Development and evaluation of automatic slip sensing device for Indoor Tyre Test Carriage

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ABSTRACT: The introduction of modified theoretical velocity (axle rpm) and actual velocitymeasurement devices made the measurement of wheel slip more precise. The design of the axle rpm and actual velocity measurement device was accurate and efficient. The proximity sensor sends pulses when the projections are at the closest distance to the sensor. Axle rpm and actual velocity are calculated using Matlab software. The smart monitoring and performing mathematical calculations in Catman and Matlab software make the data handling easier and online graphical display enables the observer with an insight into the relation of each and every parameter with one another. The final output of the experiment is obtained in an excel sheet directly. The performance of the developed device was compared with the manual method of measurement of wheel slip. For validation of the slip sensing device, the wheel slip was measured by both methods at normal loads 7.85 kN with 131 kPa, 8.83 kN and 96.6 kPa and 10.3 kN with 82.8 kPa tyre inflation pressures at varying pulls condition upto 20% slip. No significant difference in measuring wheel slip was found at 5% level of significance.

Key words: Axle rpm, inflation pressure, normal load, pull, slip sensing device, tyre, wheel slip

Slip is the reduction in distance travelled by the tyre because of flexing of tractive device, slip between the surfaces and shear within the soil. From power efficiency point of view, slip causes a reduction in power transfer as the amount of power in the axle is not transferred wholly into the wheels. Wheel slip is defined as the ratio of difference in distance travelled when the tractor is driven with zero drawbar pull and when generating a drawbar pull on the same surface to distance travelled when the tractor is generating a drawbar pull on the surface. This is a convenient method when the counting of whole numbers of wheel revolutions can be done and the traction device is tested over the same number of revolutions for both tests (Macmillan, 2002). It has been by several researches that the tractive efficiency was maximum when wheel slip of traction wheel ranged between 8 and 15% and beyond the range, tractive efficiency falls quickly. Therefore, there is a need to measure slip precisely for getting accurate tractive efficiency of traction device which helps to measures the tractor performance.

Thansandote *et al.* (1977) used modern solid state micro doppler radar sensor to measure true ground velocity of the tractor and circumferential velocity of the drive wheel. Lyne and Meiring (1977) used photo-electric transducer to monitor ground velocity including wheel velocity to measure the slip of the tractor. Tompkins *et al.* (1988) applied a technique known as single-beam radar vehicle ground velocity sensor which was used to measures ground velocity accurately than ground contacting wheel. Nevala *et al.* (1998) stated about the measuring system which was built from an ordinary proximity sensor. The measuring principle was very simple that proximity sensor recognized teeth which were grinded to a circular plate attached to a wheel hub. The single-wheel tester developed by the National Tillage Machinery Laboratory (NTML) used sophisticated programmable servo control for the measurement of travel reduction during testing of tyres (Burt *et al.,* 1980). This feature can be used to run variable travel reduction tests in a sequence without stopping the machine between tests. Tiwari *et al.* (2009) calculated actual velocity by counting number of marking point made by event marker pen of the Gould recorder and total length for counting number of point on chart paper. Theoretical velocity was calculated by knowing wheel diameter and rotational velocity. All the designs by researcher were either complicated or costly or time consuming or became an obsolete technology. The Agricultural and Food Engineering Department of IIT Kharagpur has an indoor tyre testing facility to test the various sizes of tyres used in tractors (Tiwari *et al.*, 2009; Kumar *et al.,* 2018; Kumar *et al.,* 2020). This facility, though complete in many respects, still lacks accuracy and automation in respect of slip measurement system. This paper explains the development of slip sensor for measurement of slip of agricultural tyres in the indoor testing facility.

