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Digital wheel slipmeter for agricultural 2WD tractors

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ABSTRACT

A microcontroller based digital slipmeter was developed for agricultural two wheel drive (2WD) tractors. The actual and theoretical speeds of tractor were calculated by measuring the revolutions per minute (RPM) of front wheel and rear wheels, respectively, using optical slot sensors. A microcontroller was programmed to calculate the actual forward speed and wheel slip of the tractor. These measured values were digitally displayed on the tractor dashboard. The slipmeter was fabricated in such a way that it could be mounted on any make and model of 2WD tractor. The slipmeter was rigorously tested in the laboratory as well as in the field with different tractor–implement combinations. A maximum of ±2 per cent variation was observed between measured and indicated wheel slip.

1. Introduction

Due to ever increasing prices of petroleum products, all possible efforts are required to conserve the fuel in all types of vehicles. In agricultural tractors, matching of implement size and load to a given size of tractor is very vital in optimizing the fuel efficiency. Wismer and Luth (1972) and Brixius (1987) suggested that wheel slip has a dominating role in improving the tractive performance. The tractors operate at peak efficiency if their slip is maintained in a certain optimum range (Zoz, 1972). This is, however, not possible with the existing design of rear wheel driven tractors available in developing countries due to large variation in soil conditions.

The optimization of tractor operation efficiency largely depends upon tractor operators who can adjust the operating parameters, namely, speed and depth of operation. Ismail et al. (1981) reported that operators sense the slip and move the depth control lever only after a slip of about 30 per cent had remained for 6 s. Increasing the available information to the operator has been identified as a valuable means of increasing productivity (Jahns and Speckmann, 1984). However, the utilization of this information depends upon operator's experience and fatigue level. A number of slipmeters are discussed in the literature but has not been commercially adopted by tractor manufacturers due to either the high cost or unproven reliability. Hence, the major objective of this study is to develop a low cost and robust slipmeter to provide the display of wheel slip on the tractor's dashboard so that operator can adjust the operational parameter by looking at the display.

2. Review of literature

Slip is not a directly measured value. It is calculated from two other measurements, that is actual and theoretical speed of the tractor, which can be measured either directly or computed from the rotational speed and the rolling radius of the wheels. The theoretical speed of 2WD tractors is calculated by measuring the RPM of rear wheels. However, the actual speed of the tractor is measured by the following three methods:

(1) By non-powered wheel (Lyne and Meiring, 1977; Clark and Gillespie, 1979; Jurek and Newendorp, 1983; Raheman and Jha, 2007): this method is quite simple and easy to adopt, but the actual speed depends on soil conditions, weight transfer, skid of front tyre, etc. The error in slip measurement is not more than ±2 per cent.
(2) By additional or fifth wheel device (Zoerb and Popoff, 1967; Grevis-James et al., 1981; Erickson et al., 1982; Shropshire et al., 1983; Musonda et al., 1983): the actual speed measurement is independent of weight transfer, soil condition and skidding of front wheel. However, the use of fifth wheel poses difficulty in negotiating on undulating and rough terrains.
(3) By Doppler effect device or microwave radar (Reed and Turner, 1993; Thansandote et al., 1977; Wang and Domier, 1989; Grisso et al., 1991; Freeland et al., 1988; Khalilian et al., 1989): this method provides an accurate reading of actual speed but the device is very expensive, has unproven reliability and cannot be used when speed is less than 0.5 km/h.

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Fig. 1. Overall view of the developed slipmeter.

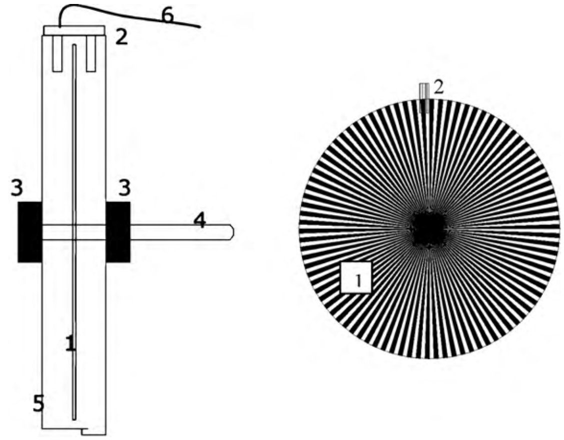

Fig. 2. Components of encoder. 1. Transparent disc; 2. Optical slot sensor; 3. Ball bearings; 4. Shaft; 5. Water proof casing; 6. Signal output cable.

