Evaluation of Fluiddynamic Loads by Means of Strain Gage Measurements

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ABSTRACT

In the Commissioning of Angra 2 Nuclear Power Plant, the discharge line of a Main Feedwater Pump was monitored with strain gages in order to evaluate the dynamic loads during pump changeover.

Based on those measurements it was possible to identify a mal-function of the check valve which caused very high pressure wave loads. After a design modification, new changeover tests showed ten times smaller forces.

This paper presents the methodology used to evaluate the fluid-dynamic loads, the procedure to monitor the dynamic loads with strain-gage measurements and the influence of the check valve internals in the pressure wave loads. The importance of monitoring tests to assure the correct behavior of check valves is emphasized.

INTRODUCTION

The design of piping and supports of Angra 2 Nuclear Power Plant was performed considering pressure wave transients caused by the closing of check valves after the failure of one pump. This load case is specially relevant for the Main Feedwater system that has the function of pumping the water from the Feedwater Tank to the Steam Generators. During normal operation two of three pumps work in parallel and the third one stays as stand-by. A failure of one pump causes a quick closing of a check valve which generates a pressure transient on this line.

The theoretical analysis in the design phase was performed in two steps: a fluiddynamic and a structural dynamic analysis. The fluiddynamic analysis generated loading transients based on the piping layout, flow conditions, pump and check valves characteristics. The structural analysis considered the flexibility of the piping, masses and damping properties of the line to determine the forces on supports and stresses acting on piping.

In the commissioning of Angra 2 the case of main feedwater pump failure was simulated and strain gage measurements were used to evaluate the actual force on supports. The differences between the measured and the design values showed an increase of the pressure wave loads caused by a malfunction of the check valve.

Modifications in the internals of the check valves were implemented to reduce the closing time of the valve, which conducted to very high changes in the transient pressure and consequently to changes in the piping support forces.

DESCRIPTION OF THE MAIN FEEDWATER SYSTEM

The main feedwater system is designed to supply water from the feedwater tank (4.76 bar) to the steam generators (64.5 bar) by means of the main feedwater pumps, during normal operation (during bypass operation to the condenser).

The main feedwater pumps are designed to provide a flow of 2055.6 kg/s on full-load operation, at which two of the three equivalent pumps are on. In the plant there are three main feedwater pumps, each one designed for 55% of the rated flow.

During full-load operation, two systems pump the feedwater to the High Pressure Feedwater heating system through a pressure line common to all the three pump sets. By a T connection and two special changeover valves the feedwater is distributed over the parallel HP feedwater heater lines.

In the feedwater heating system, the water is heated from the feedwater tank temperature (150°C) to the steam generator inlet temperature (218°C). From the HP feedwater heating system the feedwater flows towards the reactor building through a common line which splits up again into four lines before entering the four separate feedwater valve chambers.

Each chamber house has a feedwater train with a full load control valve and a low load control valve by which the plant can be started up or shut down and by which feedwater can be supplied to the steam generators.

The figure 1 shows the flow diagram of the Main Feedwater System of Angra 2 NPP.

