A rapid measurement method and device for processing quality of screw conveyor in agriculture

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Abstract. To improve the possessing quality of screw conveyor in agriculture, a rapid measurement method for possessing quality of the agricultural screw conveyor is proposed, and a rapid measurement device is developed. Measurement for processing quality of three main parameters is achieved, which are the shaft axial run-out, the screw blade axial run-out, and the screw blade pitch. The screw conveyor commonly used in the grain combine harvester was measured by the developed device. The test results show that: for the shaft axial run-out, the relative error is 1.47\%, and the absolute error is 0.019 mm; for the screw blade axial run-out, the relative error is 2.31\%, and the absolute error is 0.038 mm; for the screw blade pitch, the relative error is 1.89\%, and the absolute error is 0.066 mm. It has a positive influence on the improvement of processing quality of agricultural screw conveyor.

1. Introduction

With the advantages of simple structure, economy and high reliability, the screw conveyor is the most commonly used device for material conveying, which is widely used in industry, agriculture, mining, and construction \cite{1}. In agriculture, it is used primarily to transport materials such as seed, fruit, and fertilizer. For instance, a grain combine harvester equipped with multiple screw conveyors, which transfer materials during the harvesting process \cite{2}. Each screw conveyor delivers materials smoothly at all levels, which is a prerequisite to ensure a reliable field operation of the grain combine. Actually, the failure of the screw conveyor is one of the most important reasons for shutdown of a combine harvester. Major forms of failure include shaft fracture, stuck, blade cracking, blade excessive wear and so on. Low processing precision is the reason mainly why the screw conveyor is damageable. Currently, the welding process of the screw conveyor blade is mainly done manually. As a result, the processing quality is unreliable and poor consistency \cite{3}.

Nowadays, the measurement for processing quality of agricultural machinery and equipment is done mainly by manual in China, with low efficiency and poor reliability. In the field of vehicle and construction machinery, there is plenty of related researches about measurement technology for processing quality \cite{4}. Because of the special features and service environment of agricultural machinery, the existing measurement technology and equipment in the industry cannot be used directly \cite{5}. Owing to the characteristics of the discontinuous spatial structure of the screw blade, there
is the absence of reliable means to measure the shaft axial run-out, the blade axial run-out, and the screw pitch.

To solve the problem mentioned above, this study provides a rapid measurement method and device for the processing quality of the screw conveyor. The measurement of the shaft axial run-out, the blade axial run-out, and the screw pitch can be carried out at one time. This method has a great significance to improve the quality control of the screw conveyor.

2. Measurement device for processing quality of the screw conveyor

As a comprehensive evaluation indicator, the axial run-out can be expressed the movement stability and reliability of parts, which is commonly used to represent the roundness and cylindricity of rotating parts. The screw blade pitch is important for the processing of conveying uniform consistency, which determines the uniformity of the working load. Thus, the shaft axial run-out, the screw blade axial run-out, and the screw pitch are the core parameters which influence the performance and reliability of the screw conveyor.

Nowadays, in the field of non-contact high precision measuring, laser measurement is a widely used technique, but its measuring scale is limited in the occasion of high precision measurement [6, 7]. Therefore, it cannot be utilized to measure the screw blade with high precision directly [8]. To solve this problem, a pressing mechanism is designed. Under the force of a spring, the pressing mechanism is pressed consistently on the surface to be measured, providing a stable flat surface which is easily detected by laser sensors [9, 10]. With this method, it is convenient to measure the shaft axial run-out and the blade axial run-out. The dimension of the screw blade is relatively large, and hence a high precision drawstring transducer is used in this paper.

2.1. Measuring principle

Figure 1 is the structural drawing of the developed device. The screw conveyor 2 is powered by a servo motor 5. The component of axial motion, which is generated by the rotation of the screw blade 10, drives the guide thimble 12 to move along the sliding rail 9. In the course of operations, two fastening plates fit closely with the screw conveyor shaft and the screw blade 10 respectively under the action of the spring compression force. Two laser sensors 13 are mounted on the sliding table 15. One is used to measure the distance from the shaft, and the other is used to measure the distance from the screw blade. Thus, the shaft axial run-out and the blade axial run-out can be derived. At the same time, the screw pitch is recorded by a drawstring sensor 16, and the processing error of the screw pitch can be calculated.

Figure 1. The structural drawing of the rapid measurement device.

Figure 2. The physical photo of the rapid measurement device.

