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Dynamic analysis and simulation of long pig in gas pipeline

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ABSTRACT

This paper deals with the dynamic analysis and simulation of long pig through the two-dimensional gas pipelines. In the modeling, the pig's length is noticed. The long pig is considered as a chain body not a particle. Pig is divided into a number of elements, Newton's second law is written for all the different elements of pig and then all the equations are added to get the dynamic equation of the pig's motion. An algorithm is used to solve the differential equation of the motion based on Runge–Kutta method. Continuity, momentum and the state equations are employed to achieve the gas flow parameters like density, velocity and pressure along the pipeline since the dynamic behavior of the pig depends on the flow field characteristics. It is assumed that pig is long and there is a bypass valve in pig's body. The path of the pig or geometry of the pipeline is considered as 2D curve. Numerical examples are chosen to show the application of the proposed formulation and algorithm. The simulation results illustrate the validity and efficiency of the derived equations for online estimating of the position and velocity of the long pig in gas pipelines at any time of the motion.

1. Introduction

The pipeline is considered as the best and safest way to transport different kinds of fluids including oil and gas productions. After a period of time, pipelines do not operate effectively because of debris or residual products. In order to remove this debris and inspect the physical condition of the pipelines, pigging operation is commonly used around the world. Pipeline pigs may be broken into two fundamental groups: 1. conventional pigs, which perform a function such as cleaning or dewatering, and 2. smart or intelligent pigs which are utilized for internal inspection of pipelines. Smart pigs are usually long to install different transducers on them for detection of surface defects such as cracks, corrosion, etc.

If pigs run at a constant velocity, they can do their job effectively. This velocity is generally in the range of 1–5 m/s in liquid pipelines and 2–7 m/s in gas pipelines (Nguyen et al., 2001a). Good estimations of pig velocity and the time need for the pig to reach to the end of pipeline will help engineers design and perform a suitable pigging operation. The dynamic analysis of a pig in a pipeline can estimate these important parameters for the designers. Smart pigs regularly are long so they cannot be reflected as particle and their length should be considered in the modeling and dynamic analysis.

A literature survey has revealed few papers dealing with the motion of the pigs in pipelines. Most of the available work is experimental research or have a commercial basis. McDonald and Baker (1964) introduced probably the first investigation on the motion of pigs in pipelines. They used a successive steady-state approach to model the pigging phenomena. Barus (1982) extended this modeling and removed some limitations. The first pigging model on the basis of full two-phase transient flow formulation proposed by Kohda et al. (1988). This model is composed of correlations for pressure drop across the pig, slug holdup, pigging efficiency, pig velocity model and a gas and liquid mass flow boundary condition applied to the slug front. Some other researchers also reported their results of pigging simulation in two-phase flow straight pipelines (Minami and Shoham, 1991; Taitel et al., 1989; Scoggins and M. W. 1977; Xiao-Xuan and Gong, 1999). Nieckele et al. (2001) presented isothermal transient pigging operation through gas and liquid pipelines. Nguyen et al. (2001b) proposed a computational scheme using method of characteristics (MOC) and a regular rectangular grid for estimating the pig dynamics when it flows in natural gas pipeline. Nguyen et al. (2001c) studied dynamic model and its analysis for the pig through a 90° curved pipe with compressible and unsteady flow. One type of pig using bypass flow in natural gas pipeline was considered by some investigators such as Nguyen et al. (2001a). In their research, a simple nonlinear controller is designed based on

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Nomenclature

A	area cross section of the pipeline	L_{pig}	length of the pig
D	pipeline diameter	N	normal force acting on the pig
D_h	hydraulic diameter	K_{SC}, K_V, K_{SE}	coefficients of pressure losses
g	acceleration of gravity	F_f	friction force
g_t	tangential element of acceleration of gravity	f	coefficient of friction loss in pipeline
g_n	normal element of acceleration of gravity	P_{tail}	pressure at the tail of the pig
$f(x)$	function of centerline of the pipe in 2D	P_{nose}	pressure at the nose of the pig
sgn(x)	sign function of x	A_h	area cross section of the valve
T_i	tensional force in i-th element of pig	V_h	velocity of fluid at the valve
a_t	tangential acceleration of pig	V_{pig}	velocity of the pig
F_k	dry friction force	p	wet pipeline perimeter
μ_k	dynamic coefficient of friction	T	fluid temperature
		R	universal gas constant
		c	speed of sound

the back stepping method to control the pig velocity when it runs in natural gas straight pipeline. A numerical code has been developed by Esmaeilzadeh et al. (2009) to simulate the pig motion in liquid and gas pipelines. They found the optimum flow rate for pigging operation. Comparison of the simulation results and experimental results shows good agreement.

