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MODELLING OF A STEAM LINE WHIP AND OF A WHIP RESTRAINT BY SYSTUS PROGRAMME

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Summary: *To model the process of a circumferential crack evolution leading to the pressurized pipe rupture a special element in the programme SYSTUS is used. The stiffness and damping coefficients of this two node element may be defined as dependent on the relative displacement and velocity of its nodes. Such elements are used to model a whip restraint and a viscous GERB damper. Whip of of the steam line and its effect on the steam generator is analyzed. Large deformation and non-linear material properties are taken into account.*

1. INTRODUCTION

Safety Issues and Their Ranking for WWER-1000Model 320 Nuclear Power Plants [1] in the review of internal hazards mention the occurrence of internal hazards resulting from high energy pipe breaks. The dynamic effects of high energy pipe breaks, such as pipe whips and jet forces due to the sudden release of liquids and steam, could lead to failure of a safety related equipment.

The steam line break in the weld of the steam pipe and the steam collector is considered. The whip of the steam and dynamic effects of this steam line break on the steam generator including primary coolant piping legs are analyzed. Modelling of a steam line break concerns two cases. The steam line without a restraint and the steam line protected by a whip restraint with viscous elements applied at the postulated break cross-section [2].

In accordance with [3] it is admissible to neglect the transient process of the fluid flow variation when a pipeline is broken. Thus we may assume the fluid flow to be stationary and the pressure p_{in} in the input cross-section A_{in} and the pressure p_{out} in output cross-section A_{out} as constant.

Denoting $\mathbf{c}_{in}$ and $\mathbf{c}_{out}$ the velocities, pressures p_{in} and pi_{out} in the input area A_{in} and in the output area A_{out} respectivelyand taking into account the barometric pressure p_b, the resultant hydrodynamic force acting on a given volume may be expressed as

$$\mathbf{F}_d = \mathbf{n}_{in}\rho c_{in}^2 A_{in} - \mathbf{n}_{out}\rho c_{out}^2 A_{out} - \mathbf{n}_{in}(p_{in} - p_b)A_{in} - \mathbf{n}_{out}(p_{out} - p_b)A_{out}\,. \qquad (1)$$

Two cases of a flow out are distinguished [3]. A case of a sudden full opening of a short flow out tube and a case of a sudden full opening of a long flow out tube. The length of the flow out tube and friction losses

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contribute to the probable actual thrust time history compared in Fig. 1 with a recommended conservative approximation [3]. The force F_d is denoted as T in Fig. 1.

The steam flows from the steam generator by collecting legs to the steam collector and then to the steam line (Fig. 2). The postulated break cross-section in the weld between the steam collector and the steam line is rather far from the steam generator. Thus we have to deal with the flow out second case. The hydrodynamic force may be approximated by the pressure force. In fact it is applied as a force greater by about 9 %, due to the difference between inner cross-sectional area and the mean diameter circle area of the model.

