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Development of a test rig to evaluate traction performance of small size rubber tracks in indoor conditions

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ABSTRACT : Indoor soil bin facility allows experiments to be conducted under controlled conditions to reliably study the wheel soil interaction. An indoor soil bin based test rig has been developed to study the traction performance of small sized rubber tracks. The experimental rig consists of soil bin, track tester, power transmission system, soil mixing and compaction device, loading deviceto vary drawbar pull and control system. The developed system consisted of instrumentation system which included, torque sensor, proximity sensors and load transducer. The parameters measured by these sensors were input torque, actual and theoretical speeds, and drawbar pull, respectively. Traction performance parameters like gross traction ratio (GTR), net traction ratio (NTR), and tractive efficiency (TE) and travel reduction ratio (TRR) were calculated from these parameters. Experiments showed measurements were highly reproducible under different conditions. Preliminary results showed that net traction and gross traction increase with increase in travel reduction ratio and both stabilize after achieving a certain maximum value. Tractive efficiency first increases with increase in travel reduction ratio and then decreases.

KEY WORDS : Track tester, Soil bin, Indoor test rig, Gross traction ratio, Net traction ratio, Tractive efficiency

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Traction is the driving force generated by the traction device at soil-wheel interface to overcome all types of vehicle-resisting forces and hence keep the vehicle in constant travel (Young *et al.*, 1984). Parameters included in the traction performance of off-road vehicles on unprepared terrain are driving torque, ability to accelerate, drawbar pull, travel reduction (usually called slip), gross traction ratio, tractive efficiency, net traction ratio (sometimes called pull/weight ratio) and motion resistance or rolling resistance (Goering, 1989; Wong, 2001; Schreiber and Kutzbach, 2008 and Zoz and Grisso, 2003).Traction of off road vehicle mainly depends on the type of traction device and proper matching of traction device with other vehicle design factors.

The choice of tractive devices used on agricultural tractors has a major effect on generating tractive forces. With the advent of rubber track as a traction device, questions have arisen on its field performance with the wheeled tractors. Several studies have been conducted comparing the performance of rubber tracked tractors with the wheeled tractors (Brixius and Zoz, 1976; Evans and Gove, 1986; Esch *et al.*, 1990; Zoz, 1997; Bashford and Kocher, 1999 and Servadio, 2010).

Performance of the traction devices can be reliably determined by proper testing of traction devices. Traction device can be tested either on farm using a test tractor (Upadhyaya *et al.*, 1986, Shmuievich *et al.*, 1996, Wismer, 1984) or a single wheel tester (Hiroma *et al.*, 1997). Analysis of traction performance in field shows lot of variation due to numerous complex factors involved (Kawase *et al.*, 2006). A simple single wheel tester requires supporting the moving wheel, applying the required torque and measuring the developed force (net traction). However, there are various ways in which this can be accomplished with varying levels of complexity. Some devices have been used in soil bin while others have been directly used in fields. In some cases, testing is done using complete vehicles, with the tractive device being the drive wheels or tracks. Several single wheel testers have been developed to be used in indoor soil bin conditions for the testing of agricultural tires. The prominent among them are National Soil Dynamic Laboratory (NSDL) in Auburn, USA(1980); Silsoe Research Institute, UK (1973); University of California at Davis, USA, (1986) and University of Hohenheim, Germany (1989).

Single wheel tester developed at NSDL which is based on indoor soil bin facility has the ability of independently adjusting the speed of tester and rotational speed of wheel, capable of performing variable slip tests. University of California at Davis in the USA has developed a single wheel tester for controlled field experiments. National Institute of Agricultural Engineering developed a single wheel tester which enables tests to be carried out in field conditions and gives continuous readings of forward speed, tractive force and torque. University of Hohenheim developed as tester in which test rig is connected to four wheeled trailer which is towed by tractor during the test run. The tester can also test driven angled wheels. Soil bin facility with single wheel tester has also been developed at IIT-Kharagpur, India (2009).The developed test rig has an installed instrumentation system to measure traction performance parameters. The test tires can be changed rapidly and there is a provision for control of vertical dynamic load.