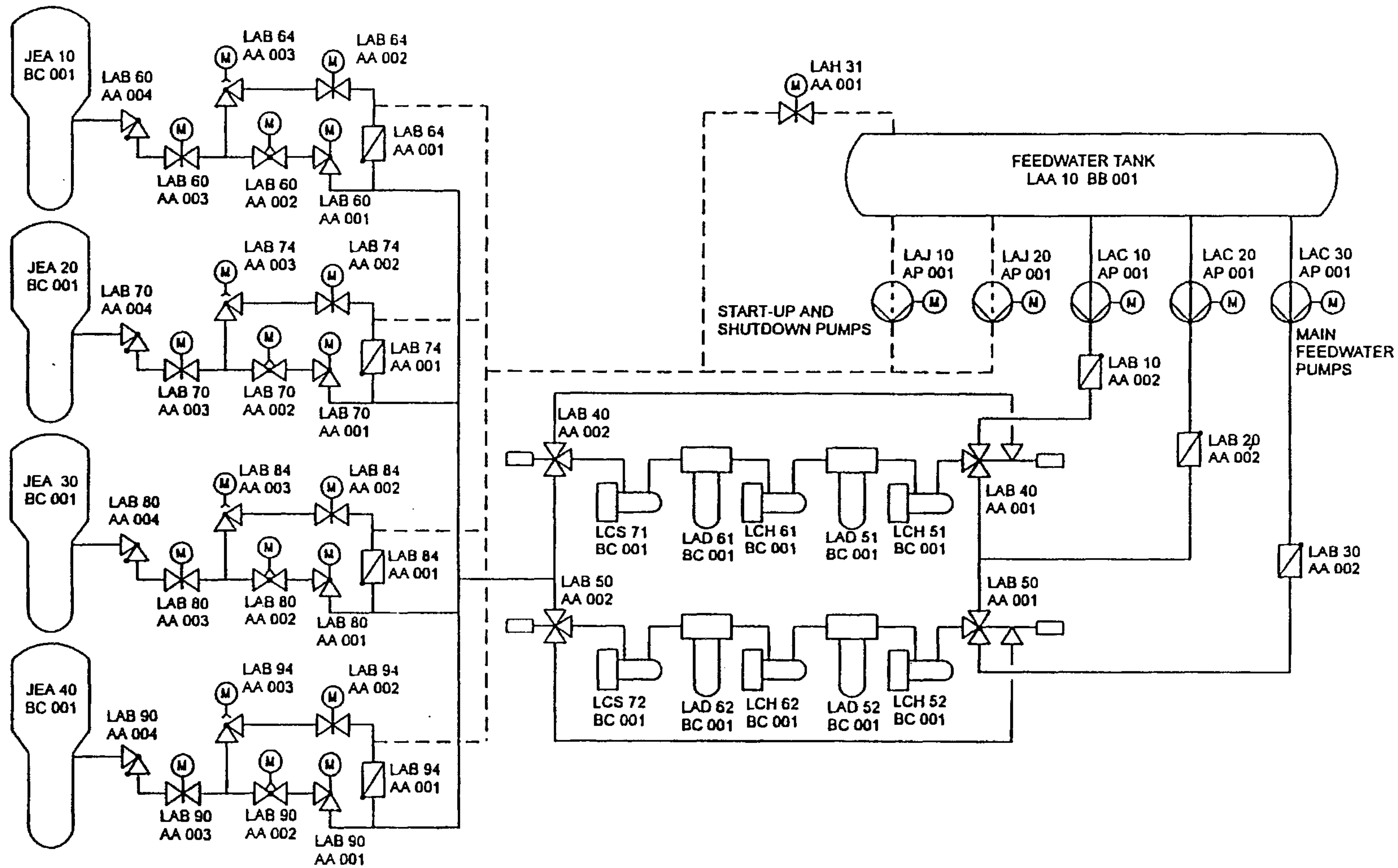

Figure 1 - Flow Diagram of the Main Feedwater System

FLUIDDYNAMIC ANALYSIS

The fluiddynamic analysis of the Main Feedwater System was performed considering all possible load cases due to failure of one main feedwater pump at 30%, 80% and 100% of power. By "pump failure" we mean an inadvertent stoppage of a pump that will cause a quick closing of the correspondent check valve, and this closing inducing loads on the piping by the propagation of a pressure wave through the system.

The program SIMDRU /1/ of the KWU/Siemens was used to calculate the transient flows considering the dimensionless homologous pump characteristics, the check valve characteristics and the frictional pressure losses at the piping and at the HP feedwater heaters. This Code simulates unsteady pressure wave and mass flow oscillation in piping systems using the Characteristics Method.

The increase of the transient pressure, generated at the check valve closure is a function of the closing time of the valve disk and of the way the flow in the system reverses. The check valve should close before the reverse flow reaches a significant velocity. The speed that the flow in a system reverses depends on numerous factors including: the numbers of pumps, the specific speed of the pumps, pipe length, friction, pipe profile and elevation change, and the presence of surge protection devices.

The results of all fluiddynamic calculations for Angra 2 were comparable with similar Siemens NPP. For instance, in the case of fluiddynamic calculation at 80% of power, when one main feedwater pump fails, the check valve closes in approximately 0.83 seconds after the beginning of the transient. The maximum pressure surge calculated was 7.5 bar after the complete closing.

STRUCTURAL ANALYSIS

The structural analysis of the Main Feedwater System was performed considering the input loads from fluiddynamic calculation for failure of pump at 30%, 80% and 100%, in addition to the normal operating loads as dead weight, internal pressure and thermal expansion.

