

Full Length Research Paper

## Development of hydraulic normal loading device for single wheel test rig

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A study was conducted to develop a hydraulic normal loading device for a single wheel test rig available in the Agricultural and Food Engineering Department of IIT Kharagpur. A hydraulic circuit was designed to apply additional normal load up to 2000 kg on wheel axle. The same circuit also can be used to remove 1350 kg load from the initial load. The circuit uses a fixed displacement pump, a 3-way-4 port-solenoid operated- spring centered directional control valve, a pressure relief valve and a double acting hydraulic cylinder. The normal load is sensed by a ring transducer and recorded in a data acquisition system. This device was used to study the effect of normal load on a radial-ply tire (14.9 to 28) under soft and hard soil condition. It was observed that, with hydraulic loading device the normal load on the wheel axle under dynamic condition was found to increase in the range of 1 to 5% for soft and hard bed soil surface.

**Key words:** Static normal loads, dynamic normal load, radial-ply tire, drawbar pull, slip.

### INTRODUCTION

The prediction of tractive performance has been a major goal for many researchers. Research results show that, about 20 to 55% of the available tractor energy is wasted at the tire-soil interface. This energy is not only wasted, but wears the tire and compact the soil to a degree that may be detrimental to crop production (Burt and Bailey, 1982). Tractive performance is influenced by tire parameters, soil condition, implement type, and tractor configuration (Brixius, 1987). The tractive characteristics of a tire depend on tire geometry (width, diameter, section and height), tire type (radial, bias), lug design, inflation pressure, normal load on axle and soil type and conditions. A tire testing facility should have provisions to measure parameters such as pull, actual velocity, torque, axle rpm, tire sinkage, and dynamic normal load on tire.

The Agricultural and Food Engineering Department of IIT Kharagpur has an indoor soil bin to test the various sizes of traction tires used in tractors. The test tire is

loaded by putting dead weights on a platform attached to the test wheel. This is a very laborious and strenuous exercise, particularly when heavy loads are required for testing large tires. This operation may be facilitated by using a hydraulic loading device. Such a device would help in testing not only the large tires at higher loads but also the small tires where reduced loads are required.

Burt investigated the role of both dynamic load and slip (S) on tractive performance. At constant S, tractive efficiency (TE) increased with increases in dynamic load on compacted soil. On the soils with an uncompacted subsurface, TE decreased with increased dynamic load (Elwaleed et al., 2006). Wonderlich developed dynamic loading device for single wheel testing unity. The loading system consists of a hydraulic cylinder and an adjustable pressure reducing/relieving valve. The hydraulic cylinder is connected to the tractor's hydraulic couplings through a pressure reducing/relieving valve which keeps the

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loading constant over varying terrain conditions (Wonderlich and Goodall, 2007). The combined effect of normal load and inflation pressure is also significant on tractive performance of tires. A study was, therefore, undertaken to address this issue with the following objectives of design, development and evaluation of a hydraulic normal loading device for applying varying normal loads on single wheel test rig under different soil bed conditions.

### Theoretical considerations

Traction performance parameters of radial and bias ply tires S, TE, coefficient of traction (COT) or net traction ratio (NTR). These parameters are defined as follows.

#### Slip (s)

When a tractor pulls a load, there is a reduction in distance traveled and/or speed that occurs because of flexing of the tractive device and shear within the soil. It is the ratio of decrease in the actual speed to the theoretical speed and is given by Kumar and Pandey (2012).

$$s = \frac{(V_t - V_a)}{V_a} \times 100 \quad (1)$$

Where s = slip in percentage,  $V_t$  = theoretical velocity, m/s, and  $V_a$  = Actual velocity, m/s

#### Tractive efficiency (TE)

It is the ratio of drawbar power to the axle power and is given by Tiwari and Pandey (2010):

$$TE = \frac{[P \times V_a]}{[T \times \omega]} \times 100 \quad (2)$$

Where T.E = Tractive efficiency, percent, P = Pull, Newton, T= Torque, Nm, and  $\omega$  = Angular velocity, rad /sec.

#### Coefficient of traction (COT)

This can be defined as the ratio of pull to the normal load on the tyre and is given by:

$$C.O.T = \frac{P}{W} \quad (3)$$

Where COT = Coefficient of traction, P = Pull, kg, W = Normal load on the tire, kg.

#### Relative deviation (RD)

It is a measure of how precise the average is, that is, how well the individual numbers agree with each other. The relative deviation (RD) is often times more convenient. It is expressed in percentage. (Kumar and Pandey, 2009):

$$RD = \frac{1}{N} \sum_{i=1}^N \frac{|P_i - O_i|}{|P_i|} \times 100 \quad (4)$$

Where P is the predicted value, O is the observed value, and N the number of observations.

