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A Comparative Study of Discrete and Modal Approximation of Hydraulic Transmission Lines

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Abstract ***- Analysis of dynamics of the fluid transmission line in the time domain requires considerable simplification of models which are used in the frequency domain. The paper compares the results of simulation of two such approximations. The first one is based on spatial discretization of a pipeline into segments with lumped parameters. Electro-hydraulic analogy is used for development of the model. The second approach is based on modal approximation. Each single-resonance mode of pipeline dynamics is described by the second order transfer function. Viscosity effect is described by the linear friction model. The bond graph technique is used in both cases for presentation of the model. Out of four causal possibilities, the case with mixed boundary conditions - flow rate and pressure as inputs is observed. The influence of the number of segments/modes and frequency of the input signal on the system response is analyzed.***

Key words: ***fluid transmission line, discrete model, modal approximation, bond graph, simulation***

I. INTRODUCTION

In a lot of applications there is a need for modelling fluid transmission lines (FTL) and fluid transmission networks. In fluid power control systems, reasons for spatial distribution of parameters can be different [1]. Due to constructionally reasons, inefficient volumes usually occur between the pump and the valve, or between the valve and the actuator. The dynamics of these long transmission lines may lead to undesired oscillations. Therefore, the analysis of dynamics of the whole system must also take into account the dynamics of lines.

Physical variables which describe these systems depend not only on the time coordinate but on the spatial coordinate as well. Hence, they are described with partial differential equations, i.e. with infinite-order models in the complex domain. For frequency domain analysis, such models can be used without any simplifications for different boundary conditions. However, certain simplifications are necessary for time domain analysis and simulation. Numerous approximation techniques are encountered in literature: method of characteristics, direct numerical methods, discrete methods, quasi-method of characteristics [1-3]. This paper presents the results of simulation of two models: one is discrete, based on the division of non-homogenous fields ($p(x,t), Q(x,t)$) into segments with homogeneous fields ($p(t), Q(t)$) of all physical variables [4], and the other is obtained by modal approximation [5,6]. The first model uses electro-hydraulic analogy, and the second one is obtained by using rational transfer functions with analytical determination of the modal coefficients.

Depending on the adopted assumptions, viscous and heat transfer effects, pipeline models range from lossless, through linear up to dissipative models [1-3]. This paper uses the linear friction model of the rigid, circular pipe with laminar, Hagen-Poiseuille flow, without heat transfer.

In order to easily notice the effects of involving dynamics of the transmission line in hydraulic control systems it is desirable to use the modular model of a single pipeline section which can easily be included or omitted from the model of the entire system. That is why the bond graph is used for presentation of both models [7]. The bond graph allows connection of pipeline models with the models of other components in fluid power control systems.

For one-dimensional distributed parameter models of a single pipeline, schematically shown in Fig. 1a, there are four causal possibilities: symmetric boundary conditions with pressure inputs (P_a, P_b) or flow rate inputs (Q_a, Q_b) and mixed boundary conditions with (P_a, Q_b) or (P_b, Q_a) as inputs. The last causal combination (P_b, Q_a - inputs, Fig. 1b) is used in this paper. This combination corresponds to long transmission lines between the valve and the actuator.

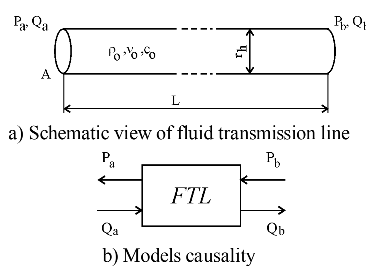

Fig.1. Fluid transmission line

II. DISCRETE MODEL APPROXIMATION

In this approach, the pipeline is observed as a cascade network of lumped elements (Fig. 2), where dynamics of each of them is described by common (linear or nonlinear) differential equations. The number of lumped elements depends on the frequency band of interest. The length of each segment should be much smaller than the shortest wavelength of interest.