, coolant temperatures, vibrations on primary coolant pumps, see Table 1a and 1b. The real-time measurements and results obtained from these signals are the main emphasis of this paper.

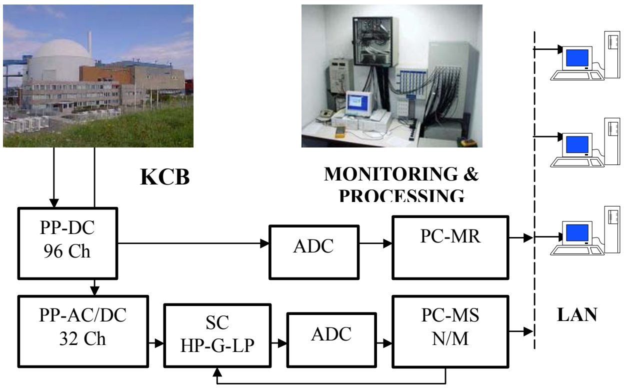


Fig. 1: Meauring system of the Borssele NPP (KCB).
PP: Patch Panel, SC: Signal Conditioner, ADC: 16 bits data card, N/M: Noise and Monitoring

Ch	*Signal Id.*	*Signal Name*	*Unit*
0	*YQ032T006*	*Core Exit Temperature*	*℃*
1	*YA001T095*	*Core Inlet Temperature*	*℃*
2	*TV050A001*	*Boron Concentration*	*ppm*
3	*SP010E001*	*Reactor Power*	*MWe*
4	*YX003X082*	*Excore Neutron Channel (50°cw)*	*V*
5	*YX003X062*	*Excore Neutron Channel (140°cw)*	*V*
6	*YX003X072*	*Excore Neutron Channel (230°cw)*	*V*
7	*YX003X052*	*Excore Neutron Channel (320°cw)*	*V*
8	*YQ023X011*	*Incore Neutron Channel*	*V*
9	*YQ023X015*	*Incore Neutron Channel*	*V*
10	*YQ023X016*	*Incore Neutron Channel*	*V*
11	*YA001P001*	*Primary Pump Pressure (L-1)*	*bar*
12	*YA002P001*	*Primary Pump Pressure (L-2)*	*bar*
13	*YA001P003*	*Primary Pump Pressure Δ Pressure (L-1)*	*bar*
14	*YA002P003*	*Primary Pump Pressure Δ Pressure (L-2)*	*bar*
15	*TA000P001*	*Plunger Pump Pressure*	*bar*

Table. 1a: Identification of the reactor signals.

III. MEASUREMENTS OF THE REACTOR PHYSICAL PARAMETERS

Observation of the core barrel motions (CBM) are very important at the Pressurised Water Reactors (PWR) which are also nearly half of the number of operating Nuclear Power Plants (NPP) on the world operating 432 NPP's (231 are PWR's). CBM can be measured from ex-core neutron detector placed around reactor vessel; core vibrations caused by primary coolant system pressure oscillations influence these signals. Several authors since last three decades investigate these effects off-line or partly on-line measurements. The possibility of the detecting CBM was first indicated by J. Thie in 1975 [4]. The method two years later investigated by J.B. Dragt and E. Türkcan in 1977 [5] and later extended in on-line applications by E. Türkcan using array processor for real-time calculations (1982, '85 and '86 [6,7,8]). Later, this method was widely used. Several PWR users in the world investigated research and extended the method in time and frequency domain analyses, are given by Pazsit, Karlsson and Garis (1998) [9] including time domain analysis. Also Lipcsei and Kiss (2000) [10] implemented and extended the method for VVR 440/213 and VVER Russian type of PWR's. Extending error analysis depending on number of ex-core neutron detectors and their position are given (e.g., Berta and Pór in 1999 [11]).

In our method, we used signals of four excore neutron detectors placed at the same height and located 90^0 from each other (50^0, 140^0 , 230^0 and 320^0). In this method primarily two noise sources (not directly measurable), such as reactivity and core support barrel motions are separated completely:

The crosspectrum $P_{x_i x_j}(n,q)$ of two neutron detector channels x_i and x_j is calculated from a linear model, assuming the noise at any detector being the sum of independent noise sources δx^l. Each noise source consist of a global (reactivity) effect δr^l and a term due to the motion of the core barrel δy^l in the direction θ_l with respect to some reference causing the neutron flux gradient to follow the same movement attenuated by a transmission factor μ : $\delta x^l = \delta r^l + \mu \delta y^l$, $\mu = 0.15\ cm^{-1}$.