### MATERIALS AND METHODS

#### Design of ring transducer normal load measuring

A proving ring with a maximum load bearing capacity of 3000 kg was selected for normal load measurement. The body of the proving ring was made of special steel, carefully forged to give maximum strength. Before mounting the strain gauges on proving ring, the surface of the ring was prepared carefully was rubbed by sand paper to remove paints and rust. The ring transducer was calibrated for load measurement using electronic pan balance (Figure 1) and found good linearity of applied load and output of ring transducer.

#### Design of hydraulic circuit for applying varying normal load

Due to sinkage of tire hydraulic load increases on the tire test rig that kept initial. During the whole procedure the system was running without any stoppage. The same procedure was followed for different hydraulic circuit with different valves that minimize increase in hydraulic normal load that kept on tire test rig. Double acting hydraulic cylinder of bore dia.80 mm, rod dia.45 mm and stroke length 250 mm was fabricated for applying different normal loads on tire test rig. The diameter of the piston rod is nearly half of the cylinder bore. Cylinder was capable of applying 2000 kg and lifting 1350 kg loads from tire test rig. The other components used in the hydraulic circuit were a pressure relief valve of size 10 lpm, a pump 12 lpm, a 3-position-4 ports solenoid operated and spring centered DCV and a 10 L reservoir.

Developed hydraulic system was fitted over tire test rig to apply hydraulic normal load on radial ply tire for traction performance. Hydraulic loading circuit is shown in the Figure 2. This hydraulic system consisted of a 10 lpm size pressure relief valve, a hydraulic cylinder (area 50.24 cm<sup>2</sup>), a solenoid operated direction control valve, compensating valve, an accumulator, a ring transducer, an external gear pump, a 2 hp electric motor, an hydraulic oil reservoir with an oil filter. A pressure compensating set up had been adopted in order to prevent cavity in the cylinder. In the pressure compensation system two set of relief valve and check valves were placed between extend and retract end. If cylinder rod moves upward due to undulation on soil surface then cavity is created at the rod end side and excess pressure at bore end side, in this situation excess oil from bore end is diverted to the rod and through relief valve 2.

In another situation if we are operating the tire setup at reduced load than the weight of tire test setup, that is, we are taking out normal load and in this situation while in motion tire sink in the soil, in this case, vacuum is created at the bore end and excess pressure is created at rod end. In this situation excess pressure



Figure 1. Calibration of ring transducer for measurement of normal load.

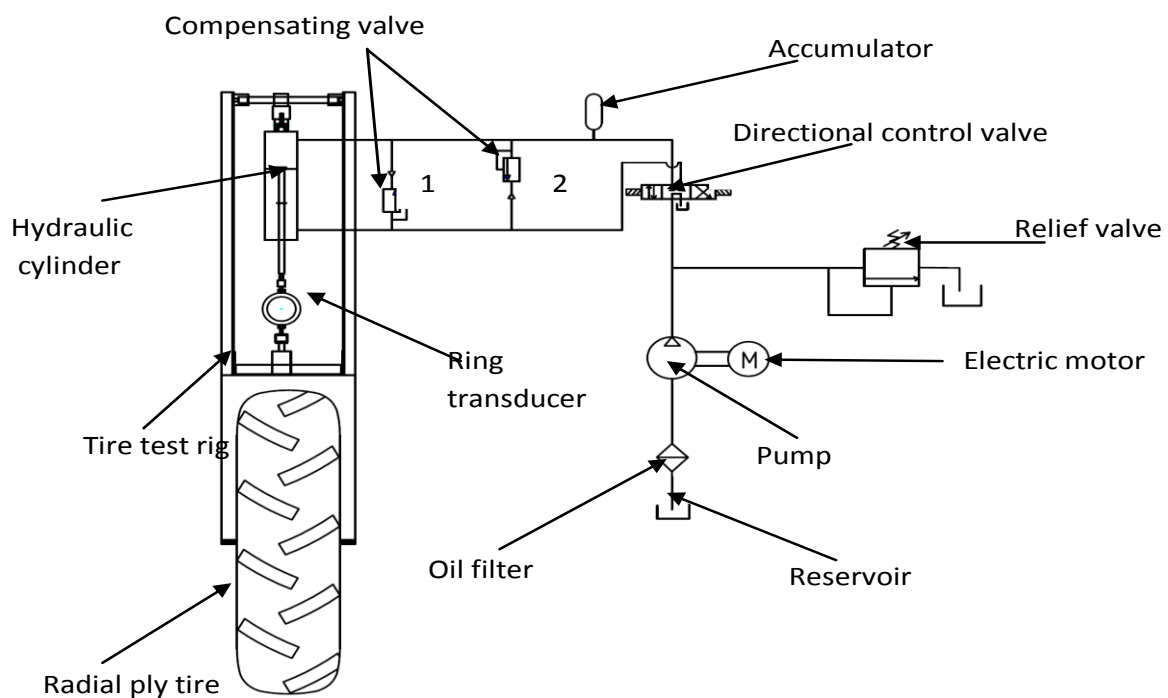


Figure 2. Hydraulic loading circuit on tire test rig.

from rod end is transferred to bore end through relief valve 1. An accumulator is used in this system to control sudden rise pressure in the system and thus, help in maintaining the applied normal load.

