Dynamic Compensation for Impact-Based Grain Flow Sensor

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Abstract. The impact-based grain flow sensor is widely used in the combine harvester yield monitor systems to measure the crop yield .but its accuracy wrecked by false signal of excessive natural vibration. A step response experiment was carried to identify the math function of the sensor. Experiment found that the math function of the sensor was a second-order vibration system, its Damping Ratio was 0.037, and its natural frequency was 125Hz, the overshoot reached 20%.To reduce the effect of the overshoot and natural vibration signal on the measurement accuracy, a dynamic compensation algorithm was designed with the series correction method. Step response experiment showed that the overshoot of the compensated sensor was reduced from 20% to 2%.

Keywords: impact-based grain flow sensor; system identification; transfer function; dynamic compensation

1 Introduction

As an important element of the combine yield monitor system The impact-based grain flow sensor measure the grain flow of the harvester by detecting the impact of grain. With the characteristics of simple structure, and low cost, the impact-based grain flow sensor is widely used in the combine harvester yield monitor systems to measure the crop yield [1~11] , But its accuracy was influent by vibration and tilt [12~15] .

With a high velocity, the grain jet out of the crop outlet of the combine harvester, and impact the detect plate of the sensor and reflect quickly. The yield monitor system acquires the impact force and calculates the grain flow rapidly. But, after impacting, a false signal last a while by overshoot and nature vibration.

A Damping material was adopted to enhance Damping Ratio of sensor, and then eliminate the affection of overshoot and nature vibration [16~18]， but reduce the sensitivity.

To investigate the dynamic characteristic, a step response experiment was carried to identify the math function of the sensor. And a dynamic compensation algorithm was designed with the series correction method in this paper.

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2 The impact-based grain flow sensor

As show in Fig. 1,. the single plate impact-based grain flow include bracket. elastic body, impact plate.

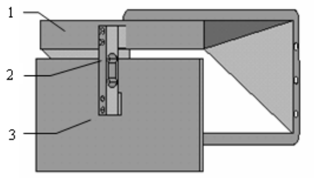


Fig. 1. Structure of impact-based grain flow sensor

The impact plate is made of a Plexiglas board with the dimensions 260mm ×120mm×4mm. It fixed at the end of elastic body which bean made of a hard aluminum-Alloy with the dimensions of 80mm ×12mm×12mm, and 2 parallel through-holes in its center.

As show in the Fig.2, a Wheatstone bridge with 4 electrical-resistance strain gages with 320 Ω bean pasted at the most sensitive surface of the elastic body.

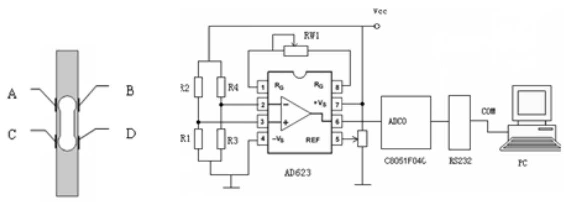


Fig.2 Data acquiring circuit for sensor

The grain impact the plate of the sensor when the combine harvester working, and then, the output signal of the sensor have a liner relationship with the impact force. The signal is amplified from 0~5mV into 0~5V by a AD623 instrumentation amplify circuit. In this way, we can calculate the grain flow by the output voltage of the sensor.

The output voltage of the sensor can be acquired by a embed ADC of C8051F040 MCU， and send to a computer by RS232 Bus.

3 System Identifications

The impact-based grain sensor belong A Mass-elastic-Damper system. According to the basic theory of automatic, the impact-based grain flow sensor is a typical attenuate vibration system of second order, its transfer function should be:

$$G(s) = \frac{\omega_n^2}{S^2 + 2\xi\omega_n S + \omega_n^2} \quad (1)$$

Where: ω --Free Vibration Frequency, rad/s;

ξ --Damping Ratio, No dimension.

The parameter of transfer function can be identified by Step Response test.

3.1 Step Response Test

As the grain flow sensor belongs a Mass elastic system, the nature frequency could be changed by put a mass-block load. So step signal can be conducted by unload a pre-load suddenly.

As show in Fig.3, fix the sensor in level, and hang a 2kg mass-block as pre-load with a slender thread. Adjust the zero point; make sure the output of the sensor is 0V.

The step signal happened by unload the preload with a pair of shears suddenly.

