ISSN: 2664-9640

Research progress and trend of threshing load condition monitoring and fault diagnosis technology of combine harvester

Sheng Jiang

School of Agricultural Engineering, Jiangsu University, Zhenjiang, Jiangsu 212013, China

Abstract

In recent years, with the significant increase in the yield of China's main grain crops like rice and wheat, the harvest mode dominated by mechanized operation has gradually become the dominant, and the number of corresponding combined harvesting machines and tools has also increased significantly. However, the failure of machines and tools has also become a problem that can not be ignored. It is exposed that there are some deficiencies in domestic combine harvesters, such as high mechanical failure rate and poor reliability. According to the data of agricultural machinery quality complaint investigation, it can be found that the blockage fault of working parts of combine harvester accounts for a large proportion. Threshing and separating device is the core part of combine harvester, and it is also a high incidence area of blocking faults. The main reason is that when the combine harvester is operating in the field, the driver can not accurately judge the machine condition only by experience and can not adjust the working state of the combine harvester in time, resulting in abnormal fluctuation of threshing load of the combine and blocking of working parts. Therefore, establishing the threshing drum load monitoring system to realize the real-time monitoring of its working state, and generating early warning information under the abnormal working state of the threshing device to prompt the operators to take corresponding measures is of great significance to improve the operation efficiency of the threshing device of the combine and reduce the failure rate. Combined with domestic and foreign literature, this paper comprehensively expounds the monitoring technology of threshing load state of combine harvester, and points out the development trend of technology in the future.

Keywords

Agricultural mechanization; combine harvester; threshing load; mechanical condition monitoring; development trend.

1. Introduction

Rice and wheat are two major grain crops in China. The development of their harvesting machinery has formed a pattern of complete types and diverse types after introduction, imitation and independent development and design since the 1950s.As early as 2012, the mechanized harvest level of wheat in China had reached 91.05%, and the mechanized harvest level of rice was 69.32%, and most of the rice and wheat harvesters were combined rice and wheat harvesters, which could basically meet the actual needs of production.

According to the latest statistics, by 2018, the comprehensive mechanization rate of crop cultivation and harvest in China had reached 69.10%, an increase of 1.87 percentage points. The comprehensive mechanization rate of wheat cultivation and harvest was 95.89%, including machine tillage rate of 99.67%, machine sowing rate of 90.88% and machine yield of 95.87%, all of which increased by nearly 1 percentage point. The whole process mechanization of wheat production has been basically realized. The comprehensive mechanization rate of rice production exceeded 80%, and the mechanization rate of rice planting also reached 50.86%.

ISSN: 2664-9640

It is precisely because of the wide application of various modern agricultural machines and tools, especially combine harvesters, that the agricultural production efficiency is improved, the labor intensity of farmers is reduced, the working conditions are improved, and it is convenient to rush for farming, creating conditions for rush planting of next crops. However, at present, there are many common problems of combine harvesters in China, such as low scientific and technological content, many faults and great potential safety hazards, which has become the main factor restricting the development of combine harvesters in China. According to statistics, in 2008 and 2009, the agricultural machinery product quality complaint supervision station of the Consumer Association received 272 and 1733 complaints about the quality of agricultural machinery products, of which complaints about combine harvesters accounted for 49.2% and 28.9% respectively.

Therefore, it is an urgent problem to further improve the technical level, operation efficiency and reduce the failure rate of the combine harvester. According to the investigation report on the failure frequency of agricultural machinery in 2005, the blocking failure frequency of threshing drum of combine harvester accounts for 30% of the blocking failure frequency of combine harvester and 10% of the total failure frequency of operation. The blocking failure of threshing drum has evolved into one of the main factors restricting the improvement of operation efficiency of combine harvester.

Threshing device is an important part of combine harvester, which determines the working quality and production efficiency of combine harvester to a great extent. Due to the influence of grain humidity, crop density, feeding amount, walking speed, drum speed and other factors, drum blockage often leads to drum blockage. Drum blockage is the most common fault in combine operation. In the past, the common solution to such problems was to operate the combine only based on the experience and feeling of the driver, which was not only difficult to give full play to the best efficiency of the threshing device, but also easy to lead to blocking failure and reduce the working efficiency of the combine harvester. Once a blockage fault occurs, the troubleshooting time is long, which not only affects the rush time in the harvest season, but also brings huge economic losses to the manipulator.

With the increasing development of combine to large-scale, automatic, intelligent, efficient and comfortable, it has become very difficult to identify faults only by the vision and hearing of the manipulator. It is urgent to study the corresponding fault monitoring means and automatic control method to adjust the performance parameters of the combine.

