Design of A Position Detection Sensor for Linear Synchronous Motors

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ABSTRACT: This paper presents a relative position sensor for traction system of linear synchronous motors in high speed maglev train. A kind of flat coils has been designed to realize sensitive relative position detection. A kind of signal processing method by N time multiplication is described to achieve specified resolution. Also to avoid errors induced by levitation gap, a kind of sample normalized method is proposed. Experiments prove its feasibility. With prototype sensor, control system can realize a resolution of 2.68mm for traction of maglev train traction at low speed.

1 INTRODUCTION

During past years, high speed maglev train driven by a kind of large linear synchronous motor is commercialized in Shanghai, China. In order to drive the motor, it is required to know mover's relative position which can be measured by sensors directly or by estimation without sensors. When the train is at low speed, signal of EMF is too low to be separated from noises, relative position sensor is especially needed[1-4].

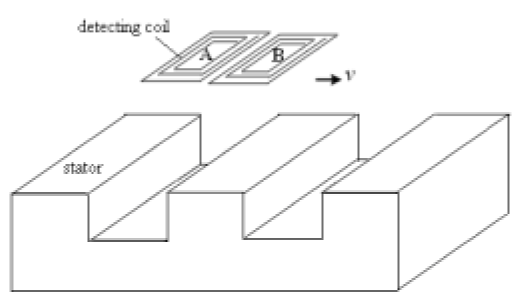


Figure 1. Scheme of detection coil and one section of stator

Since inductive sensors can achieve extremely high resolution and low sensitivities to humidity and dirt, it is fitful to mount in the train to measure relative position by inducing slot pitch structure of long stator. Figure 1 shows the scheme. There is a pair of flat rectangle windings which each covers only one slot width. A simple method to detect the numbers of slot can only achieve coarse resolution of 86mm which is the length of one slot pitch and can not meet traction requirements. Some papers propose linear interpolation to improve precision which is necessary for low speed traction when train is at constant speed. Since high speed maglev train always accelerates or decelerates during low speed stage, methods mentioned above are not effective[3,4]. To improve detection precision, this paper presents a kind of relative position sensor, in which a kind of normalized method and method of N time multiplication are used. This work improves the resolution of position and decreases error at variable speed.

2 DESIGN OF SENSOR

2.1 Detection coils

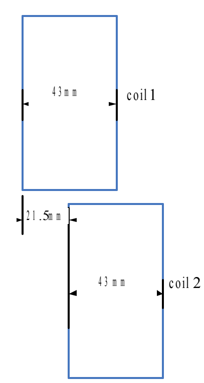


Figure 2 A pair of flat rectangle winding coils

As figure 2 shows that the detection coils compose two plate rectangles which are staggered by width of 21.5mm. The winding is energized by an AC voltage source, which induces a magnetic flux through the coils and the stator. As the sensor moves along, the reluctance between the sensor and the slot varies nearly sinusoidal. Figure 3 shows the result.

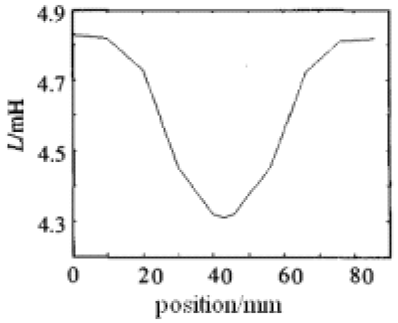


Figure 3. Equivalent inductance along a slot

The two coils integrated into a differential structure to improve the sensitivity. The electrical equivalent inductive circuit is showed in figure 4. Hence, yields the equivalent inductance as

$$L = L_1 - \frac{\omega^2 M^2 L_2}{R_2^2 + \omega^2 L_2^2} \quad (1)$$

Where, R_0 is the resistor in series with the detection coil, C is parallel connection capacitor with coil. R_1 is the resistance of coil. L_1 is inductance of coil. M is mutual inductance between coil and conductor. L_2 is the inductance of conductor. R_2 is the resistor of conductor. ω is the frequency of the excited current[5].

