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Dynamic simulation and experimental research on the motion of odometer passing over the weld

Xiaoxiao Zhu*, Xiaolong Li, Chunhua Zhao, Shimin Zhang, Shuhai Liu**

College of Mechanical and Transportation Engineering, China University of Petroleum, Beijing, Changping, Beijing, 102249, China

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ABSTRACT

Odometer wheel system, designed to measure the traveled distance and the instantaneous velocity of the intelligent inspection pig in operation, is an important part of the pig to define the position of pipeline defects. High accuracy positioning of pipeline defects can greatly improve the pipeline maintenance efficiency and highly reduce the costs. However, due to the peculiarity of its construction, the odometer is prone to unbounded accumulative errors and pipeline weld is the main reason. As a result, research on the motion and accuracy of odometer system is essential. In this paper, the motion of the odometer passing over the weld was investigated. Mathematical and simulation models were presented to describe and analyze the errors of the odometer, which was verified by the experiment. Research results indicate that the error of the measured distance can be divided into two conditions. At low velocity, the measured distance is larger than the actual distance, while the measured distance is smaller than the actual distance at high velocity. The results in this paper can provide better understanding of the accumulative errors of the odometer, and contribute to find a way to improve the accuracy of the odometer wheel system.

1. Introduction

Periodic inspection of oil and gas pipelines is essential to be carried for the integrity maintenance, and it has become a standard industry procedure (Azevedo et al., 1996; Nieckele et al., 2001; Kim et al., 2003; Botros and Golshan, 2009; Davoudi et al., 2014; Li et al., 2015). The inspection task is widely performed by a type of special instrument called pig (pipeline inspection gauge). Pipeline defects, such as corrosion, internal damage, cracks et al., can be monitored with an intelligent pig. Product losses and environmental pollution can be prevented according to timely maintenance (Sadovnychiy et al., 2006; Quarini and Shire, 2007; Mirshamsi and Rafeeyan, 2012).

Odometer wheel system, designed to measure the traveled distance and the instantaneous velocity of the pig in operation, is an important part of the pig to define the position of pipeline defects, as shown in Fig. 1. It can compensate drift error results from Inertial Measurement Unit (Kim et al., 2003). Cooperated with magnetic reference station (located by Global Positioning System), the pig with odometer wheel system can identify the location of defects with higher accuracy.

The odometer system usually comprises two or three instrumented wheels, which are sprung against the inner surface of the pipe. The rotation of the wheel is detected by a toothed gear wheel on the same shaft and a proximity detector (for example, Hall sensor) that generates a pulse as each tooth passes the detector (Flournoy and Kersey, 1973). Knowing the wheel perimeter and the amount of received pulses with each turn, the traveled distance is easily to be computed (Reed et al., 2004). However, due to the peculiarity of its construction, the odometer is prone to unbounded accumulative errors (Sadovnychiy et al., 2006; Santana et al., 2010). Methods to improve the accuracy of odometer wheel system are essential and meaningful, since numbers of the magnetic reference stations can be greatly reduced or even removed due to the improved accuracy. Inspection costs can finally be reduced relatively. Consequently, research on the motion and accuracy of odometer system has brought to more and more attention than before.

Kim D.K., et al. (Kim et al., 2002) proposed a method for the error compensation based on the analysis of the odometer's behavior around the girth welding point of a pipe, and the experiment was conducted to verify that the developed odometer system can be used for the intelligent pig with good performance. Sadovnychiy and Lopez (Sadovnychiy and Lopez, 2005; Sadovnychiy et al., 2006)

* Corresponding author.
** Corresponding author.
E-mail addresses: x.zhu@cup.edu.cn (X. Zhu), liu_shu_hai@163.com (S. Liu).

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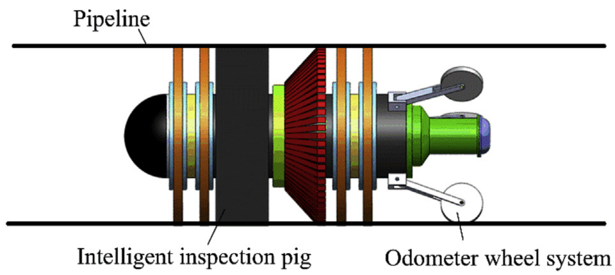

Fig. 1. Intelligent pig with the odometer wheel system in the pipeline.

presented the scenario of the odometer behavior in the moment of passing through the welding seams. The effects of weld size, spring force, pigging speed and the fluid in the pipeline on the accuracy of the odometer were investigated separately. Wang et al. (Wang et al., 2015). classified the errors of the odometer into systematic errors and random errors. The mathematical models of the errors were obtained according to quantitative analysis and contrastive analysis. The relationship of the errors and the effects of each error on total errors were finally concluded. Li et al. (Li et al., 2015). proposed a new method to improve the accuracy of a caliper pig with the odometer wheel system according to the counting of girth welds. The experiment indicated that the accuracy of the caliper pig had been effectively improved. Abdel-Hafez, M. and S. Chowdhury (Chowdhury and Abdel-Hafez, 2016) presented a technique that used an inertial measurement unit, a speedometer and a set of reference stations to estimate the position of a pig. Experimental research was conducted to verify the estimator's consistency.