Therefore, the threshing drum load monitoring system of combine harvester came into being. These systems or technologies can monitor the load status of the threshing device of the combine in real time, master its working state, and automatically or timely notify the operator to take corresponding measures under the abnormal working state of the threshing device, so as to improve the operation efficiency of the threshing device and reduce its failure rate. So as to improve the performance and reliability of the combine, improve the operation efficiency, ensure the operation quality and reduce the labor intensity of operators. At the same time, the research on the monitoring technology of the threshing device of the combine is conducive to the improvement of the overall level of grain harvesters in China.

This review will list the typical threshing load monitoring systems of combine harvesters at home and abroad, analyze and summarize the advantages and disadvantages of these existing technologies, and give the future prospect and development trend.

ISSN: 2664-9640

2. Domestic and foreign technology of threshing load monitoring system

2.1. Domestic related technology research status

Zhan Jie (2002) established a feeding amount monitoring system by installing an extrusion force sensor on the inclined conveyor[1]. According to the monitored feeding amount, the walking speed is automatically adjusted to make the feeding amount of the threshing device uniform and stable. Binbin Ji(2005) of Jiangsu University also established the relationship between the torque of the feeding driving shaft and the feeding amount through experiments, predicted the crop density of the header according to the crop density information detected by the feeding driving shaft by using the fuzzy neural network theory, and adjusted the walking speed of the combine to ensure the stability of the feeding amount[2]. Wentao Lu (2008) used the hydraulic oil pressure in the hydraulic stepless speed change device of threshing drum of combine harvester to represent the load condition of threshing drum, and established the relationship equation between threshing drum torque and oil pressure, as well as the relationship between oil pressure and feeding amount[3]. Du Chen(2008) used fieldbus torque speed sensor to measure the speed and torque of threshing drum, and proposed a method to monitor the feeding amount by drum torque[4]. All these lay a foundation for the establishment of feeding quantity control system.

Threshing drum blockage is a common fault of combine harvester. In order to prevent blockage and reduce faults, various monitoring and alarm devices have been developed one after another.

Shuhong Zhang(2002) and Jin Chen(1997) of Jiangsu University designed the automatic alarm system of combine harvester according to the characteristics of the decrease of drum speed when the threshing drum is overloaded. This method of directly measuring speed is simple and convenient, but it has poor adaptability to the active change of speed, and there are many influencing factors of speed change, poor reliability and high false alarm rate.[5]

To solve the above problems, Lidan Yi (2010) of Jiangsu University designed the blockage fault monitoring system of combine harvester[6]. By installing Hall sensors on the power output shaft, threshing drum power shaft and grain lifting auger power input shaft, the output pulse square wave of each sensor is sampled, the fault judgment characteristic parameters are extracted, and the judgment rules are given to realize the three-level decision-making of normal operation, blockage early warning and blockage alarm of the combine. This method can actively adapt to the changes of speed and forward speed, and has high reliability of fault diagnosis. The speed monitoring module in the integrated monitoring system of combine designed by Jianping Wang(2011) and others not only monitors the speed, but also monitors the temperature of drum bearing. When the working process is abnormal and the monitored speed and temperature exceed the preset range, an alarm signal will be sent immediately. The research shows that the torque of threshing drum can reflect its load more accurately than the drum speed.

Therefore, some monitoring systems monitor the drum torque through the torque sensor, and send an alarm signal when the torque is too large. However, the torque sensor is expensive, inconvenient to install, and its application is limited.

Through the monitoring system, the failure of the threshing device will be early-warning and alarm, which greatly reduces the failure rate of the combine to a certain extent. However, once the blockage failure occurs, it still needs to manually take out the blockage, which is time-consuming and laborious. The working part control system of combine designed by Jinkui Hao(2011) relies on single chip microcomputer to monitor the working condition of each part[7]. In case of failure of working parts of the machine, the engine power will be cut off automatically while reminding the driver by sound and light. When the working parts stop rotating due to blockage or the speed is too low, the driver reverses the working parts through the control

handle to discharge the blocked crops, eliminate faults, reduce the driver's labor intensity and improve work efficiency. The threshing drum speed is an important factor affecting the threshing effect. By adjusting the drum speed, the threshing device can give full play to its best performance under different harvest conditions.

Lanjuan Yan(2007) of Northwest Agricultural and Forestry University designed the speed monitoring system of threshing device of combine harvester based on feeding amount and moisture content[8]. The speed of threshing drum is adjusted with the feeding amount as the main parameter and the moisture content as the secondary parameter to make the combine in the best working state.

Yaoming Li(2018)of Jiangsu University designed a threshing drum load monitoring and concave clearance adjustment device composed of concave clearance adjustment system and oil pressure acquisition system at the back of concave screen[9]. The oil pressure of oil cylinder at the back of concave screen is used to characterize the threshing drum load, so as to realize real-time monitoring and adjustment.

