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RESEARCH ARTICLE

Dynamic effect of a pressure wave on a bypass pipeline of a compressor

László Écsi / *Pál* Élesztős

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Abstract

Under certain circumstances where there is a relatively great difference between inner pressures of output and input pipelines of a compressor, a so-called bypass pipeline is used to connect the pipelines of the compressor. When a control valve is quickly opened, the pressure difference generates a pressure surge that might affect the operational safety of the pipeline along which the pressure wave propagates. In this work dynamic effects of a pressure surge created in the bypass pipeline of one of the compressors of a transit gas pipeline are investigated using the finite element method.

Keywords

pipeline · reparation of a bypass pipeline · pressure wave

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László Écsi

Institute of Applied Mechanics and Mechatronics, Faculty of Mechanical Engineering, STU Bratislava, Nám. slobody 17, Bratislava, 812 31, Slovak Republic
e-mail: ladislav.ecsi@stuba.sk

Pál Élesztős

Institute of Applied Mechanics and Mechatronics, Faculty of Mechanical Engineering, STU Bratislava, Nám. slobody 17, Bratislava, 812 31, Slovak Republic
e-mail: pavel.elesztos@stuba.sk

1 Introduction

In this work we carried out a complex analysis of a pressure surge and investigated its influence on a bypass pipeline of a compressor during the pipeline shutdown due to a malfunction of the compressor. The immediate ($t < 1$ s) switching the flow and the inner pressure difference between the output and bypass pipelines generate a transitory pressure surge which loads the pipeline dynamically. As a result vibration occurs and the operator will detect dynamic deflections visible to the naked eye. The primary goal of this work is to predict the response of the bypass pipeline to the dynamic excitation caused by the pressure surge.

2 The dynamic effect of the pressure surge on the bypass pipeline

The numerical simulation of the bypass pipeline loaded with time-varying inner pressure generated by the pressure surge propagating along the pipeline after a quick opening of the control valve consisted of the following steps [1, 2]:

- Non-stationary fluid flow simulation to determine the time-varying inner pressure in the bypass pipeline [3, 4, 6].
- Dynamic structural analysis of the bypass pipeline [3].
- Displacement field and stress field evaluation [3].
- Strength, failure and low-cycle fatigue analysis at critical locations of the pipeline [5].

In the non-stationary fluid flow analyses natural gas material properties have been used. In the transit gas pipeline average annual properties of the natural gas were used as initial material properties. The inner pressure value in the suction (input) pipeline was *4.95* MPa and the inner pressure in the discharge (outlet) pipeline was *6.3* MPa in the analysis. The initial temperature of the expanding gas was *50*°C before the valve and *23* °C behind the valve.

In the structural analysis we considered the actual dimensions of the transit gas pipeline using D_{v2} = 920 mm outer diameter and t_2 = 17.8 mm wall thickness of the discharge pipe. The outer diameter of the bypass pipeline was $D_{vb2} = 530$ mm, and its wall thickness was $t_{b2} = 17.8$ mm.

Fig. 1 depicts the spatially discretised models of the compressor suction, discharge and bypass pipelines. In the non-stationary fluid flow simulation, a 3D finite element analysis has been carried out using a sufficiently smooth mesh that ensured the required accuracy even at the locations of the most turbulent flow [1]. We used the same time step size, approximately *0.01* s, in both the fluid flow analyses and the dynamic structural analyses. The initial pressure and the initial temperature distribution over the pipes are depicted in Fig. 2, and Fig. 3.

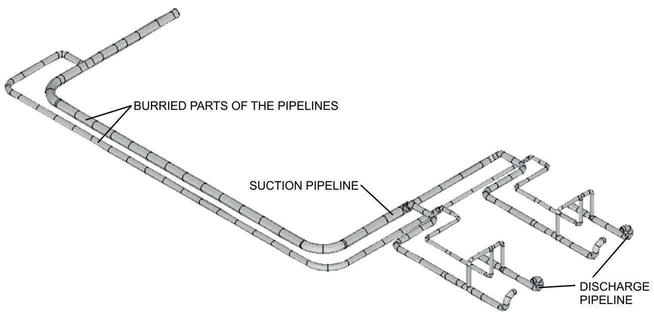

Fig. 1. Spatially discretized model of the suction, discharge and bypass pipelines.