Straightforward calculation of the crosspectrum due to the noise source δx^l (omitting the block index q for simplicity) gives:

$$P_{x_i y_j}(n) = P^l_{rr}(n) + \mu^2 P^l_{yy}(n)\cos(\theta_i - \theta_l)\cos(\theta_j - \theta_l)$$

$$+ \mu P^l_{yr}(n)\cos(\theta_i - \theta_l) + \mu P^l_{ry}(n)\cos(\theta_i - \theta_l)$$

θ_i the angle of detector x_i to reference axis $P^l_{rr}(n)$, $P^l_{yy}(n)$, $P^l_{yr}(n)$ and $P^l_{ry}(n)$ the different auto- and crosspectra of reactivity and motion of δx^l.

Now, by means of the transfer functions (F denotes Fourier transform)

$$T^l_1(n) = \frac{F\left[\delta r^l(k)\right]}{F\left[\delta x^l(k)\right]},\ T^l_2(n) = \frac{F\left[\delta y^l(k)\right]}{F\left[\delta x^l(k)\right]},\ T^l(n) = \overline{T^l_1(n)}\, T^l_2(n)$$

and assuming the δy^l to be uncorrelated, it is possible to write down the real and imaginary part of the crosspectrum, now involving all noise sources l, as follows:

$$\mathrm{Re}\left[P_{x_i x_j}(n)\right] = \sum_{m=1}^{6} A_m(n) C^A_m(i,j);\quad \mathrm{Im}\left[P_{x_i x_j}(n)\right] = \sum_{m=1}^{2} B_m(n) C^B_m(i,j)$$

$$A_1(n) = \sum_l P^l_{rr}(n) \qquad C^A_1(i,j) = 1$$

$$A_2(n) = \frac{1}{2}\sum_l \mu^2 P^l_{yy}(n)\cos 2\theta_l \qquad C^A_2(i,j) = \cos(\theta_i + \theta_j)$$

$$A_3(n) = \frac{1}{2}\sum_l \mu^2 P^l_{yy}(n)\sin 2\theta_l \qquad C^A_3(i,j) = \sin(\theta_i + \theta_j)$$

$$A_4(n) = \frac{1}{2}\sum_l \mu^2 P^l_{yy}(n) \qquad C^A_4(i,j) = \cos(\theta_i - \theta_j)$$

$$A_5(n) = \sum_l \mu P^l_{xx}(n)\mathrm{Re}\left[T^l(n)\right]\cos\theta_l \qquad C^A_5(i,j) = \cos\theta_i + \cos\theta_j$$

$$A_6(n) = \sum_l \mu P^l_{xx}(n)\mathrm{Re}\left[T^l(n)\right]\sin\theta_l \qquad C^A_6(i,j) = \sin\theta_i + \sin\theta_j$$

$$B_1(n) = \sum_l \mu P^l_{xx}(n)\mathrm{Im}\left[T^l(n)\right]\cos\theta_l \qquad C^B_1(i,j) = \cos\theta_i - \cos\theta_j$$

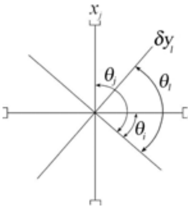
$$B_2(n) = \sum_l \mu P^l_{xx}(n)\mathrm{Im}\left[T^l(n)\right]\sin\theta_l \qquad C^B_2(i,j) = \sin\theta_i - \sin\theta_j$$

From these equations, the reactivity, the rms value of the vibration amplitude and the direction of the movement can be calculated from the following equations:

$$REA(n,q) = \sqrt{A_1(n,q)}$$

$$RMS(n,q) = \frac{1}{\mu}\sqrt{A_4(n,q) + \sqrt{A_2^2(n,q) + A_3^2(n,q)}}$$

$$DIR(n,q) = \frac{1}{2}\arctan\frac{A_3(n,q)}{A_2(n,q)}.$$



In Fig. 2 shows the NAPSD functions of the ex-core lower neutron detector signals spectra for one measurement. Spectral change depending on detector position. The 9.2 Hz in the global effect caused by the delta pressure of two primary coolant pumps. Other peaks are related in core barrel motions (10 – 17 Hz's), 25 Hz peak created by the pump speed.

