Development of a tractor-pulled motion resistance test rig for traction studies on towed narrow wheels

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Abstract: This work presents the development of a test rig (tractor pulled) for measurement of motion resistance of towed narrow wheels with a view to obtaining new design information to enhance the use of narrow wheels as traction members for low cost agricultural machines affordable by the low income earners or rural populace whose occupation is predominantly farming. The narrow wheels that can be used on the developed test rig are pneumatic bicycle wheels of different sizes, rigid bicycle wheel, motorcycle wheel and lugged-rigid wheel for a planting machine. The towing force which is equal to the motion resistance will be measured by the Mecmesin Basic Force Gauge (BFG) with a maximum capacity of 2.5 kN installed on the test rig. The gauge is connected to a notebook with a Dataplot program to record the towing force and import the measured force per unit time to the spread sheet for further analyses. The test rig comprises two parts, one part holding the wheel and the second part hitched to the tractor, in between the two is the BFG to measure the towing force and it is RS-232 interfaced to notebook PC. The test rig is designed for field use on different terrains to make comparison and obtain enough data to assist in the design and development of narrow wheel agricultural machinery. The effect of the different wheel sizes, axle loads and inflation pressures on the motion resistance of the test wheels can be investigated easily using the developed test rig.

Keywords: motion resistance, traction, wheels, basic force gauge, data acquisition, tire design parameters
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1 Introduction

Narrow wheels are defined with respect to this research as wheels with smaller width sizes ranging from 35 mm to 100 mm. These include bicycle wheels, motorcycle wheels and motor scooter wheels. These narrow wheels could be pneumatic, rigid, pneumatic-lug, rigid lug or the non-lug rigid and pneumatic wheels within the category.

Motion resistance refers to the resistance to motion of a wheel caused by the absorption of energy in the contacting surfaces of the wheel and the soil upon which the wheel rolls. The motion resistance may be expressed as

$$MR = MR_c + MR_b + MR_t \quad (1)$$

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The total motion resistance force, *MR* is therefore made up of the MR_c, the component due to soil compaction, MR_b, the component due to horizontal soil displacement and MR_t, the component due to flexing of the tire. For vehicle operating on a hard surface, MR_t, constitutes the largest percentage of the motion resistance force and this, can be slightly reduced by increasing the inflation pressure and the effective stiffness of the tire. In off-road situations, however, the components MR_c and MR_b make up the largest proportion of the motion resistance force and increasing the inflation pressure and the tire stiffness have shown to increase the motion resistance[1].

Motion resistance may be described as the total drag opposite to the steady motion of a free motion wheel across a horizontal surface. It can also be defined as integral of the horizontal component of the radial stresses[2]. The later definition being suitable for a study of the nature of the stresses on the soil–wheel interface. Usually, the motion resistance is expressed in terms of motion resistance ratio (τ). Thus, mathematically, the motion resistance ratio is as expressed in Equation (2)

$$MRR(\tau)=\frac{MR}{W} \quad (2)$$

Where *MR* is the motion resistance force suffered by the wheel and *W* is the normal load on the wheel.

The performance characteristics of a towed wheel are described usually by a towing force (motion resistance), sinkage and skid. The most pertinent parameter of the towed pneumatic wheel is the motion resistance, which is influenced by the tire design, system parameters and terrain characteristics. In studying the soil-wheel interaction, the behaviour of the soil and the most important design parameters of the wheel form the basic inputs and need to be quantitatively defined[3].

Traditionally, design parameters of the tire include diameter of the wheel, section width, section height, inflation pressure and load deflection relationship. All these are considered to have varying degree of influence on the tire soil interaction[4]. The terrain characteristics include the types of soil, soil moisture content and its compaction level and the system parameters comprise the dynamic (normal) load on the wheel and forward speed[5].

In off road conditions, vehicle designers prefer to minimise the motion resistance in order to minimise the energy wasted to overcome the motion resistance[1]. The drawbar pull is a measure of the tractive performance of off road agricultural vehicle and it is related by Equation (3), decreasing the motion resistance, will increase the drawbar pull[6].

$$P=H-R \quad (3)$$

Where, *P* is the drawbar pull, N; *H* is the tractive force, N; and *R* is the motion resistance, N.

The motion resistance ratio is used to determine the mobility classification into good, fair and poor. High motion resistance indicates poor mobility, and Table 1 shows mobility classes based on motion resistance ratio.

Table 1 Mobility and trafficability classes based on motion resistance ratio

Mobility and trafficability class	Motion resistance ratio
Good	< 0.20
Fair	0.20 to 0.30
Poor	> 0.30

Source: (Saarilahti, 2003).