It is well known that the weld is the main reason resulted to the accumulative error of the odometer (short for the odometer wheel system), as it is located every 12 m or less, compared with of T/Y connectors infrequently appeared. However, the characteristics of the odometer's motion is still unrevealed. Consequently, the motion of the odometer passing over the welds was investigated in this paper. Mathematical and simulation models were presented to describe and analyze the errors of odometer, which was verified by the experiment.

2. Mathematic modeling

2.1. Structure of odometer wheel

The odometer wheel usually consists of odometer, gear, Hall sensor, spring and supporting structures, as shown in Fig. 2. Bottom base is fixed on the pig, and the rest parts of the odometer wheel can rotate around the axis of arm. The odometer can tightly contact with the inner surface of the pipeline due to the spring force. As a result, when the pig running in the pipeline, the odometer rolls along the pipeline, and the rotation is detected using a toothed gear wheel and a Hall sensor, or an encoder on the same shaft with the odometer. Electrical pulses or turning rounds are counting and the pigging distance can be calculated.

As mentioned before, due to the special structure of the odometer wheel, the error is generated as the loss of the contact with the internal surface of the pipe, when the odometer comes across T/Y connectors or welds. Consequently, unbounded accumulative errors mainly result from bouncing against welds.

2.2. Mathematic model

In order to investigate the motion of the odometer passing over the weld, the mathematical model was proposed in this section and then simulation was conducted using ADAMS (Automatic Dynamic Analysis of Mechanical Systems).

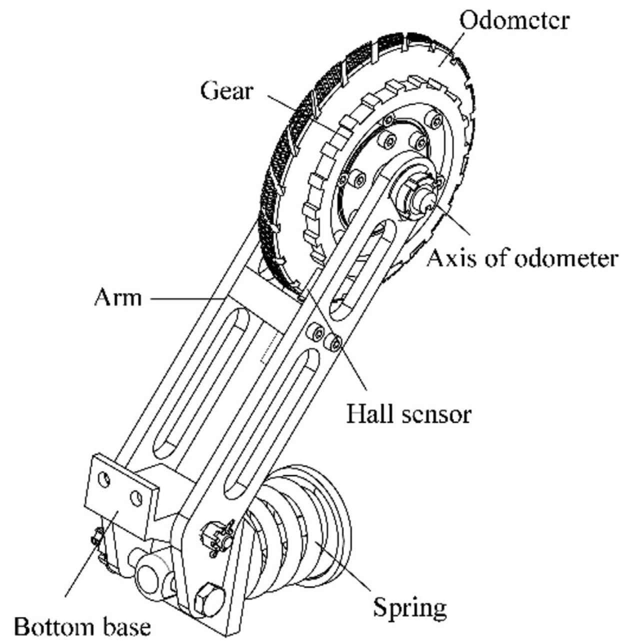

Fig. 2. Structure of the odometer wheel.

As shown in Fig. 3, the interaction of the odometer with the weld can be divided into two stages, uphill stage (OP section) and downhill stage (PQ section). The duration of each stage depends on the velocity of the pig. A further analysis will be presented in the following to clearly describe the dynamic motion.

Before colliding with the weld, it can be assumed that the odometer rotates along the inner surface of the pipeline with a constant angular velocity. There are four forces working together on the odometer, the contact force against the pipeline which is provided by spring (F_{y1}), the traction force induced by the arm of the odometer (F_{x1}), the friction force from the pipeline inner wall (F_{f1}) and the reacting force from the pipeline (F_{N1}), as shown in Fig. 4. The internal rotational friction force of the odometer is neglected, compared with the spring induced contact force. The odometer can run in the pipeline with a constant velocity by the action of these four forces.

Once the odometer contacts with the weld at point O, a collision will occur and the rotational velocity will be greatly reduced, as shown in Figs. 4 and 5. The equation can be expressed as following:

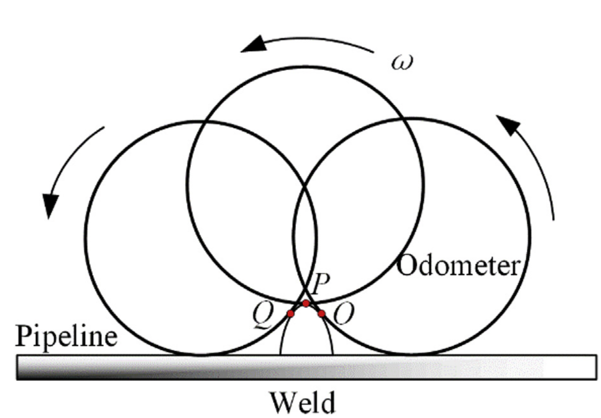

Fig. 3. Trajectory of the odometer wheel passing over the weld.