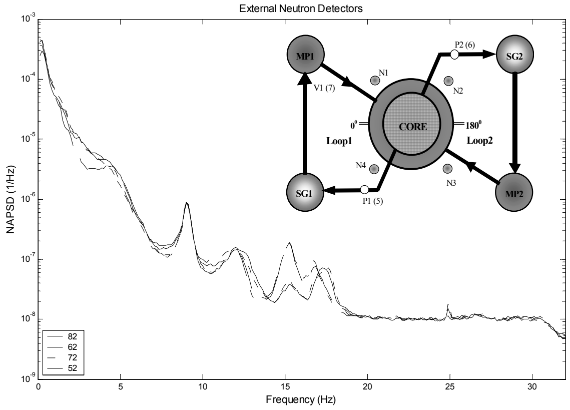


Fig 2. Showing the normalized APSD of the excore neutron detectors, positions and the pressure sensors.

The NI Lab-View software is used for above mentioned calculations as well as for graphical display. In the operational fuel cycle 28 measurements are displayed in the following figures (Fig. 3 - 9):

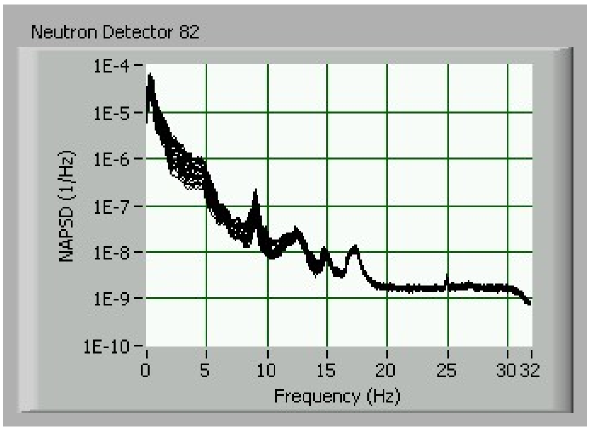


Fig. 3: Figure displays NAPSD(f) functions during the operation of 180 days. Spectral changes at low frequencies as well as at 9.2 Hz. After 20 Hz the white noise level is constant.

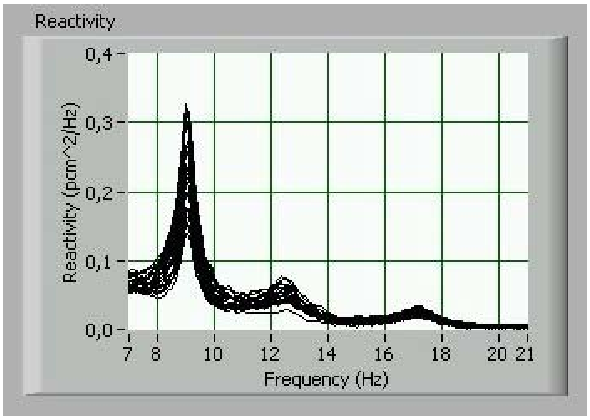


Fig. 4: Indicates spectral changes at 9.2 Hz. The total area under this peak is a measure for the reactivity and it is a function of boron concentration which is decreasing with burn-up each day (about 4 ppm/day).

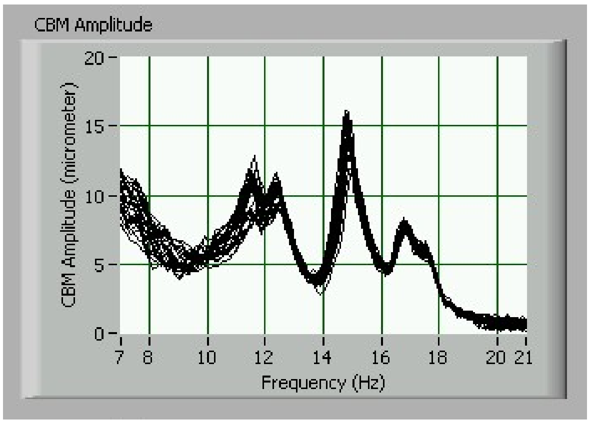


Fig. 5: Decomposed spectra of the Core Barrel Motion amplitudes in due time.