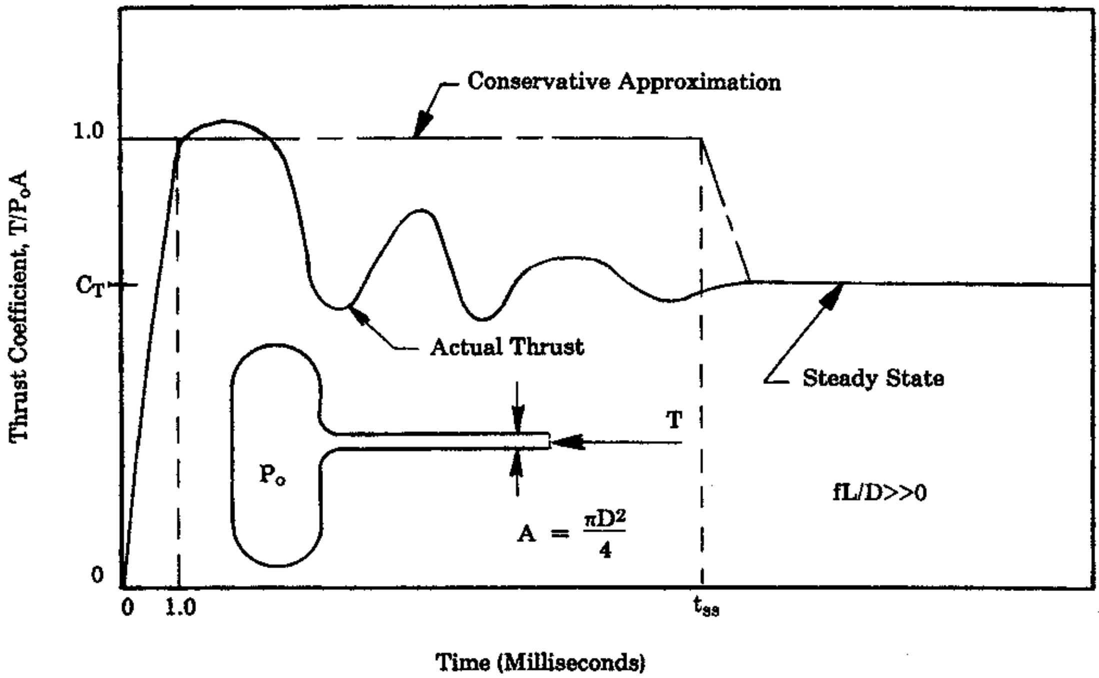

Fig. 1

2. SHELL MODEL OF THE SYSTEM

The finite element model of the system is shown in Fig. 2 with the reduced stress distribution due to overpressure. The model consists of the following portions:

Steam generator – SG
Steam collecting legs, collector, steam line till penetration - SL
Reactor coolant pump (simplified) – RCP
Primary pipeline hot leg - HL
Primary pipeline cold leg - CL

The steam generator is supported by rolling supports. The supports are assumed to be frictionless because of high frequency vibrations caused by primary coolant pressure pulsation. There are six viscous dampers GERB applied to the steam generator to limit the magnitude of its plane motion.

The steam collecting legs are joint by sockets to the steam generator and to the steam collector. Special SYSTUS 1602 elements are inserted between the respective nodes of the collector and steam line shell models. These elements are used to model the steam pipeline break and the whip restraint function. The steam pipeline is supported by elastic supports and build in the containment wall penetration.

The model of the reactor coolant pump is rather simplified. It has to represent mainly its inertial properties. Thus it has vertical supports only.

The primary coolant pipe legs are assumed to be build in the reactor vessel wall.

