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# Studies on applications of electronics in wheel slip control of agricultural tractor

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**Abstract**
The slippage of tractor wheels drastically affects the tractive efficiency which needs to be enhanced by regulating and optimizing the slippage. By suitable regulation and management of slip within certain optimum range during the field use, tractive efficiency can be maximized resulting into the improvement of fuel efficiency and field capacity. The existing draft control system is not an effective method as the depth is varied through frequent adjustment of depth control lever by the tractor operators. It is very strenuous and needs efficient judgments and hence, generally not achievable by the driver as per the requirement. The slip control provides faster response than the existing draft control method. The slip control device developed in this study would enable achieving efficient field of 2-wheel drive tractor and is capable of installation on any make and model of the tractor.

**Keywords:** Applications, electronics, wheel slip control, agricultural tractor

## Introduction

Applications of technologies through Electronics, Telecommunication and IT are the need of the hour in each and every sector of national development due to their precise and efficient performance. It is also easy to integrate the technology directly with the management system. Modern technology in agricultural sector requires error free sensors, compatible actuators and powerful software for effective control and optimized output from the machinery. In addition to computation methods and algorithms, acquisition, processing, transmission, conversion and storage of data, decision support systems etc. are also necessary for obtaining optimum efficiency. These systems must become more and more independent from the involvement of the operator and be capable to carry out more complex decisions independently. However, the safety aspects and special operational conditions of the technology in the farming environment are most important. Economizing the operations of farm tractors is a critical factor in performing the farm operations. Tractors should be designed to work near their maximum efficiency by optimizing their weight, CG (centre of gravity), tyre pressure and the operating speed. In the farming activities, it is required to measure the online performance while carrying out various field activities. The challenges in performance measurement require robust setup, precise instrumentation and cost effective solutions. It has been always a challenge to me*et all* such requirements in the tractors used by farmers. The online performance measuring technique helps farmers to minimize the cost of operations by setting the operation optimally in an intelligent way.

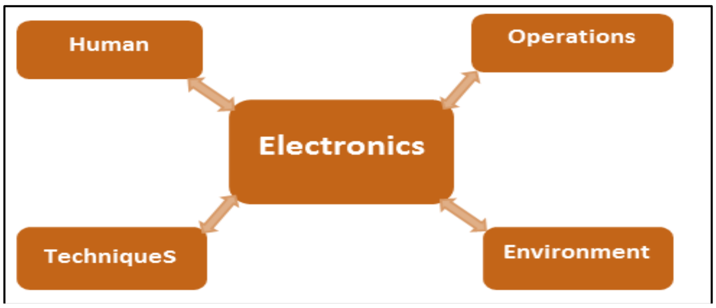


**Fig 1:** Area of Employment for Electronics in Agriculture Technology

To encourage the farmers, the benefits of the optimized solutions should be explained with practical results so that the technology can be easily adopted by them. The efficiency of tractors can be defined as the maximum volume of drawbar work performed with respect to the energy produced by burning of the fuel. For a tractor, drawbar work can be explained in terms of its speed and the pull.

The ideal tractor should convert the total energy provided by the fuel into the useful works for the drawbar operations. It is observed that the major part of the available energy i.e. 25-51% is lost in the process for converting the chemical energy by burning of fuel to mechanical energy for useful work in addition to the loss for translating the engine power to the implement system through the drive train mechanism. According to the study, about 25-55% of the available energy by the burning of fuel is lost in the entire process in the soil interface. The wasted energy cause wearing of the tyres and compacts the soil to an extent which may cause detrimental effect on the growth of corps. (Burt *et al* 1982). Efficient operations of tractors maximize the tractive advantage by reducing the percentage of slip, selecting optimum travel speed for a required tractor implement system and maximize the fuel efficiency of engine and drive train. The most energy consuming operations in the field is land preparation. The energy utilized by the tillage depends on terrain type, depth of operations and hitch geometry of the implement system. Proper matching of implements with tractors immensely improve the performance. The slippage of tractor wheels drastically affects the tractive efficiency which needs to be enhanced by regulating and optimizing the slippage. Hence, slip plays a very important role in the efficient operations of agricultural tractors.