MATERIALS AND METHODS

Manual Method for the Measurement of Wheel Slip

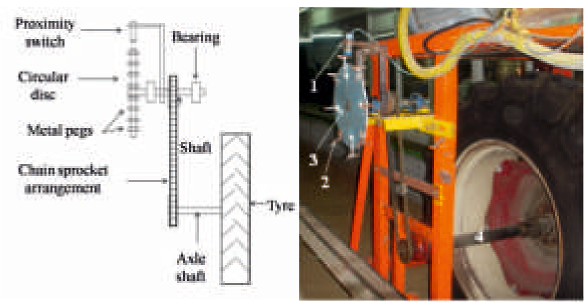
Wheel slip is manually measured by formula given by Macmillan (2002) which is given below. In this method, twenty revolutions were taken to measure distance travelled by wheel for zero drawbar pull and specific drawbar pull.

$$\text{Wheelslip } (S_m) = \frac{do-d}{d0} \times 100 \quad ...(1)$$

where, S_m = measurement of wheel slip by manual method, d_0 = distance travelled when the tractor is driven with zero drawbar pull on the surface and d = distance travelled when the tractor is generating a drawbar pull on the surface.

Development of Axle Rpm Measurement Device

A disc of 300 mm diameter with pegs welded around circular disc was mounted on a shaft extended from the wheel axle with the help of chain and sprocket arrangement. The distance between the sensor and the surface of the projection was kept less than 10 mm so as to have good sensing, as the range of the proximity sensor was 15 mm. This instrument detected the proximity of a magnetic material projected out of the circumference of a disc, sensed and sent peak signals at the closest interaction point. As the wheel rotated, the external wheel also rotated allowing eight pegs around the wheel to come in proximity with the sensor one after another. As soon as it nears the range of sensor, the sensor gave a signal and recorded the peak value at the closest point. When eight peak values are obtained it mean that the wheel has turned one revolution.



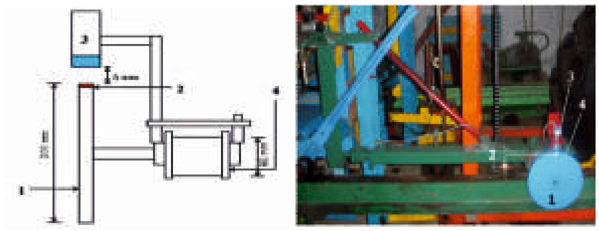
1. Proximity sensor 2. Metal pegs 3. Circular disc 4. Wheel axle shaft

Fig. 1: Diagram of axle rpm measurement

The constructional details are shown in Fig. 1. The care has been taken to ensure that even if the external wheel has slightest lateral play then also the vertical distance from the proximity sensor and the horizontal iron rod will remain the same; ensuring a clear and sharp peak at the closest position between them.

Calculation of Axle Rpm from Peak Signals

For the calculation of axle rpm from peak signal data, the proximity sensor connection is made with the data acquisition system (DAS). The DAS takes variation of voltage reading from the sensor and records it against time. A time versus peak signal plot shows regular peaks.



1. Circular disc 2. Metal strip 3. Proximity sensor 4. Roller drive shaft

Fig. 2: Actual velocity measurement device

The disc has eight pegs around it, so eight consecutive peaks will mean that it has turned one revolution.

Let, the number of peaks over a time range t sec be = P

Number of revolution per unit time = $\frac{P}{t}$

Therefore, revolutions per minute of wheel, $N_t = \frac{60P}{8t}$

Now angular velocity of the wheel, $\omega_t = \frac{2\pi N}{60}$

Hence, theoretical velocity, $V_t = \omega_t \times r$ … (2)

where r = rolling radius of the tire in m

Development of Actual Velocity Measurement Device

A circular disc of 200mm diameter with one metal strip fixed on its periphery was mounted on the drive shaft of 90mm diameter roller with the help of two bearings. The distance between the proximity sensor and the metal strip surface was kept well below 10 mm so as to have good sensing. When the traction wheel moves forward, the roller mounted on the railtrack rotates which helps to rotate the circular disc to come in proximity with the sensor. The principle to obtain the pulse for each interaction is the same as explained for axle rpm measuring device. The constructional details are shown in Fig. 2.