At present, the drive modes of threshing drum of combine harvester are mainly chain drive, belt drive and hydraulic drive. The speed adjustment of chain drive can be realized by replacing the sprocket, but replacing the sprocket in the field is time-consuming and laborious, and can not be carried out frequently. The belt drive adopts variable speed drive pulley, which is realized by the driver in the cab. The belt drive is applied under the condition of large torque, with short service life, easy slip and high maintenance cost. In comparison, using hydraulic drive threshing drum, hydraulic pump and motor can improve high torque and the speed is easy to adjust.

2.2. Foreign related technology research status

The research on the automation and intelligence of combine harvesters in foreign countries started earlier. Since the 1990s, in order to improve the operation quality of the machine and make it work efficiently, safely and reliably, a large number of electronic information technologies have been integrated into the R & D process of combine harvesters, such as electronic manipulation, automatic driving, fault diagnosis, etc, which greatly improved automatic and intelligent level of combine harvester .

Friesen et al. (1966) considered that the threshing loss increased with the increase of feeding amount, and designed the feeding amount control system in order to reduce the threshing loss[10]. The system installs a spring idler on one side of the drive chain tension of the threshing drum, and the tension of the drive chain is proportional to the torque of the drum. The device is connected with the handle of the machine travel speed control valve through the spring damping system, so as to adjust the travel speed according to the torque of the threshing drum, control the feeding amount and reduce the threshing loss.

Because the feeding amount signal measured on the tilt conveyor has a long lag relative to the header straw layer, Huisman. W (1977) of the Netherlands monitored the torque of the feeding auger and established the walking speed control system.[11]

The goal of establishing the combine monitoring system is to improve the machine performance and reduce grain loss. New Holland establishes the combine walking speed control system through the monitoring of the index parameter threshing loss, so as to ensure the low loss and high efficiency of the combine.

Brizgis (1978) detects the change of soybean moisture content through the moisture content sensor. The output of the sensor is used to control the speed of the motor, so as to control the speed of the driving pulley and drum.[12]

Michael P. mailander (1982) and others designed the threshing drum speed and conveyor control system[13]. The system controls the drum speed according to the feedback of drum

speed and the pressure compensation of drum torque increase. When the drum is blocked, it can also change the rotation direction of the drum to eliminate faults.

Jim Kruse (1983) adjusted the traveling speed of the machine by detecting the load of the engine, so as to ensure the feeding amount[14]. When the harvested field is flat and the ground is not wet, the load of the engine can be maintained at a fairly constant operating speed. However, when the machine works on slopes or mountains, the power required to drive the machine changes. In addition, the hardness and compaction of the soil have an impact on the change of power demand. Therefore, the system has no adaptability.

The load control system of threshing device of combine designed by Robert. J. Arner (2000)[15].The threshing drum is driven by the hydraulic motor, and the control system adjusts the traveling speed of the machine according to the hydraulic oil pressure of the driving motor, so as to maintain the constant feeding amount.

3. Summary and Prospect

By summarizing the existing technology, it is not difficult to find that compared with the previous manual experience, the existing threshing load monitoring technology has the following advantages: (1) Using signal feedback to guide the operators to make adjustments, so as to realize the real-time monitoring of threshing load to a certain extent, so as to reduce the probability of failure;(2) Make the adaptability of the combine stronger, make the threshing drum load stable within the expected range when the crop density steps, and meet the operation requirements of different density distribution in the same plot;(3) To a certain extent, it improves the operation quality and ensures the operation efficiency. At the same time, the disadvantages of the existing technology are also obvious: (1) The current threshing load monitoring technology mainly measures the speed or torque of the threshing drum. However, due to the delay effect of the crop conveyor of the harvester, the excessive harvesting speed can be reflected in the drum operation parameters after a period of time, so the control process lags behind.(2) The torque sensor for detecting the drum torque is expensive and large, which affects the layout of the whole machine, inconvenient installation and easy to be affected by the environment.(3) Through the detection of crop thickness on the conveyor belt to obtain the feeding amount of the drum, the lag can be improved to a certain extent. However, only the volume information of harvested crops can be obtained, and the information such as water content can not be obtained, which has limited effect on the control process.

In addition, in recent years, there are new technologies to detect the crop density in the field to be harvested by image spectral analysis of crop canopy density, and combine it with the driving speed of the harvester to obtain the feeding amount of the harvester. This method can effectively reduce the control effect introduced by the large lag of the harvester, but the cost of the detection equipment is very high, affected by the field dust, the detection accuracy is very low, and it is difficult to be applied in practice.

In the future, threshing load monitoring technology will be combined with emerging technologies such as machine learning, big data and information fusion to improve adaptability and detection accuracy, shorten early warning response time and greatly reduce the failure rate of harvesting machinery.

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