The most desirable method for improving tractive efficiency could be by controlling and maintaining the slip within optimum range by changing the depth of operations. It is required that a system continuously measures and provides input to the driver to maintain slip within an optimum range throughout the operations. As soon as the slip deviates beyond the range, the operator should notice the indications on the slip meter and bring back the slip to specified range by operating the depth control lever. The slip control provides faster response than the existing draft control method. This system could overrun the draft control mechanism for effective and efficient operations. Hence the on-line measurement of slip while operating the tractor is necessary and its details have been discussed below.

**On Line Slip Measurement**

Manual measurement of slip is not only a difficult task during field operation but the accuracy is also not consistent. For measurement of on line wheel slip, there is a necessity to use automatic measurements method. Many researchers felt the necessity of online measurement of slip for which the automatic method is the only solution. For the performance measurement of tractors, continuous data is necessary which is possible only through automatic measurements. Online slip sensing and control process serves as a source of information for the driver while doing the field operations to control the slip within optimum range for achieving maximum tractive efficiency.

Whismer and Luth (1973) [18] automated the slip computation by using an analog computer. In their experiment, slip measurement was done continuously during field use of tractors. Although the evaluation of the slip was performed by the computer, there was a necessity for setting the initial value of slip. Unlike present situation, the full capability of computer was not utilized by them. Setting of initial value of slip was dependent on some assumptions and experiences of the driver which differed from individual to individual. Two major disadvantages were observed in this procedure for which the instrument was not so popular.

A. The full capability of computer was not explored and was used in a small scale.
B. The initial setting was to be done manually. The manual setting of values caused undesirable errors due to assumption and approximations.

A different technique was developed for automatic measurement of slip by Lyne & Meiring (1977) [8] who used photo electric transducer for sensing the revolution of wheels of tractor. They made arrangements for the display near the dashboard of the tractors to guide the drivers about the measured slip value so that driver could adjust the control levers to maintain slip within optimum range to obtain maximum efficiency. The instrument was capable of the online slip measurement with display and recording facility. The measurement system using photo-electric transducers performed accurately within 1-2% over the entire range of normal operating speeds. The speed of the front wheel was chosen for surface velocity calculation. In this method, the speed of both the front wheels was monitored and the faster of the two was considered for calculation purpose. For slip calculation, the front wheel velocity was considered as actual velocity and the drive wheel velocity was considered as theoretical. The percentage difference between the two velocities was indicated as slip. This was achieved by comparator circuits. It was observed that there was error in ground speed calculation in Lyne & Meiring method which resulted in occurrence of error in the slip calculation. Hence, the instrument was not adopted commercially.

A non-contact method was developed by Thansandote *et al*. (1977) with modern solid state MW Doppler radar for ground speed and RPM measurements. Radar sensor works in the principle of Doppler effect. The MW frequency focused to the surface gets reflected with a different frequency. According to the Doppler effect, the difference of the frequency between the radiated and reflected signal is proportional to the speed of the vehicle where the sensor is installed. The method for slip measurement with Doppler radar instrument had higher accuracy. Although the accuracy was high, the system could not be put to commercial use as the cost of the radar sensor is quite high and not affordable by tractor operators.

In order to achieve better accuracy of the slip measurements, Grevis-James et.al (1981) [3] designed a power monitor. The monitoring system included magnetic transducers, display system, associated circuitry for detection of ground speed, drawbar pull, drawbar power and wheel slip. For ground speed measurement, one of the front wheels was considered. In case of a 4WD tractor, a 5$^{th}$wheel was attached for the measurement of surface speed. A magnetic pick up device was deployed with an amplifier to boost the pickup voltage up to 6 V. The reliability of the developed instrument was satisfactory.

Tompkins & Wilhelm (1982) [16] developed a system which incorporated a DAS for computation of slip in a tractor. A 5$^{th}$ wheel was attached for the surface speed measurement. To facilitate the same, a magnetic sensor and 72 geared wheel assembly was mounted with the rear axle.

$$S = \frac{V_r - V_f}{V_r} \times 100$$

where,
S = wheel slip;
$V_r$ = voltage from the rear wheel sensor
$V_f$ = voltage from the front wheel sensor