Many researchers have used various soil bin designs in the laboratory to control test conditions. The justifications for this include; better control of soil physical parameters[8] and setting of operation variables[9] and the possibility of replicating tests over short periods independent of weather[10]. However, it is difficult to simulate actual soil conditions in a soil bin. In cases where a tool is to be tested over a wide range of soil types, the economic implications of the soil media would be enormous[11]. Considerable theory in tillage mechanics and tire traction testing devices has been substantiated from soil-bin and laboratory experiments. However, verification under realistic field conditions is always necessary[12].

Different designs of single wheel testing devices have been developed for indoor traction testing[13-18]. Other researchers developed on field tire traction testing devices for wider agricultural tires[19-21]. All these devices measure at least the input parameter torque *T*, and rotational speed ω, and the output parameters, pulling force F_p and the driven velocity v of the wheel[22].

A lot of efforts have been put towards the development of accurate and convenient instrumentations for traction and tillage researches. Tractor is a traditionally self propelled machine that has been permanently instrumented[23-26]. On-board computers and auxiliary instrumentations have been used for signal conditioning, data processing and storage[25,27]. Higher Considerations are given to portable instrumentation on traction test devices and source of power[28,29]. Owonde and Ward[11] reported that the cost of an instrumented tractor is high and the instrument is bulky, relatively complex and special attention is required to guarantee reliability. In remote areas, there is need for elaborate power source.

Advances in electronic data acquisition systems have made measurement in traction studies reliable, easy and convenient. Traction studies under realistic conditions is now possible through the use of sensors interfaced with portable computers and data loggers[11].

Data-loggers have been used to excite and records the output signals from load cells and other compatible transducers[26,29-32]. Portable computers can be battery powered. It makes data processing possible on the field so as to detect faults immediately in the measurement system and the expected trends can be confirmed[11].

The agricultural mechanization strategies of developing and the developed countries are not identical and the adoption of such by the developing nations has failed because of the misplaced strategies and wrong adoption processes. These constraints are: paucity of fund to procure agricultural equipment, land fragmentation and lack of technical know-how on maintenance and repair of such equipment. Therefore, simple and low-cost appropriate machines will help to increase the productivity of the developing countries' agriculture. Hence, agricultural mechanization development in developing countries is the key solution to increased agricultural productivity and economic survival[33]. Therefore, the objective of this study was to develop a simple motion resistance test rig for all terrain traction testing for narrow wheels especially the non-lug type with the auxiliary instrumentations installed. This would facilitate research on the use of narrow wheels for low cost and easy to maintain agricultural machines with narrow wheels as traction members for low income farmers and rural dwellers with additional advantage of causing less compaction on agricultural field as the compaction caused by narrow wheels of higher inflation pressure is less than that caused by wider wheels of low inflation pressure[34].

2 Design requirements

The developed motion resistance test rig is simple and suitable for both laboratory and field motion resistance studies for narrow wheels. It has the following features.

1) It is portable and collapsible (assembly and dismantling) for ease of movement to the field and in the laboratory.

2) It is made from readily available materials such as hollow pipe, angle iron and mild steel that make it simple to construct, repair or replace.

3) It can accommodate various narrow wheels in the specified categories without any modifications.

4) The data acquisition system can easily and readily be powered by batteries which can last for a number of runs before being recharged.

5) It is painted to allow usage in all weather without fear of corrosion and or rusting.

3 Components and description of the test rig

The motion resistance rig was designed to measure the towing force of a single test wheel when towed by a tractor. The towing force was equal to the motion resistance of the wheel. The motion resistance of different narrow wheels can easily be measured with this device on various terrains to obtain new design information for narrow wheels especially the non-lug type under the specified categories.

The motion resistance test rig is a very simple apparatus which comprises the frames, the BFG, the connecting links for different parts and cables/connectors for the transmission of the signals or measured quantity from the BFG to the notebook. The test frames are divided into two parts (i.e. the first part that is hitched to the tractor and the test frame holding the test wheel) and connecting links. The platform on which the BFG was horizontally placed to pull, measure and record the towing force is permanently welded to the centre base of the three point hitch connecting frame and behaves as a single unit (Figure 1). On either sides of the three-point hitch connecting frame were two vertically placed parallel 30 mm×30 mm angle iron 800 mm apart and 290 mm long each. A groove of length 80 mm and width of 12 mm each was made 20 mm from the top end of the angle iron that is fixed to the three-point hitch connecting frame for adjusting the height of the test rig when necessary and to serve as a connecting link. To the lower end (20 mm) of this angle iron, was welded a 50 mm long 10 mm rod, to be inserted in the groove made on the elongated side bracket as described below.