The disc has one metal strip around it, so one peak will mean that it has turned one revolution.

Let, the number of peaks over a time range t sec = P

Number of revolutions over the time range = $\frac{P}{t}$

therefore, revolution per minute, $N_a = \frac{60P}{t}$

Now angular velocity, $\omega_a = \frac{2\pi N}{60}$

Hence actual velocity, $V_a = \omega_a \times r$ … (3)

Where r = rolling radius of the pulley in m.

Measurement of Slip by Development Slip Sensor and its Validation

Wheel slip was measured by developed slip sensor using the formula.

$$\text{Wheel slip} = \frac{Vt-Va}{Vt} \times 100 \quad … (4)$$

where, V_t = theoretical velocity and V_a = actual velocity measured by developed device.

The wheel slip was measured by two methods viz. developed slip sensing device (using equ. 4) and manual method (using equ. 1). The variation in slip measured by developed slip sensing device w.r.t manual method at different inflation pressures and normal loads at varying pulls condition was measured for its validations. The drawbar pulls were taken from zero to 20% wheel slip. It was recommended that the tyre should be loaded to match with the inflation pressure as specified by the tyre manufacturers (Kumar, 2009). Therefore, normal loads on the tyre were 7.85 kN at 131 kPa, 8.83 kN at 96.6 kPa and 10.3 kN at 82.8 kPA tyre inflation pressure were taken for bias ply tyre of size 13.6×28 for the validation of slip measurement from developed device. The soil compaction level was taken from 600 kPa to 800 kPa to maintain soft soil condition. The bin was filled with locally available lateritic sandy clay loam soil. The percentage difference of slip by both methods was calculated. Paired t-test was conducted using SAS 9.3 to check any significance difference between measuring slip by these two methods.

Data Acquisition System (DAS) and Processing of Data

The MGC data acquisition system (Fig. 3) is modular in construction. Depending on the enclosure variant, up to 16 slots are available for one channel and multi-channel in plug-in modes. Each amplifier plug in mode operates in standalone mode through the internal CPU. Data conditioning such as tarring, filtering and measuring range adjustment is carried out in digital form. All measurement signals can be captured in parallel, since each channel has its own A/D converter. This ensures continuous digital filtering and highest possible signal stability. As the data acquisition system takes all the data against time, the time range for eight peaks in case of wheel axle RPM and one peak in the case of actual velocity can be found out. The data were first acquired by the data acquisition system, processed and conditioned using Catman software and then fed to Matlab software for mathematical calculation.

Fig. 3: A MGC plus data acquisition system

Matlab for data analysis and calculations

The proximity sensors show peak signal of voltage. Thus, a program is needed to determine actual velocity and rpm from the raw data, by counting the number of peak signals over a time period. A program is written in Matlab to calculate actual velocity and wheel rpm which is used to determine the slip. The final results are displayed on the Matlab screen with graphical display during each experiment and final values were saved in an excel file. The logic diagram of the entire data processing system is given in the Fig. 4.

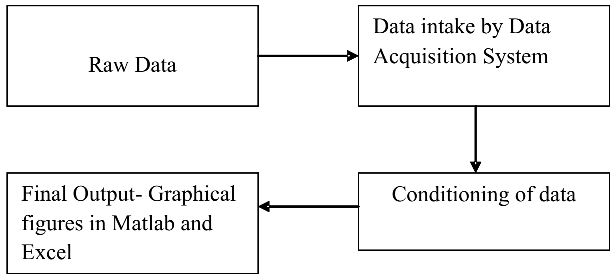


Fig. 4: The logic diagram of data acquisition and processing system

Statistical Analysis

An experiment for the validation of automatic slip sensing device was carried out to collect data based on wheel slip measurement by developed sensing device (L1) and wheel slip measurement by manual method (L2). The difference between L1 and L2 was tested using t-test procedure available in SAS 9.3. The significance of equality of variances of L1 and L2 were tested by two sample t-test using Folded F method before making inferences about the significant difference between L1 and L2 in case of equal/unequal variances. The interpretations of the results of statistical analysis have been carried out at 5% level of significance.