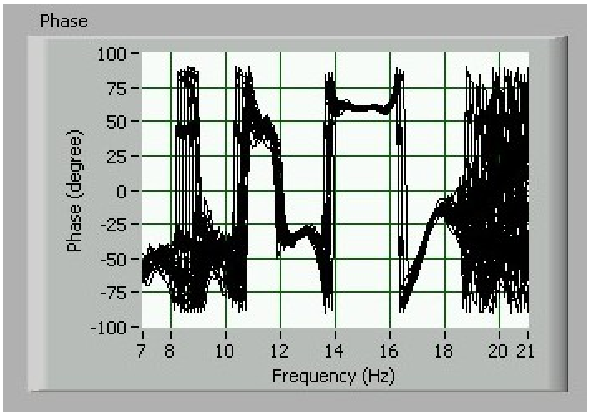


Fig. 6: Phase information of the decomposed Core Barrel Motion, it indicates the movement direction of the CBM for each frequency.

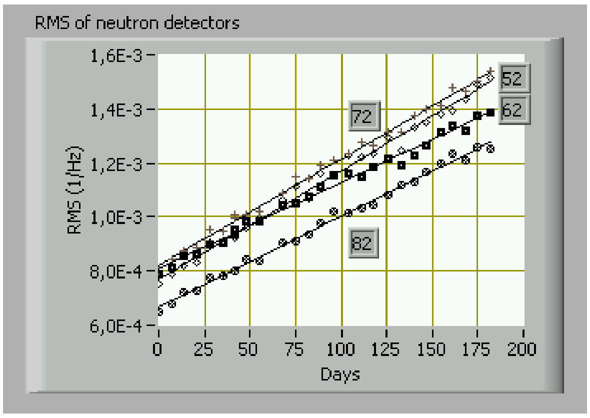


Fig. 7: The change of the total rms values of four excore neutron detectors during the operational period of 180 days.

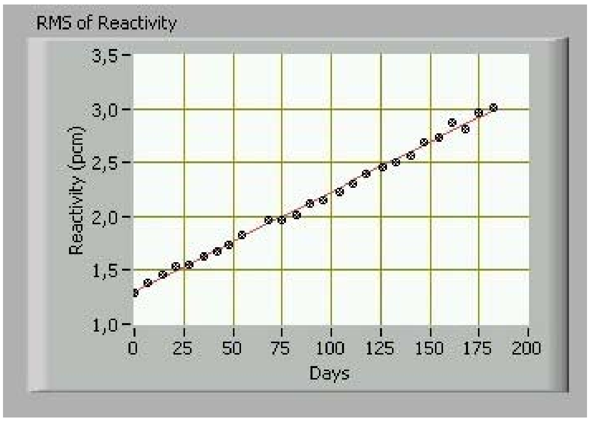


Fig. 8: The change of the rms values of the reactivity during the operational period of 180 days.

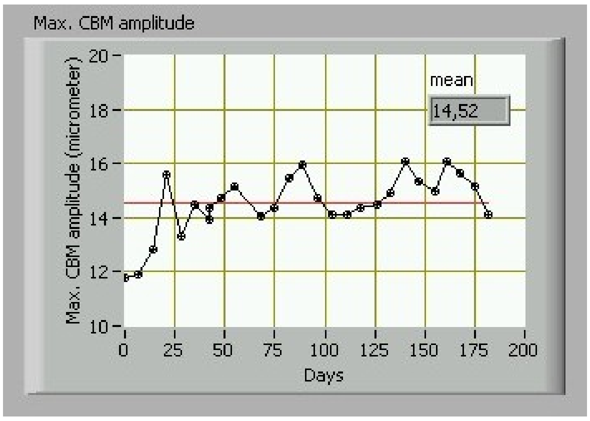


Fig. 9: The maximum CBM magnitude at 14.87 Hz, the average value of the CBM is around 14.5 μm.

