Whip Analysis of Guide-Pipes of Instrumentation Below PWR Vessels

A. Millard, P. Jamet, J.L. Lieutenant, B. Schwab
C.E.A., CEN Saclay, DEMT/SMTS/LAMS, F-91191 Gif-sur-Yvette Cedex, France
D. Goetsch
C.E.A., CEN, IPSN/DAS/SASCEL, B.P. No. 6, F-92260 Fontenay-aux-Roses, France

Abstract

The purpose of this paper is to present the methodology used to evaluate the consequences of a guillotine-break of a guide-pipe of instrumentation below a PWR vessel. The problem consists in determining if the break of one pipe may cause subsequent breaks of other pipes, which would result in a fast drying of the reactor heart. For this purpose, a program was defined, based on experimental and computational approaches. The most critical pipe was selected for the study. The following tests were performed :

- measure of jet force, the pipe being fixed.
- whip and measure of the impact force on a neighbouring pipe.

During the first test, pressures were recorded at various locations along the pipe.
For the computations, two problems have been uncoupled :

- A thermohydraulic was first performed using the code PLEXUS of the CEASEMT System, in order to determine the fields of pressure and fluid velocities along the pipe. This computation accounts for the waves propagations which occur at the beginning of the phenomenon and the mass transfer which happens afterwards. The water was treated as an homogeneous compressible diphasic fluid. The results were compared with the measured experimental data.
- Then, these pressures and fluid velocities were used to calculate a dynamical pressure which was introduced in the piping finite element code TEDEL. The calculations was performed using the global plasticity model, the following force and large displacements capabilities of the program, as well as unilateral constraints in order to determine the contact forces at the impact with another pipe. Results were also compared with experimental data.

I. INTRODUCTION

At the bottom of the PWR vessels, many pipes are used as guides for various instruments in order to make measures in the vessel. For safety requirements, the sudden guillotine-break of a pipe and its consequences are studied : indeed, the whipping pipe may hurt a neighbouring pipe and thus cause a sequence of pipe breaks which would lead to a fast drying of the reactor heart.

In order to investigate this question, a program has been defined, based together on experimental and computational approaches.
The aim of this program was double :

- on one hand, to qualify computer codes by comparison with experimental results.
- on the other hand, to apply these computer codes to real situations (900 MW and 1300 MW reactors), in order to evaluate the risk of a sequence of pipe breaks.

II. DESCRIPTION OF THE TESTS [1]

For the study, the pipe which was capable of the most important whip-displacement before impact with a neighbouring pipe has been selected in order to maximize its kinetic energy. The typical configuration is shown on Figure 1. The geometrical characteristics of the pipe are the following :

- bend radius : R = 2512,7 mm
- external diameter : ϕ_e = 25,4 mm
- thickness : e = 7,6 mm

The material was a 304 L stainless steel.
The pipes were fixed on clamps ; the guillotine break was supposed to happen at the location of one of these clamp. The pipes were connected to a pressure vessel which was brought to the following conditions :

Pressure : 150 bars
Temperature : 270°C

Two series of tests were performed on a benchtest, which is shown on Figure 2.
In the first serie, the pipe was fixed near the opening, in order to measure the jet force, the reaction force and the static pressure at several locations on the pipe. Care was brought to these measures so that they were not disturbed by temperature variations. The guillotine break opening was simulated by means of a calibrated membrane.
In the second serie, the pipe was free to whip and to impact a neighbouring pipe. The gap between the two pipes was 350 mm. During these tests, the accelerations of both impacting and impacted pipes were recorded at some locations, as well as the displacements of the impacting pipe and the reaction of the impacted one.
Some typical results are shown on Figure 3 to 5 :

Figure 3 : Pressure inside the vessel
Figure 4 : Pressure in the pipe near the opening
Figure 5 : Acceleration of the free end of the whipping pipe.

III. DESCRIPTION OF THE CALCULATIONS

In order to perform the computations, the hydraulic and the mechanical problem were dissociated. Consequently, a first study was made in order to determine the dynamic pressure in the pipe, versus time, assuming that the movement of the pipe would not change significantly these values. Then, these values were introduced for the calculation of the mechanical response of the pipe.

III.1 - Hydraulic calculations

The purpose of this study was to obtain the fields of pressure, velocities and density versus time, during the pipe whip. The calculation was performed using the code PLEXUS [2][4] of the CASTEM System [5].

The elements used were unidimensionnal. The mesh was composed of 32 elements. The material used for the fluid was an homogeneous steam-water mixture.

The breaking membrane was treated by means of a diaphragm type boundary condition, assuming a loss of head leading to a critical flow rated at the opening ($K = 4$).

At the other end, the pressure was prescribed to the value during the test. Initially, the fluid and the pipe are at room temperature, and it was expected that the thermal exchanges during the test between the hot fluid and the cold pipe might play a significant role. This was then accounted for by means of a thermal exchange coefficient, assuming a constant temperature in the pipe.

