Straight Pipeline Simulation

Volodymyr Ladogubets, Oleksii Tchkalov, Oleksandr Beznosyk, Oleksii Finogenov

National Technical University of Ukraine "Kyiv Polytechnic Institute"
sasha@cad.kiev.ua

I. Introduction

The technique to create non-electrical object macromodels as equivalent circuits has been described in [1, 2]. In contrast to the problems of defining self-resonant frequencies, it is important to take into account a damping factor for transient analysis tasks. Let's consider a possibility to use the technique proposed for tasks with a defined damping factor by the example of straight pipeline simulation.

II. Example Description

Consider a long straight pipeline *AB* of cross-section area *S* filled with a compressible fluid of density γ and the coefficient of elasticity *E* (Fig. 1). Taking into account only transient processes, let's neglect fluid particle displacements caused by fluid ordered motion and convective currents considering any particle movement to be caused by an elastic compression of the fluid. Radial deformation of the pipeline is considered as negligible. Also, the friction between pipeline surface and fluid particles is negligible (the surface is unwettable). The last assumption makes it possible to consider the following hypothesis: the fluid particle displacement is the same one at any pipeline's plane section perpendicular to its axis.

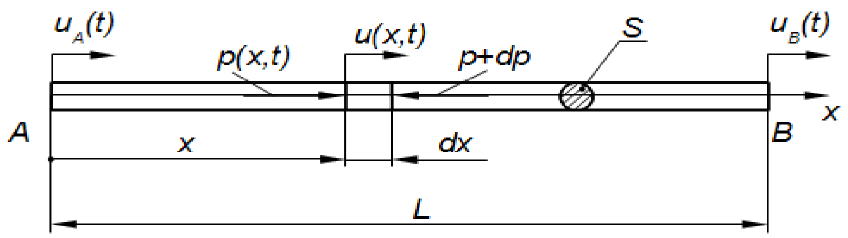

Fig.1 Straight pipeline design diagram.

Let's connect an axis *x* with the pipeline matched its beginning with a section *A*. Every section could be identified uniquely by its coordinate *x* at the undeformed system. Variable in time displacement of any fluid particle at the section *x* (hereinafter referred to as «section displacement») let's indicate as *u(x,t)*. Fluid pressure at this section let's indicate as *p(x,t)*. The problem is to define the dynamic distribution of pressures and displacements in the pipeline depending on the coordinate *x* and time *t*. For determinacy, let's assume that the section *A* is closed by a hard plug, and the outer pressure source $p_B(t)$ is connected to the section *B*.

To construct and investigate the pipeline's finite-element model, ANSYS Multiphysics v.10.0 [3] software has been used. The following parameter values are accepted: pipeline length L=25 m, fluid density $\rho=10^3$ kg/m^3, fluid's coefficient of elasticity $E=2\cdot10^6$ MPa, damping factor λ=0.001.

The left end of the pipeline (node 1) is considered fixed — the fluid velocity at the respective section is identically equal to zero; the right end (node 2) is considered free — the fluid pressure at the section is identically equal to zero.

For simulation, the initial conditions for all the nodes have been accepted as zero ones except the node 2 (pipeline's free end). Its velocity has been initialized as v_0=1,5 m/sec. So, in fact, the process of distribution of a pressure impulse by the pipeline has been under investigation.

III. SIMULATION RESULTS

The plots of the fluid velocity changing at the sections corresponding to the nodes 2 (the free end) — VX_2 (red line) and 4 (located at the 2 m distance from the closed end) — VX_4 (green line) are presented on Fig. 2.

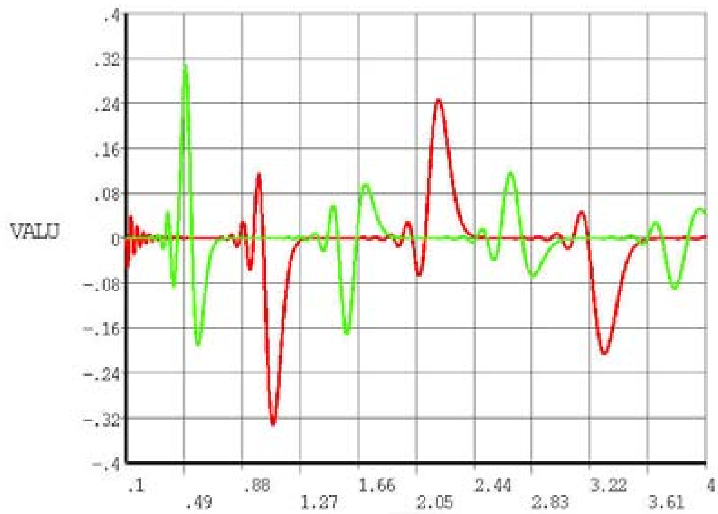

Fig. 2 Straight pipeline ANSYS simulation results.

By means of the plots presented it is possible to monitor the process of the pressure impulse distribution. The time of the impulse spreading at 23 m (this is a distance between nodes 2 and 4) measured as a time interval between moments when VX_2 and VX_4 variables reach their maximal values is near 0,5 s. This value matches well to the theoretical value of the deformation wave spreading velocity at a fluid. Really, for the model parameters considered, the velocity in question is $c=\sqrt{E\gamma^{-1}}=\sqrt{\left(2\cdot10^6/10^3\right)}=44{,}7$ m/s that is for the distance $L_1=23$ m the time of the signal passing is $T=L_1/c=0{,}51$ s. After reaching the closed end, an impulse reflects and spreads back. Further, the process repeats. It is possible also to observe a step-by-step attenuation of the impulse's maximum due to mechanical energy dispersion (damping). Reduction of the maximal value of the fluid velocity at a section does not influence on the velocity of the impulse spreading along the pipeline.