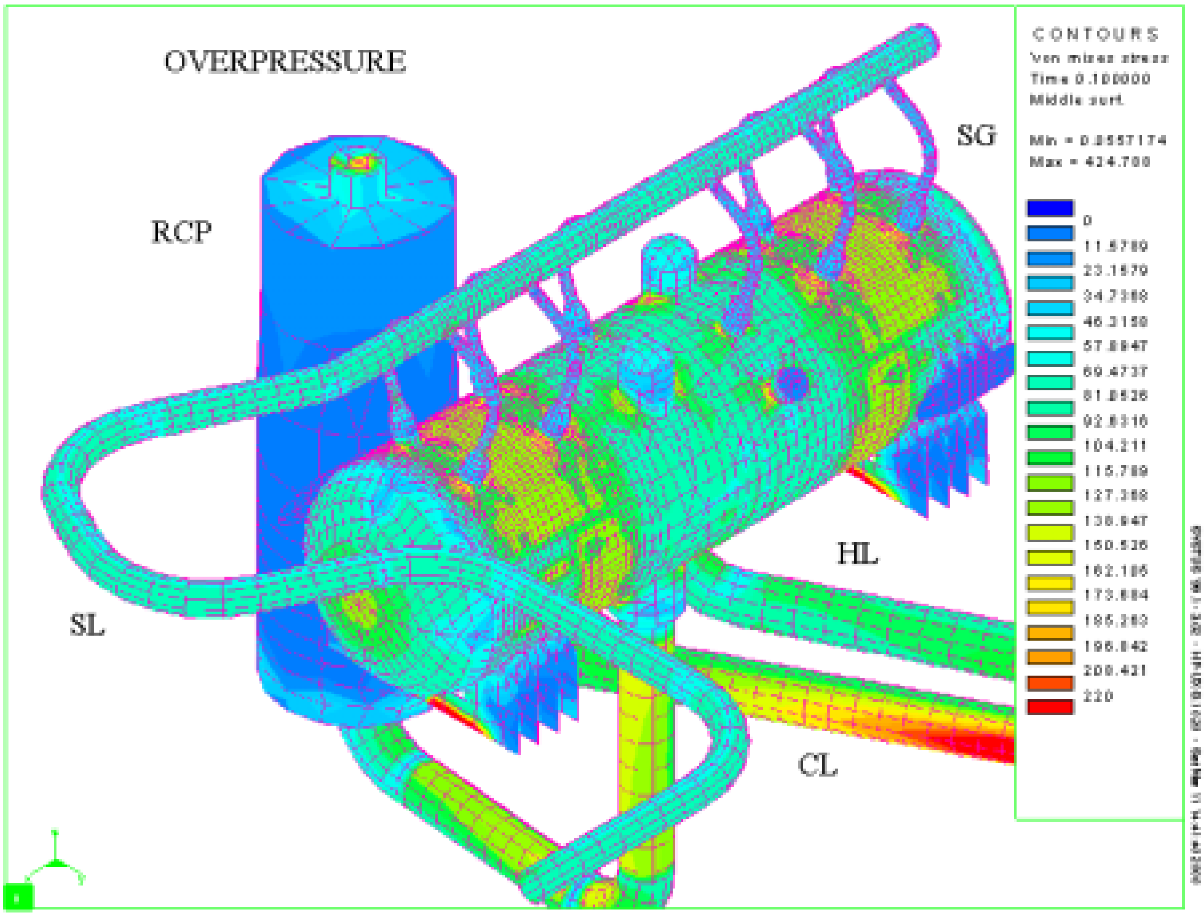

Fig. 2

To model a break up of the steam pipe twelve special elements SYSTUS 1602 are used. They are inserted in an artificial gap between the models of the steam collector and the steam pipeline. These elements are parallel and connect corresponding nodes of the shell models [2].

The pipeline is statically loaded by an internal pressure slightly smaller than the given maximum one. Then the internal pressure is gradually increased to approach the given value.
Up to the elongation of the element u_x = 0,18 mm, the longitudinal and lateral element stiffness coefficients are

$$k_x = k_y = k_z = 800 \text{ MN/m}. \qquad (2)$$

The longitudinal stiffness decreases to zero between u_x = 0,18 mm and u_x = 0,182 mm, i.e. during the elongation change by Δu_x = 0,002 mm. In the case without a restraint the lateral stiffness becomes zero at a relative displacement smaller than the relative displacement which would be attained due to the given static overpressure. For instance the relative displacements of a pair of an element nodes No. 12736 and No. 7325 would attain values

$$u_x = 0{,}208475 \text{ mm}, \; u_y = 0{,}00987 \text{ mm}, \; u_z = 0{,}00031 \text{ mm}. \qquad (3)$$

The stiffness k_y should become zero at u_y = 0,009 mm, the stiffness k_z at u_z = 0,00028 mm during e.g. Δu_y = 0,0002 mm and Δu_z = 0,00002 mm respectively.

The computation has shown that the complete pipe break is simulated during a time interval of about 0,0001 s.

3. MODEL OF THE WHIP RESTRAINT

The whip restraint with viscous elements [4] is applied to the steam line at the cross-section of its postulated break. Elastic constraints are introduced in a lateral direction by the whip restraint between the collector and the steam line pipe. The forces arising between the collector and the steam line pipe in the longitudinal direction depend on their relative displacement and relative velocity according to an example of the characteristics shown in Fig. 3. The shift from static to dynamic characteristics is due to the viscous property of the element 1602.