Notes: 1. Bed 2. Screw conveyor 3. Belt 4. Belt wheel 5. Motor 6. Driver 7. Controller 8. Screen 9. Sliding rail 10. Screw blade 11. Pressing mechanism 12. Guide thimble 13. Laser sensor 14. Sensor bracket 15. Sliding table 16. Drawstring transducer
2.2. Overall design
A rapid measurement device is designed for the processing quality of the screw conveyor. Figure 2 is the physical photo of the device. It comprises of a bed, a driving system, a sliding guide system, a measuring system, a data acquisition and analysis system, and a control and display system.

2.2.1. Driving system. The driving system consists of a Delta ECMA-C30604PS servo motor, a Delta ASDA-A2 servo driver, and a screw conveyor to be measured.

2.2.2. Sliding guide system. The sliding guide system consists of a sliding rail 9 and a sliding table 15, which serves to mount the pressing mechanism 11, guide thimble 12, laser sensor 13, and sensor bracket 14. When the screw conveyor rotates, it drags the sliding table 15 through the guidance of the guide thimble 12 to achieve the full range measuring of the parameters.

The sliding rail 9 is installed on the bed 1. The axis of the screw conveyor in parallel to the sliding rail 9. The sliding table 15 fits closely with the sliding rail 9. The laser sensor 13 and the guide thimble 12 are installed on the sliding table 15. The guide thimble 12 is connected with the blade of the screw conveyor to be measured.

Figure 3 shows the structure in detail of the pressing mechanism 11, which consists of a fastening plate 17, a pressing shaft 18, a fixing bracket 19, a limiting plate 20, a spring 21, two linear bearing 22, a signal receiving plate 23, and a nut 24.

![Figure 3. The structural drawing of the pressing mechanism.](image)

17. Fastening plate 18. Pressing shaft 19. Fixing bracket 20. Limiting plate 21. Spring 22. Linear bearing 23. Signal receiving plate 24. Nut

Under the action of the compression force of spring 21, one fastening plate 17 is fit closely with the screw shaft, and the other fastening plate 17 is fit closely with the screw blade. Thus, we got two reliable signal receiving plates 23, which are easily detected by laser sensors.

2.2.3. Measuring system. The goal of the measuring system is to implement the dynamic acquisition of distance signals. It includes two laser sensors OPTEX CD33 and a high precision drawstring transducer HUAKI MPS-S-1000. The two laser sensors are placed on the sliding table 15, and the signals are transmitted vertically to the signal receiving plates 23. The drawstring transducer 16 is installed on the bed 1 and the drawstring suspension point is fixed on the sliding table 15.

2.2.4. Data acquisition and analysis system. Basing on the data recorded by the laser sensors and the drawstring transducer, the data acquisition analysis system collects the information from the sensors and calculates the processing errors of the shaft axial run-out, the blade axial run-out, and the screw pitch. This system gives an alarm when the error exceeds the given boundary conditions, and reminds the operators to correct the errors.

2.2.5. Control and display system. The control and display system is installed in the bed 1, and consists of a driver 6, a controller 7, and a touch screen 8. The driver is attached to the controller 7 and drives the motor 5 to rotate. The motor 5 connects to the screw conveyor 2 by a synchronous belt 3. The controller 7 is connected to the touch screen 8 and the sensors.
2.3. Measurement procedures and working process

2.3.1. Measurement procedures. The rapid measurement process includes three steps mainly: measuring, analyzing, and making decisions. The steps in detail are as follows.

The first step is to measure. The motor drives the screw conveyor to rotate and pushes the guide thimble to drive the sliding table and the laser sensor moving along the sliding rail, and the controller collects the distance signals acquired by the laser sensors. The second step is to analyze. The controller analyzes the collected signals, and calculates the shaft axial run-out, the blade axial run-out, and the screw pitch. The third step is to make decision. According to the given boundary conditions, the controller determines whether the screw conveyor is qualified and displays it on the screen.

2.3.2. Working process. The working process is being divided into four steps. The essence of each is as follows.

The first step, the screw conveyor is placed on the measuring device. The position of the screw conveyor shaft is adjusted relative to the sliding table. The axis of the screw conveyor should be parallel to the sliding rail, and the screw conveyor is fixed on the bed. The second step, the synchronous belt is installed and properly tensioned by adjusting the position of the motor on the bed. The third step, the measuring device is started. The driver drives the servo motor. The screw conveyor rotates and pushes the guide thimble to drive the sliding table and the laser sensors moving along the sliding rail. The controller collects the distance signal acquired by the laser sensors, and converts the signal into the measuring data and displays it on the touch screen. The final step, after the measuring is done, the controller drives the motor, the sliding rail and the laser sensors moving back to the initial position. The screw conveyor is removed from the bed.