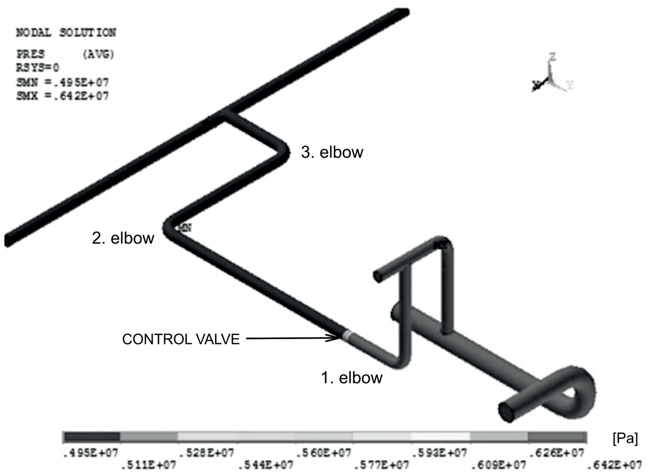

Fig. 2. Initial pressure distribution in the non-stationary fluid flow simulation.

Fig. 4 depicts the inner pressure distribution at time *0.231* s, immediately after opening the control valve. We can see that the pressure distribution is non-linear and that due to the reflecting waves the flow velocity oscillates along the pipe (Fig. 6). In Fig. 5 the maximum pressure time histories at the elbows of the bypass pipeline are depicted. We can easily determine there the initial inner pressure values in the figure, as the initial inner pressure at elbow 1 coincides with the initial inner pressure of the discharge pipeline, while at elbows 2 and 3, the initial inner pressure values correspond to the initial inner pressure of the suction pipeline. We can also see the time shifts between the peaks of the pressure wave propagating along the pipeline.

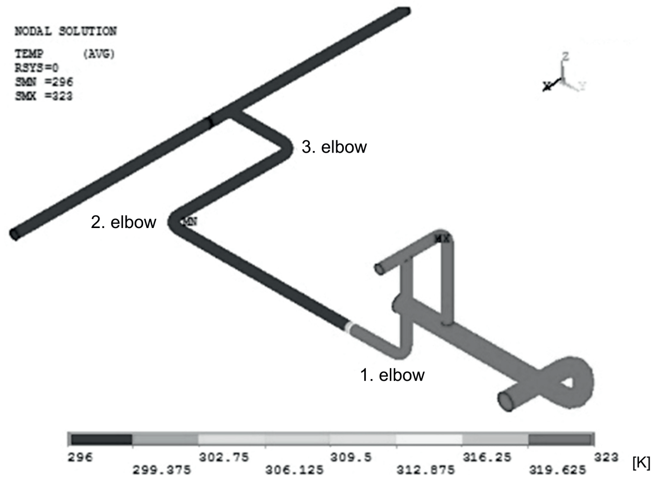

Fig. 3. Initial temperature distribution in the non-stationary fluid flow simulation.

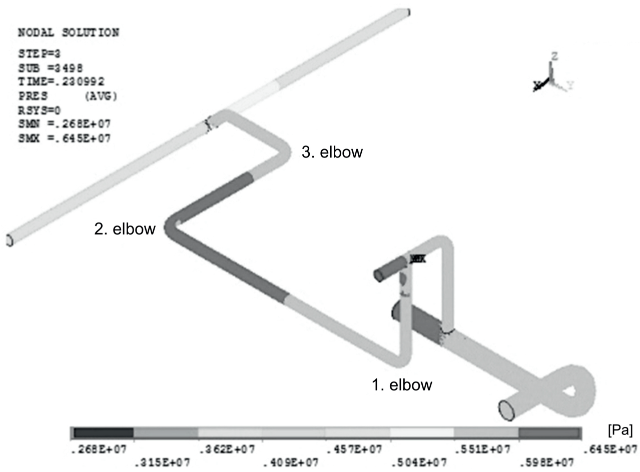

Fig. 4. Inner pressure distribution at time *0.230992* s after opening the control valve.