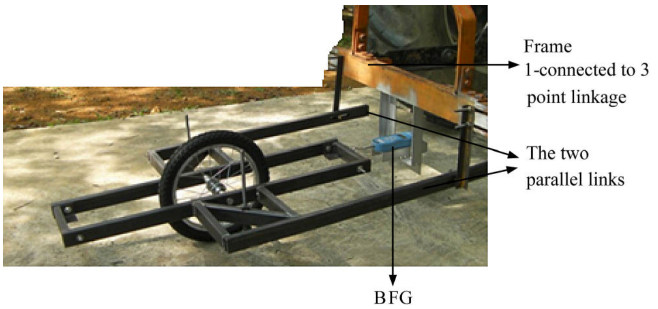
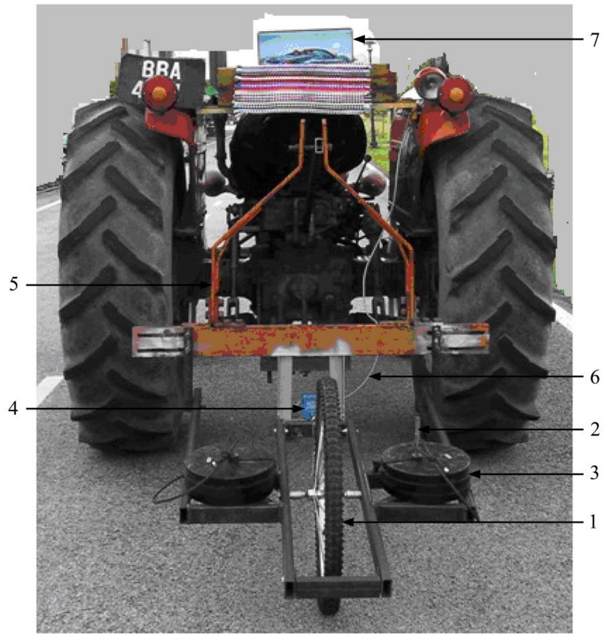


Figure 1 Two parallel links and the Mecmesin BFG

The second part of the frame which was made of mostly rectangular (25.4 mm×50.8 mm×2.7 mm) hollow mild steel and angle iron of (25.4 mm×50.8 mm×2.7 mm) holds the wheel and the various vertical loads (dynamic load) whose effect is to be investigated in the studies (Figure 2).

The frame holding the test wheel at the centre was made from 2 parallel hollow rectangular mild steel (25.4 mm×50.8 mm×2.7 mm) with a total length of 1 100 mm, long enough to accommodate 900 mm planter rigid-lug wheel and 660 mm diameter pneumatic bicycle wheel with enough clearance at both ends for free rotation of the wheel. A side bracket of 250 mm× 250 mm was welded to the centre of each of the two parallel hollow mild steel holding the test wheel. The outer side of the bracket was elongated to a length of 1 000 mm with a groove length of 100 mm and width of 12 mm from the top end (100 mm) of the elongated side bracket. A 310 mm long hollow mild steel of the same dimension was welded diagonally to the side bracket for rigidity and a 12 mm hole was drilled at the centre to hold the 12 mm steel rod in which the various dead weights are placed. A total of 491 N (50 kg) dead weight can be hanged on each side bracket during the studies. The two ends of the parallel hollow mild steel were connected by 200 mm hollow mild steel of the same dimension joined by an angle iron (50.8 mm ×50.8 mm×2.7 mm) via 8.5 mm bolts and nuts. The top end close to the tractor was connected to the hook on the BFG by a cable for pulling test rig (test frame and the wheel).