3. Measurement method of processing quality

To elaborate the measuring and calculation method specifically, the structure parameters in the testbed are defined, as showed in Figure 4.

![Figure 4. The structure parameter indicator diagram.](image)

3.1. Measuring method of the shaft axial run-out

According to the geometric position relation of mechanical structure, the shaft axial run-out $e_1$ can be expressed by the Formula (1):

$$e_1 = \max (C_0 - A(t) - \frac{E_0}{2})$$  \hspace{1cm} (1)

Wherein, $C_0$ is the distance between the blade sensor and the axis line of the screw conveyor shaft, $A(t)$ is the measured distance between the sensor and the shaft at time $t$, and $E_0$ is the diameter of the shaft.
3.2. Measuring method of the screw blade axial run-out

According to the geometric position relation of mechanical structure, the screw blade axial run-out $e_2$ can be expressed by the Formula (2):

$$e_2 = \max \left( C_4 - B(t) - \frac{P_0}{2} \right)$$  \hspace{1cm} (2)

Wherein, $C_4$ is the distance between the sensor and the axis line of the screw blade, $B(t)$ is the measured distance between the sensor and the blade at time $t$, and $P_0$ is the outer diameter of the screw blade.

3.3. Measuring method of the screw blade pitch

According to the geometric position relation of mechanical structure, the screw pitch $e(P)$ can be expressed by the Formula (3):

$$e(P) = \max(P(t) - P_0) = \max \left( D \left( t + \frac{30}{n_0} \right) - D \left( t - \frac{30}{n_0} \right) - P_0 \right)$$  \hspace{1cm} (3)

Wherein, $P(t)$ is the measured screw blade pitch at time $t$; $P_0$ is the theoretical value of the screw blade pitch. $D(t)$ is the measured distance of the screw blade pitch from the sensor at time $t$; $n_0$ is the loading speed.

We defined the start time as $t_0$ and the end time as $t_1$, then:

$$t_1 = \frac{60l_0}{n_0P_0}$$  \hspace{1cm} (4)

Wherein, $l_0$ is the length of the blade.

The measured distance of the screw blade pitch at time $t$ is $D(t)$, so the measured pitch $P(t)$ at time $t$ expressed by the Formula (5) :

$$P(t) = D \left( t + \frac{30}{n_0} \right) - D \left( t - \frac{30}{n_0} \right), \text{ where } t \in \left( \frac{30}{n_0}, \frac{60l_0}{n_0P_0} - \frac{30}{n_0} \right)$$  \hspace{1cm} (5)

4. Experiment results and discussion

The performance of the measurement device was tested on a grain screw conveyor of 4YZP-4HA combine harvester machine produced by Shandong Wuzheng Group Co. Ltd. The test contents and results are as follows.

4.1. Measuring of the screw blade axial run-out and the shaft axial run-out

To verify the feasibility of the method for the measuring of the screw blade axial run-out and the shaft axial run-out, a static test was conducted. Firstly, the sensors were all mounted on the sliding table stably and reliably. Secondly, we started the servo motor to make the screw conveyor rotate uniformly for a complete cycle, and the distance from the sensors to the screw blade and the shaft were measured respectively. Thirdly, after changing the position of the sliding table, we repeated the above operations for six times. Then, we got data from six replications. As a consequence, for the shaft axial run-out, the maximum relative deviation is 1.22%, and the standard deviation is 0.013mm; for the screw blade axial run-out, the maximum relative deviation is 2.26%, and the standard deviation is 0.034 mm. Repeated tests show that the method is consistent.

We measured them according to the standard GB/T1958-2004: a.6.4 cylindricity error measurement methods. Talyrond130 cylindricity meter was used for manual measurement. Compared to the standard measurement method, we got the following conclusions: for the shaft axial run-out, the absolute error and the relative error are 0.019mm and 1.47% respectively; for the screw blade axial run-out, the absolute error and the relative error are 0.038mm and 2.31% respectively.

In dynamic conditions, we started the motor to make the screw conveyor rotate uniformly firstly, and the blade pushed the sliding table via the guide thimble and carried the laser sensors moving along the sliding rail, which was parallel with the screw conveyor axis. As a consequence, the laser sensors measured the blade screw axial run-out and the screw conveyor shaft axial run-out simultaneously. The measured data are plotted as showing in Figure 5.
Figure 5. The measured data of the screw blade axial run-out and the shaft axial run-out.