IV. MONITORING OF THE COOLANT PUMP VIBRATIONS

The main interest is to measure the reactor noise at reactor power operation by ex-core and in-core neutron detectors, thermocouples and primary pressures and the coolant pump vibrations. In the last IAEA Istanbul-meeting (1998) [12], periodical measurements in the sense of main coolant pump vibrations are strongly recommended. The same request and interest came from the maintenance group of the Borssele NPP. In Table-1 given number of signals were selected by the maintenance group and continuously measured and analysed using the MS-system. Very interesting results obtained from the both primary pump vibration signals: Vibration characteristics of the both coolant pumps nearly same for the sensors at same position and the absolute value of the vibration spectra and the rms values for given ‘Vibration Criterion Chart’ indicates the range of “allowable” for all measured sensors from the “Electric Motor”, “Fly-Wheel”, “Seals” and “Recirculation Pump”. Table 1b indicates measured signals from the both coolant pumps.

Ch.	*Signa Id.*	*Signal Name*	*Unit*
16	*YD001V003*	*Vibration Radial Fly-wheel*	*mm/s*
17	*YD001V004*	*Vibration Axial Fly-wheel*	*mm/s*
18	*YD001V018*	*Vibration Axial Fly-wheel*	*mm/s*
19	*YD001V006*	*Vibration Radial Fly-wheel*	*mm/s*
20	*YD001V005*	*Vibration Radial Fly-wheel (90° cw)*	*mm/s*
21	*YD001V017*	*Vibration Axial Seals*	*mm/s*
22	*YD001V009*	*Vibration Radial Seals*	*mm/s*
23	*YD001V010*	*Vibration Radial (90° cw) Seals*	*mm/s*
24	*YD002V003*	*Vibration Radial Fly-wheel*	*mm/s*
25	*YD002V004*	*Vibration Axial Fly-wheel*	*mm/s*
26	*YD002V018*	*Vibration Axial Fly-wheel*	*mm/s*
27	*YD002V006*	*Vibration Radial Fly-wheel*	*mm/s*
28	*YD002V005*	*Vibration Radial Fly-wheel (90° cw)*	*mm/s*
29	*YD002V017*	*Vibration Axial Seals*	*mm/s*
30	*YD002V009*	*Vibration Radial Seals*	*mm/s*
31	*YD002V010*	*Vibration Radial (90° cw) Seals*	*mm/s*

Table 1b: Identification of the vibration transducers.