RESULTS AND DISCUSSION

Measurement of Theoretical Velocity (Axle Rpm) and Actual Velocity

Fig.5 and Fig. 6 shows peak signals for measuring theoretical and actual velocities of wheel, respectively. Eight peaks obtained over a time range mean one revolution of the wheel as the disc has eight projections. Finally, the speeds were calculated using equation 2 and 3.

Valtidation of Slip Sensing Device

Different slips at 7.83, 8.33 and 10.3 kN load and 131, 96.6 and 82.8kPapressure at different pulls(0 to 3.21kN) upto 20% slip were measured and reported in Tables1, 2

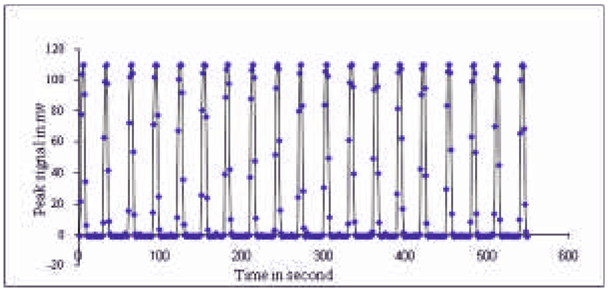


Fig. 5: Plot of peak signals versus time for axle rpm

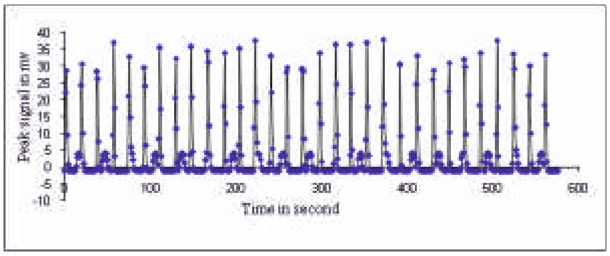


Fig. 6: Plot of peak signals versus time for actual rpm

Validation of Slip Sensing Device

and 3.Pull vs slip graphs at different normal load and inflation pressure are plotted and shown in Fig 7. The similar trend was observed by Wulfsohn *et al*. (1988), Macmillan (2002), Zoz and Grisso (2003), Schreiber and

Table 1: Validation of Slip Sensing Mechanism at 7.83 kN normal load and 131 kPa inflation pressure at various pulls

Pull, kN	Average measurement of slip by developed device	Average measurement of slip by manual method	Avg% difference	Test Statistic
0.00	0.95	0.98	3.06	NS
0.94	3.19	3.12	2.24	NS
1.63	7.29	7.43	1.88	NS
2.05	8.75	8.98	2.56	NS
2.46	13.26	12.96	2.31	NS
2.87	19.11	19.65	2.75	NS
3.03	20.76	20.54	1.07	NS

Average% difference 2.27, Pr>|t|=0.66, *NS-non significant at 5% level of significance*

Table 2: Validation of Slip Sensing Mechanism at 8.33 kN normal load and 96.6 kPa inflation pressure at various pulls

Pull, kN	Average measurement of slip by developed device	Average measurement of slip by manual method	Avg% difference	Test Statistic
0.00	1.52	1.58	3.80	NS
0.88	3.65	3.56	2.53	NS
1.43	6.77	6.53	3.68	NS
1.99	8.16	8.28	1.45	NS
2.40	11.26	11.46	1.75	NS
2.77	15.91	16.33	2.57	NS
3.21	20.06	20.54	2.34	NS