Then, based on the mass, damping and stiffness matrices got from ANSYS the equivalent electrical circuit of the system under consideration has been constructed [1]. It has 76 nodes and 496 elements. Due to its rather large size, the circuit has to be reduced making possible its simulation by circuit design software. The electrical circuit nodes 73 and 4 corresponding to the ANSYS project's nodes VX_2 and VX_4 (where output characteristics is being observed) should be marked as those that could not be excluded during the reduction process. So, after the reduction process is completed, the obtained circuit contains 30 nodes and 119 elements. The task for simulation in NetALLTED circuit design software [5] task control language is presented on Fig. 3 (using the install directive allows setting up an initial condition). The output characteristics build by NetALLTED circuit design software as a result of the respective simulation are presented on Fig. 4. The numerical results of simulation by NetALLTED fully coincide with those obtained by ANSYS.

For the reduced circuit with a smaller number of nodes and elements, the shape of the output characteristics differs significantly from the source ones (Fig. 5), however the attenuation effect remains.

CONCLUSION

The technique proposed is applicable for the problems with damping effect too. However, it should be noted that defining different characteristics under the transient analysis mode, unlike to defining self-resonant frequencies, requires more exact equivalent circuit (that is, it would have a smaller coefficient of reduction).

```
&&
task
tr;
install V73=1.5;
const tmax=4;
const nstep=100000;
const maxstep=1e-3;
plot V4,V73;
&&
end
```

Fig. 3 NetALLTED simulation task.

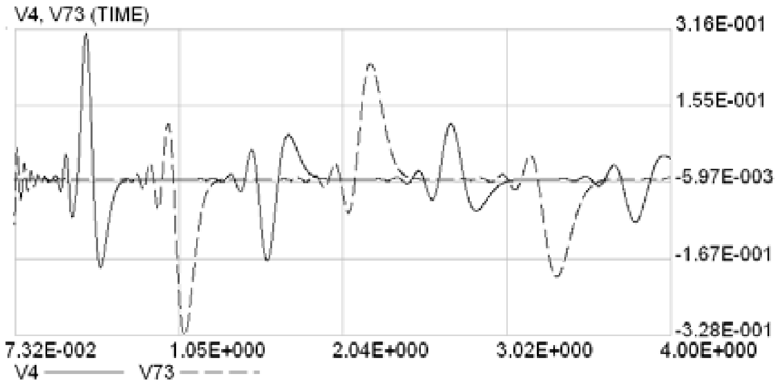

Fig. 4 Straight pipeline NetALLTED simulation results (larger circuit).

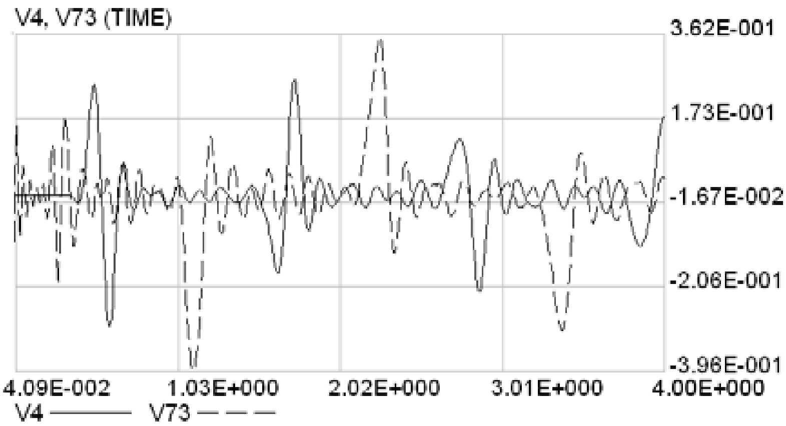

Fig. 5 Straight pipeline NetALLTED simulation results (smaller circuit).

REFERENCES

[1] O. Beznosyk, O. Finogenov, V. Ladogubets, and O. Tchkalov, "Using circuit design software to simulate microelectromechanical components", Perspective Technologies and Methods in MEMS Design: IV-th International Conference of Young Scientists MEMSTECH'2008, 21-24 May 2008, Lviv-Polyana, Ukraine: proc., Lviv : Publishing House Vezha&Co, 2008, pp. 130–133.

[2] A. Petrenko, V. Ladogubets, O. Beznosyk, and O. Finogenov, "Using Optimization Procedures to Calculate Parameters of MEMS Macromodels", The Experience of Designing and Application of CAD Systems in Microelectronics : 10-th Anniversary Intern. Conf. «CADSM'2009», 24-28 February 2009, Polyana-Svalyava (Zakarpattya), Ukraine : proc., Lviv, 2009, pp. 511–514.

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[4] A. Petrenko, V. Ladogubets, V. Tchkalov, Z. Pudlowski, ALLTED – a computer-aided engineering system for electronic circuit design. Melbourne: UICEE, 1997. – 205 p.