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Model Tractor Teaching Tool

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Abstract

A model tractor was developed to teach students about power consumption and wheel slip of farm tractors. The model was selected because of safety and resource issues. Using this model in the lab provided a safe and quiet atmosphere where the principals of power consumption and wheel slip could be demonstrated and learned. The students that participated in the lab appeared to grasp the concepts that were presented.

***Keywords*:** Agricultural safety, agriculture education, teaching tools, power consumption, wheel slip.

Introduction

Engineers are well aware of the value of constructing models to evaluate complex water structures, buildings, and other engineering structures. Models help designers effectively study performance before actual construction (Schuring, 1977; USBR, 1980). Models can also provide hands-on experiences for learners to develop a working knowledge of critical concepts and procedures (Riskowski et al. 2009). Educators often agree that hands-on laboratories help demonstrate the concepts that are presented in class (Torraja et al 2005). Well-designed laboratories build understanding through first hand experiences.

There are numerous papers that describe the benefit of developing a model to provide hands-on training. Flick (1993) describes how properly designed hands-on models are important to develop deeper understanding in students. Pella and Ziegler (1967) report on how hands-on models build a greater understanding in elementary students. A complicated process called thermohaline circulation is demonstrated with a model defined by Dudley (1984). Riskowski et al. (2009), present a study where students better understand water treatment by involving them in the construction of a water purification model. Fundamental geology and hydrology concepts are demonstrated in a simple hands-on model of a dam (Passey et al. 2006). Ali et al. (2009) report on a study where students are taught about trauma patient treatment using a real person and a mechanical model. In this study, the students preferred using the mechanical model. Aerodynamic principals were taught to middle school students using models in a wind tunnel. Students that participated in this study became more involved in class and more interested in engineering (Pols et al. 1994). Evans and Ray (1954) report on a study where a larger model and a regular micrometer were used to instruct students on their use. In both cases, the students achieved equivalent understanding. Torroja et al. (2005) specify an electro-mechanical model that is used to teach students about microcontroller control. In many cases, instructional funds are limited so Kulkarni et al. (2008) specify an inexpensive power engineering laboratory that gives students hands-on training and deeper understanding of important concepts. Krein and Sauer (1992) also describe a power engineering lab that is used to safely teach power engineering principals in a safe environment. Power engineering laboratories are also reported by Balog et al. (2005), Jewell and Banavasi (2005), Nwankpa et al. (2005), and Mohammed et al. (2005),.

Models have also been developed to demonstrate agricultural principals and concepts. Bruns and Byrne (2004) describe a model that shows how soil organisms interact with soil. They claim that this model helps students and adults understand the various processes that occur between the microorganisms and the soil particles. Poe et al. (1994) present a model of an agricultural confinement barn that can be used to teach heating and ventilation principals. A hydrostatic transmission test stand is reported by Cundiff and League (1988, 1990). This test stand is used to teach students about the operation and characteristics of hydrostatic transmissions that are found in lawn and garden tractors and farm machinery. Johnson et al. (1991) present a device for teaching students about row planters in the laboratory. Several different makes of planters are used in this device to expose students to the varied technologies. This laboratory unit was used to teach students about problems that occur with planters and how they can be corrected. Dickinson et al. (2007) developed a compact variable rate sprayer that is guided by global positioning system (GPS) technology. This device was developed to educate farmers, secondary school teachers, extension agents, and students about GPS technology.

A need exists to create a safe and challenging environment to teach students about power efficiency and fuel efficiency.

There are several reasons to utilize models. Safety is essential (Lehtola & Boyd, 1992; Thompson & Garton, 1997), especially when utilizing large and dangerous equipment. Models are also useful when time is of the essence during laboratory sessions and class size is unmanageable to effectively and efficiently put all of the students through the laboratories. Financial resources may also limit using a full scale example so a lower cost model can be used instead. In some cases, proper facilities may not be available. Set up time may be an additional constraint considering that it often takes less time to set up a model rather than travel to or set up a full scale system. When budgets are limited and student safety concerns are a high priority, relying on models, especially in farm power laboratories are a realistic alternative. Using agricultural models are less expensive, more convenient, provide a safer lab environment for students, and they can be used as a program recruiting tool.