The figure 6 shows a comparison between the static pressure calculated and measured at the mid point of the elbow. It may be noted that a double phasis changeover happens at $t = 320$ ms.

A similar calculation has been performed in the case of a real reactor, that is with an input pressure maintained high over a long period. The display of the degree of humidity on Figure 7 indicates that water has vaporized in the last four elements, due to the drop of pressure near the opening and the water temperature increase.

III.2 - Mechanical calculations

The field dynamical pressure $p_d = p + \rho V^2$ was derived from the above mentioned calculations and was introduced in the piping elements. In order to simulate the pressure drop at the opening, a following force was introduced at the free end of the pipe, opposite to the jet force. The computation was performed using the TEDEL code [6][7][8] of the CASTEM System. Many non-linearities were accounted for in the analysis :

- large displacements which require to write the equilibrium on the actual configuration.
- plasticity which developped mainly in the vicinity of the clamp, that is where the rotation was prevented. The global method, based on the classical concept of plastic hinges has been used.
- following force.
- unilateral contact in order to prescribe the non penetration condition when the two pipes come into contact.

A first computation was performed with the pipe fixed near the opening in order to reproduce the reaction for. The pipe whip was then analysed. The Figure 8 shows the displacement of the free end versus time. It may be noticed that in this case, no impact is predicted. Some other calculations were performed, leading to close results :

→ introduction of damping for high frequency modes.

→ loading of the pipe only by a following jet-force.

The case of a real reactor was than analysed. In this case, the impact on the neighbouring pipe occured at $t = 0{,}238$ s, and the maximum contact force reached 188 Newton (see Figure 9).

IV. CONCLUSION

The problem of the whip of guide-pipes of instrumentation below PWR vessels has been investigated experimentaly and computationaly. The main conclusions are the following :

- The measure of quantities like fluide pressure, pipe acceleration, jet reaction must be done very carefully.
- The flow in the pipe is much dependant on the boundary conditions and particularly the existence of loss of head at each end of the pipe.
- The effect of temperature exchanges is important and must be accounted for in the analysis.
- The decoupling between hydraulical and mechanical calculations should be checked by comparison with a fully coupled computation. This will be done with the code PLEXUS in the very near future.
- For the case of a real 900 MWE reactor, the maximum impact force has been obtained.

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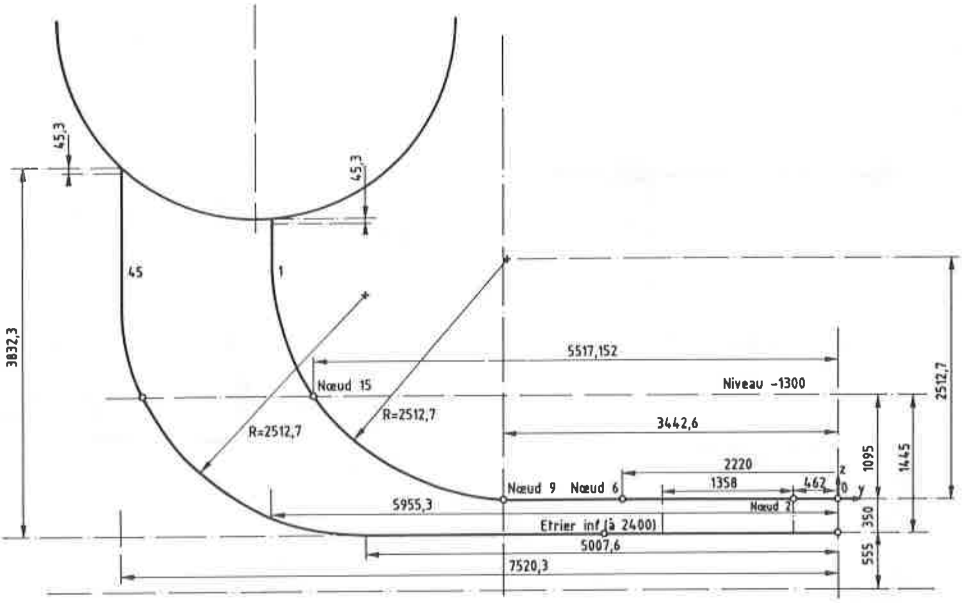