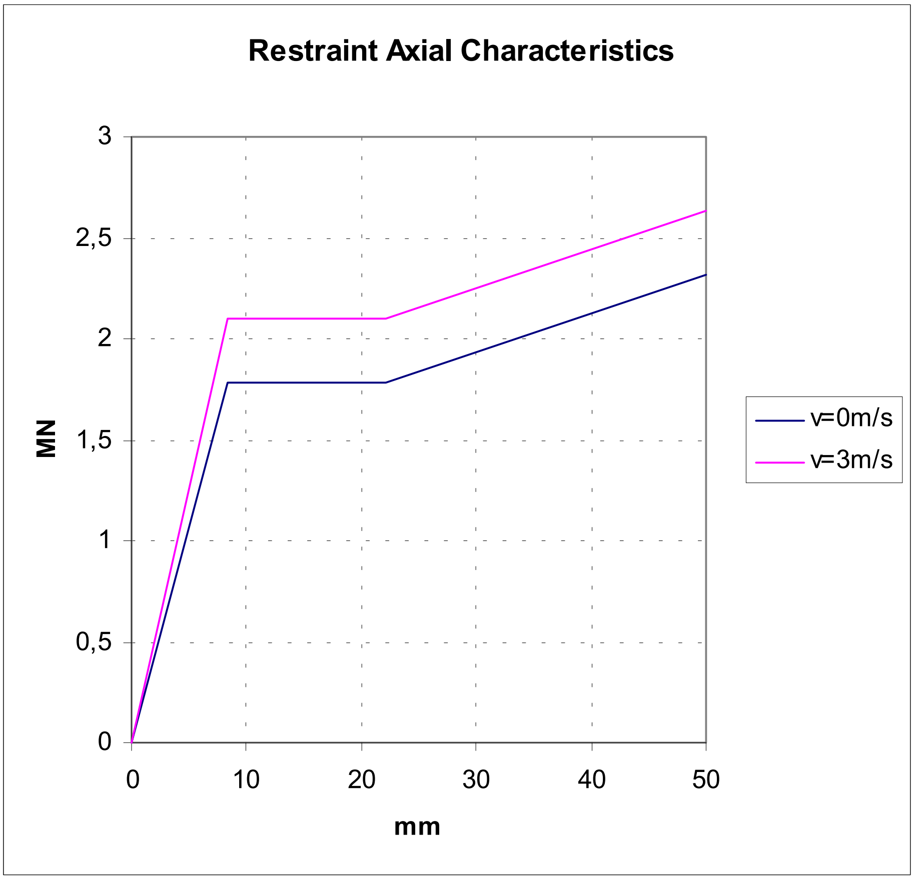

Fig. 3

With an initial gap of 1 mm the resultant stiffness of the elements 1602 modelling the restraint axial static characteristic leg is related to relative displacement as shown in Fig. 4.

Fig. 4

4. Model of the GERB viscous damper

A GERB viscous damper is characterized by its nominal load and by its so called equivalent stiffness. However this equivalent stiffness has nothing to do with the stiffness properties of the damper. When displacing with a velocity of 0,33 mm/s at the structural temperature the resistance force of the damper is 2% of the nominal load only.

Such a behaviour corresponds to a Maxwell model. To satisfy better the characteristics of the damper a twofold Maxwell model (Fig. 4) is recommended.

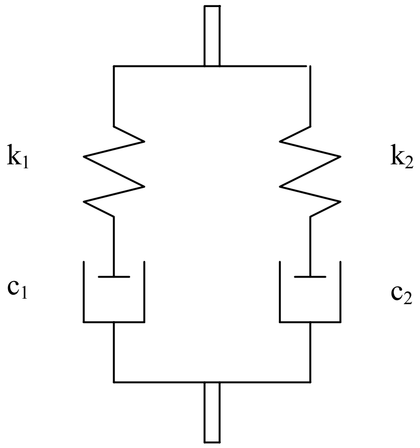

Fig. 4

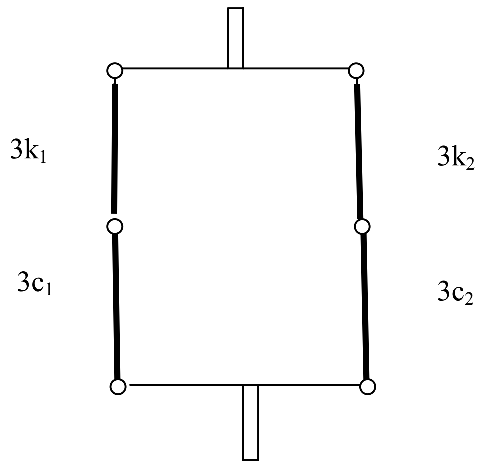

Fig. 5

Six GERB viscous dampers are applied to the steam generator in groups by three. The resultant model of each group consists of four elements 1602. Two of them have stiffness coefficients $3k_1$, $3k_2$ and the other two damping coefficients $3c_1, 3c_2$ (Fig. 5).

These coefficients are chosen to fit the frequency dependent equivalent stiffness. The approximation is illustrated by a comparison of the given equivalent stiffness K and the equivalent stiffness K_M of the model in Fig. 6