Average% difference 2.59, Pr>|t|=0.21, *NS-non significant at 5% level of significance*

Table 3: Validation of Slip Sensing Mechanism at 10.3kN normal load and 82.8kPa inflation pressure at various pulls

Pull, kN	Average measurement of slip by developed device	Average measurement of slip by manual method	Avg% difference	Test Statistic
0.00	1.46	1.52	3.95	NS
0.93	2.69	2.76	2.54	NS
1.68	5.87	6.01	2.33	NS
1.99	8.26	8.36	1.20	NS
2.52	11.01	11.46	3.93	NS
2.92	15.02	15.61	3.78	NS
3.23	16.63	17.01	2.23	NS
3.52	20.16	20.54	1.85	NS

Average% difference 2.72, Pr>|t|=0.07, *NS-non significant at 5% level of significance*

Kutzbach (2008), Battiato and Diserens (2013), Katrenčík *et al*. (2013) and Kurkauskas *et al.*(2016) for pull vs slip.

Minimum percentage difference in slip measured by developed device was 1.07, 1.75 and 1.20 at normal loads of 7.85, 8.33, 10.3 kN and at tyre inflation pressures of 131, 96.6 and 82.8 kPa. The maximum percentage difference was 3.06, 3.80 and 3.95 at the same operating

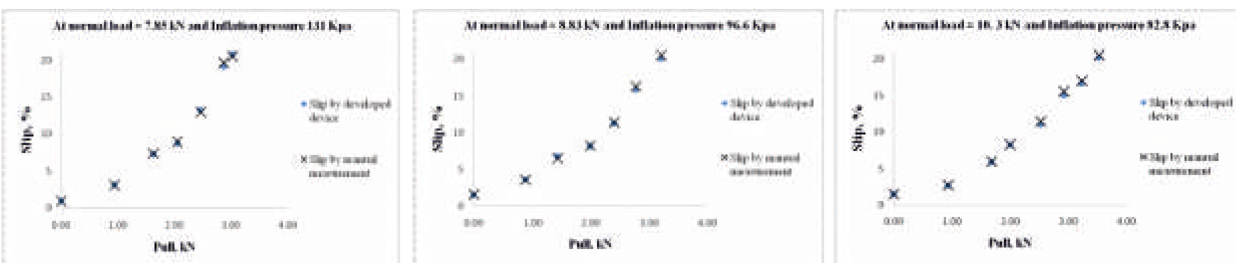


Fig 7: Pull vs Slip curve at different normal loads and inflation pressures

parameters. The average percentage difference of slip between the developed device and manual method of measurement of slip was 2.53. The difference in measurement of wheel slip may be was due to error associated with manual method of measuring wheel slip.

The hypothesis is whether the measurement of slip by the developed method is significantly different than manual method at 5% level of significance. At 7.83 kN normal load and inflation pressure of 131 kPa at various pulls, average difference between developed sensor and manual methods was 0.22 and the test statistics and p-value were 0.46 and 0.6600, respectively. Similarly, at 8.33 kN of normal load and 96.6 kPa of inflation pressure at various pulls, the average difference was 0.23 and the test statistics and p-value were -1.39 and 0.2145, respectively. The average difference at 8.33 kN normal load and 96.6 kPa inflation pressure was 0.3 and test statistics and p-value were -0.378 and 0.0069 were found. The results indicated that there is no significance difference in wheel slip measured by two methods at 5% level of significance. Overall, the average percentage difference in wheel slip was 2.27–2.72 at selected operating parameters.

CONCLUSION

The average difference and percentage average difference in wheel slip measured by developed device as compared to manual method were found 0.22–0.30 and 2.27–2.72, respectively at different normal loads and inflation pressures at varying pulls condition upto 20% slip. For all the cases, the magnitudes of test statistics were greater than its p-value at 5% level of significance. Therefore, it was concluded that there was no significant difference in wheel slip measured by two methods.

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