Transactions of the VŠB – Technical University of Ostrava, Mechanical Series
No. 2, 2010, vol. LVI
article No. 1778

Marian BOJKO[*]**, Lumír HRUŽÍK**[**]**, Martin VAŠINA**[***]

MATHEMATICAL SIMULATION OF DRIFT OF SOLID PARTICLES IN LIQUID PHASE

MATEMATICKÉ MODELOVÁNÍ UNÁŠENÍ PEVNÝCH ČÁSTIC V KAPALNÉ FÁZI

Abstract

Failure-free operation belongs to basic requirements of machineries. Particle occurrence in hydraulic systems belongs to negative effects at operation of hydraulic systems. It is necessary to eliminate the occurrence of these particles into fair level (e. g. by application of filter equipments). Hence it is necessary to set these particles in motion at liquid flow. The aim of the paper is a mathematical simulation of motion of metal particles at oil flow in pipe. The simulation was performed by the computer program ANSYS Fluent12.1.4 at different edge conditions.

Abstrakt

Bezporuchový provoz patří k základním požadavkům strojních zařízení. Výskyt částic v hydraulických systémech patří k negativním jevům při provozu hydraulických systémů. Tento výskyt je třeba eliminovat na přijatelnou úroveň (např. aplikací filtračních zařízení). Z tohoto důvodu je nutno uvést tyto částice do pohybu při proudění kapaliny. Předmětem tohoto příspěvku je matematické modelování pohybu kovových částic při proudění oleje v trubce. Tato simulace byla provedena v počítačovém programu ANSYS Fluent 12.1.4 při různých okrajových podmínkách.

1 INTRODUCTION

Different types of impurities come up at operation of hydraulic equipments. Metal abrasions in hydraulic circuits have a negative influence on their abrasive and erosive wear [1]. There are different particles in hydraulic circuits, e. g. small pieces of sealing materials. The purpose of the paper is to simulate a levitation of metal impurities (with the diameters of 50 μm and 100 μm). This simulation was performed in the pipe with the diameter D = 20 mm and the length L = 300 mm by oil velocity profile introduction on input of the pipe. Metal particles are located at the pipe bottom in the start phase. The liquid flow in hydraulic circuits is characterized by a multiphase flow of oil and impurities. After the velocity profile introduction, it is possible to predict the levitation of the secondary phase.

2 CHARACTERISTICS OF MATHEMATICAL MODEL

The drift problems of solid particles in liquid phase was solved by CFD program system ANSYS Fluent 12.1 which makes possible to simulate transfer effects in liquid (i. e. transfer of mass, momentum, warm, ingredients etc.) at laminar and turbulent flow. Numerical simulations of many physical effects are nearly connected with simulation of definite motion form by system of partial differential equations. There are two-dimensional processes, axially symmetric or generally three-dimensional and time-dependent. The drift of solid particles (impurities) in liquid phase in the computer program ANSYS Fluent 12.1 is characterized as a multiphase flow in Euler-Lagrange conception. The liquid phase is supposed as continuum and is solved by Navier-Stokes equations and the

---

[*] Ing. Marian Bojko, Ph.D., VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Hydromechanics and Hydraulic Equipments, Třída 17. listopadu 15, Ostrava, tel. (+420) 59 732 4385, e-mail marian.bojko@vsb.cz

[**] Dr. Ing. Lumír Hružík, VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Hydromechanics and Hydraulic Equipments, Třída 17. listopadu 15, Ostrava, tel. (+420) 59 732 4384, e-mail lumir.hruzik@vsb.cz

[***] Ing. Martin Vašina, Ph.D., Tomas Bata University in Zlín, Faculty of Technology, Institute of Physics and Material Engineering, Nad Stráněmi 4511, Zlín, tel. (+420) 57 603 5101, e-mail vasina@ft.utb.cz

dispersed phase (i. e. particles) is solved by tracing of great number of particles in a flow pattern in this case. The dispersed phase makes possible to change momentum, mass and energy with the connected phase. A small volume fragment of the dispersed phase belongs to the basic hypothesis of the model. Particle trajectories are individually calculated during the connected phase calculation in predefined intervals in terms of balance of active forces on particles. The particle (or nanoparticle) motion is influenced by hydrodynamic resistance, gravitation and lifting forces.

2.1 Motion Equation of Solid Particles in Liquid Phase

The motion equation of solid particles is given by balance of power by application of Lagrange conception and is defined by the following equation [2], [3]:

$$\frac{d\vec{u}_{\mathrm{P}}}{dt} = F_{\mathrm{D}}(\vec{u} - \vec{u}_{\mathrm{P}}) + \frac{\vec{g}}{\rho_{\mathrm{P}}}(\rho_{\mathrm{P}} - \rho) + \vec{F}_{\mathrm{L}}(\vec{u} - \vec{u}_{\mathrm{P}}) \tag{1}$$