Regardless of the demonstration equipment being used, the previously mentioned researchers all agree that learners need to be engaged in the learning process and hands-on opportunities must be available. For these reasons, a hands-on model tractor was developed for teaching proper ballasting and how ballasting affects power consumption.

Using a full size tractor to demonstrate wheel slip may be just as easy as using models because a tractor and tillage implement, an accessible field, and tractor ballast, are sometimes more accessible. If there is reasonable weather and a means of measuring distances, the lab could be conducted with little preparation time. However, considering that large machinery is being used and several students are in the laboratory, there is a potential for injury. Hopefully, the students are supervised and the likelihood of injury is low. However, the potential for a mistake is increased as the class size increases. In a ballasting lab, it is desirable to change the weights to demonstrate how they affect wheel slippage and power use. Changing the ballasting on a full size tractor is dangerous, time consuming, and inconvenient. Most tractor wheel weights are at least 80 lbs and in most cases, have to be bolted to the tires. On the other hand, changing the ballast weights on a model tractor is much easier and safer.

If a ballasting lab is combined with a tractor power consumption lab, more specialized tools are required. A means of measuring the fuel consumption and a pull dynamometer are also required. An apparatus that can measure fuel consumption is relatively easy to fabricate, but a pull dynamometer is expensive and data collection is problematic.

A tractor model (Figure 1) can be constructed so that power consumption can be measured, weights can be easily mounted and removed, pull can be measured, and wheel slip can be estimated. All of this can be accomplished in the classroom or laboratory and there is limited opportunity for student injury. The model also provides plenty of opportunity for students to be involved and engaged in the learning process.

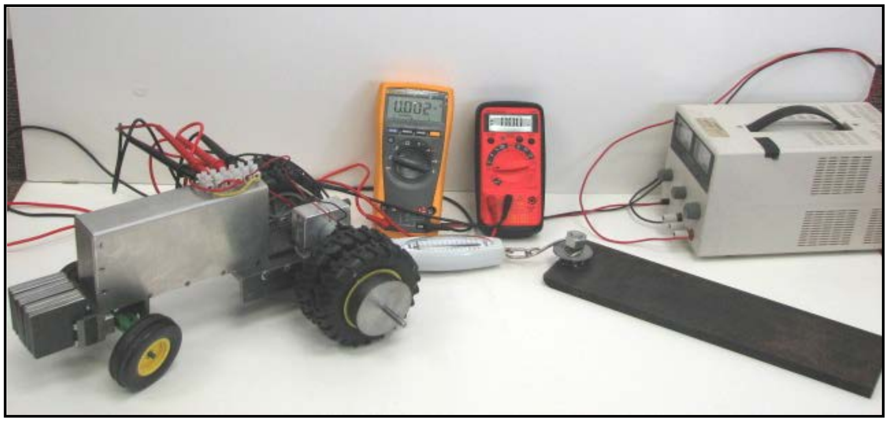

Figure 1. Model tractor, spring scale, sled, multimeters, and power supply.

Tractor Model Design

A DC motor was selected to power this model because it was easy to measure voltage, current, and calculate power consumption from these two values. The power input to the motor can be varied in order to control model speed. An AC motor may have been used, but varying the input voltage to control speed may cause problems with this motor. Both DC and AC motors are quiet and make it easier to communicate in a lab environment. Verbal communication is better with these quiet models compared with teaching outdoors while an internal combustion engine is running. The quiet lab environment allow for students to easily understand instructions. DC motors are relatively inexpensive and easy to install. The motor that was used on this project was capable of consuming about 0.1 amps at 24 volts DC under full load. The motor was geared to turn at 50 rpm and produce 3.6 inch-pounds of torque. It is important to use a motor with a minimum of these specifications because a motor that uses less current and voltage may stall. It should be noted that this tractor was not built to scale. Building the tractor to scale would complicate construction. Considering that this model was developed to teach principals of slip and power consumption all that is required is that the students understand the concepts that are being demonstrated. The model was made to look like a tractor to help the students understand the application.