3. Development of slipmeter

The theoretical speed of the tractor was calculated by measuring the average RPM of the rear wheels, while the actual speed was computed by measuring the RPM of front wheel. These signals were sent to a microcontroller for calculating the slip.

The overall view of the developed slipmeter is shown in Fig. 1. Encoder #1 and Encoder #2 measure the RPM of the two rear wheels, and Encoder #3 measures the RPM of one front wheel. Finally the slipmeter displays the RPM of the measured wheels, actual forward speed (ms^{-1}) and wheel slip (per cent).

3.1. Development of encoder

A device, known as encoder, was developed to measure the RPM of the front and rear wheels. Two encoders were used for the rear wheels and one encoder for the front wheel. The signals received from the rear wheel encoders were used to calculate the theoretical speed by multiplying the average readings with the distance traveled by the rear wheel in one revolution on hard surface without load. Similarly, the output of the front wheel encoder is multiplied with the distance traveled by the front wheel in one revolution on test surface to get the actual forward speed.

The encoder consists of a transparent disc with alternating clear and opaque stripes (Fig. 2). These stripes were provided at an angle of 4° in the disc to get 90 pulses in one rotation of the tractor wheel. An optical slot sensor was used to detect the clear and opaque stripes. The sensor is provided with an emitter and a detector. When a black stripe of the disc comes in between the emitter and detector, the photo-transistor turns off and the potential at the collector rises. On the other hand, when transparent stripe comes, the transistor turns on and the collector potential drops. In other words, presence of clear and opaque stripes between the emitter and detector of the sensor is detected and converted into an electrical signal without contacting it.

3.2. Development of microcontroller

Microcontroller is a highly integrated chip which consists of a CPU, RAM, some form of ROM, I/O ports, and timers. Unlike a general-purpose computer, which also includes all of these components, a microcontroller is designed for a very specific task of controlling a particular system.

Encoders were given excitation voltage separately from instrument box and pulses were received in the same box. The fluctuation and noise of excitation voltage were corrected beforehand by electronic circuit. The received signals were fed to the *NAND 94LS132* for converting analog signal into digital signal. The digital signals were sent to the inbuilt timer pin of the Atmel (AT89S8252) microcontroller. The microcontroller program was written in Assembly language (X8051.EXE). The received pulses from the encoders were read as E_{r1}, E_{r2} and E_f, for rear wheel #1, rear wheel #2, and front wheel, respectively. The following equations were used to calculate the actual speed and slip from the received signal of pulses.

Calculation of rear and front wheels' RPM:

$$\left.\begin{aligned} N_f &= \frac{E_f \times 4}{360 \times T} \\ N_{r1} &= \frac{E_{r1} \times 4}{360 \times T} \\ N_{r2} &= \frac{E_{r2} \times 4}{360 \times T} \end{aligned}\right\} \quad (1)$$

Calculation of actual and theoretical speeds:

$$V_a = d_f \times N_f \quad (2)$$

$$V_t = d_r \times \frac{N_{r1} + N_{r2}}{2} \quad (3)$$

Calculation of wheel slip:

$$S = \left(1 - \frac{V_a}{V_t}\right) \times 100 \quad (4)$$

where E_f = no. of pulses from front wheel in T seconds; E_{r1} = no. of pulses from right real wheel in T seconds; E_{r2} = no. of pulses from left rear wheel in T seconds; N_f = rps of front wheel; N_{r1} = rps of right rear wheel; N_{r2} = rps of left rear wheel; T = refreshment time i.e. 1.5 s; V_a = actual velocity, m/s; V_t = theoretical velocity, m/s; d_f = distance covered in one revolution by front wheel on test surface, m; d_r = distance covered in one revolution by rear wheel on hard surface, m; S = wheel slip, %.

The slip, actual speed and depth of operation were displayed on the LCD screen of the meter with data transfer port via serial input and parallel output ports. The detailed circuit diagram for measuring the slip and displaying it on the tractor dashboard is given in Fig. 3.

3.3. Generalized program for slipmeter installation

The versatility of the developed slipmeter lies in its wide range of use. The slipmeter can be used on any make and model of 2WD tractors. There is a need to change some of the input parameters of the slipmeter when shifted from one tractor to another. These include distance traveled in one revolution by rear wheel on hard