Single members of the above-mentioned equation express forces referential on unit of particle mass (i. e. acceleration). The first member on the right side is the hydrodynamic resistance force [3] referential on unit of particle mass, whereas:

$$F_{\mathrm{D}} = \frac{18\mu}{\rho_{\mathrm{P}} d_{\mathrm{P}}^2 C_{\mathrm{c}}} \tag{2}$$

$$C_{\mathrm{c}} = 1 + \frac{2l}{d_{\mathrm{P}}}\left(1.257 + 0.4e^{\,(1.1 d_{\mathrm{P}}/2l)}\right) \tag{3}$$

where: u – liquid velocity [m·s^{-1}], uP – particle velocity [m·s^{-1}], g – acceleration of gravity [m·s^{-2}], μ – dynamic viscosity of liquid [kg·m^{-1}·s^{-1}], ρ – liquid density [kg·m^{-3}], ρP – particle density [kg·m^{-3}], dP– particle diameter [m], l – mean free trajectory of molecules [m].

The second member of the equation (1) represents the force of gravity influence. The third member represents the lifting force referential on unit of particle mass [3], whereas:

$$F_{\mathrm{L}} = \frac{2\nu^{1/2} \rho d_{ij} 2.594}{\rho_{\mathrm{p}} d_{\mathrm{p}} (d_{\mathrm{lk}} d_{\mathrm{kl}})} \tag{4}$$

where ν – kinematic viscosity of liquid [m^2·s^{-1}], d_{ij} – strain tensor. The Sasfman's lift force F_{L} is used from expression provided by Saffman [4].

3 SIMULATION PARAMETERS

The pipe (see Fig. 1) with the length L = 300 mm and the diameter D = 20 mm is the computing area of the simulation. The pipe is defined by few edge conditions. The input edge condition for the primary phase (in this case for oil) is defined by a velocity edge condition by means of velocity profile on the left side. The output edge condition is pressurized (i. e. atmospheric pressure on the area output). The remaining edge conditions are given by pipe walls. The discrete phase (i. e. spherical metal impurities) input is demonstrated too (see Fig. 1). The impurities have a zero initial dynamics. They are pulled by the primary phase after the velocity profile introduction on the pipe input.

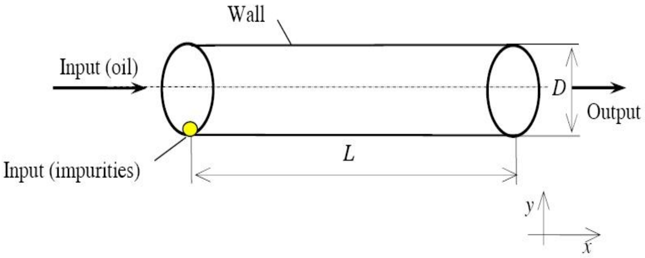

Fig. 1 Computing area of pipe

The computing net was created in GAMBIT 2.4 software with total number of cells $N = 261936$. The liquid flow is assumed as laminar in the entire area in terms of the Reynolds number calculation. The flow is also defined as incompressible and isotherm.

The parameters of liquid and metal impurities are given in Tab. 1. The mathematical simulations were performed for different input velocities u (i. e. 2.5 [$m\cdot s^{-1}$], 3 [$m\cdot s^{-1}$], 4 [$m\cdot s^{-1}$] and 5 [$m\cdot s^{-1}$]). Furthermore the forces of gravity are assumed in the negative direction (see Fig. 1).

Tab. 1 Parameters of phases

Primary phase	Value
Density [$kg\cdot m^{-3}$]	890
Viscosity [$kg\cdot m^{-1}\cdot s^{-1}$]	0.064525
Discrete phase	Value
Density [$kg\cdot m^{-3}$]	7890
Particle diameter [μm]	50 and 100

4 SIMULATION OF PARTICLE MOTION FOR DIFFERENT VALUES OF INPUT MEAN OIL VELOCITY

The trajectory motion of impurities is evaluated for different values of the mean oil velocity (see above) and the diameter of metal impurities ($d = 50$ μm and $d = 100$ μm) on the pipe input. The trajectory is evaluated by means of y coordinate through the pipe length (i. e. x coordinate) – see Fig. 1. A levitation of metal particles through the pipe cross-section is evident from the dependence of y coordinate (see Fig. 2 and Fig. 3). In the case of metal particles with the diameter $d = 50$ μm, it is evident the particle levitation to the steady position in the horizontal distance of $x = 0.08$ m (see Fig. 2). The metal particles with the diameter d =100 μm are similarly lifted to the steady position in the horizontal distance of $x = 0.05$ m (see Fig. 3).

Single variants are compared with the time of achieving of the steady state too. For example in the case of the minimal mean velocity $u = 2.5$ $m.s^{-1}$, the stabilization time $t = 0.107$ s (for $d = 50$ μm) or $t = 0.0647$ s (for $d = 100$ μm). The values of the stabilization time t for the appropriate mean velocities u and the particle diameters d are given in Tab. 2. These times were individually determined for 90 % of the equilibrium position $y_{\max}$ in any case of the mathematical simulation.