The present study aimed to develop a test rig with complete instrumentation system to evaluate the tractive performance of small sized rubber tracks.

■ METHODOLOGY

Description of the testing facility:

The testing facility consists of the following (Fig. A).

- Soil bin
- Track tester
- Power transmission system
- Mixing and compaction device
- Drawbar pull loading device
- Control system

Soil bin:

The overall dimensions of the soil bin are 15 m×1.8 m×0.6 m. To support and to facilitate the movement of soil processing trolley and guide trolley of tester, two horizontal rails 100 mm ×50mm of mild steel channel were provided along the length of the soil bin. The bin was filled with lateritic sandy clay loam soil.

Fig. A : General view of soil bin

Track tester:

It consisted of a main frame to accommodate the track and a guiding trolley to facilitate movement of main frame on rails, a loading platform,a power transmission system, and a four bar parallel linkage to connect guide trolley with the main frame. The main frame of size 1500 mm × 900 mm × 500 mm was made up of mild steel angle irons. It was fitted with two wheels, each wheel is supported on a shaft of diameter 40 mm. The diameter of the rear drive wheel was 420 mm and the front idler was 340 mm. The test rubber track was fitted on these two wheels as shown in Fig. B. Guide trolley was of rectangular shape of size 1470 mm × 1010 mm made of mild steel. It was equipped with eight rollers to facilitate its movement on side rails. The main trolley was connected with guide trolley through four bar linkage. The four bar linkage system allowed free vertical movement of tester and helped in transferring total weight on to the track. Power to the track was given by a 7.5 kW, 3 phase electric motor rotating at 1425 rpm.A controller switch was provided to facilitate to and fro movement of the track tester. The speed of the motor was initially reduced by gearbox with a reduction of 40:1 and then by chain and sprocket mechanism with a reduction of 2:1. The final linear speed of axle obtained was 1 km/h with a rim diameter of 42 cm.

Fig. B : **Constructional details of track tester 1. Induction motor 2. Torque transducer 3. Gear box 4. Chain drive 5. Test track 6. Main frame 7. Guide trolley**

Mixing and compaction device:

To control the state of the soil and compaction level, mixing and compaction devices were provided. It consisted of a rotary tiller, a leveler blade and a compaction roller, with the tiller in the front and the roller at the rear. Leveler blade attached at the rear helped in leveling the tilled surface. The device could be pulled along the rails by a steel wire driven at constant speed by the electric motor.

Drawbar loading device:

A drawbar loading device was provided to vary the horizontal pull of track tester. It consisted of a steel drum 200 mm in diameter and 650 mmin length. The drum was mounted on a shaft of 50 mm diameter with both ends supported on bearings (Fig. C). A shoe type braking arrangement was provided at one end of the shaft, which was operated by applying downward force by means of dead weights in a pan. A steel wire rope was attached to the guide trolley of track tester and other end of the steel wire was rolled on the drum. The rope was unwrapped as the wheel moved forward and in turn, being a positive drive mechanism, it rotated the drum. The rotary motion of the drum could be restricted by varying the braking force on the drum, thusmade it possible to provide varying drawbar loads to the test wheel/track.

Fig. C : **Drawbar loading device1. Drum 2. Dead weights 3. Lever 4. Shoe type brake 5. Rope**

Control panel:

A control panel consisting of electrical switches and starters was provided near the soil bin wall to operate the soil processing trolley and the track tester in forward and reverse directions.

Instrumentation for measurement of torque, slip and pull :

Measurement of torque:

Input torque to the drive wheel of track was

Fig. D : **Torque transducer mounted between prime mover and load shaft1. Induction motor, 2. Bellows coupling, 3. Torque transducer**

measured with the torque transducer. The torque transducer was mounted between prime mover and a load shaft through two sets of bellows coupling as shown in Fig. D. The torque transducer had a capacity of 1000 Nm. The output of the torque transducer was fed to a data acquisition system. The static calibration of torque transducer was carried out as shown in Fig. E. For calibration, 31 cm steel arm was fixed to the load shaft and loaded by standard weights. Motor shaft was prevented from rotation during calibration. The calibration results of torque transducer are shown in Fig. F.