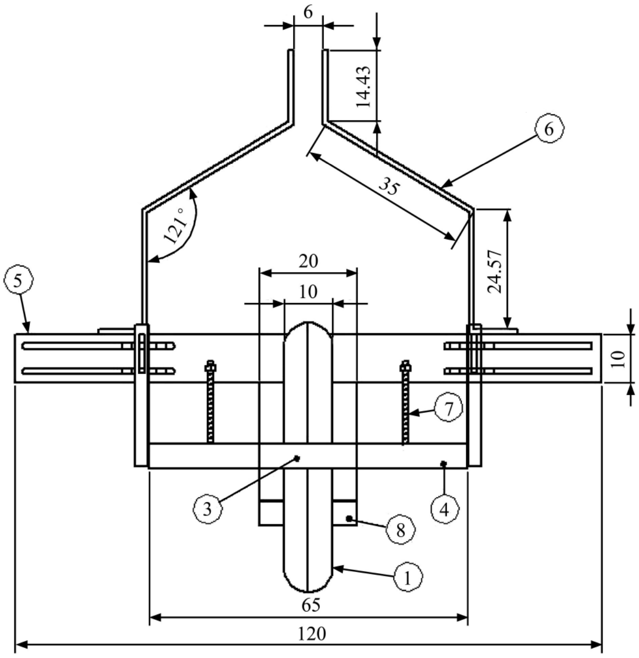


1. Test wheel 2. Load hanger 3. Load 4. The BFG
5. Three-point hitch frame 6. Connecting cable 7. Notebook PC

Figure 2 Complete test rig coupled to the tractor during field test (paved surface)

The connecting link: The 10 mm rod at the tip ends of the two vertically placed parallel angle iron described above is inserted into the groove made on the elongated side bracket and hold the test rig (frame and the test wheel) in position during testing. The BFG placed on the first part of the frame is connected to the test frame via the cable attached to the BFG hook. With the aid of the groove and the connecting cable, the test frame oscillates within the groove and allow for vertical and the horizontal movement of the test frame during field test.

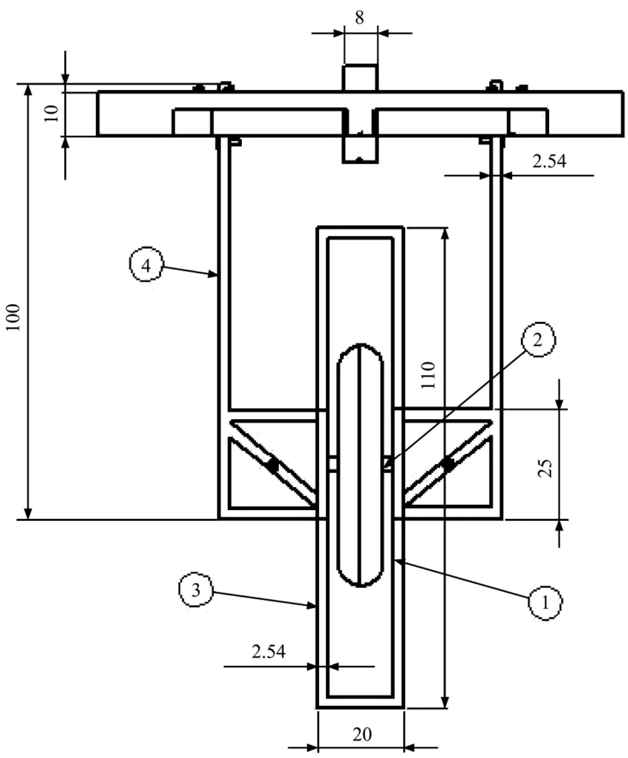
The dynamic (vertical) load comprising the weight of the test frame, test wheel and the added dead weight were measured in the laboratory using the multi-function bench scale (AND HW-100K). These loads rest on the test wheel shaft at the centre of the test rig (Figures 3A-3C) and the tire deflection could be measured for further analysis.



All dimensions in cm

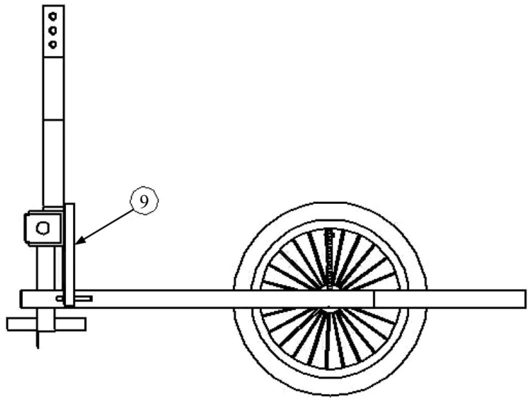
1. Test Wheel 2. 3. Centre Rectangular Frame 4. Side bracket
5. 3-Point Hitch connector base frame 6. 3-point Hitch Connector
7. Load Hanger 8. Platform for BFG