Tab. 2 Stabilization times t [s]

Mean velocity u [$m\cdot s^{-1}$]	Particle diameter $d = 50$ μm	Particle diameter $d = 100$ μm
2.5	0.107	0.0647
3.0	0.0952	0.0607
4.0	0.0754	0.0591
5.0	0.0661	0.0583

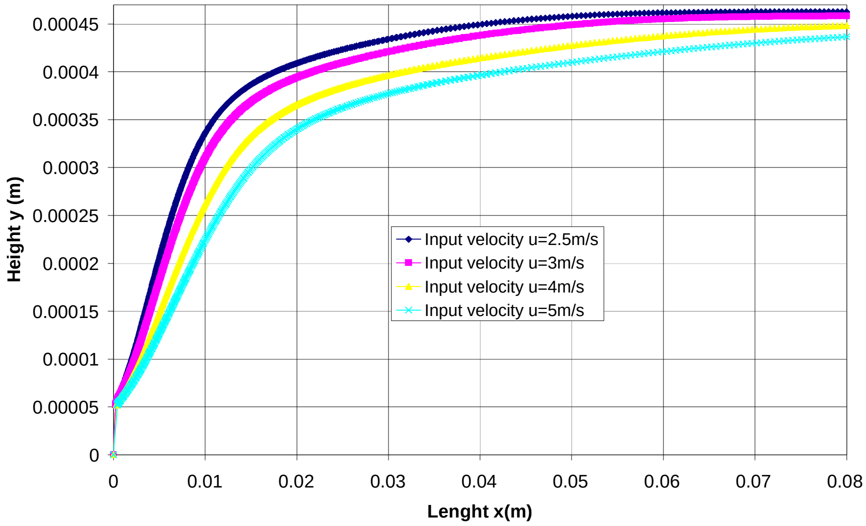

Fig. 2 Motion trajectory of impurities (*d* = 50 μm) for different oil velocities *u* on input side

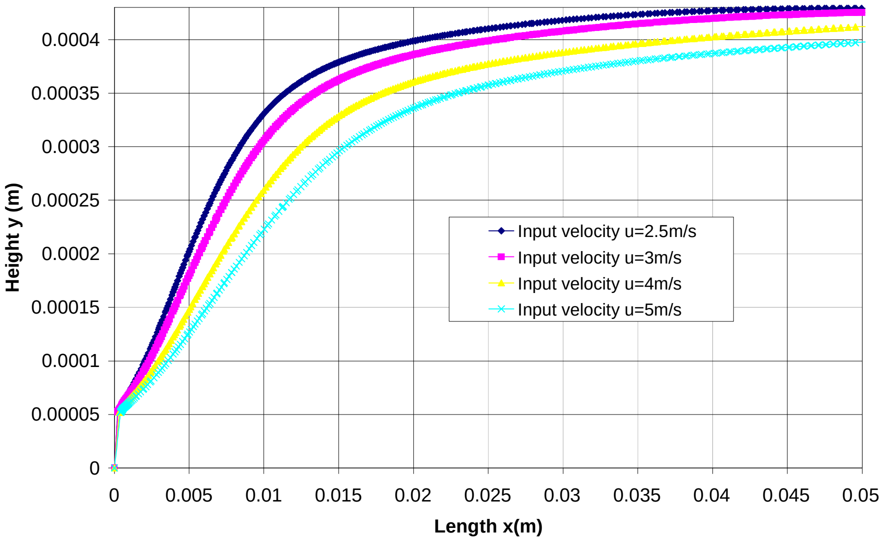

Fig. 3 Motion trajectory of impurities (*d* = 100 μm) for different oil velocities *u* on input side

5 CONCLUSIONS

The paper deals with problems of multiphase flow (hydraulic oil with metal particles) in the pipe with the diameter D = 20 mm for different sizes of metal particles and different values of mean velocities of hydraulic oil on the input side of the pipe. The motion equation of the secondary phase (i. e. metal particles) in continuum (i. e. hydraulic oil) is nearly defined during the introduction of the paper. The motion trajectories are obtained by numerical simulations by means of y coordinate through the pipe length. There is an evident difference in achieving of the distance x at which the particles are in equilibrium positions. The particles with the diameter d = 50 μm obtain the positions in the distance x = 0.08 m. In the case of the particles with the diameter d =100 μm the positions are in the distance x = 0.05 m. The courses of particle trajectories are different depending on the input oil velocity (see Fig. 2 and Fig. 3).

REFERENCES

[1] KOPÁČEK, J. *Technická diagnostika hydraulických mechanismů*. SNTL Praha, 1990, 159 p. ISBN 80-03-00308-3.

[2] KOZUBKOVÁ, M. *Modelování proudění tekutin FLUENT, CFX*. Ostrava: VŠB-TU, 2008, 154 p., ISBN 978-80-248-1913-6, (Electronic publication on CD ROM).

[3] FLUENT: Fluent 12 - *User's guide,* Fluent Inc. 2007. VŠB-TU Ostrava. <URL:http:// http://spc.vsb.cz/portal/cz/documentation/manual/index.php>.

[4] SAFFMAN, P. G. The Lift on a Small Sphere in a Slow Shear Flow. *Journal of Fluid Mechanics*, vol. 22, pp. 385 - 400, 1965.