

# Study on optimized algorithm for mileage wheel of magnetic flux leakage detector

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**Abstract.** Pipeline integrity is significant to safe operation of long-range pipeline. To avoid critical failure of the pipeline, which may lead to great loss of property and life, MFL\_PIG is often used to detect the corrosion and leakage of the pipeline. To accurately locate the defects, mileage pulses emitted by the mileage wheel are used to and emit signal to single-chip microcomputer for position. This paper investigates the factors that may affect the precision of mileage wheel, an important part of pipeline corrosion and leakage detector (MFL\_PIG), investigate its working principle and present an optimized algorithm for mileage wheel to increase the precision of detection.

## 1. Introduction

Long-range pipeline is important transportation tool in modern society and safety operation is crucial to pipeline. The pipeline corrosion and leakage detector (MFL\_PIG) is one of the most widely used detectors to measure the integrity of the pipeline [1]. However, the situation in the pipeline is extremely intricate due to complex pipeline structure, transportation media, warp, and so on. Generally, the diameter is used to before MFL\_PIG to clean the objective pipeline. There are many factors that may affect the positioning precision of detection of MFL\_PIG, and the mileage wheel, as an important part of magnetic flux detector, plays significant role in the detection process. The mileage wheel is mileage measurement device, and its working condition is essential to measurement accuracy and reliability of MFL\_PIG [2].

When MFL\_PIG is marching in the pipeline, slippage or other failure may occur on the mileage wheel, which will lead to error of positioning. Therefore, 2 or more mileage wheels are often adopted. During the marching, each mileage wheel will emit a pulse signal when it rotates, which carries operating speed information of the diameter.

The signal which has the minimum error should be used as the distance measurement signal, that is, the tracking signal. Therefore, the signals which are received from different mileage wheel should be compared in real time to judge if it is suitable for tracking.

Selection of accurate tracking signal is important to ensure the mileage wheel's accuracy in the complex pipeline environment, and the design of the optimized algorithm for mileage wheel signals is discussed in detail in this paper.

After the introduction, the paper is organized in the following sections. Section 2 describes factors that affect the precision of the mileage wheel, and its working principle. Section 3 investigates the principle of optimized algorithm in detail, discusses the effect of different parameters on inverse time



function K. Section 4 presents an experiment conducted on the pipelines to verify the optimized algorithm. Section 5 presents conclusions of the article.

## 2. Analysis of the factors affecting the structure and precision of the mileage wheel

### 2.1. Factors affecting the precision of the mileage wheel

There are many factors that may affect the measuring precision of mileage wheel [3-5].

#### A. Spring torque of the mileage wheel

Spring torque is one of the important factors which may affect the positioning accuracy of mileage wheel. The mileage wheels in the pipeline attached to the inner wall of the pipe firmly, and turn with the running of the detector. If the positive pressure between mileage wheel and pipe wall is large enough, the friction force should be increased to reduce the probability of slippage of the mileage wheel. Therefore, the torsion spring of the mileage wheel should be designed to maximum torque.

#### B. Tread pattern of the mileage wheel

The tread shape and depth of the mileage wheel is another factor affecting the positioning accuracy. The surface roughness of the mileage wheel directly affects coefficient of friction between the mileage wheel and the inner wall of the pipe. The rotation of mileage wheel is similar to a car driving on an icy road. Due to the effect of pipe wall wax, mileage wheel will slip. In order to increase the friction coefficient, with exception of increasing the positive pressure between mileage wheel and pipe wall, the mileage wheel surface is grooved and pressed with pattern, which can improve positioning accuracy of mileage wheel. In practical application, the space of mileage wheel surface groove is about 20mm, and the depth is about 3mm.

#### C. Wear of the mileage wheel

The diameter of steel mileage wheel is about 145mm. The wheel surface is treated with high-frequency quenching. Small magnetic blocks embedded in the spoke. When surface of the mileage wheel wear, the diameter of the mileage wheel decreases, result in changes in mileage pulse. Thus, errors occur in detection data. In practice, the error range of diameter mileage wheel is  $\pm 1.5$  mm. If the error is greater than the range, the mileage wheel should be changed.

#### D. The rotation flexibility and swing error of the mileage wheel

Rotation flexibility and swing of mileage wheel are also one of the factors that affect the positioning accuracy of the mileage wheel. If the rotation of the mileage wheel is not flexible, the probability of mileage wheel slippage will be increased. When mileage wheel completes one turn, the number of mileage pulse is certain. If the gap between the mileage wheel and the arm is too large, the hall element installed on the arm of mileage wheel will not be able to perceive a signal caused by small magnetic blocks, resulting in less mileage pulse acquisition. Therefore, the gap between the swing range the mileage wheel and the arm should be less than 0.5mm.

