Budapest University of Technology and Economics Dept. of Hydrodynamic Systems

Dynamic Behaviour of Hydraulic Drives

Theses

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New scientific results

1. Thesis

1.a Novel technique were presented for the 1D calculation of unsteady pressure and velocity distribution in hydraulic transmission lines with constant diameter in the case of linearly compressible hydraulic fluid. The method consists of a finite element technique for spatial discretisation and a fourth-order explicit first stage, singly diagonally implicit Runge-Kutta scheme. It was shown that the presented technique has several advantages over the method of characteristics in terms of accuracy and computational time.

1.b The main disadvantages of the two most widespread unsteady friction models (large storage need and computational effort of the Zielke model and instabilities of the Brunone-Vítkovsky model) were eliminated. A fast and accurate method was given for the implementation of Zielke's unsteady friction model. With one minor approximation, the Brunone-Vítkovsky model became suitable to include in the numerical scheme described in 1.a. Thus, the implicit nature of the time integration guarantees the stability of the unsteady friction model.

Corresponding papers: [4] and [6].

2. Thesis

2.a Analytical relationship was given for the pressure distribution along a poppet valve with long, conical valve seat and for the flow rate through the valve. Due to their simplicity, the formulae are suitable for valve design. The accuracy of the formulae were verified by CFD calculations.

2.b Closed-formed relationship was given for the force on the poppet valve body due to the pressure distribution. The results were compared to CFD calculations.

2.c The force on the poppet valve due to the wall shear distribution was given analytically and it was concluded that it consists of two terms:

$$F = K_1 \,\Delta p \, H + K_2 \frac{v}{H}, \quad \textbf{where} \quad H = x \, \sin\alpha.$$

Here F is the viscous force, $\Delta p = p_1 - p_0$ is the pressure drop through the valve, v is the velocity of the valve body, x is the displacement of the valve body, H is the gap width and α is the half cone angle. K_1 and K_2 are geometrical constants. The above relationship reveals that in the case of poppet valves with long, conical seats significant damping forces arise for small displacements. The analytical relationships were verified by CFD computations.

2.d It was shown that compared to chamfered-type seats, the long, conical valve seats are dynamically advantageous as smaller damping is needed for stable operation.

Corresponding publication: [5]

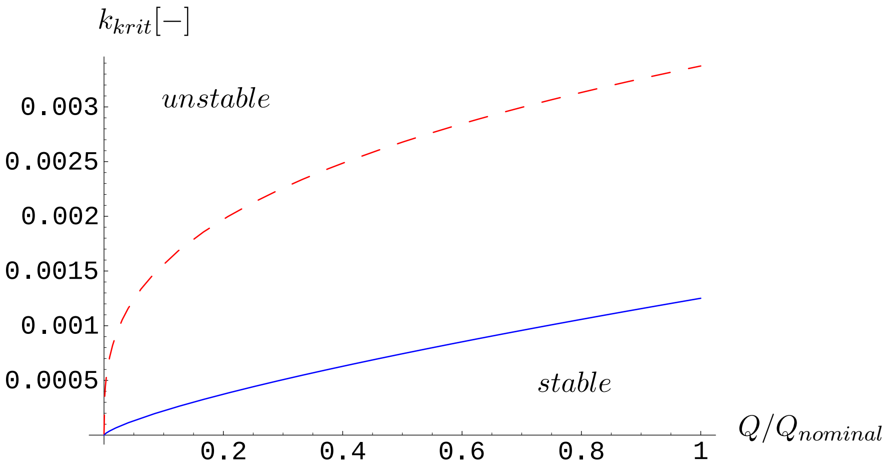

Figure 1: Critical damping parameter vs. relative flow rate. Dashed line corresponds to the short, chamfered type seat and the solid line represents the long, conical valve seat.