#### Experimental setup for validation of the designed hydraulic circuit and ring transducer under dynamic loading condition in soil bin

The experimental set-up consisted of a radial ply tire, tire test carriage, an indoor soil bin, a soil processing trolley, and a drawbar

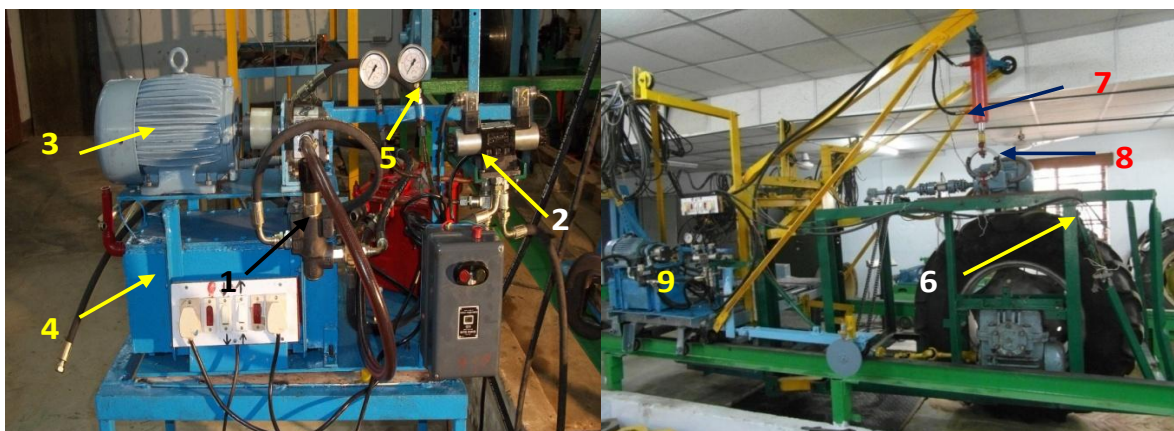
pull loading device is shown in Figure 3. The different units of the experimental set-up are shown in Figure 4.

#### Test procedure

To investigate the effect of hydraulic normal loading behavior on soft and hard soil condition, first, soil bed was prepared with the help of soil processing trolley and cone index was measured with the help of hydraulic cone penetrometer up to the soil compaction level of 600 to 1800 kpa. Normal load of 1150 kg (750 kg test rig



**Figure 3.** General view of the tire traction testing facility. 1= Drawbar pull loading device, 2= Radial ply tire, 3 = Indoor soil bin, 4 = Soil processing trolley, 5= Dead weight loading platform, 6 = Parallel bar linkage.



**Figure 4.** Constructional details of the tire test carriage along with designed hydraulic normal loading system . 1= Pressure relief valve, 2 = DCV 3. electric motor, 4= Reservoir 5. pressure gauge, 6 = Main frame, 7= Double acting hydraulic cylinder, 8 = Ring transducer, 9 = Hydraulic power system.

weight + 400 kg hydraulic weight) applied on the test tire (14.9 R 28) with the help of pressure relief valve. The tire was tested at two different bed conditions at different drawbar pulls until wheel indicate up to 15% S. Drawbar pull was applied with the help of drawbar loading device: S, drawbar pull and actual hydraulic normal load experience by the wheel were measured with the help of MGC plus data acquisition system. A program is written in matlab to calculate parameters like average pull, normal load, actual and theoretical velocity. These data were used to determine the COT, S and TE and angular velocity of the wheel. The final results appeared on a matlab screen with graphical display and during each experiment the final values were saved in an excel file.

## RESULTS AND DISCUSSION

### Performance evaluation of develop hydraulic circuit in dynamic condition on different soil bed

A hydraulic normal load of 400 kg was set on wheel carriage by using the developed hydraulic circuit on soft

and hard bed condition. The directional control valve was set in extending mode and the wheel was set in motion. During the entire process of run, the load fluctuated because of tire sinkage. The average dynamic normal load was found to be slightly more than the normal load that was kept initially on the tire. The normal loading behavior of the tire with drawbar pull for soft and hard bed condition is presented in Tables 1 and 2, respectively. The variation in dynamic load is shown in Figures 5 and 6 for soft and hard bed, respectively. The dynamic normal load on the radial tire was found to be 1 to 5% more than what was kept initially under static condition within 15% S on soft bed condition and 2 to 4.5% for hard bed condition.