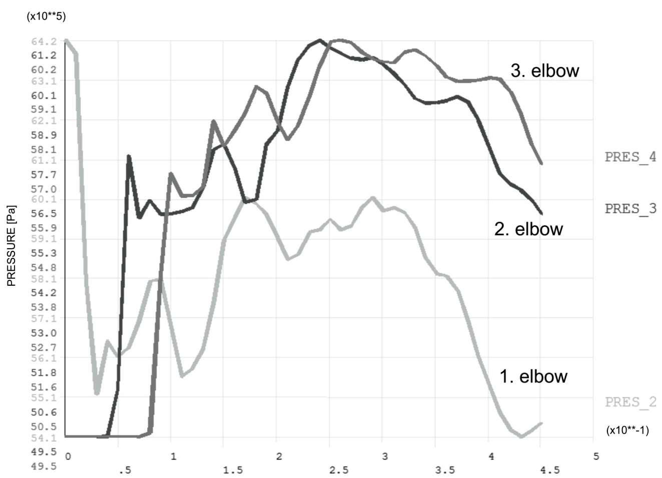

Fig. 5. Maximum pressure time histories at the elbows of the bypass pipeline.

The maximum pressure values at the second and third elbows are almost identical and equal to *6.42* MPa. There are big differences between the axial velocity values at the elbows due to

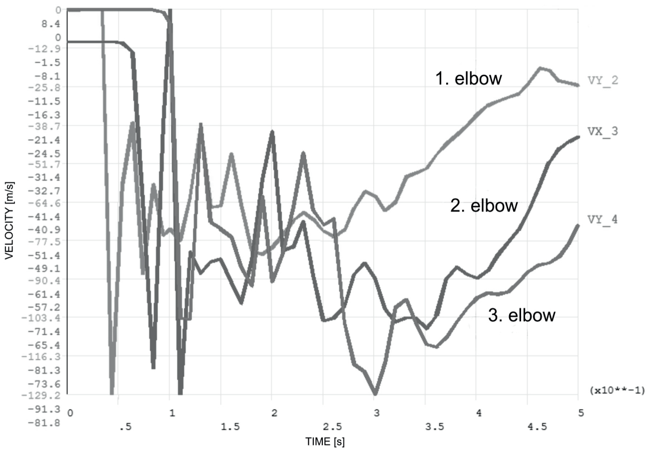

Fig. 6. Axial velocity time histories at the elbows of the bypass pipeline.

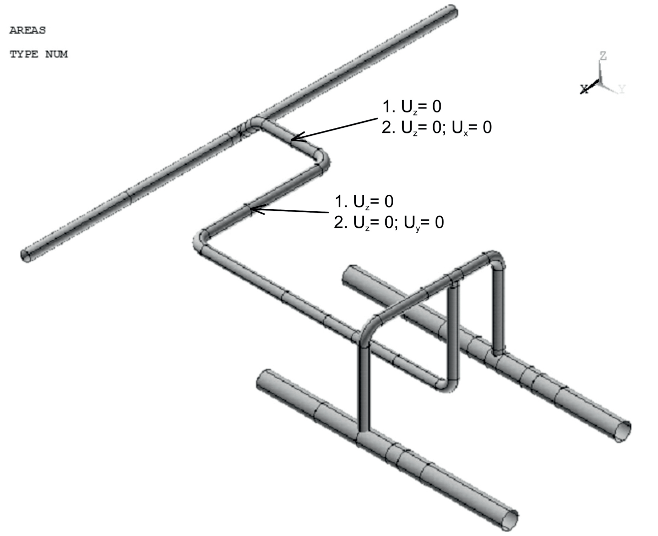

Fig. 7. Spatially discretized model of the bypass pipeline in the dynamic structural analysis.

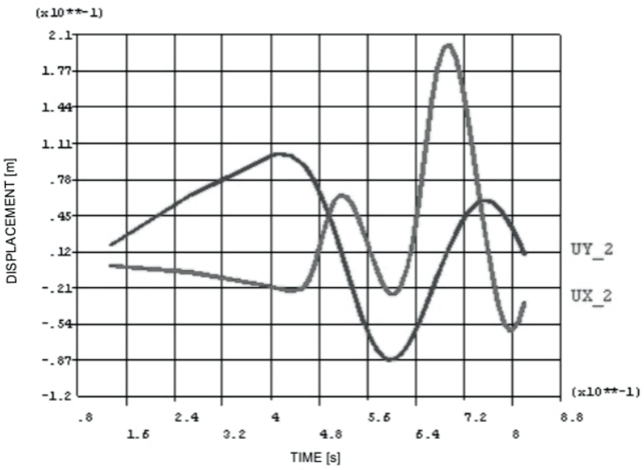

Fig. 8. Displacement time histories at the centre of the second elbow using simple supports.

the significant differences in the corresponding pressure waves immediately after opening the control valve [1, 2], which after ca. *0.5* s stabilize (Fig. 6).

