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Effects of throughput and operating parameters on cleaning performance in air-and-screen cleaning unit: A computational and experimental study

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ABSTRACT

The influences of throughput and operating parameters on internal airflow and cleaning performance for the air-and-screen cleaning unit were investigated. The throughput experiment showed that, the airflow velocities above the vibrating screen decreased by 1.3–15.5% for every 1.0 kg s^{-1} increase of throughput and which below the vibrating screen decreased by 2.7–8.1%. As a result, the cleaning performance has declined. Then, the airflow velocity measurement and cleaning performance tests were taken under 4.0 kg s^{-1} throughput with single factor experiment in which fan speed, airflow deflector angle and sieve opening were as factors. And, the Computed Fluid Dynamic (CFD) numerical simulations were carried out to analyze the movement trend of internal airflow as an auxiliary analysis method. The following viewpoints were obtained, the fan speed has a large effect on cleaning performance by affecting the overall airflow velocities in the cleaning unit. And, the airflow velocities above the vibrating screen increased from 0.2 m s^{-1} to 0.4 m s^{-1} for every 150 r min^{-1} increase of fan speed, which below the vibrating screen increased from 0.4 m s^{-1} to 1.1 m s^{-1}; The highest airflow velocities area above the vibrating screen moved forward to the central position in the longitudinal direction as the airflow deflector angle increased; With the reduction for each 4 mm of chaffer opening, the airflow velocities above the vibrating screen increased by 0.2–0.4 m s^{-1}. At last, making mathematical relations between each operating parameter and the cleaning performance, and proposing the method of adjusting the single operating parameter under rated condition according to the throughput. They provide a basis for real-time automatic adjustment of the operating parameters in the air-and-screen cleaning unit.

1. Introduction

The cleaning unit is a core component of rice combine harvesters. It removes grains from short straws as well as small impurities and other sundries from the grain-MOG mixture while excreting short straws and tiny impurities to provide clean seeds. In the field harvest operation, the throughput in the whole machine and cleaning unit changed rapidly caused by the uneven density of the crop per unit area, differences of large yield, changes in the height of cut stubble and walking speed. Then it would affect the inlet airflow field and cleaning performance (Coen et al., 2010). To solve the problem of fluctuations in cleaning performance caused by changes in throughput, a self-adaptive cleaning unit should be developed to monitor cleaning performance parameters in real time (Craessaerts et al., 2010) such as cleaning loss ratio and the grain impurity ratio, so that operating parameters, for instance, the fan speed and chaffer opening could be adapted automatically (Craessaerts et al., 2007). Therefore, effects of the main operating parameters on the inlet airflow of the cleaning unit and cleaning performance must be investigated to provide a basis for cleaning process controlling when the throughput are changing.

Many scholars and agricultural machinery companies, such as John Deere, CASE, CLAAS, Kubota, have conducted numerous theoretical and experimental studies on cleaning unit in combine harvesters. New cleaning unit structures have been designed by reasonably arranging the distribution of each component in the interior space of a cleaning unit to improve the cleaning efficiency (Ponpesh & Giles, 2009; Liu et al., 2015). A new type of cross-flow centrifugal fan has also been used to increase the uniformity of airflow distributions and to limit the attenuation of airflow at the end of a vibrating screen (Gebrehiwot et al., 2010). In describing turbulent vortex airflow via combine harvester cleaning unit selection and in analyzing related causes and effects on cleaning performance (Zhong et al., 2010; Ueka et al., 2012), scholars have proposed a means of limiting the vortex airflow. CFD (Computational Fluid Dynamic) has also been utilized to analyze the internal

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airflow field distribution of a cleaning unit (Kenney et al., 2005; Xu et al., 2014) to improve the airflow distribution in a cleaning unit and save design cost. The main working parameters of combinations of cleaning units have been optimized, and field cleaning orthogonal tests have been conducted (Li et al., 2016).

The above mentioned studies have mainly focused on the structural design of cleaning units, the optimization of cleaning unit parameters, the analysis of airflow in a fan, or the study of airflow field distribution in cleaning units. And they carried the airflow measurements under the condition of no internal cleaning materials. Thus, these studies also did not consider the influence of different throughput on the airflow and the cleaning performance. In addition, the effects of each individual operating parameter on the internal airflow and cleaning performance were not studied separately, which could provide a basis for automatic control of the cleaning unit under changed throughput condition.

The objective of this study was to gain insight in the effect of throughput levels and the different operating parameters on the internal airflow and the cleaning performance by CFD numerical simulation and experimental methods. First, the internal airflow field measurement and cleaning performance tests under different throughput were carried out on the designed test bed in the laboratory. Then, using the FLUENT software to learn the airflow velocity distribution of the cleaning unit. And, the single factor effects of the main operating parameters were studied by measurement and cleaning performance tests under 4.0 kg s^{-1} throughput. At the same time, the CFD numerical simulations were also carried out to analyze the movement trend of internal airflow. According to these simulation and test results, the adjustment methods of optimizing cleaning performance were summarized under changed throughput. It was expected that this research would provide a basis for real-time automatic adjustment of the operating parameters of the cleaning unit to maintain the cleaning loss and grain impurity ratios within a reasonable range in the combine harvester.

