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Embedded digital draft force and wheel slip indicator for tillage research

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ABSTRACT

A mechatronic based embedded digital draft force and wheel slip measuring devices was developed. It includes a load cell based dynamometer to measure the draft force, hall sensor based magnetic pins mounted discs to measure wheel slip, an amplifier to amplify the sensing unit signals of dynamometer, and a microcontroller to process the received load cells, hall sensors data to calculate draft force, wheel slip and display on the LCD screen as well as record the data in SD card module. To compare and assess the degree of accuracy of the developed draft measurement system, wheel slip measurement system, a system involving instrumented three point linkages was developed to measure draft force simultaneously and a non contact type radar sensor was used to validate the wheel slip measurement system. It was observed that, a maximum variation of ±410 N draft forces was observed between the developed and strain gauge dynamometer also found close to draft force values calculated by ASABE equation and a maximum variation of ±2.1% wheel slip was observed between developed and manual measured values. The developed devices are simple in construction and can be mounted on any make and model of agricultural tractor implements. The developed devices will be very much helpful for educational institutions and research needs in drawbar performance studies.

1. Introduction

Tillage operation is one of the biggest power consuming operations in an agricultural production system and hence the evaluation of tillage effort is a field of great interest for many researchers. Tractors are mostly used for pulling or pushing agricultural machinery, for various farm operations and these operations are performed by attaching implements to the tractor using a three-point hitch. Most of the field operations are conducted using a tractor implement combination; hence forces exerted by the implements on the tractor plays an important role in the tractor performance (Al-Janobi and Al-Suhaibani, 1998).

The major force exerted by the implement on the tractor is draft force which is the horizontal component of pull of an implement and it is a major factor in matching of tractor implement in various farm operations. Maximum tractive efficiency of tractor may depend up on proper matching of tractor implement under actual field condition. Draft and power requirements are major parameters for predicting the drawbar performance of tractor implements and are essential for proper matching of tractor implement (Grisso et al., 1996; Al-Janobi and Al-Suhaibani, 1998).

Many of instrumentation systems are developed and reported by several researchers for measuring the draft force of implement under various farm operations to know the power requirement of tractor; most of them are designed particularly for a specific tractor and implement and not easily adaptable to other. Several researchers have developed different draft measurement systems by using extended octagonal rings transducer and strain gauge based hitch pins (Zoerb et al., 1983; Kirisci et al., 1993; Leonard, 1980; Gu et al., 1993; Tessier et al., 1992; McLaughlin, 1996; Reece, 1961 to measure draft force and read the data by using commercial data logger. Baker et al. (1981) developed a load cells mounted frame to measure various forces of implement. Chung et al. (1983) developed a quick attachment coupler using pins mounted as strain gauge cantilever beams for draft force measurement.

The three-point linkage dynamometers used for measuring the draft of tillage implements may be classified into two main groups (Chaplin et al., 1987). The first group consisted of those in which the transducers were mounted on a frame between the implement and the tractor, whereas the second group consisted of integral system in which the dynamometer arms were modified to accommodate the transducers. Frame type was built in many shapes with adjustments suitable for different tractors implement combination (Scholtz, 1964; Johnson and Voorhees, 1979; Carter, 1981; Chaplin et al., 1987; Smith and Barker, 1982; Garner et al., 1988; Thomson

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Nomenclature

b	wheel width (in.)	Dd	draft force by developed system
S	wheel slip (%)	T	tensile force in lower link (kg)
α	angle between lift rod and lower link (deg)	C	compressive force in top link (kg)
DAS	data acquisition system	θ	angle of lower link with horizontal plane (deg)
D	draft force (kg)	V_t	theoretical speed (m/s)
V_A	actual speed (m/s)	W	width of cut (m)
γ	angle of top link with horizontal plane (deg)	φ	angle of lower link with vertical plane (deg)
F_{tR}	tensile force of the right lower link	F_{tL}	tensile force at the left lower link
F_{cT}	compressive force of the top link	Dt	theoretical calculated draft
Ds	draft force by strain gauges	LR	right lower link force
LL	left lower link force	TL	top link force

and Shinners, 1989; Al-Jalil et al., 2001). The second group accommodated the force transducers in tractor links itself without distorting the original geometry and were usually designed to measure the forces in the longitudinal and the vertical planes (Neuholt, 1959; Nadre, 1977; Luth et al., 1978; Collins et al., 1978; Upadhyaya et al., 1985; Majumdar, 1993; Singh, 1993; Sivaprasad, 2004), however, these methods have their own limitations and the output data must be recorded by using commercial costly data loggers which is cumbersome task and these devices cannot display the data digitally.