Grogan *et al* (1987) [4] developed a microcomputer based system to compute the slip of 2WD traction device. The same system was also used for optimization of tractive performance through necessary guidance system for the driver. By setting the throttle and gear optimally, the consumption of fuel was reduced by about 15-27%
Jesurajan (1988) [7] developed a device containing of photo electric transducer to sense the speed of the front and rear wheels. The unit had an up/down counter with a digital display unit. Reference was obtained from the fifth wheel for speed measurement purpose. But, the measurement was not free from the errors. The issue with the device was that the measured value was much less than the actual due to improper sensing of distance. This could be because of the skid of the front wheel.
Behera (1989) [1] and Prasad (1990) [11] developed a device for the computation of slip. The device computed slip by the comparison between the actual and theoretical speed. Photo sensors were utilized for counting the wheel rotations for the speed measurement. A disc with 6 nos. holes at the interval of $60^0$ was mechanically positioned to rotate by the axle of the tractor. On either sides of the discs, light sources and detectors were installed to sense the revolutions. The calculation was done by a microprocessor with the data generated by the sensors. The system had the drawback due to accumulation of dust and mud on the passage of light which is very common in farm operations. This, in turn, resulted into errors in the slip calculations. The errors also occurred due to skidding of front reference wheel.
Wang and Zoreb (1990) [17] devised an information system for the drivers. Intel's 8052 MLC-I microcontroller was used for their measurement system. The schematic diagram is presented in the below Fig. 2. to explain the working of the driver information system. The system optimized the fuel efficiency, tractive efficiency (TE) and overall cost of operations. Driver was

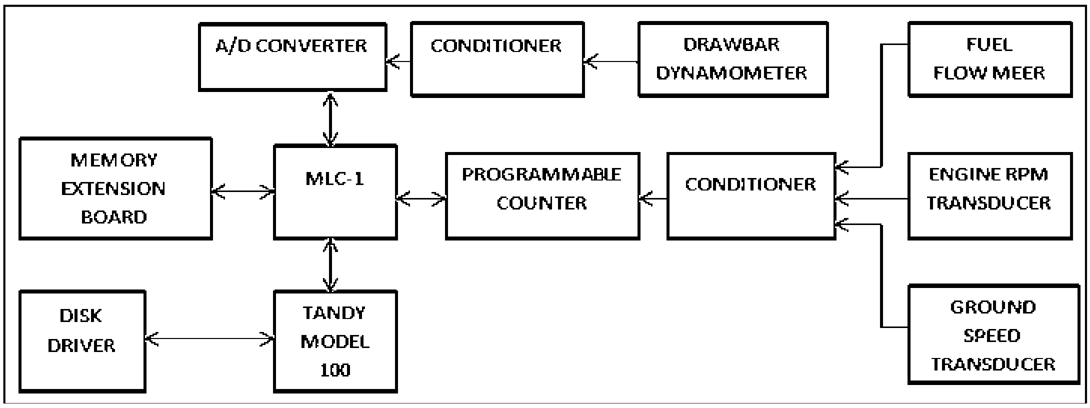


**Fig 2:** Tractor Driver's Information System (Wang and Zoerb, 1990) [17]

provided guidance to adjust various controls to adjust right drive speed and throttle positions. Operation cost was minimized and the field capacity could be improved. However, the reliability of this system was not as per the customer expectations.
Salaeque and Jangiev (1990) [14] developed a measurement system for 4WD farm tractors. The system monitored few operational parameters including slip. The data processing was done by a microcomputer. The parameters such as slip, speed and TE could be measured by this instrument. However, the system did not receive wide acceptance due to the complexity of operations.
Reed & Turner (1993) [13] developed a method for the accurate measurement of slip values of a 2WD traction device with the help of radar sensor after reviewing the contemporary and previous computation techniques. The principle used by the radar sensor was Doppler effect. When a radio wave from a moving vehicle is focused towards a surface, the wave reflects with a change in frequency. The percentage difference between the two frequencies is directly proportional to the speed of the vehicle. In this case, the radio signal was focused by the radar gun towards the ground and difference of the frequencies was considered for slip calculation. The device was compatible with any make and model of 2WD tractors. The measuring system exhibited good accuracy but the system was not widely adopted due to very high cost of the radar sensors. Also the system did not work well when the ground speed was less than 0.5 Kmh. However, for laboratory use, the device worked satisfactorily. The radar gun used on a traction device is shown in Fig. 3 and Fig.4 below.
Velocity

