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Load control of threshing cylinder of small-sized harvester based on current detection

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ABSTRACT

A load control system was designed to keep the threshing load of the small-sized harvester in the rated load range, and the current detection for the motor driving the harvester cylinder was presented as a new method to detect the cylinder torque indirectly. First the mathematical relationship was established between the cylinder torque and the motor current, and the cylinder-load model was presented. Then the motor current according to the rated cylinder load was obtained by tests as the reference for the load control system. The results showed that the coefficient of variation of consistency of the motor current decreased from 10.7% by manual control to 7.4% by the load control system, and labor intensity index decreased to 8 from 13 after using the load control system. It indicates that the cylinder load control can improve the harvester performance and relieve manual labor required.

1. Introduction

Under the condition of the rated threshing load, the harvester shows good performance such as high threshing quality, small-amplitude block vibration and low blockage possibility (Schrock, 2005). The torque of the threshing cylinder can reflect the threshing load of the harvester timely and accurately, so the torque control for the harvester cylinder is widely used to keep the cylinder load in the range of the desired threshing load (Reyns et al., 2002). There are two ways to detect the cylinder torque as the feedback of the torque control. One is the direct detection; the other is the indirect detection. The ZX3000 head-feed combine from Kubota detects the cylinder torque directly by the torque sensor installed on the threshing cylinder for the load feedback (Ito, 1990). Compared to the single way of the direct detection, the indirect detection is various in forms. For instance, Jim Kruse (1983) investigated the relationship between the load torque of the harvester engine and the cylinder torque; Wentao et al. (2008) proposed to detect the cylinder torque indirectly by measuring the oil pressure of the hydraulic cylinder driving the threshing cylinder and Chengwen et al. (2013) measured the tension of the transmission chain linked with the cylinder axis to obtain the cylinder torque indirectly.

The objective of this study is to improve the small-sized harvester performance and relieve manual labor. The load control system was designed for the automatic operation of the harvester based on the current detection for the DC motor driving the threshing cylinder which is a new method to detect the cylinder torque indirectly.

2. Materials and methods

2.1. Small-sized harvester

The harvester (Model: 4GQT-50; Manufacturer: Southwest University; City: Chongqing; Country: China; hereinafter referred to as 4GQT-50 harvester) used for this study was the new agricultural machinery for threshing prior to cutting of the wheat in the hilly rural areas of southwestern China. Its structure diagram is shown in Fig. 1a, the dashed lines representing the power source, and Fig. 1b indicates the power flow of the harvester from the engine to the DC motor. First, the gasoline engine outputs power to the transfer case which can distribute the power to each part needing power of the harvester by different output shafts. Then, one of the output shafts of the transfer case delivers power to the power supply unit including a small generator and a voltage stabilizer, and it provides stable DC voltage for the DC motor. Furthermore, Fig. 2 shows the 3D model of the head-feed threshing

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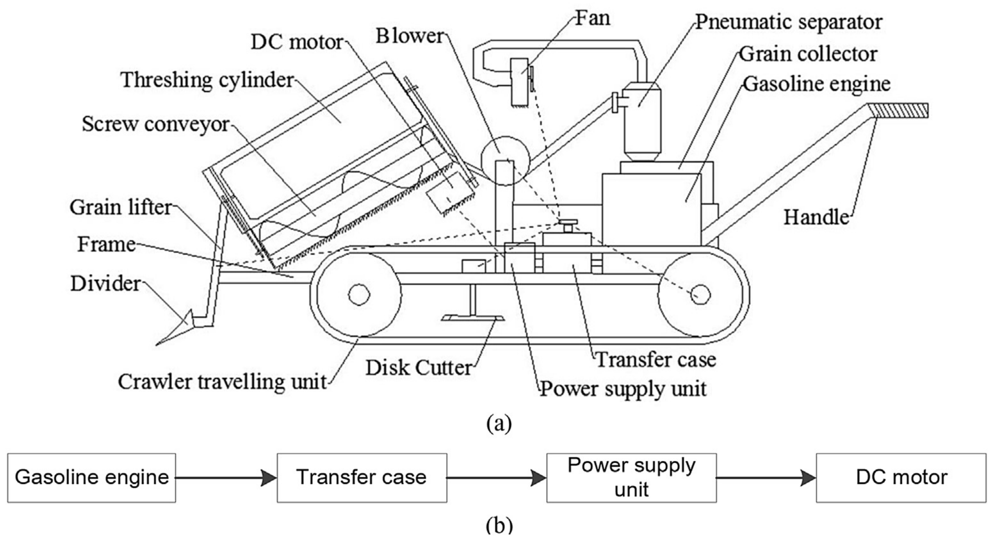

Fig. 1. (a) Structure diagram of 4GQT-50 harvester, (b) Power flow diagram from engine to DC motor.