Fig. E : Setup for calibration of torque transducer

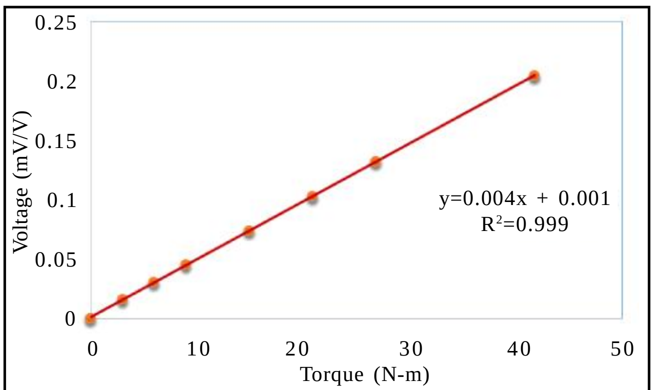


Fig. F : Calibration results of torque transducer

Measurement of pull:

The pull was measured using strain gauges arranged in wheatstone bridge mounted on a flat bar attached between the towing trolley and the drawbar loading device. Two electric strain gauges each of 350 Ω and gauge factor 2.6 were mounted on a flat bar and other two dummy strain gauges were mounted on a flat to form wheat stone bridge (Fig. G). The bridge was calibrated for tensile loads under static conditions with the help of crane as shown in Fig. H. The results of calibration of the wheatstone bridge is shown in Fig. I below :

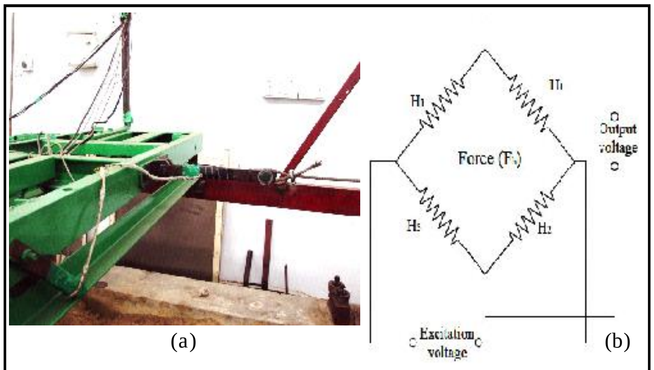


Fig. G : (a) Transducer for measuring pull (b) Wheatstone bridge for force

Fig. H : Set-up for calibration of transducer for measuring pull

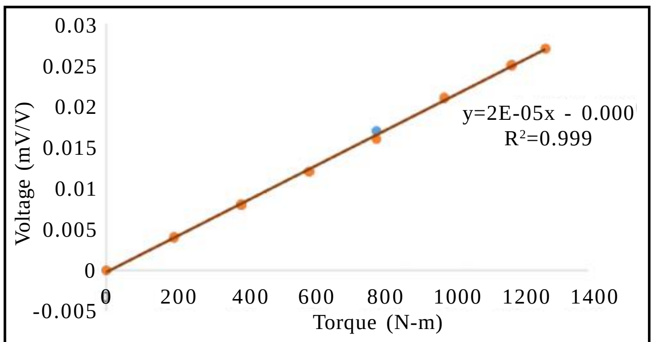


Fig. I : Calibration of transducer

Measurement of slip:

For rpm measurement, a steel ring with 6 projections was installed on the shaft of the rear axle of the track tester and a proximity switch was installed close to the projections (Fig. J). Voltages generated by the proximity switch was converted into rpm of shaft.