The attached piping at discharge side of the Main Feedwater Pump is made of ferritic material WSTE 36 with an outer diameter of 550mm and 39mm thick. The design conditions were: pressure at 120 bar and temperature of 250°C. The operating conditions were: 100bar and 150°C.

The stress analysis was carried out according to the procedure established in ASME Code Section III /2/ , with additional requirements of the piping specification for Angra 2 NPP. The dynamic analysis was performed using the finite element program KWUROHR /3/ with Time History Direct Integration.

The load case "Failure of one Pump" was considered as upset condition and the highest stress combination obtained, considering the theoretical water hammer loads, was 66% of the allowable limit.

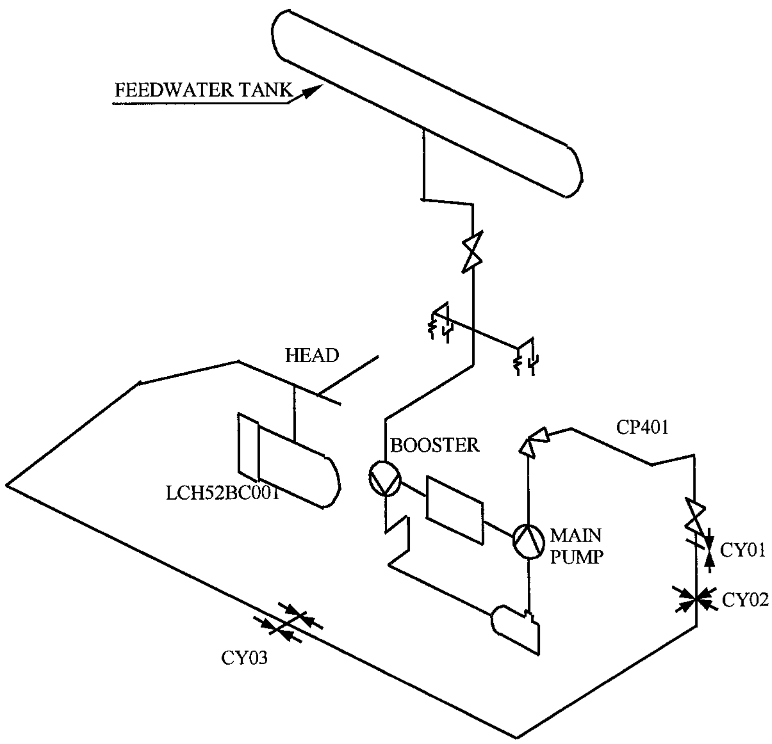

Figure 2 - Position of the Strain Gage Measurements : CY01, CY02 and CY03

COMISSIONING TESTS

Changeover tests of the Main Feedwater Pump were performed during Commissioning Phase of Angra 2. Pressures, support forces and piping displacements were recorded as they were measured. The monitoring of the forces were conducted by using Strain-Gages fixed to the struts of axial and guide piping supports. The Figure 2 shows an isometric of the line with the position of the measured support points CY01, CY02 and CY03, for which the loads were monitored.

RESULTS

Changeover tests with the original design

On August, 10th 2000 it was executed the first Changeover Test of the Main Feedwater Pump at 30% power. The test consisted of the shut-down of the pump LAC 30, which was the only one running, and the start of the pump LAC 20. At this operating level only one feedwater pump is necessary. The pressure transient measured shows that the check valve took 0.80 seconds to close and that the pressure raised from 67.7 bar to 80.9 bar. The strain gage measurements showed that the support forces were smaller than the expected ones.