To make the representation of the data on the graph intuitive and comparable, we used equal ordinate spacing. It is observed that the deviation of the screw blade axial run-out much larger than the shaft axial run-out. The shaft is turning with higher precision than the screw blade with welding processing, which is consistent with common sense. Processing accuracy varies greatly in different positions. Thus, manual measuring is of great randomness because of the selection of positions, which affects the measuring precision.

4.2. Measuring of the screw pitch

To verify the feasibility of the method for the measuring of the screw pitch, a test was conducted. Firstly, we started the motor to make the screw conveyor rotate uniformly. Secondly, the measurement point of the drawstring transducer driven by the sliding table was measured in real-time, and a high precision marking point was selected on the moving guide rail for comparison with the measuring data. The measured values of the drawstring sensor were plotted, and the screw line error and pitch error of the measuring point were calculated as showed in Figure 6.

Figure 6. The measured values, the screw line error, and the pitch error of the screw pitch.

It can be observed that the screw pitch error varies a lot in different positions. Thus, manual measuring is of great randomness because of the selection of positions, which affects the measuring
precision of the screw pitch. Comparing with the precision calibrated points on the sliding rail, the relative error is 1.89% and the absolute error is 0.066 mm. The results of repeated tests show that the system is stable and can meet the specification.

The measuring method was implemented to the processing quality measuring of a combine harvester screw conveyor. The results demonstrate that the device measured the parameters of the shaft axial run-out, the blade axial run-out, and the screw pitch effectively. The test takes 10 seconds to complete all the parameters for one screw conveyor, while the traditional manual measuring method takes 20-25 minutes. With the advantages of precision, efficiency, and reliability, the developed device can be used in the measurement of screw conveyor instead of the traditional manual measuring method.

5. Conclusions

In this paper, a rapid measurement method for processing quality of the screw conveyor is proposed, and a rapid measurement device is developed. Measurement for processing quality of three main parameters is achieved, which are the shaft axial run-out, the screw blade axial run-out, and the screw blade pitch.

With the assistance of the pressing mechanism, a rapid measurement method and device for the shaft axial run-out and the screw blade axial run-out of the screw conveyor are achieved, avoiding the measuring errors caused by a random selection of locations manually. It takes 10 seconds to complete all the parameters for one screw conveyor, while the traditional manual measuring method takes 20-25 minutes.

The screw conveyor commonly used in the grain combine harvester was measured by the developed device. Compared to the standard measurement method, the test results show that: for the shaft axial run-out, the relative error is 1.47%, and the absolute error is 0.019 mm; for the screw blade axial run-out, the relative error is 2.31%, and the absolute error is 0.038 mm; for the screw blade pitch, the relative error is 1.89%, and the absolute error is 0.066 mm. The tests prove that the method can be used to measure the processing quality of the screw conveyor efficiently, accurately, effectively, and reliably. This presented method has a positive influence on the improvement of processing quality of agricultural screw conveyor.

Acknowledgements

This work was supported by the National Key Research and Development Plan of China (Project No. 2017YFD0700205 & 2017YFD0700101) and Project of Jiangsu Synergistic Innovation Center of Modern Agricultural Equipment and Technology (Project No. 4091600023 & 4091600016).

References

[1] Ning Y Z, Wang J and Fu L 2019 [J]. Journal of Hunan University of Arts and Science (Science and Technology) 31 35-38
[2] Xu X M, Li F X, Li Y X, Shen C P, Meng K P and Chen J 2019 [J]. Transactions of the Chinese Society for Agricultural Machinery 50 89-97
[3] Chen A D and Wang X Y 2000 [J]. Engineering Science 2 73-77
[4] Ji J W 2019 [J]. Bulletin of Science and Technology 35 105-113
[5] Li M, Ma C and Yang X Q 2004 [J]. Journal of Image and Graphics 24 145-146
[6] Li Z B, Liu B S and Liu Y H 2019 [J]. Electric Engineering 51 150
[7] Hu W W, Li Y L, Gu X K, Zhang Y P, Zhang Y M and Liu H X 2019 [J]. Laser & Infrared 49 273-281
[8] Men T, Zhen D, Xu R and Yang Y A 2018 [J]. Laser & Infrared 48 1451-57
[9] Li Y Q, Li R W, Li Z L, Zhai D S, Fu H L and Xiong Y H 2015 [J]. Infrared and Laser Engineering 44 3324-29
[10] Li W 2013 [J]. Laser & Infrared 43 864-866