2. Materials and methods

2.1. Device and airflow field measurements

The test object of this paper is a tangential longitudinal flow rice combine harvester that was developed by our group (Xu et al., 2016). And its throughput can reach 9.0 kg s^{-1}. To cope with so large volume of throughput, an air-and-screen cleaning unit which composed of a return plate, a oscillating plate, a sawtooth screen (the tailing screen), a chaffer (upper screen of the vibrating screen), a woven screen (lower screen of the vibrating screen), and a multi-duct centrifugal fan (double airflow outlets with a four-duct centrifugal fan), has been designed. To study the distribution of the airflow field in cleaning unit and its cleaning performance, a cleaning test bed (Liang et al., 2017) was developed based on the real structure of the tangential longitudinal flow combine harvester. This test bed was constructed with a feeding device, an air-and-screen cleaning unit, a transmission device, frame, and a control cabinet, as shown in Fig. 1. The test bed had four variable frequency motors and several motor cylinders to control the fan speed, airflow deflector angle, chaffer opening, vibration frequency of the vibrating screen, and return plate. In addition, the cleaning throughput can be changed in the range of 0.5–4.5 kg s^{-1} by controlling the vibration frequency of the electromagnetic feeder.

Two measuring surfaces were arranged in the test bed. The first measuring surface was positioned 80 mm above the chaffer, and the second measuring surface was positioned 50 mm below the woven screen. The two measuring surfaces (1200 × 960 mm) were evenly arranged with 25 measurement points. The left side of the front of the vibrating screen was used as the coordinate origin, and the established coordinate systems are shown in Fig. 2.

Hot-wire anemometers (Nanjing Neng Zhao Technology Co., Ltd. Type VS110, with a scope 0.5–50 m s^{-1} and a resolution of 0.01 m s^{-1}) were used to measure the internal airflow velocities at the measurement points, as shown in Fig. 3. Their probes were composed of a special stainless steel material, with a diameter of 3 mm. Thus, the impact resistance was much higher than that of a traditional hot-wire

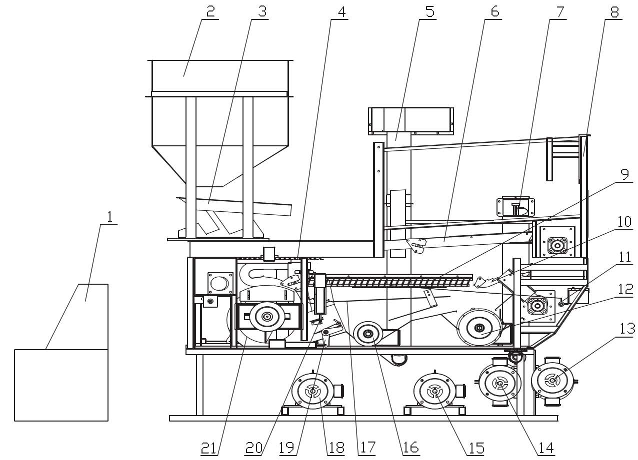

Fig. 1. Air-and-screen cleaning test bed: 1. control cabinet, 2. feeding device, 3. electromagnetic feeder, 4. oscillating plate, 5. vertical grain auger, 6. return plate, 7. vertical impurity auger, 8. frame, 9. chaffer, 10. tailing screen, 11. opening adjusting mechanism of chaffer, 12. horizontal impurity auger, 13. vibrating screen drive motor, 14. return plate drive motor, 15. grain/impurity auger drive motor, 16. horizontal grain auger, 17. woven screen, 18. fan drive motor, 19. airflow deflector I adjustment mechanism, 20. airflow deflector II adjustment mechanism, and 21. multi-duct centrifugal fan.

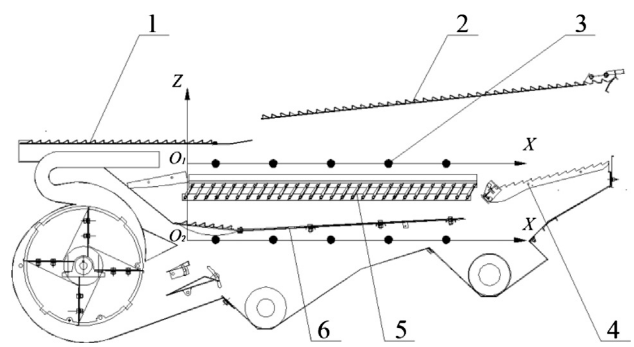

Fig. 2. Schematic representation of the measurement coordinate system: 1. oscillating plate, 2. return plate, 3. measurement points, 4. tailing screen, 5. chaffer, and 6. woven screen.

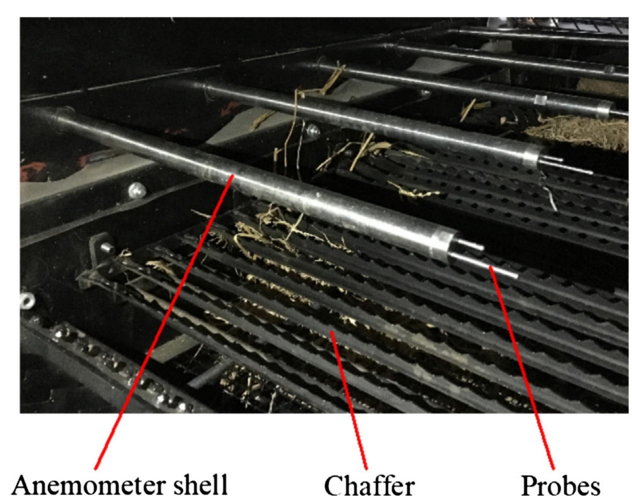

Fig. 3. The hot-wire anemometers above the chaffer in cleaning unit.