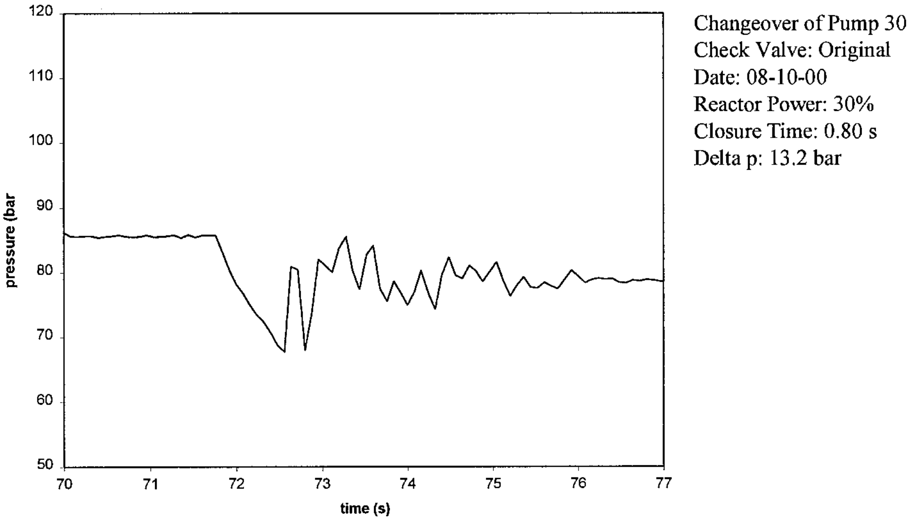

Figure 3 – Pressure Transient, 30% of Reactor Power, Check valve – Original Design

The Changeover test, at 80% power was performed on August, 23rd 2000. The pumps LAC10 and 30 were running in parallel, as it is necessary for this range of operating power. The pump 30 was stopped while the pump 10 continued operating. The check-valve took 1.78 seconds to close and generated a very strong water hammer. During this event the pressure of 66.7 bar raised to 103.1 bar in approximately 16 milliseconds. The strain gage measurements showed support forces, higher than the design ones. The measured displacements were also compatible to the pressure and forces.

After the test, detailed visual inspections of the supports were performed and did not present any damage. A new piping stress analysis was done considering the fluiddynamic loads times a correction factor based on the ratio "theoretical / measured" support loads. This analysis showed that even with the high induced water hammer no stress was greater than the yield limit.

A task force was formed to investigate the problem. The engineers investigated the differences between the theoretical pressure curve and the real one. The conclusion was that the closing speed of the valve was too slow, so causing a strong reverse flow with a velocity of approximately 3 m/s. An improvement of the check-valve became necessary for reducing the water hammer effects.

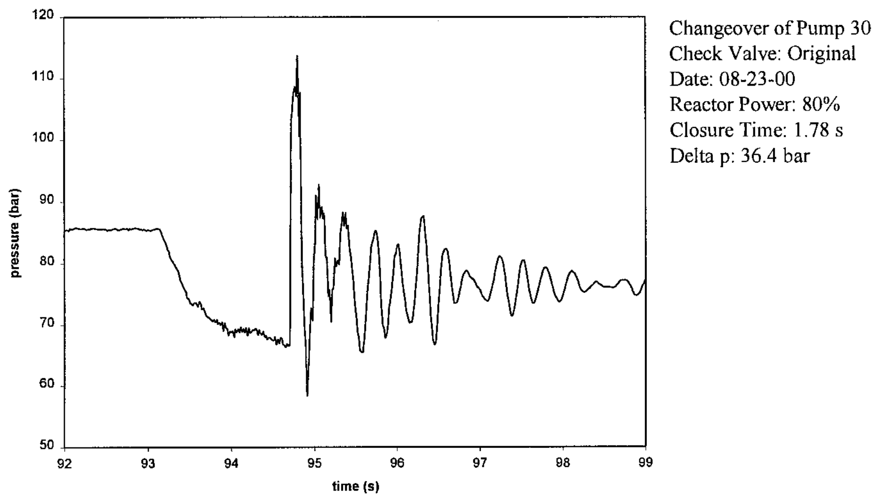

Figure 4 – Pressure Transient, 80% of Reactor Power, Check valve – Original Design

Improvement of the check valve

The water hammer magnitude is a function of how fast the flow reverses and the closing time of the check-valve. Specially for 80% of reactor power, when two pumps work in parallel , the good functioning of the valve is extremely important. The ideal valve would be the one that closed with a flow velocity close to zero.

The check valve adopted for this system has a 90° angle between the inlet and outlet. The closing element is a disk connected to a guided shaft which moves in a vertical direction. The velocity of closure depends on the weight, the pressure difference between inlet and outlet and the friction forces acting on the clearances between the shaft and guide surfaces.

The following changes were taken to improve the behavior of the check valve:

- Increase of the weight of the disk by adding an additional ring of 90kg,
- Reduction of the travel from full open to close (with the same ring),
- Increase of the clearances of 0.25mm.

The Figure 5 shows a sketch with the modifications implemented on the valve design. New commissioning tests were executed for 30 and 80% of reactor power after the modifications.