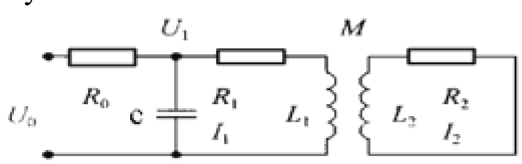


Figure 4. Equivalent detection circuits for the sensor

2.2 Frequency multiplication

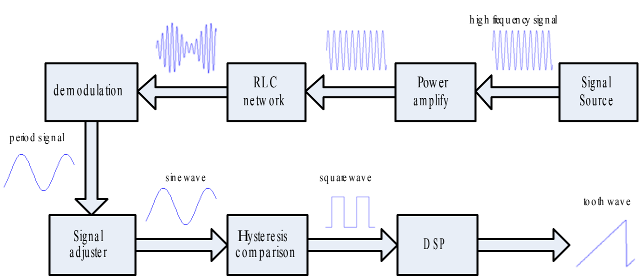


Figure 5. Signal processing circuit

As figure 5 shows, a RLC network which includes detection coil can transformed the variety of equivalent inductance into the variety of amplitude of high frequency modulate signal, which is sinusoidal. The output can be converted to square wave or pulse sequence signal by hysteresis comparison. By this means, DSP processing system counts pulses and transfers it into phase angle of secondary of motor.

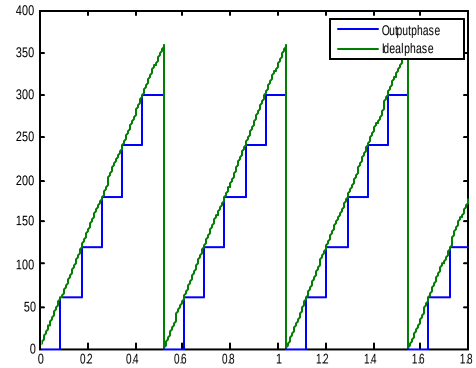


Figure 6. The output without multiplication

Figure 6 shows result with coarse resolution of 86mm which represents 60 degrees change and the position output is a ladder. It is too rough to control traction. To improve the precision of position detection, it is needed to improve the resolution by frequency doubling.

The position can be derived by[6]

$$l_2(t) = \int_0^t v(\tau)\,d\tau \quad (2)$$

Where $v(\tau)$ is speed of secondary at time τ.

Since detecting circuit is only affected by the relative position between detecting coil and stator, the output is expressed as,

$$U_2(t) = \sin\left(2\pi \frac{\int_0^t v(\tau)\,d\tau}{S}\right) \quad (3)$$

By frequency multiplication, yields

$$U_{2d}(t) = \cos\left(4\pi \frac{\int_0^t v(\tau)\,d\tau}{S}\right) \quad (4)$$

It can be found that the position is divided into half of original period. Thus, position resolution has been improved and it doesn't produce any error.

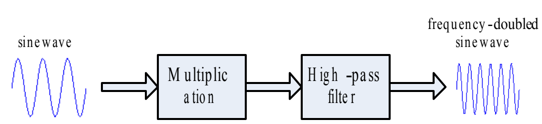
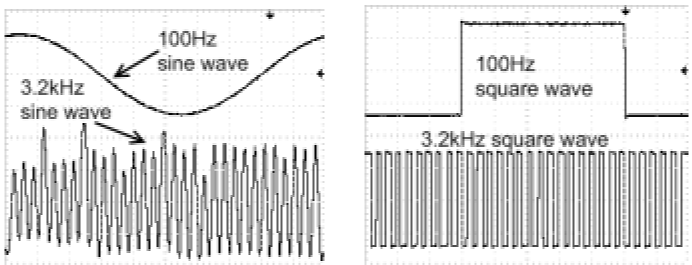


Figure 7. The structure of frequency multiplication circuit

Based on figure 5, signal adjuster and hysteresis comparison are added in circuit. Suppose the original resolution is S. By once multiplication, the resolution becomes S/2. Since output is still sinusoidal, to improve resolution much more signal can be multiplied more times. After N times, resolution is $S/2^N$. Figure 8(a) shows the signal which has been multiplied five times. Figure 8(b) shows the pulses which have been modified. Thus, the position detecting resolution achieves 2.68mm, i.e., 1.875 degree of phase angle of secondary, which is enough for traction control.



(a) (b)

Figure 8. The result of frequency multiplication

2.3 A kind of sample normalized method

When the train is at very low speed, the method mentioned above is not fit because there is no complete sinusoidal wave. A kind of sample method is proposed with the specific relation between samples and position when the train is levitated at a constant gap. Since levitation gap needs to adjust from 8mm to 14mm according to speed, the output of detection circuit is changing. It is showed in the figure 9. It is necessary to decrease error deduced by gap fluctuation.