Fig. 1 - GENERAL GEOMETRY OF THE SYSTEM

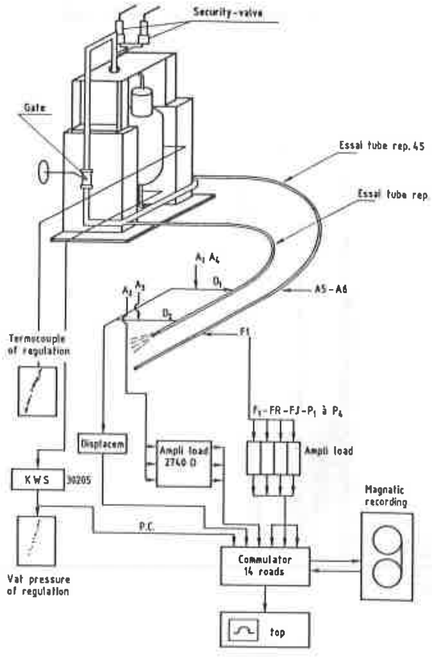

Fig. 2 - EXPERIMENTAL SETUP

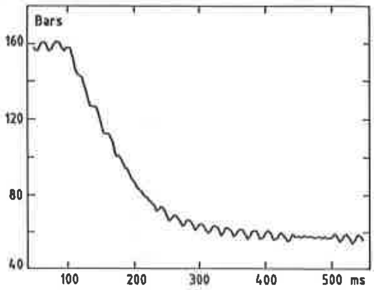

Fig. 3 - VESSEL PRESSURE VERSUS TIME

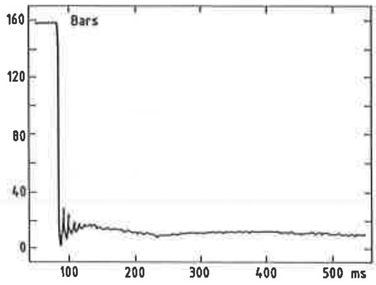

Fig. 4 - PRESSURE VERSUS TIME AT ONE POINT OF THE TUBE

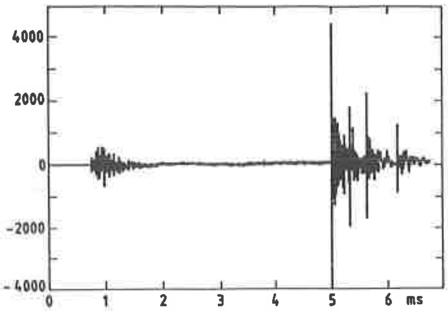

Fig. 5 - ACCELERATION VERSUS TIME

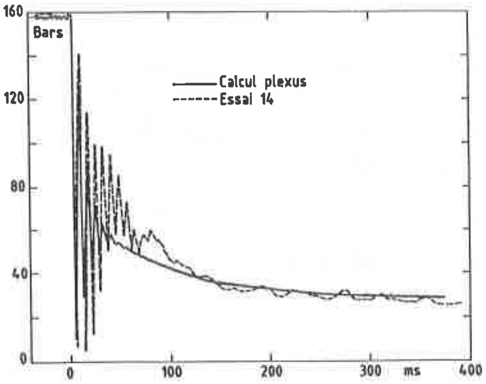

Fig. 6 - COMPARISON BETWEEN EXPERIMENTAL AND NUMERICAL VALUES OF PRESSURE

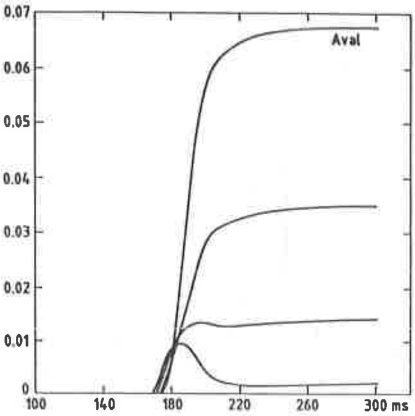

Fig. 7 - DEGREE OF HUMIDITY

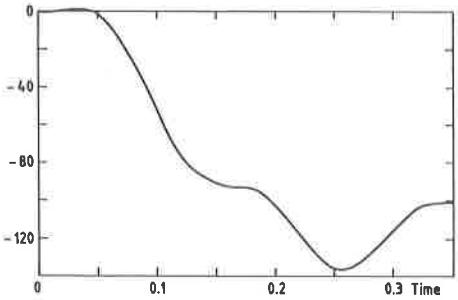

Fig. 8 - DISPLACEMENT OF WHIPING TUBE

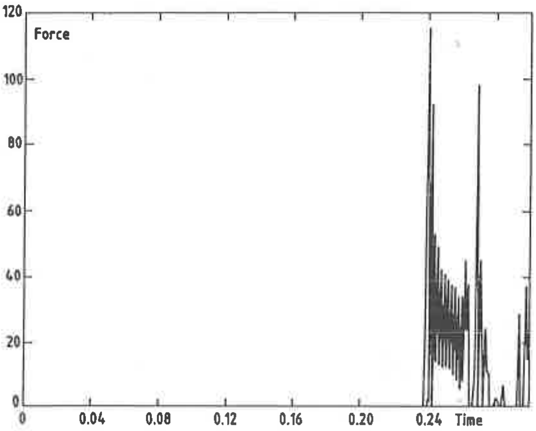

Fig. 9 - CONTACT FORCE