Figure 3A Back view of the test rig frame

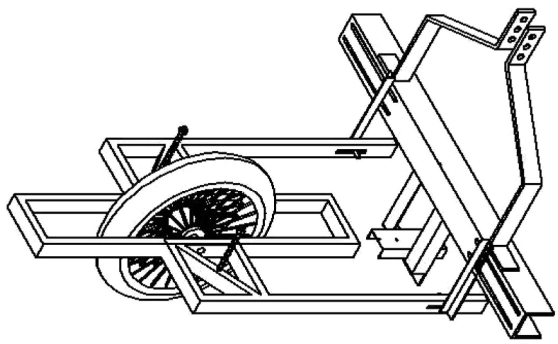


1. Test Wheel 2. Wheel shaft 3. Centre Rectangular Frame
4. Side bracket

Figure 3B Top view of the test rig frame



Side view of the test rig frame



9. Connecting link

Figure 3C Isometric view of the Test Rig Frame

A plank platform was improvised on the tractor at the back of the operator's seat to place the notebook PC for ease of data acquisition. The size of the notebook PC was a determining factor in the design of the platform. The base of the platform was perforated to air-cool the HP Pavilion dv6000 notebook PC.

Figure 2 shows the complete motion resistance test rig containing the two connecting frames, the test wheel and the data acquisition systems coupled to the tractor to tow during the field test/data acquisition.

4 Basic Force Gauge (BFG 2500)

This BFG is manufactured by Mecmesin Limited, UK. The Mecmesin BFG is a member of a series of highly versatile display units. It is made up of integrated circuit technology. It can be used to measure tensile and compressive forces accurately either in Newton, kgf or lbf. It has 19 mm diameter compression plate, test hook, 30 mm long extension rod to make measurement and readings easy.

BFG can be powered directly from the mains via the adapter or by rechargeable alkaline AAA batteries supplied together. It has a digital LCD display to make reading easy and for display of input through the keypad (control panel containing 5 keys and the on/off key), accuracy of ±0.25%, resolution of 1:5 000 and sample rate of 1 000 Hz. It is also equipped with data output: RS 232 Mitutoyo digital or analogue. The maximum load capacity it can measure is 2 500 (2.5 kN) and it shows an overloading warning in case the maximum capacity is exceeded.

5 Data acquisition system

The data acquisition system for the test facility comprised the BFG that is RS-232 interfaced to HP Pavilion dv6000 notebook PC with installed Mecmesin Dataplot software.

The complete Dataplot software is capable in real time to record the measured compression or tension forces per unit time as specified and a plot of the graph showing the forces measured in desired units against time intervals. The maximum force can be determined from the graph and the area under the curve can be determined all in real time.

The data used for the plot can be imported to a spread sheet (Microsoft Excel, lab view or any other specified programme) for further analyses. Figure 3 shows a sample of data acquisition obtained during the field test, and shows the maximum, minimum and the mean towing force recorded during the field test on a tarred surface using a bicycle wheel diameter of 20” (51 cm) when a vertical load of 316.7 N (weight of the frame and the test

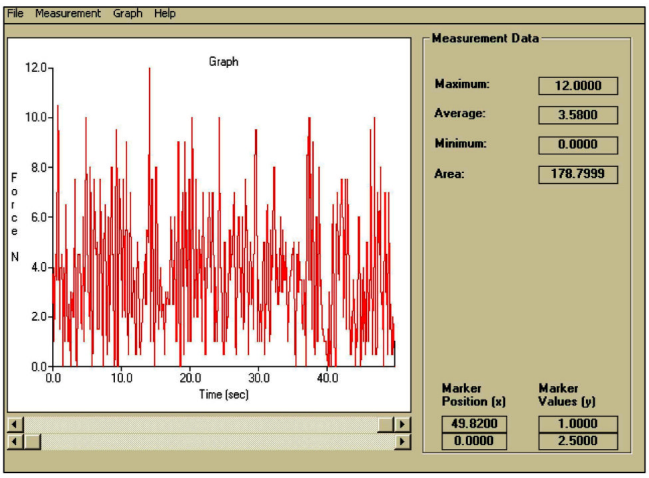


Figure 4 Sample of data obtained during a field test on paved surface

wheel inclusive) at an inflation pressure of 40 Psi. The area under the force-time curve is also calculated and recorded and shown in Figure 4. The area under this curve is visualised as the impulse (F.t, Ns)[35], which increases as the magnitude of the towing force increase per second.

6 Conclusions

A single wheel motion resistance test rig has been developed that can be used to determine the motion resistance of narrow wheels for traction studies with a view to obtaining new design information for the development of low cost and easy to maintain agricultural machinery and equipment with narrow wheel as traction members. The effect of different inflation pressures and various vertical loads on the motion resistance of the narrow wheels can be investigated on different terrains. The total expenditure for the development was US $1 500. This test rig has proved to be simple and convenient for motion resistance studies for narrow wheels.

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