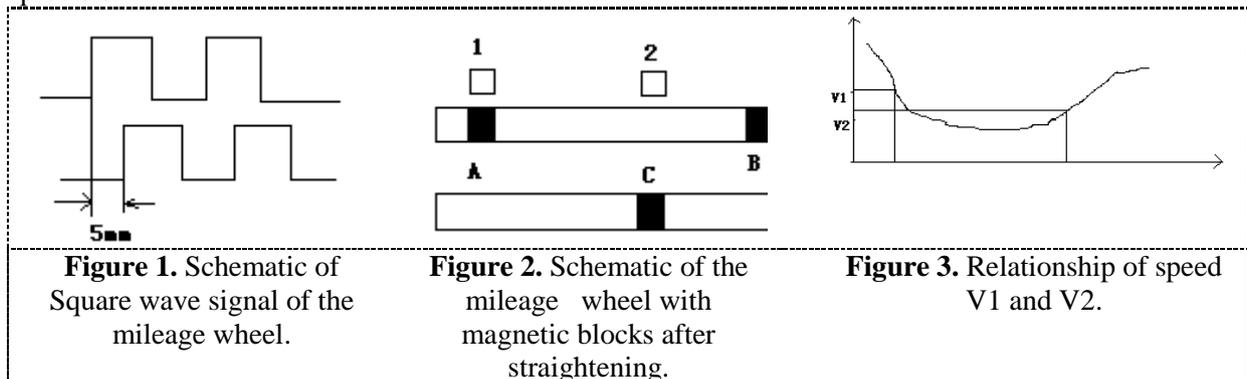
Furthermore, the sundry goods in the pipe should be cleaned in case that the mileage wheel be wound by debris, which stuck the mileage wheel and lead to the loss of detection of data.

### 2.2. Working principle of mileage wheel

The When MFL\_PIG operates in the pipeline, the mileage wheel firmly attaches to the inner wall of pipe rolling with the smooth running of the detector. A Hall element is installed on the arm of the mileage wheel, and small magnetic blocks mounted at even distance on mileage wheel. As the mileage wheel rotates, Hall element generates a pulse signal, which will be acquired, multiplied, and sent to single-chip computer for optimization. The optimized signal will then be stored in the hard disk, and a square wave signal is formed (see Figure 1, above part).

The magnetic blocks are evenly distributed on the mileage wheel, and each two adjacent magnetic blocks corresponds to the distance of 10mm (mileage wheel rotation). In order to reduce the period of square wave cycle and improve the accuracy of the signal, another Hall element is placed in the middle of the magnetic blocks. Therefore, the distance between rising and falling part of the square wave is reduced from 10mm to 5mm (see Figure 1, low part).

In order to illustrate the working principle, the mileage wheel is extended into a straight line, as shown in figure 2. Assuming that there is only one Hall element C, the signal rolls when magnetic block 1 and 2 pass C respectively. The distance between block 1 and 2 is 10mm. When two Hall elements are provided, and the distance between the two components of A and B is 1.5 times of the distance of the magnetic blocks, the period of the signal decreased to half of the original. The distance between adjacent rising edge of the square wave reduced to 5mm, which increase the measuring precision.



### 3. Principle and implementation of the optimization algorithm for the mileage wheel [6-7]

#### 3.1. Speed calculation algorithm of mileage wheel

When the mileage wheel is running normally or the speed is not particularly slow (that is, there is no stuck or serious slippage of the mileage wheel), the speed can be calculated as below,

$$V_1 = 0.005 / (T_1 - T_2) \quad (1)$$

Where  $T_1$  and  $T_2$  are time of two adjacent rising edge of the mileage wheel signal.

However, when the mileage wheel is not running, or even stuck, the later rising edge is delayed for a long time, Equation (1) could not be used. At this time, another equation should be used instead.

$$V_2 = 0.005cn / T \quad (2)$$

In which  $n$  is decided according to the actual situation,  $0.005 * n$  means the distance which  $n$  rising edges passed, and  $T$  represents the time used for  $n$  rising edges.

$V_1$  in equation (1) is instantaneous speed of the mileage wheel and  $V_2$  describes the average speed of  $n$  rising edges. The relationship between  $V_1$  and  $V_2$  is shown in figure 3.

