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Modeling and simulation of Hydraulic Long Transmission Line by Bond Graph

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This paper address the issue of modeling of the hydraulic long transmission line. In its base, such model is nonlinear with distributed parameters. Since general solution in closed-form for such model is not available, certain simplifications have to be introduced. The pipeline in the paper has been divided to a cascaded network of π segments so that a model with lumped parameters could be reached. For segment modeling, a standard library of bond graphs element has been used. On the basis of models with lumped parameters, the effect of the number of segments, pipeline length and effective bulk modulus on the dynamics of long transmission line has been analyzed.

Keywords: Long transmission line, lumped parameters, π segments, bond graph

1. INTRODUCTION

Existence of a long transmission line (LTL) in hydraulic systems makes their dynamics significantly complex. This is especially emphasized with building and mining machines, agricultural machines, transportation machines, machine tools and other devices where connection between the actuators energy source achieved by a long hydraulic line. Physical variables, pressure and volumetric flow featuring the energy transfer along the hydraulic line, besides the time coordinate, depend on spatial coordinate as well. These physical variables' dependency on spatial coordinate conditions spatial distribution cannot be neglected in long hydraulic line modeling. Therefore they are described with models with distributed parameters. Models with distributed parameters are described with partial differential equations and they are of infinitesimally high order. Use of such a model in analysis o dynamic behavior in time domain is not practical because it requires work with transcendent transfer functions and their approximations using Bessel functions.

In this paper we have used the method of description of a long hydraulic pipe with lumped parameters in a way that it was divided to n equal segments of Ls length. π and T model with lumped parameters have been used whose electrical analogies are given in the paper. On the basis of equivalent electric circuits, adequate bond graphs of these circuits were made and connected into a cascade of n segments, which defines the mathematical model of the hydraulic pipe. On the basis of the mathematical model and simulation, we have analyzed the impact of certain parameters on the character of the transfer process and its results are given in the paper.

2. MODELING OF HYDRAULIC LONG TRANSMISSION LINE

One-dimensional flow of compressible, viscous fluid through the LTL is represented by a set of nonlinear partial differential equations [1]. Applying physical principles of mass conservation, Newton's second law and energy conservation leads to:

$$\frac{A}{a^2}\frac{\partial p}{\partial t} = -\rho\frac{\partial Q}{\partial x} \tag{1a}$$

$$\frac{1}{A}\frac{\partial Q}{\partial t} + g\sin\alpha + \frac{\lambda}{2dA^2}Q^2 = -\rho\frac{\partial p}{\partial x} \tag{1b}$$

That is a pair of quasilinear hyperbolic partial differential equations describing pressure change p and volumetric flow rate Q depending on time t and distance x along the pipeline. Generally, there is no closed-form solution for these equations. The problem is particularly expressed in case of turbulent flow which introduces stochastic parameters. Models with distributed parameters are described by differential equations and the model thus obtained is of infinitesimally high order [2-5].

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