Fig. J : Proximity switch attached on main frame with steel ring with projections ondrive shaft for measurement of rpm of drive wheel

Theoretical speed is calculated from the rpm of drive wheel of track using the Eqn. 1

$$V = \frac{2\pi rN}{60} \quad (1)$$

where, r = rolling radius of rear wheel; N = RPM of drive wheel

Rails have steel projections fixed along the side at an interval of 500 mm (Fig. K). When guide trolley attached with proximity switch moves along the rails, the proximity switch generates a signal whenever it passes over a steel projection. Therefore, actual speed was calculated from the number of pulses generated the proximity switchand the time elapsed.

Fig. K : Proximity switch attached on guide trolley for measurement of actual speed

Slip is calculated from the theoretical speed and the measured value of the actual speed using Eqn. 2.

$$S = \frac{v_t - v_a}{v_t} \quad (2)$$

where v_t=Theoretical velocity; v_a = Actual velocity; S = Slip

Test procedure:

The tests were conducted in lateritic sandy clay loam soil. In order to check the uniformity of the bed conditions, important soil parameters such as soil cone index, bulk density and moisture content were measured before starting the experiment.

Soil cone index was used as a measure of soil strength (consistency). It is the force per unit base area required to penetrate a cone shaped probe into the soil at a steady rate. Hydraulically operated soil cone penetrometer with a cone angle of 30^0 and base area of 323 mm^2 was used to measure the cone index of the soil (Fig. L. a). The cone penetrometer was operated at a speed of 30 mm per second. To measure the force required to push it and the displacement of the penetrometer, octagonal ring transducer and linear potentiometer were used, respectively.

Soil moisture content was measured with the help of infrared moisture meter (Fig. L. b). Soil samples were kept in it for 5 min at 105 ^{0}C and moisture content on dry basis was obtained.

(a) (b)

Fig. L : (a) Cone penetrometer and (b) Infrared moisture meter

RESULTS AND DISCUSSION

The main aim of the test rig is to evaluate the tractive performance of rubber tracks. After ensuring uniformity of soil bed by measuring moisture content and cone index, tests were conducted with a rubber track. Each test was carried out for a length of 5m in the middle span of the soil bed. The variables recorded for each test were the input torque to the drive axle, slip and pull. The tests were conducted with different values of pull. Traction performance of the track system was determined by calculating the net traction ratio (NTR), tractive efficiency (TE), motion resistance ratio (MRR) and TRR. From the observed tractive performance data (torque, pull and travel reduction ratio), gross traction ratio (GTR) and MRR were directly computed using Eqns. (3) and (4)

$$\mathbf{GTR} = \frac{\mathbf{T}}{\mathbf{r \times w}} \qquad (3)$$

$$\mathbf{MRR} = \frac{\mathbf{T}/\mathbf{r} - \mathbf{P}}{\mathbf{w}} \qquad (4)$$

where T = Input torque, Nm; r = Rolling radius, m; P = Pull, N; w = dynamic load on tractive devices (N)

Net traction ratio (NTR) was then calculated from the values of GTR and NTR as follows.

$$\mathbf{NTR = GTR - MRR} \qquad (5)$$

Travel reduction ratio (TRR) is computed as

$$\mathbf{TRR} = \frac{\mathbf{v_t - v_a}}{\mathbf{v_t}} \qquad (6)$$

where v_t=Theoretical velocity; v_a = Actual velocity

These terms are defined as per ASAE Standards: ASAE S296.4.

The typical reading for drawbar pull, input torque and data from proximity switches are shown in Figs.1, 2 and 3, respectively.