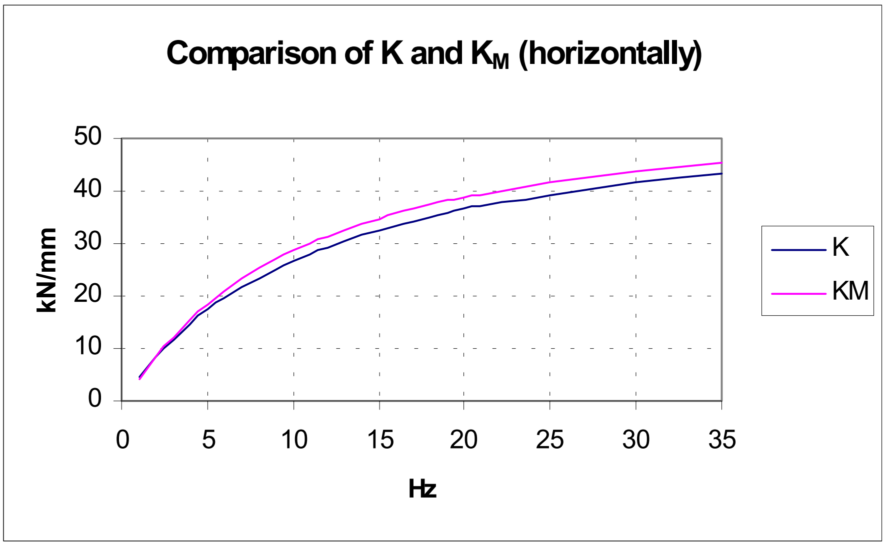

Fig. 6

5. WHIP OF THE STEAM LINE

In case of a steam line whip without a restraint the displacement of the broken end of the steam pipe attains during few hundredths of second a displacement indicating a destruction of the pipeline. In a hypothetical elastic state the displacement will be up to 17 m axially and 9 m laterally within 0,6 s.

The displacement of the collector broken end node relative to the steam generator attains nearly 80 mm (Fig. 7) and the velocity 4 m/s (Fig. 8).

In case of a steam line whip with a restraint the relative displacement of a node No. 12726 of the steam pipe relative to the node No. 73525 attains about 33 mm The respective relative velocity does not exceed 2,5 m/s

The relative displacement of the collector broken end node relative to the SG centre of mass is shown in Fig. 9. It does not exceed 5 mm and the respective relative velocity attains 0,8 m/s (Fig. 10).