At the beginning of calculation,  $V_1$  mode is used as reference speed, marked as  $V_1'$  ( $V_1'$  is determine in terms of actual situation of the inspection, varies between 0.5m/s to 5m/s.), and the following calculated speed will be compared with  $V_1'$

If  $V_1 > V_1'$ , still use the  $V_1$  as calculation speed;

If  $V_1 < V_1'$ , switch to  $V_2$ .

After switched to the  $V_2$  calculation speed, the value of calculated speed  $V_2$  will be compared with reference speed  $V_2'$ ,

If  $V_2 > V_2'$ , switch to  $V_1$  mode;

If  $V_2 < V_2'$ , keep using the  $V_2$  as calculation speed.

Here  $V_2'$  is determined according to the actual situation. The range of  $V_2'$  is 0.5m/s~ 5m/s.

#### 3.2. Speed calculation algorithm of mileage wheel

Inverse time algorithm is used to construct the inverse function:

$$K = A / (BX^n + C) \quad (3)$$

Where  $A$ ,  $B$ , and  $C$  are coefficients ( the influence of these coefficients on  $K$  will be discussed in the following part ), and  $X$  is the difference between the speed of two mileage wheels ( $V_0$  and  $V_s$ ), that is

$$X = V_0 - V_s \quad (4)$$

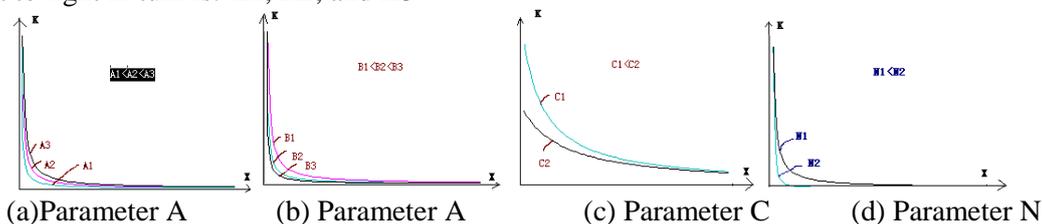
When the speed difference  $X$  is less than  $0.01\text{m/s}$ , the system operate normally without switching. When the speed difference is over  $0.1\text{m/s}$ , the algorithm switches immediately. When the speed is just in between  $0.01\text{m/s}$  to  $0.1\text{m/s}$ , inverse algorithm in equation (3) is used.

Therefore, When  $X=0.01$ ,  $K$  approaches infinity in equation (3); when  $X=0.1$ ,  $K$  approaches 0.

The influence of coefficient  $A$ ,  $B$ , and  $C$  on function  $K$  will be investigated in this part.

A. 1<sup>st</sup> situation: the influence of parameter  $A$  on function  $K$  when parameter  $C$  and  $B$  are fixed, shown in figure 4 (a). It can be seen from figure 4 that  $K$  becomes larger with the increase of value of parameter  $A$ . And the curve becomes farther to the original of the coordinate ( $A_1 < A_2 < A_3$ ). The curve from left to right in turn is  $K_3$ ,  $K_2$ , and  $K_1$ .

B. 2<sup>nd</sup> situation: the influence of parameter  $B$  on function  $K$  when parameter  $A$  and  $C$  are fixed, shown in figure 4(b). It can be seen from figure 5 that  $K$  decreases with the increase of value of parameter  $B$ . And the curve becomes farther to the original of the coordinate ( $B_1 < B_2 < B_3$ ). The curve from left to right in turn is:  $K_1$ ,  $K_2$ , and  $K_3$



**Figure 4.** Effect of parameter  $A$ ,  $B$ ,  $C$  and  $N$  on function  $K$ .

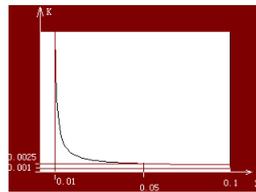
C. 3<sup>rd</sup> situation: the influence of parameter  $C$  on function  $K$  when parameter  $A$  and  $B$  are fixed, shown in figure 4(c). The influence of parameter  $C$  on function  $K$  is almost the same parameter  $B$ , the difference is that the curve of  $K$  becomes smoother with the rising of  $C$ . The curve from left to right in turn is:  $K_2$  and  $K_1$  ( $C_1 < C_2$ ).

D. 4<sup>th</sup> situation: the influence of parameter  $n$  on function  $K$  when parameter  $A$ ,  $B$  and  $C$  are fixed, shown in figure 4(d). When parameters  $A$ ,  $B$ , and  $C$  are fixed, the larger parameter  $n$  is, the steeper the curve of function  $K$  becomes. And the curve approaches to the original. The curve from left to right in turn is:  $K_2$  and  $K_1$  ( $n_1 < n_2$ ).