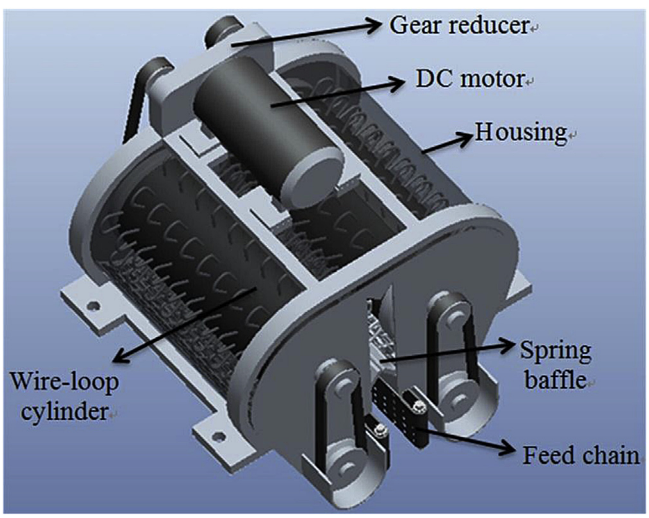

Fig. 2. 3D model of head-feed threshing machinery.

machinery of the 4GQT-50 harvester.

The wheat was fed into the head-feed threshing machinery with two wire-loop cylinders rotating in reverse for the upward threshing via the grain lifter and the feed chain. After threshing completion, the wheat straw was cut off by the disk cutter and pushed out along one side of the 4GQT-50 harvester. Moreover, the obliquity of the threshing machinery installed on the front of the 4GQT-50 harvester can be adjusted within a certain range for adapting different wheat heights. Furthermore, the DC motor was used as the individual power of the threshing machinery in order to simplify the transmission, and the gasoline engine supplied power for the rest of the 4GQT-50 harvester such as the crawler travelling unit, the grain lifter and so on. More illustrations and descriptions about the 4GQT-50 harvester have been explicated by Peixiang et al. (2012), Meng et al. (2012) and Peixiang et al. (2013).

2.2. Detection principle of cylinder load

It is difficult to install the torque sensor on the oblique cylinder of the 4GQT-50 harvester for measuring the cylinder torque directly because of limited mounting space. In this study the threshing cylinder is driven by the DC motor fixed on the threshing machinery, so the load current of the DC motor can reflect the cylinder load indirectly.

The DC motor has hard mechanical characteristic, that is, the motor speed changes a little with great variation in load, good speed control performance benefitting to adjust the cylinder speed and large starting torque which can effectively reduce blockage possibility of the threshing cylinder, so these characteristics meet the operation requirements of the threshing cylinder. The relationship between the motor current and the motor torque can be expressed as (Chapman and Stephen, 2012):

$$T_m = C_T \Phi_N I_a \approx C_T \Phi_N I \tag{1}$$

where I is the input current of the motor (A); I_a is the armature current of the motor (A); T_m is the electromagnetic torque of the motor (N·m), and it is approximately equal to the output torque of the motor; C_T is the torque constant about the motor structure and Φ_N is the excitation flux (Wb).

The mechanical structure of both cylinders of the 4GQT-50 harvester is symmetrical, so theoretically both cylinders have the same torque and speed during threshing process, and the relationship between the output power of the motor and the single-cylinder power required is established as follows:

$$\mathrm{P_m} = 2\mathrm{P_c}/\eta \tag{2}$$

where η is the transmission efficiency between the motor and the single cylinder, P_m is the output power of the motor (W), P_c is the single cylinder power (W). Combining the basic relationship $P=T{\cdot}n/9550$ among power(P), torque(T) and speed(n), the mathematic relation between the cylinder torque and the motor current is obtained by equation (1)–(2) as follows:

$$I = 2T_c/i\eta C_T \Phi_N \tag{3}$$

where i is the transmission ratio between the motor and the single cylinder, $i = n_m/n_c$, where n_m is the motor speed (r/min) and n_c is the cylinder speed (r/min), and T_c is the cylinder torque (N·m). In equation (3), i and η are certain for the transmission transferring the power of the motor to the cylinder and C_T is the torque constant about the motor structure. When the supply voltage of the motor is stable, Φ_N is also a constant without regard to demagnetizing effect