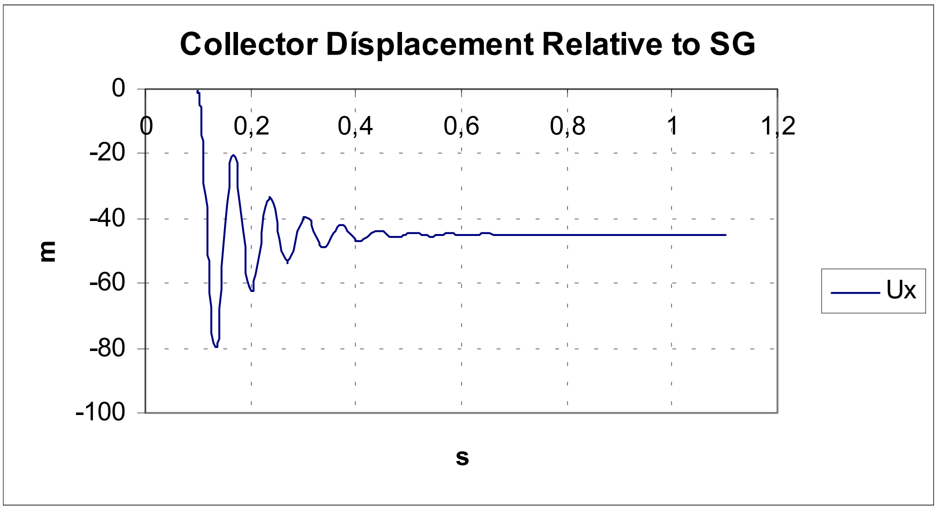

Fig. 7

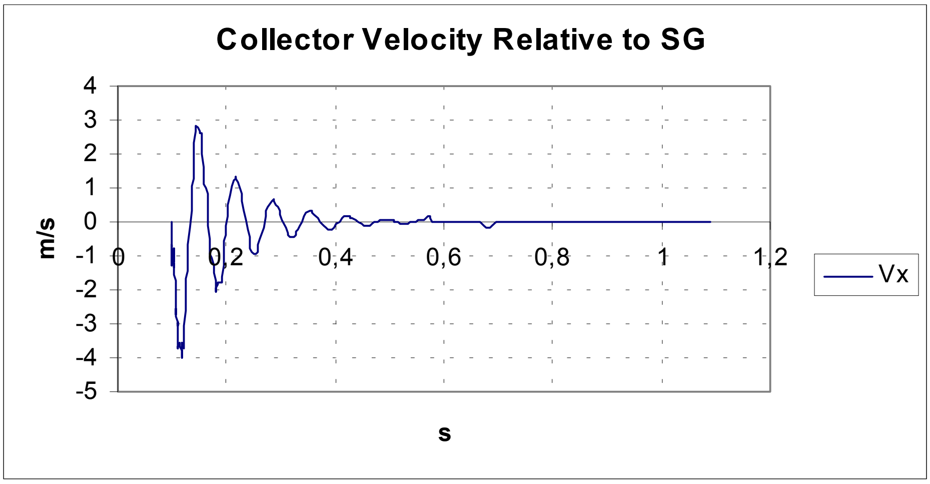

Fig. 8

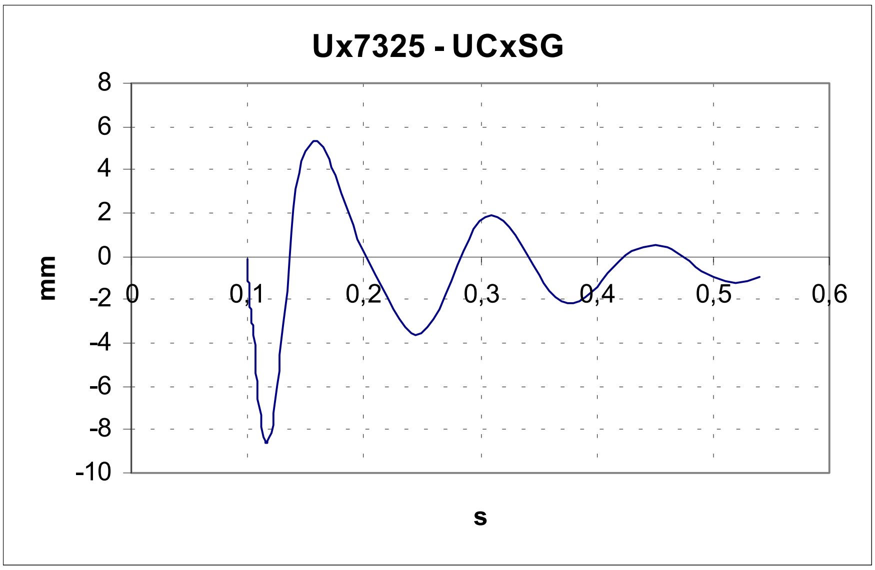

Fig. 9

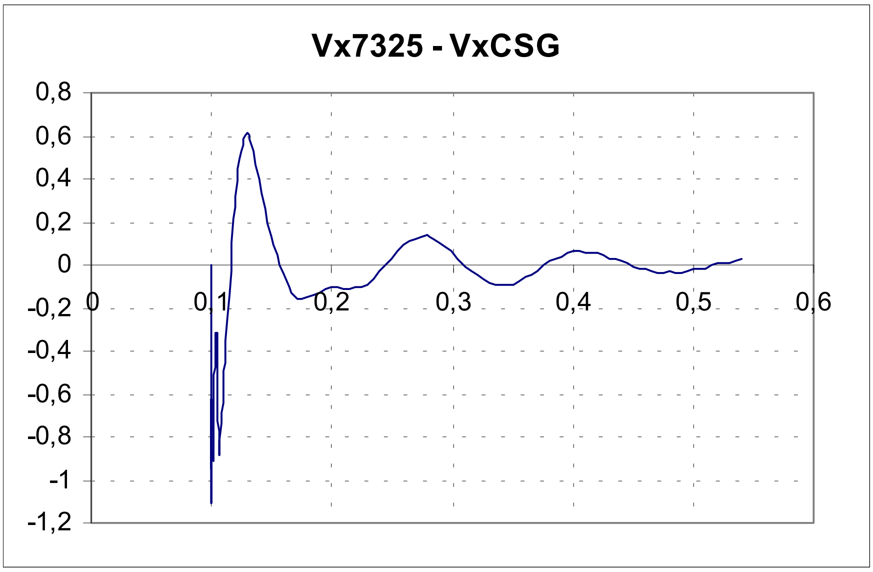

Fig. 10

6. CONCLUSION

The knowledge of the dynamic behaviour of a high energy pipeline in case of its postulated break creates conditions for an environment protection against a whip hazard. Programme SYSTUS enables to model and to analyse efficiently a probable circumferential crack occurrence and a pipeline whip without or with a restraint.

It has been found that a steam line break at the postulated weld crack with the steam generator collector cannot endanger the integrity of the steam generator system

7. REFERENCES

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