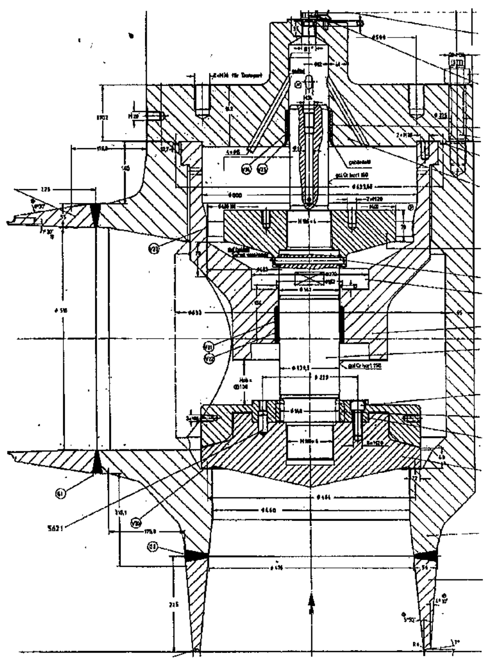

Figure 5 – Modified Check Valve

Changeover tests with the modified design

After the placing the new internals, the changeover of the main feedwater pump was repeated for 30%, 80% and 100% of power. Pressure, support forces and displacements were measured. The pressure curves for 30%, 80% and 100% of power are presented on Figures 6, 7 and 8 respectively.

The Changeover for 80% of power shows that the valve closed in 0.74 seconds and the pressure raised from 70.7 to 77.9 bar in 92 milliseconds.

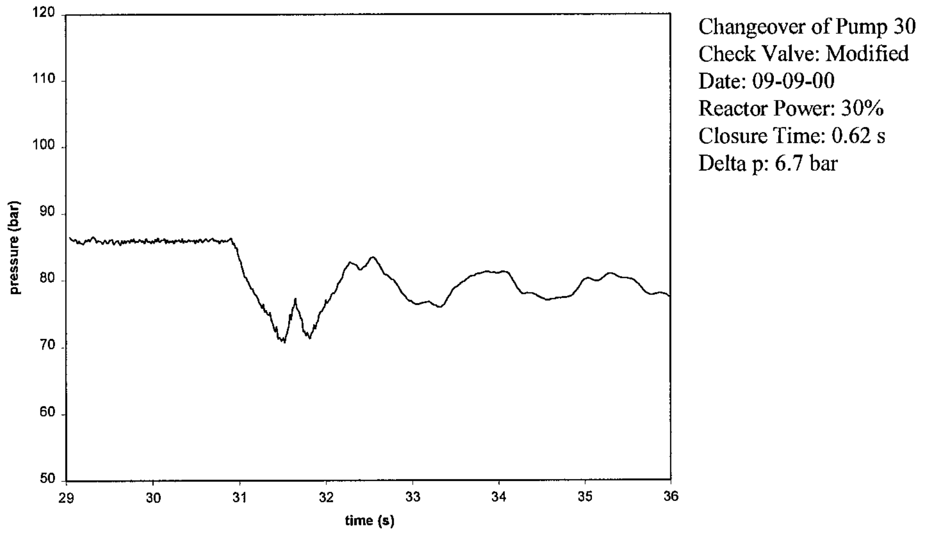

Figure 6 – Pressure Transient, 30% of Reactor Power, Check valve – Modified Design

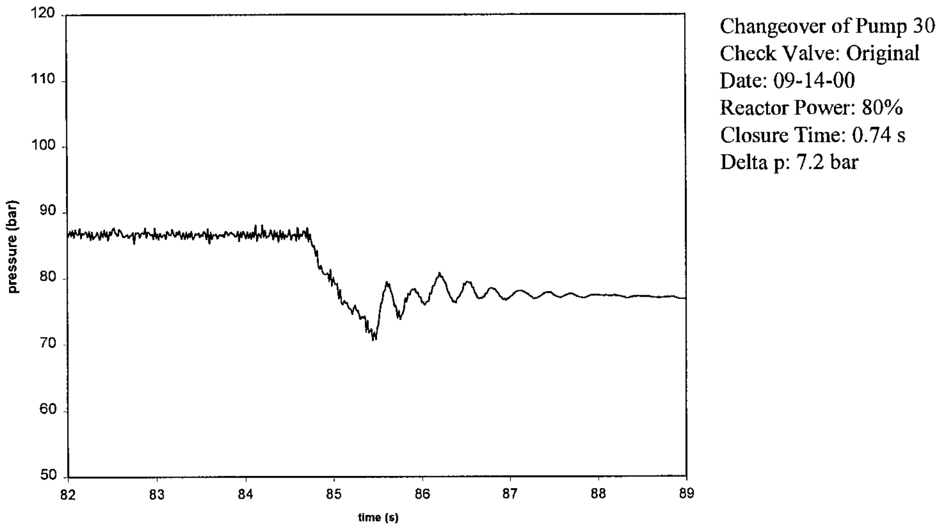

Figure 7 – Pressure Transient, 80% of Reactor Power, Check valve – Modified Design