It can be known from the above that the parameters  $A$ ,  $B$ ,  $C$  and  $n$  have different effect on the shape of the curve of function  $K$ . In order to get the appropriate  $K$ , it is necessary to select  $A$ ,  $B$ ,  $C$  and  $N$ . The final expression of the  $K$  is as follows:

$$K = 0.0001 / (X - 0.01) \quad (5)$$

The final curve of  $K$  is shown in figure 5.



**Figure 5.** Final curve diagram of  $K$ .

The next step is to determine the switch time, a superposition parameter is established,

$$Z_{N+1} = Z_N + H/K \quad (6)$$

Equation (6) eliminated iterative and inverse operations. When  $V_0 < V_s$ ,  $H/K$  is negative, it is not possible to switch; only when  $V_0 > V_s$ ,  $Z$  increase, and gradually reach the required  $Z_0$  to switch.

#### 4. Experimental verification of the optimization algorithm of mileage wheel

In the experiment, three channels of signal generator or single-chip microcomputer system is used to emit three square wave pulse, which is to analog the mileage pulse signal sent by two mileage wheels. Signals are collected respectively and input to PCA module of the microcontroller, frequency and speed are calculated in real-time, and the above comparison rules are adopted. The experimental data based on three channels of analog pulse emitted by MCU system is shown in Table 1.

When frequency of the mileage square wave signal varies within 100Hz to 1MHz, the optimized algorithm can select the output pulse signal of the highest frequency correctly. By setting appropriate mileage accumulated error threshold  $s_e$ , the system can accurately calculate switching time needed and complete the channel switching. The sensitivity is less than 30Hz (which is independent with  $s_e$ ).

In addition, when frequency of the three pulse signal from mileage wheel changes continuously, the system can determine the correct output signal by selecting the signal with highest frequency and the sensitivity is less than 10Hz. However, when the frequency of input signal is greater than 1MHz, false output channel may be selected and switch action may occur.

**Table 1.** Test data sheet for the optimization algorithm of mileage wheel

Time (second)	1	2	3	4	5	6	7	8	9	10	11
Pulse 1 (Hz)	100	200	300	500	700	1000	800	830	830	830	900
Pulse 2 (Hz)	100	200	200	500	700	1000	800	800	860	860	900
Pulse 3 (Hz)	100	200	200	500	700	1000	800	800	800	890	900
Output pulse	3	3	1	1	1	1	1	1	2	3	3
Result	√	√	√	√	√	√	√	√	√	√	√

## 5. Conclusion

There are many factors that affect the operation of mileage wheel, for example, the rotation flexibility, spring torque, swing angle, wear, or tread pattern of the mileage wheel of the mileage wheel. Of which, the most important is to determine the reference speed of the mileage wheel. The optimized algorithm is presented with detail working principle of mileage wheel and the parameters which have effect on inverse time function are investigated. Flow chart shows the judgment process of the system, and verification experiments were conducted to confirm the theoretical analysis of the algorithm.

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## References

- [1] Sun L Y, Li Y B 2011 Hardware design of diameter analyzing system for liquid and gas pipeline *Applied Mechanics and Materials* 88-89 587-591.
- [2] Wu X, Jin S J, Li Y B, et al. 2010 Above-ground marker system of pipeline internal inspection instrument based on geophone array *Nanotechnology and Precision Engineering* 8(6) 553-557.
- [3] Sun L Y, Li Y B 2011 Large vertical storage tank bottom evaluation via Acoustic Emission signal analysis *Proceedings of the 2011 Chinese Control and Decision Conference* 3554-3558.
- [4] Li Y, Zhou C, Liu S, Zhu H, Sun L 2015 An enhanced above ground marking method based on acoustic sensor array *Nanotechnology & Precision Engineering* 13 (2) 120-127.
- [5] Li Y, Liu S, Dorantesgonzalez D J, Zhou C, Zhu H 2014 A novel above-ground marking approach based on the girth weld impact sound for pipeline defect inspection *Insight: Non-Destructive Testing & Condition Monitoring* 56 677-682.
- [6] Li Y B, Cui Y Y, Sun L Y, Xiang H 2013 Azimuth Coefficient estimation of pipeline inspection gauge location system based on TDOA *Journal of Tianjin University (Science and Technology)* 46 (2) 186-189.
- [7] Liu H, Liu M R, Zhang G J, et al. 2013 Study of a new scheme for MEMS vector sensor used for pipeline ground mark *Transducer and Microsystem Technologies* 32(11) 14-17.