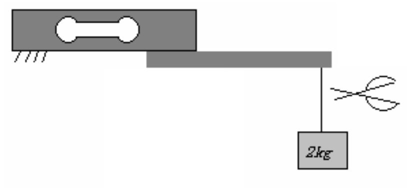
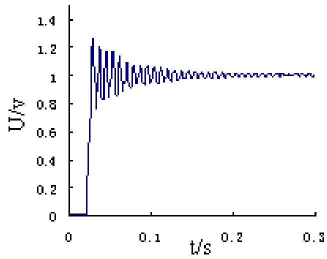


Fig3 Step load method

3.2 Test Results

The output voltage under step signal excitation was acquired by C8051F040, and recorded by PC. As show in Fig.4, the step response curve indicates that the grain flow sensor is a typical Second Order System.



o

t/s

Fig.4 Step response of the sensor

According to the basic theory of automatic，there is：

$$\omega_d = \omega_n \sqrt{1-\xi^2} \tag{2}$$

$$\xi\omega_n = \frac{1}{T}\ln(\frac{A_1}{A_2}) \tag{3}$$

Where ω_d -- angular frequency under damped vibration，rad/s；

T--period of damped vibration, s;

A_1 --the first peak voltages，V;

A_2 -- the second peak voltages，V。

From the curve，T=0.008s，$A_1 = 0.265v$，$A_2 = 0.210v$，$\omega_d = 2\pi\frac{1}{T} = 785rad/s$. Then $\omega_n \approx 785 rad/s$，$\xi \approx 0.037$，the transfer function of the grain flow sensor is:

$$G(s) = \frac{616225}{S^2 + 58S + 616225} \tag{4}$$

The overshoot reached 20%, the accuracy of the sensor could be damage by overshoot and free vibration.

4. Dynamic Compensation

4.1 basic theory of compensation

For a second order system with small Damping Ratio，it's necessary to compensate the Damping Ratio up to 0.6~0.7 for the stability. Take an additional Damping material can improve the Damping Ratio in some degree, but it is not enough. Series/parallel correction methods are widely used in sensor dynamic compensation [15~16].

If the original transfer function is $G(s)$， the series correction system is $G_c(s)$， the after correction system should be：

$$G'(s) = G(s)G_C(s) \tag{5}$$

According to the formula (1), If the appropriate Damping ratio is 0.6，and keep the nature frequency, then the ideal corrected system should be：

$$G'(s) = \frac{616225}{S^2 + 942S + 616225} \tag{6}$$

By Matlab simulate, we got the step response curve of the original system and the corrected system. As show in Fig.5, the simulation result showed that the overshoot of the corrected system can be limited significantly. The corrected system should keep more stability.

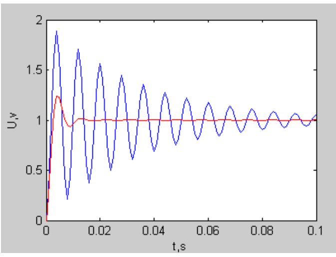


Fig.5 Step response by simulation

According to the formula (5)and (6)，the series correction system should be：

$$G_c(s) = \frac{S^2 + 58S + 616225}{S^2 + 942S + 616225} \tag{7}$$

4.2 Compensation Algorithm

It is difficult to reality the formula（7）by create a suitable hardware circuit . But it is easy for software. For that, the correction system must describe in discrete transfer function.

Make a Z Transform by Matlab function named C2D with a 0.001s sampling period，the formula (7) transform into discrete transfer function:

$$G_c(z) = \frac{0.6849\,z^2 - 0.9246\,z + 0.619}{z^2 - 1.01z + 0.03898} \tag{8}$$

According to formula (8), If the input of the correction system is x，the output is y, the second order difference equations of the correction system is：

$$\begin{aligned} & y^*(t+2T) - 1.01y^*(t+T) + 0.03898y^*(t) \\ & = 0.6849x^*(t+2T) - 0.9246x^*(t+T) + 0.619x^*(t) \end{aligned} \tag{9}$$

Where y* -- discrete value of output variable y；

x* -- discrete value of input variable x；

T –sampling period，0.001s。

According to formula（9）,get the iterative equation:

$$\begin{aligned} & y^*(k+2) = 0.6849x^*(k+2) - 0.9246x^*(k+1) \\ & + 0.619x^*(k) + 1.01y^*(k+1) - 0.03898y^*(k) \end{aligned} \tag{20}$$

Where k—positive integer；

initial condition of the iterative equation：

$$\begin{aligned} & x^*(0) = 1 \qquad && y^*(0) = 0 \\ & x^*(1) = 1 \qquad && y^*(1) = 0 \ \ldots \end{aligned} \tag{31}$$

Finally, program the compensation formula (10) and (11) into fire ware of C8051F040.

4.3 compensation result

Step response test carried again after compensation. Show as at Fig.6.

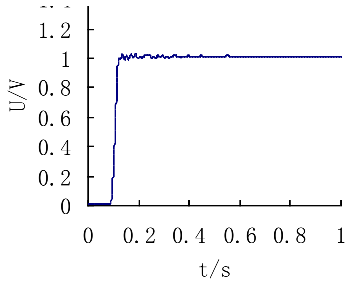


Fig.6 Step response after compensation

The response curve of the compensated showed that the overshoot been limited from 20% to 2%，the dynamic characteristics improved significantly.

5. Conclusion

The impact-based grain flow sensor system was identified by a step response test. The step response curve indicated that the transfer function of the grain flow sensor is a under Damping second-order system with 125Hz free frequency and 0.037 damped Ratio.

A compensation algorithm was introduced to improve the dynamic characteristics without change the real damped Ratio. After compensation, the overshoot limited from 20% to 2%.The dynamic characteristics have been improved significantly.

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