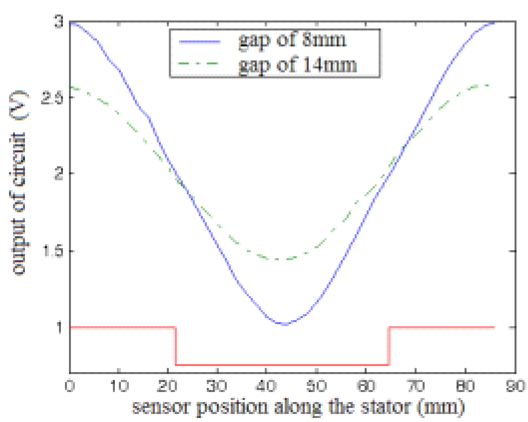


Figure 9. Output of detection circuit with different gap

A simple method by normalizing samples with different gaps into those with the standard of gap of 8mm by multiplying conversion coefficients is proposed. These conversion coefficients are showed in figure 10.

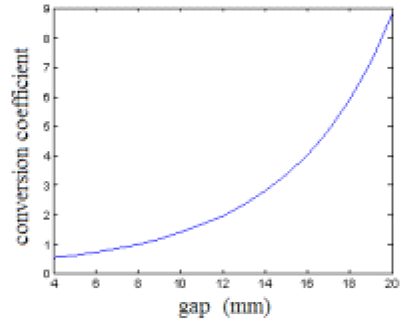


Figure 10. Conversion coefficients with different gaps

Figure 11 shows that the position detecting resolution under gap of 8mm achieves 1.43mm, i.e., 1 degree of phase angle of secondary. And the position detecting resolution under gap of 14mm achieves 2mm, i.e., 1.4 degree of phase angle of secondary. There is no clear error between different gaps.

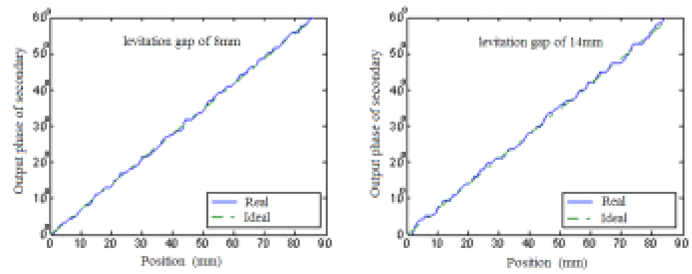


Figure 11. Experiment of position detection with different gaps

3 EXPERIMENT AND CONCLUSION

As figure 12 shows, relative position output of a prototype sensor approximates the ideal with the resolution of 2.68mm in the traction control. When train accelerates, this sensor still works effectively as showed in the figure 13. There are no clear errors induced by gap fluctuation.

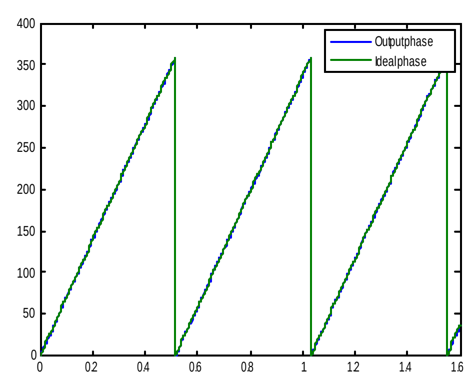


Figure 12. Output with multiplication

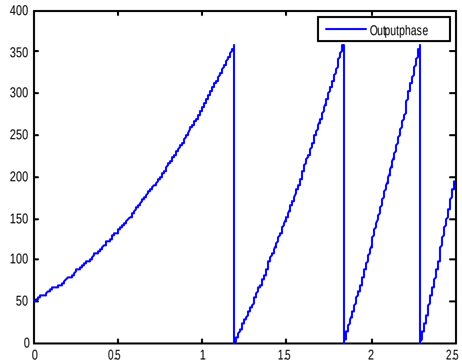


Figure 13. Output when train in traction

To improve detection resolution, a kind of signal processing method by N time multiplication is described to fulfill traction requirements of linear synchronous motor at low speed or in acceleration. Also a kind of sample normalized method is proposed to improve precision with considering about fluctuation of levitation gap. Based on these methods, traction experiments show that a resolution of 2.68mm has been achieved at low speed.

4 REFERENCES

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