$$= \frac{\lambda}{2\cos\theta} \times F_r - F_R$$

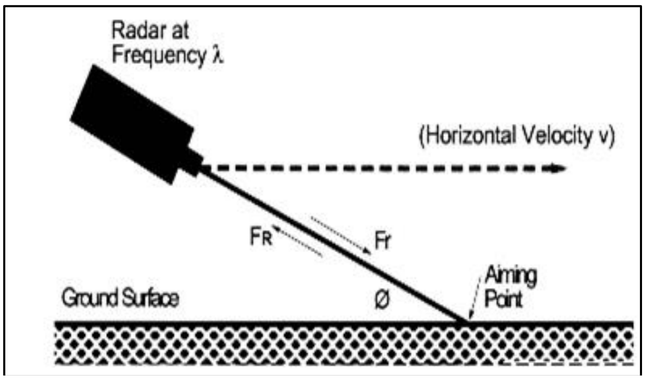


**Fig 3:** Radar Sensor (Reed and Turner, 1993) [13]

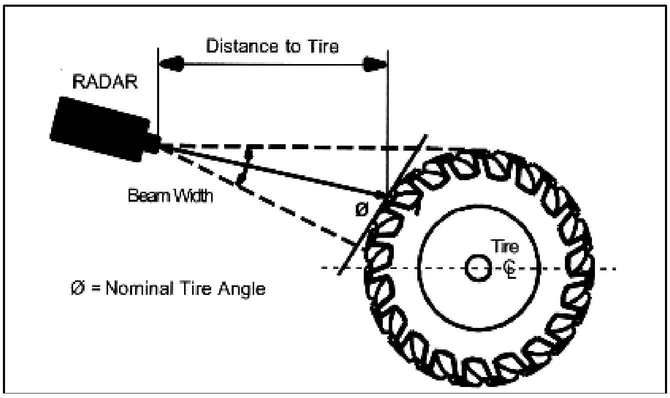


**Fig 4:** Use of Radar Sensor on a Tractive device (Reed and Turner, 1993) [13]

A general purpose instrumentation system was designed by Mclaughlin *et al* 1993 [9]. The system was checked for its performance in a tractor for the evaluation of different parameters such as consumption of fuel, speed of engine, speed of wheels, ground velocity and the torque of the front and rear wheels. He used transducers for sensing various parameters. The output data from the transducers were amplified before feeding to the microprocessor based data logger which was controlled by flexible software. The device was designed to accommodate future up-gradation.

A microprocessor based measuring device was developed by Sinha (2001) [15]. A steel wheel having spokes at 20° interval was fixed to rotate by the axle of a 2 WD tractor. For sensing the rotation, a proximity sensor was placed close to the spoke of the wheel. When the wheel rotated, the spoke at the interval of $20^0$ approached the proximity sensor. The magnetic pick up signal generated a voltage which was fed to the microprocessor unit. The microprocessor sensed and compared the data from front and rear wheels with no load and load conditions. The microprocessor was programmed accordingly to calculate the slip. The sensed slip was matched with the manual calculations to validate the performance.

Raheman and Jha (2007) [12] designed a microcontroller based slip measuring system for 2WD tractor for the computation of slip during practical use. Sensor used for the instrument comprised of various components such as power supply; throttle position sensor, gear position sensor, the sensor for wheel RPM, data processing system, display system etc. Power supply for the device was catered from the starter battery of the tractor. Proximity switches and rotary potentiometer were equipped on the tractor for the indication of throttle position and wheel rotation. The performance was evaluated both on tarmacadam road and on actual field. There was a 5-10% variation between indicated and actual slip for both the surfaces which appears to be at good level of accuracy.

From the above literature survey, the three methodologies have been emerged as given below for the measurement of the actual ground speed of the tractor which is essential for slip measurement.

i. **Use of non-powered wheel:** In the case of non-powered vehicles, the method was quite simple where the speed depends on soil texture, weight transfer and skid of front tyre. In such cases, the error in slip measurement is not more than ± 2%.
ii. **Use of additional or fifth wheel:** Generally, the 5th wheel was used in the case of 4WD vehicles. The measurement of speed is independent soil conditions, weight transfer and skidding of front wheel. However, the use of fifth wheel has difficulty in managing on undulating and rough terrains.
iii. **Doppler device:** It was possible to measure the actual speed accurately by using this device. The device has absolute reliability but very costly. However, the demerit of the device is its unsuitability for the speed below 0.5 km/h.

Because of the low cost, choice of front wheel as reference for actual speed measurement is widely considered.