The Table 1 shows the values of the forces acting on piping supports for 30% and 80% with the original design and for 30%, 80% and 100% power after the modification. For the 80% power the highest support force was reduced from 1291 kN to 132 kN showing the success of the new design of the valve internals.

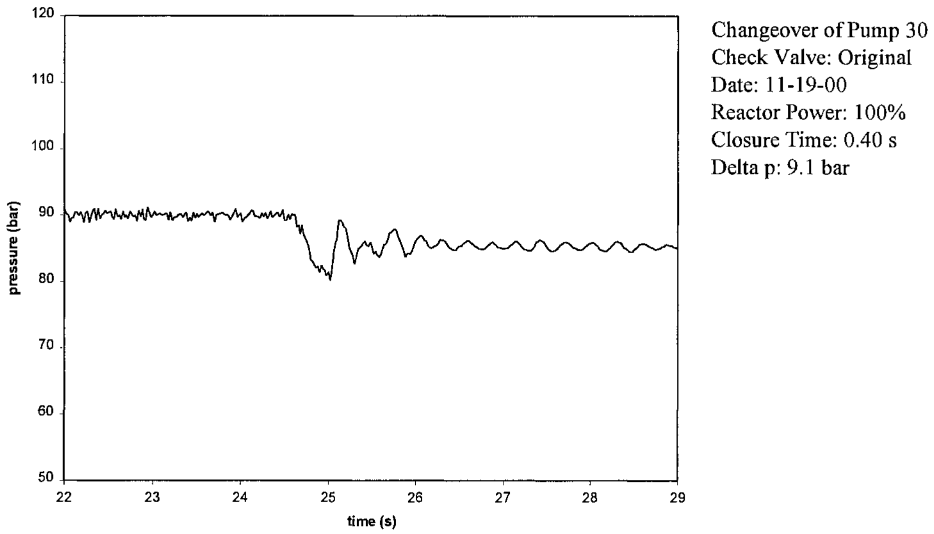

Figure 8 – Pressure Transient, 100% of Reactor Power, Check valve – Modified Design

Table 1 - Comparison of the Forces on Supports

Piping	Design	Forces on Supports (kN)				
Support	Forces	Changeover 30%		Changeover 80%		Changeover 100%
	(kN)	OD	MD	OD	MD	MD
CY_01	219	155	20	548	45	58
CY_02 - L (W)	130	125	13	280	26	33
CY_02 -T (V)	164	104	29	397	29	44
CY_03	504	394	139	1291	132	213

OD - Check Valve with Original Design
MD - Check Valve with Modified Design

CONCLUSIONS

The experience with the Changeover tests of the Main Feedwater System in Angra 2 showed the importance of evaluating the performance of the check valve for the reliability of the piping system. Small differences in the valve design can cause very high transient pressures which could result in stresses on piping greater than the admissible ones.

Care should be taken in systems where rapid flow reversals could occur, specially for main feedwater systems when one pump stops and the other stays in operation. In this case it is very important to consider this load case in the design phase and, during the commissioning, operating procedures shall be followed by monitoring of the pressure and forces.

The main conclusions after the comissioning phase of the Main Feedwatwer System of Angra 2 NPP were:

- Small geometry or weight changes in check valve can cause significant differences in the fluiddynamic loads.
- The modification in the internals of the check valve reduced its closing time from 1.78 to 0.74 seconds, which caused a reduction of the force on piping support from 1291 kN to 132 kN.
- The best way to check the valve behavior is to monitor system pressure and support forces.

REFERENCES

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2. ASME - Boiler and Pressure Vessel Code, Section III
3. KWUROHR, Piping Analysis System, Version 7.0.0, - SIEMENS AG, Power Generation Group KWU
4. EPRI NP-5479s Ver. 1, "Application Guide for Check Valves in Nuclear Power Plants" June 1993.