In few studies, mathematical models were also developed for predicting the draft force (Arvidsson et al., 2004; Grisso et al., 1996; Taniguchi et al., 1999; Bowers, 1989). The magnitude of draught is affected by soil type and its condition, tool characteristics, working speed and depth (Gill and Vanden Berg, 1968; Kydd et al., 1984; Grisso et al., 1996; ASAE Standard, 2003). The relationship between the draught of plane tillage tools and speed of operation in different soils has been found to be linear, second-order polynomial, parabolic and exponential (Rowe and Barnes, 1961; Siemens et al., 1965; Luth and Wismer, 1971; Godwin and Spoor, 1977; Godwin et al., 1984; McKyes, 1985; Swick and Perumpral, 1988; Gupta et al., 1989).

Several empirical polynomial/multi-linear regression models have been developed in the past by various researchers for the prediction of draught of tillage implements (Wang et al., 1972; Gee-Clough et al., 1978; Kepner et al., 1982; Upadhyaya et al., 1984; Grisso et al., 1996; Kheiralla et al., 2004; Sahu and Raheman, 2006; Godwin et al., 2007). However, most of these models are often subjected to multi-co linearity problems and their application is limited to those soils and implements conditions for which they were developed.

Working efficiency of agricultural tractor depends on wheel slip, tire parameters, soil parameters and other operating parameters, but the soil and tire parameters are consider being approximately equal for various operations. The wheel slip is one of the major parameter to be considered for getting maximum tractive efficiency. The wheel slip depends on the draft force of the implement, as the draft force increases wheel slip also increases and as the draft force increases, weight transfer takes place from the tractor front axle to the rear axle.

Wheel slip is defined as the relative movement in the direction of travel at the mutual contact surface of a traction device and the support surface (ASAE, 1983). Slip has, therefore, a greater role in determining tractive effort. Zoz (1972) has shown that for each soil condition, there is an optimum range of slip (12–15%) where tractive efficiency is the highest. During the field operation of tractors, a significant portion of the energy is lost due to rolling resistance as well as the slippage of the traction wheels. Maximum tractive efficiency results from a compromise between minimizing rolling resistance and optimizing slip of the wheels. Knowing the importance of wheel slip, several attempts have been made to measure this parameter. Researchers have used different techniques like Doppler/microwave radar device (Stuchly et al., 1976; Freeland et al., 1988; Wang and Domier, 1989; Khalilian et al., 1989; Grisso et al., 1991; Reed and Turner, 1993) and electronic circuits using photo-transducer (Zoerb and Popoff, 1967; Lyne and Meiring, 1977; Clark and Gillespie, 1979; Jurek and Newendorp, 1983; Grevis-James et al., 1981; Erickson et al., 1982; Shropshire et al., 1983; Musonda et al., 1983) for accurate measurement of slip. Most of these techniques were tractor specific, costly and of unproven reliability for instantaneous measurement of slip. These techniques were based on calculation of theoretical velocity on test bed instead of operating on a hard surface which is essential for defining zero condition.

There are few commercial costly devices to measure and display the percentage wheel slip for particular tractors, but there is no device which could measure and display the draft force, also no device which could measure and display the real time wheel slip and draft force of tractor implement simultaneously for tillage research. The wheel slip depends on the draft resistance of the implement, as the draft force increases wheel slip increase.

Hence to overcome this problem, an attempt was made to develop instrumentation and embedded system which could work precisely and easily accessible to first two categories of tractor implement to measure draft resistance and wheel slip simultaneously under tillage research to improve the fuel efficiency and tractive performance of tractor and to increase the tractor stability by maintaining optimum range of wheel slip and draft force with prior information to the operator (audible and visible warnings). Also, the draft of a tillage implement with the associated slip can also be measured at different speed of operation and soil condition. It is very helpful to find the perfect match of tractor and implement for specific soil condition.

2. Theoretical considerations

The following theoretical and empirical equations were used to calculate the draft force and wheel slip in various methods.

2.1. Draft (D)

The horizontal component of resultant force required to pull a machine in the field is draft. According to ASAE standard (1997) D497.3, it can be calculated by

$$D = F_j(A + BV_a + CV_a^2) * W * d_1 \quad (1)$$

where F_j is dimensionless soil texture adjustment parameter ($j = 1$ for fine, 2 for medium and 3 for course textured soils), and A, B and C are machine specific parameters and are presented in Table 1.