For the first time, Saeidbakhsh et al. (2009) studied the dynamic analysis and simulation of small pigs in space pipelines. For simplicity in that research, the influence of the flow field is modeled only by time dependent driving force acting on the pig. The effect of flow field was considered by Lesani et al. (2012). They extended the model for a bypass flow pig through two and three dimensional liquid pipeline. In this extension, fluid is assumed to be incompressible. Speed control of the bypass flow pig using the QFT method was done by Mirshamsi and Rafeeyan (2012) to keep the pig velocity near a constant value In that study, they assumed fluid as incompressible and the pipeline is two dimensional. Mirshamsi and Rafeeyan (2015) considered the influence of flow field on the pig's trajectory through two and three dimensional gas pipeline. They assumed that fluid is compressible. Two differential equations were derived and solved. First, the differential equation of fluid is solved to get compressible fluid properties such as velocity, pressure and density along the pipelines. Then, the differential equation of pig motion is solved to get the pig velocity and position in pipeline.

In all the mentioned studies, length of the pig is ignored in the dynamic modeling of the pig and pig is considered as a particle. Therefore, the motivation for the present work is the obvious gap in the dynamic analysis of a long pig motion in the pipelines by considering the length. In this study, the fluid is assumed compressible and a long pig is considered as a chain body not a particle. Pig is divided to elements, Newton's second law is written for all different elements of pig and then all the equations are added to get the dynamic equation of the motion of pig. An algorithm is used to solve the differential equation of the motion based on Runge–Kutta method. Numerical examples are chosen to illustrate the application of the proposed formulation and algorithm.

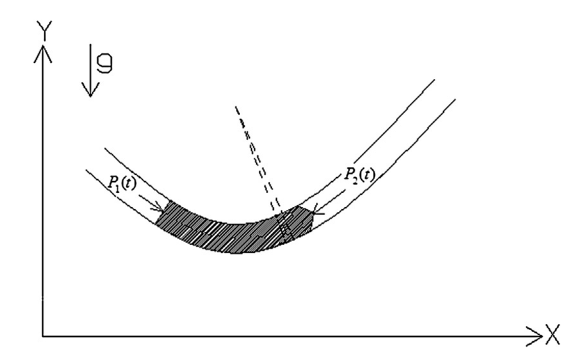

Fig. 1. A long pig inside a 2- dimensional pipeline.

2. Modeling

2.1. Case 1: modeling the pig in no-friction pipeline

In Fig. 1 a typical chain pig moving inside a two-dimensional pipeline is shown. Variable forces $P_1(t)$ and $P_2(t)$ are forces applied on the tail and nose of the pig by the fluid and will be obtained in part 2.3. For dynamic analysis of pig motion, chain pig can be divided to numbers of small elements. Forces acting on the arbitrary element of pig are shown in Fig. 2.

For the i-th element, we can write Newton's second law in t-direction as:

$$T_{i+1}\cos\left(\frac{d\theta_i}{2}\right) - T_i\cos\left(\frac{d\theta_i}{2}\right) + g_{ti}dm_i = a_{ti}dm_i \tag{1}$$

where g_{ti}, dm_i and a_{ti} are tangential element of acceleration of

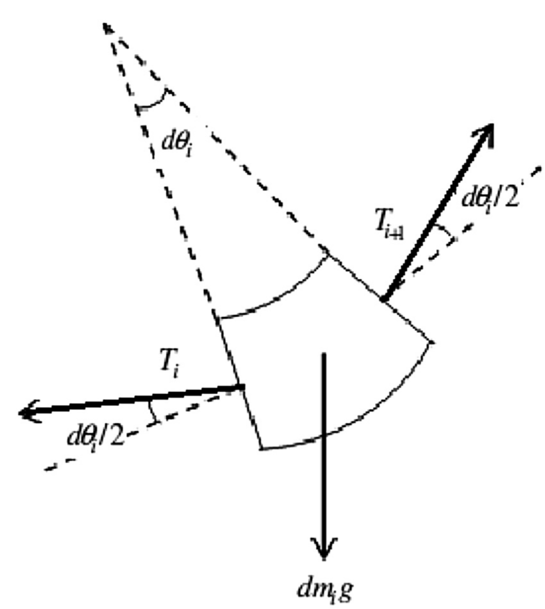

Fig. 2. Forces acting on an arbitrary element of chain pig in no-friction pipeline.