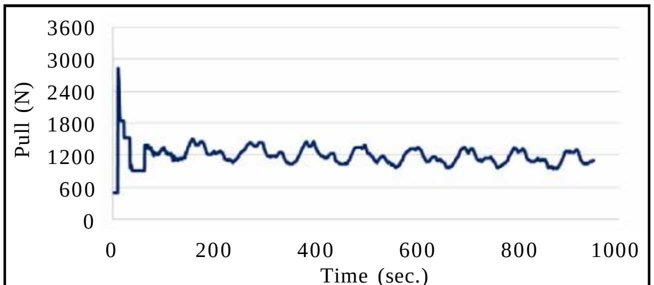


Fig. 1 : Typical reading of pull vs time

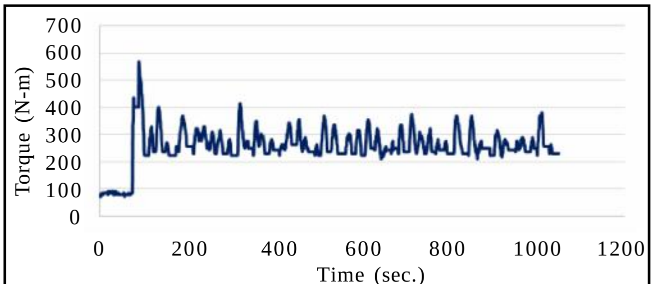
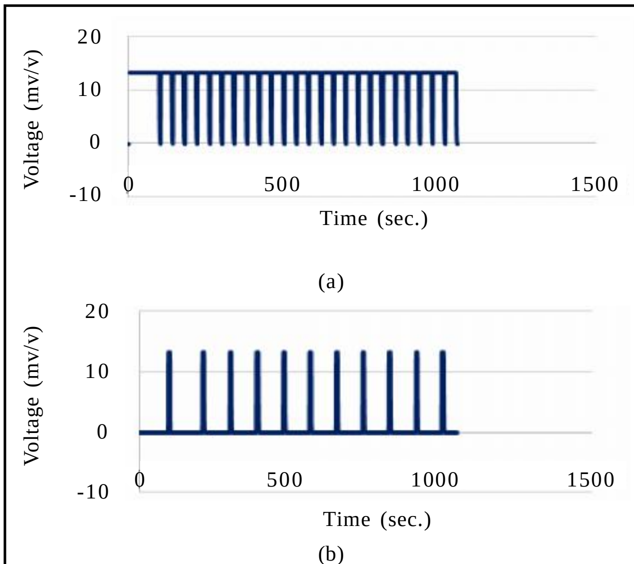


Fig. 2 : Typical reading of torque vs time



(a) Recording of proximity switch for measurement of rpm of drive wheel (b) Recording of proximity switch for measurement of actual velocity

Fig. 3 : Typical recording of proximity switches for the measurement of slip

Preliminary testing of the test track was conductedin sandy clay loam soil. The performance of the rubber track is shown in Fig. 4.

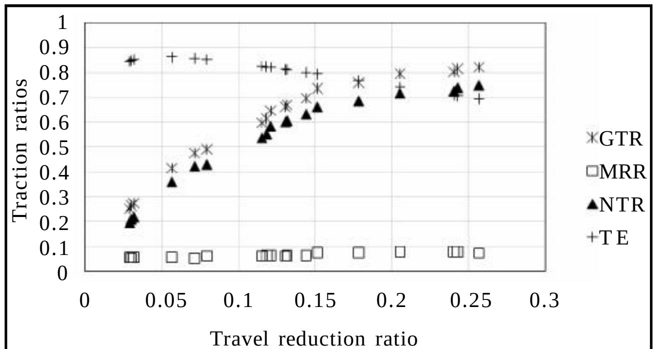


Fig. 4 : Typical result of track testing

The general shape of the performance curve indicates that NTR increases with increase in TRR value as well as with soil strength and then levels off at higher TRR values. Preliminary tests indicated that test rig worked well and was suitable for testing of rubber tracks.

Conclusion:

Most of the energy in off-road vehicles is wasted at soil wheel interface. Performance is mainly dependent on type of traction device. Performance can be improved by matching the type and size of traction device with the vehicle design. To determine the suitability and uses of various traction devices, they should be tested under controlled soil conditions. Test rig to test small sized rubber tracks has been developed. Performance of a test rubber track has been evaluated using the developed test rig. Input torque, drawbar pull and actual and theoretical speeds were measured. From these variables, traction performance parameters like gross traction ratio (GTR), net traction ratio (NTR), and tractive efficiency (TE) and travel reduction ratio (TRR) were calculated. Experiments showed that the measurements were highly reproducible under different conditions using the developed test rig equipped with instruments.

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