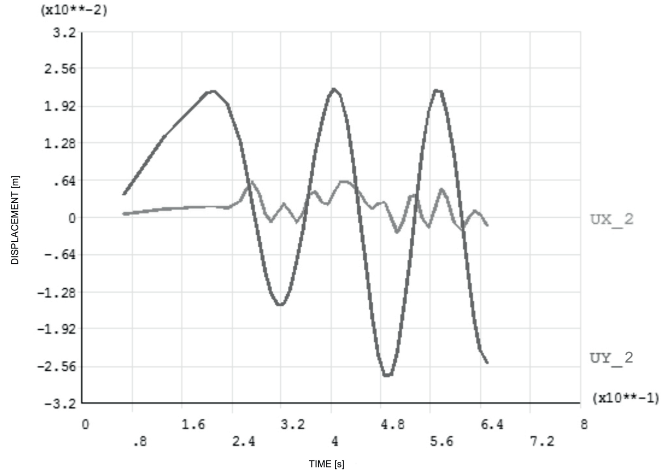

Fig. 9. Displacement time histories at the centre of the second elbow using rigid quides.

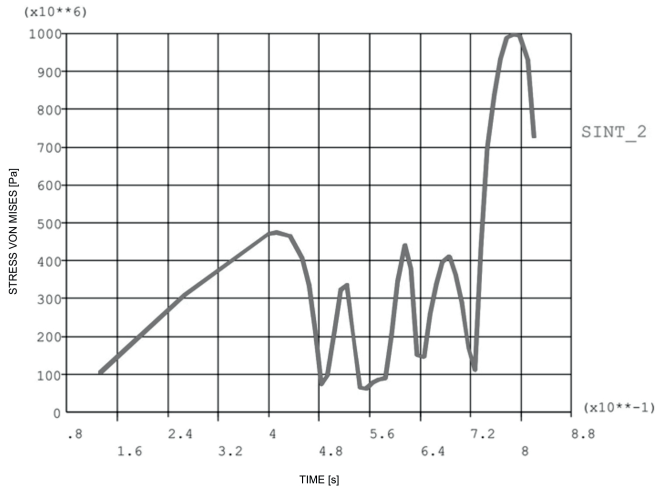

Fig. 10. The maximum stress intensity time history in the horizontal plane that crosses the second elbow using simple supports.

The dynamic structural analysis has been carried out as a load vector coupled or sequentially coupled analysis using the calculated inner pressure values as loads from the non-stationary fluid flow simulation at discrete times [7, 8]. Because we didn't know the stiffness's of the pipe supports, the guides in the analyses were modelled in two different ways corresponding to extreme loadings. The locations of the supports are depicted in Fig. 7. In both cases friction between the support and the pipe was considered. In the first case we replaced the guides with simple supports, so that the pipe was free to move in transverse horizontal direction. The corresponding *X* and *Y* displacement time histories at the centre of the second elbow are shown in Fig. 8.

In the second case, we renewed the rigid constraints in the transverse horizontal directions, i.e. we used rigid guides, which resulted in smaller displacements. The corresponding *x* and *y* displacement time histories at the centre of the second elbow are depicted in Fig. 9.

In the first case the bending moments reached extreme values and generated maximum stresses at the second elbow. In the second case with rigid guides, the maximum stress values were at the locations of the supports.

3 Conclusions

From the numerical results the following conclusions can be drawn:

1 The main pressure wave, caused by expansion of the gas at discharge pressure when the control valve is entirely open, passes through the unburied part of the bypass pipeline in *0.45* s.

2 The second and the third elbows of the bypass pipeline are loaded the most in bending with maximum stress values. Only insignificant portions of the volumes of the elbows are affected by plastic deformations, during which the yield stress of the material is exceeded.

3 The analysis results imply that opening of the control valve on the bypass pipeline during the compressor malfunction causes a low-cycle fatigue loading; as a result each opening during the overall operation of the pipeline should be recorded.

4 Considering the lifetime assessment of pipelines [5], we can state that the low-cycle fatigue loading due to the pressure surge during opening of the control valve is significant from the lifetime assessment point of view, but it can be minimized by appropriate choice of pipe supports.

5 The plastic deformations are invisible to the naked eye which the operator also confirmed.

6 In order to compare the analysis results with experimental results [9], nonlinear material law has to be considered.

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