**Slip Control System**

In order to enhance the utilization of engine power, Ismail *et al*. (1981) [5] carried out an experiment by controlling the tractive efficiency through slip variations. It was discussed as to how the tractive efficiency can be improved by slip control mechanism. Adjustment of axle load and co-efficient of traction or wheel slip was made to achieve the desired results. An analogue o/p of the slip was used to activate a 12V DC motor whenever slip deviated from the desired range. Through a chain of gear mechanism, the motor could rotate the draft control shaft of the tractor hydraulics. Whenever the slip varied beyond the desired limit, the implement height was raised or lowered by the operators as per the requirement to bring slip within a definite range. It was observed from the field results that there was possibility to manage the slip within desired range. The field parameters such as slip, draft and both 'slip & draft' were compared by Ismail *et al*. (1983) [6] to evaluate the field performance.

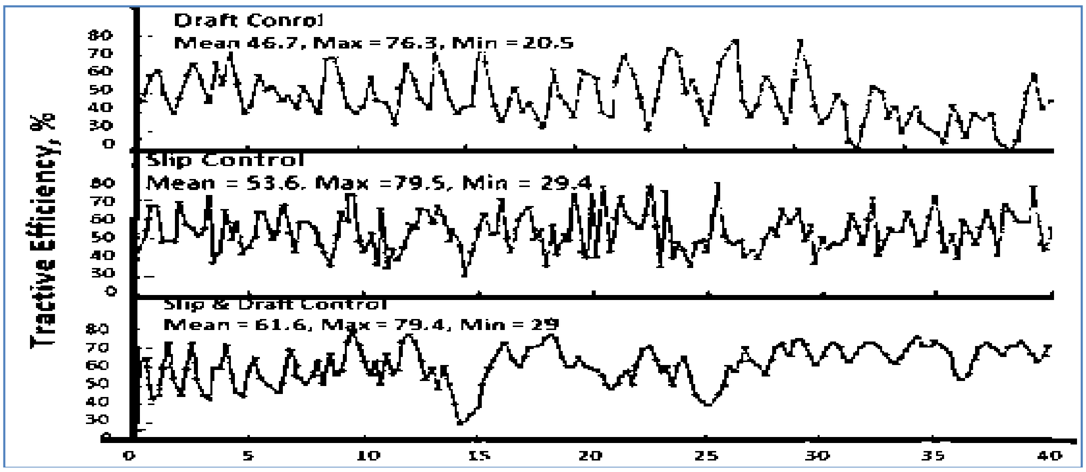


**Fig 5:** Draft, Slip and Combined Control System

The draft control system (DCS) was compared with slip control system (SCS) on the same tractor by using force on the top link as a control process. As per the observation, it was noticed in Fig. 5 that the slip control established better controlling effect over the draft control process resulting higher efficiency. Pranav P.K. *et al*. 2010 developed a slip sensing and control system for 2WD tractor and compared the drawbar performance parameters such as tractive efficiency, fuel consumptions, field capacity, depth measurements with the existing DCS for different field conditions and the advantage of slip control to improve the performance. He established that the slip control methodology is the best method to control the performance of the tractive device with respect to draft control system. He used automatic control of depth through stepper motor arrangements to maintain the slip within a desired range. Hence, it was established that tractive efficiency could be improved by controlling the wheel slip during actual field operation.

## Conclusion

Many researchers have come to the conclusion that the present draft control system possesses disadvantages for the driver as it is difficult and impracticable to make frequent adjustment of depth control levers which results in poor efficiency of tractive system. It is observed that in case of draft control process, the driver operates the depth control mechanism very frequently. In a typical example, driver has to operate the depth control lever at the rate of 3.13 times per minute out of which 40% of efforts made to avoid slip. This therefore necessitates a control system which would continuously measure the slip to help the driver for managing wheel slip within a given range under varying soil and field conditions. The following conclusions can be drawn with the use of slip control system.

1. The on line slip meter efficiently indicates the slip which provides the driver to maintain the slip within a range with a maximum standard deviation of 3.45
2. The control time in slip control process is significantly less as compared to draft control system. The indicators provided in the slip meter guide the operator for controlling the depth.
3. Slip meter provides necessary input to the driver to prevent excessive slip in a convenient manner. By doing this, the field capacity increases from 9%, 11% and 16.6% in case of ploughing harrowing and tilling respectively.
4. There is substantial fuel savings by slip control system The fuel saving is found to be 6%, 12%, 27% in ploughing harrowing and tilling operations respectively as compared to DCS.
5. The variation in depth of operation is drastically reduced in case of the slip control system as compared to the existing draft control system for all modes of field operations.

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