## Conclusions

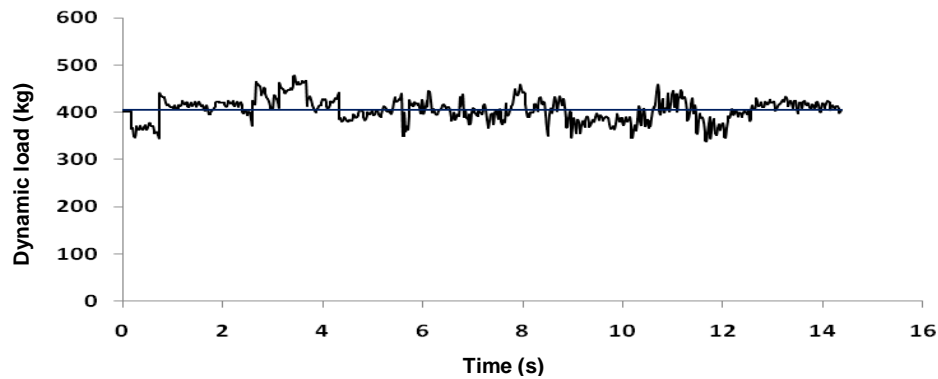
A hydraulically varying normal load application system

**Table 1.** Increase in hydraulic normal load during dynamic condition of radial ply tire on soft bed.

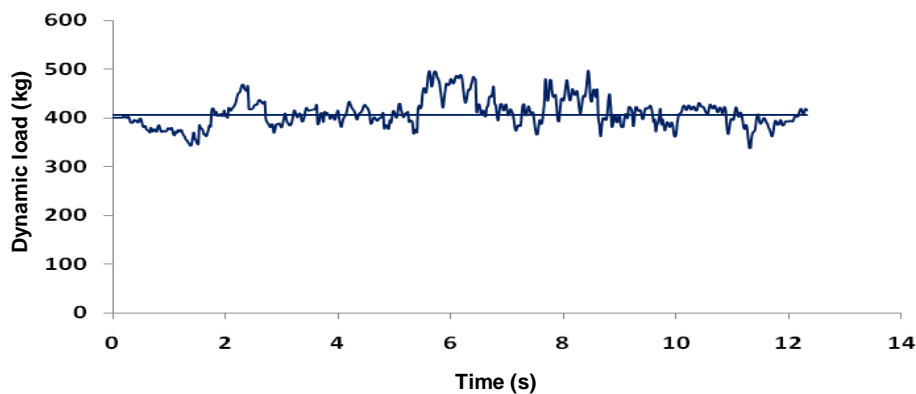
Pull (kg)	Slip (%)	Initial applied hydraulic load (kg)	Average Hydraulic Load during motion (kg)	Increase in load (kg)	Increase in load w.r.t. static load (%)	Standard deviation	RD (%)	Tractive efficiency (TE) (%)
64.65	1.29	400.33	405.05	4.72	1.18	23.10	9.41	49.58
227.83	4.63	400.01	408.85	8.84	2.21	23.82	9.51	63.36
315.63	8.33	400.47	416.87	16.40	4.1	27.76	11.50	67.97
391.03	15.65	400.17	420.21	20.04	5.01	29.42	9.85	64.98

**Table 2.** Increase in hydraulic normal load during dynamic condition of radial ply tire on hard bed.

Pull (kg)	Slip (%)	Initial applied hydraulic load (kg)	Average hydraulic Load during motion (kg)	Increase in load (kg)	Increase in load w.r.t. static load (%)	Standard deviation	RD (%)	Tractive efficiency (TE) (%)
61.45	1.90	400.35	407.95	7.60	1.90	25.58	9.70	25.92
238.64	6.29	400.23	411.39	11.16	2.79	26.50	11.97	52.62
357.34	12.36	400.63	414.37	13.74	3.43	32.23	13.45	70.75
420.64	15.55	400.42	418.47	18.05	4.51	28.74	11.51	65.95



**Figure 5.** Variation in dynamic load with time for pull 64.65 kg on soft surface under dynamic condition.



**Figure 6.** Variation in dynamic load with time for pull 61.45 kg on hard surface under dynamic condition.



instead of manual loading for traction studies of agricultural tires in a soil bin was designed and developed to reduce the drudgery of the labor. This system is simple and it has easy mode of operation. The hydraulically varying normal load application unit was tested rigorously and found satisfactory results. The designed and developed hydraulic loading device was capable of applying normal load of 2000 kg and lifting a maximum normal load of 1350 kg. The dynamic normal load on the radial tire was found to be 1 to 5% more than what was kept initially under static condition within 15 % S. The variation in soft bed condition was slightly more than that in hard bed condition.

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