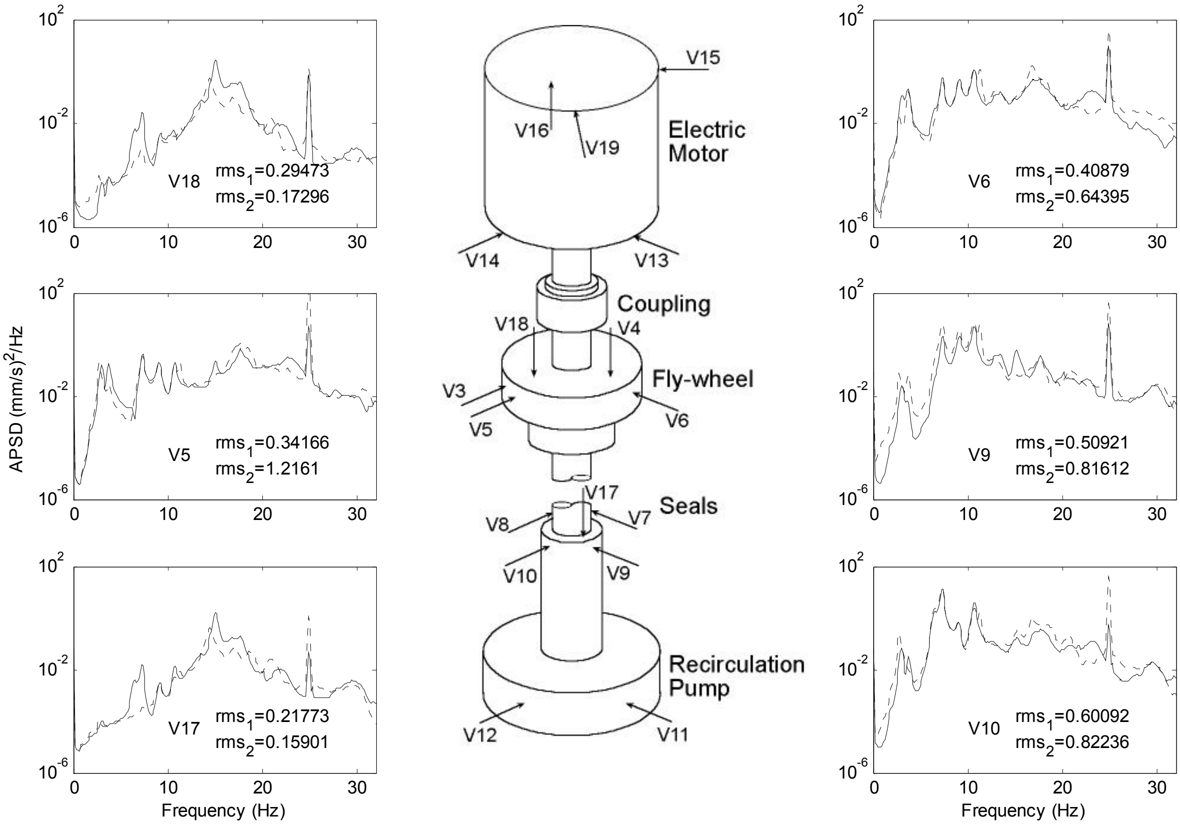


Fig. 10: Examples of the measured spectra from the main coolant pump-1 (solid line) and pomp-2 (dashed line).

Fig. 10 gives selected six vibration sensors APSD functions for comparision. Pressure waves induced from the two large primary coolant pumps (each of them about 6 MWe) caused by structural vibrations, which are induced by external excitations of by flow. In this case the phase behavior is determined by propagation with the velocity of sound (which is rather temperature dependent). The frequency of the peak is determined by external sources or mechanical resonances is not dependent on temperature. The standing waves causing peaks in the power spectra with frequencies proportional to the sound velocity [6]. The coolant pressure of both coolant loops (Fig. 11) as well as the vibration transducers signals of the both coolant pumps are highly coherent at same frequencies (Fig. 12). Standing waves at 6.5 Hz as well as 9.2 Hz global effects are very strongly exist at the coherence functions.

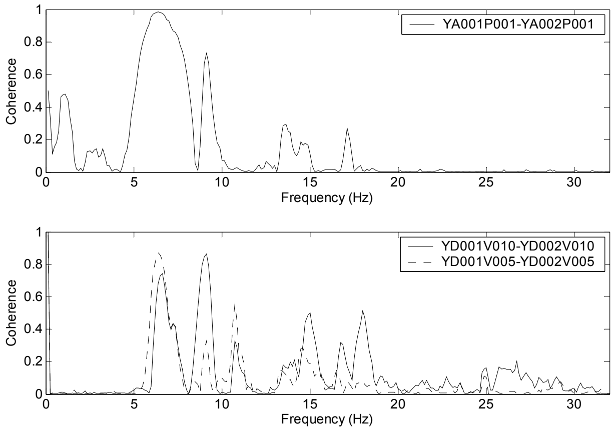


Fig. 11: Indicates coherences between pressure and vibration transducers.

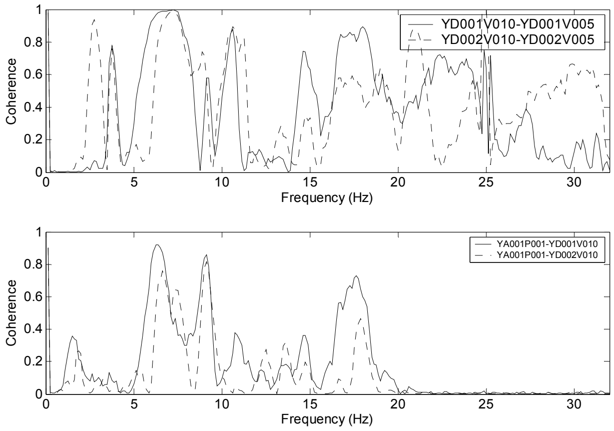


Fig. 12: Indicates coherences between pressure and vibration transducers.

V. CONCLUSION

The new system for reactor diagnostics is functioning satisfactorily. Core barrel motion and the trend identification of the physical parameters measured and calculated. The continuous checking of the rms values of the pump vibrations and these trends are included in NI Lab-View software. It is amusing to measure in real time CBM amplitudes and directions, while the shaking core barrel, which is about 150 ton and the multi directional movements are about 15 µm during the power operation.

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