3. Thesis

3.a It was shown that geometric singular perturbation theory is a suitable tool for qualitatively analysing the dynamics of hydraulic systems. Using this technique and separating the slow and fast motions, it was demonstrated why the oil compressibility leads to instabilities. It was also concluded that neglecting the fluid compressibility when analysing dynamic phenomena in hydraulic systems may lead to improper results.

3.b The critical parameter values corresponding to the onset of self-excited vibration were given in the case of positioning with two-way proportional valve. Let p and d denote the proportional and differential gain of the controller and k denote the viscous damping on the hydraulic piston. It was shown that if $p < dk$ is satisfied, the control is stable independently from other system parameters.

3.c The critical parameter values corresponding to the onset of self-excited vibration were given in the case of positioning with proportional valve. It was shown that if $p < dk$ is satisfied, the control is stable independently from other system parameters (where the notation is as before).

3.d the delay due to digital sampling and controlling cannot be neglected as it influences the stability boundaries significantly. For the case of proportional PD control the critical proportional gain was calculated as a function of the sampling interval. The results were experimentally verified, see figures 2 and 3. Although the delay notably destabilises the systems, examples were given when an originally unstable system was stabilised merely by adding delay.

Corresponding publications: [3], [2] and [1].

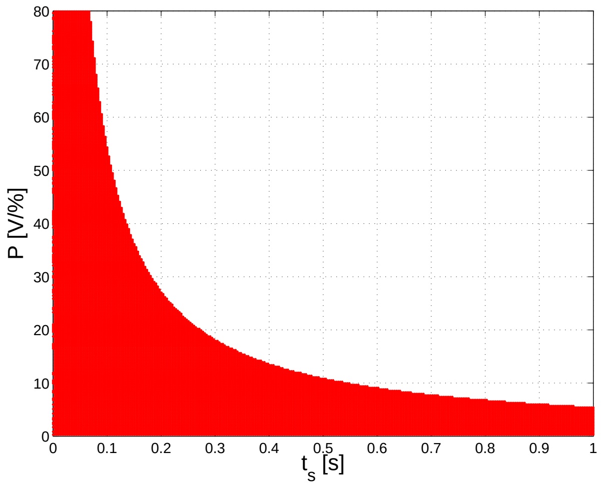

Figure 2: Computed stability boundary, proportional gain as a function of the sampling interval. The stable region is filled.

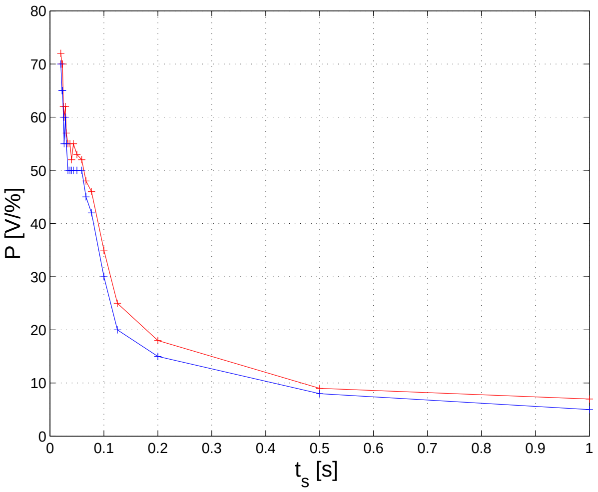

Figure 3: Experimentally determined stability boundary, proportional gain as a function of the sampling interval. The stable region is below the lower line, the unstable region is above the upper line. The region between the lines is uncertain.

References

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[4] Cs. Hős and L. Kullmann. Variable time step methods for 1D hydraulic transmission line modelling. In *Proc. of the 22nd IAHR Symposium on Hydraulic Machinery and Systems*, pages B07–3, June 2004.

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[6] I. Vaik and Cs. Hős. Computation of 1D unsteady pipe flow and the evaluation of the wall shear stress. In *Proc. of the fourth Conference on Mechanical Engineering (Gépészet'04)*, pages 332–336, 2004.