This tractor was designed using wheels from 16th scale toy tractors. Wheel parts of this size are readily available which made for easy design and fabrication. An initial concern was for the solid mounting of the drive wheels to the drive axle. Hubs were machined out of 2 ½ inch cold rolled steel and mounted inside the rim of the toy tractor wheel (Figure 2). A 1 ¼ inch long Allen screw extends down through the radius of the wheel hub to the drive axle. The 1 ¼ inch long Allen screws fastened the hubs to the drive axle. These hubs fit inside of the toy tractor wheel rim.

Figure *2*. Wheel hub and wheel. Screws go through holes on the wheel into the wheel hub. An Allen screw is located at the top of the hub that fastens the hub to the drive axle.

The rear frame was constructed of ¼ inch thick steel plate (Figure 3). The sides are one inch wide and 4 inches long while the top of the frame is 2 ½ inches wide and 4 inches long. The sides are attached to the top of the frame using screws because welding these components would likely warp the frame and make it difficult to achieve proper alignment. Considering that this model was developed to demonstrate energy use of a farm tractor, it is not desired that energy is lost because of improper alignment.

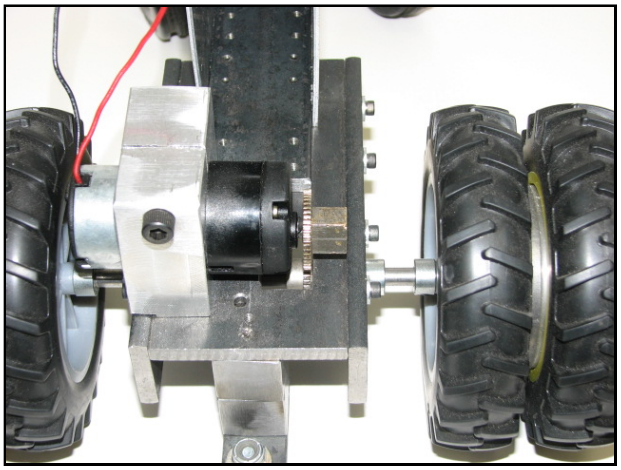

Figure 3. Rear frame of the tractor.
The DC motor is held in place with a pinch clamp.

Holes were drilled in the side of the frame so that ¼ inch bearings could be slid inside the holes. After the bearings were placed in the side, the frame was laid on a flat surface and a center punch was used to make 3 to 4 small divots in the metal close to the bearing so that the bearing was held in the frame by a friction fit. Divots were placed around the bearing on the opposite side to ensure that the bearing was mounted securely (Figure 4).

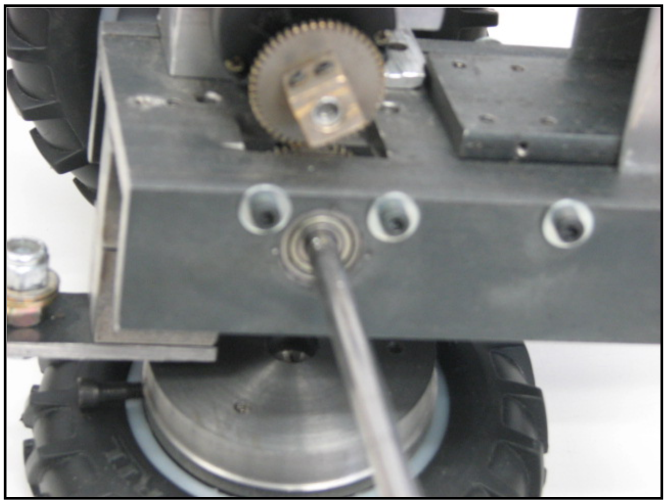

Figure 4. Bearing mounted in the rear frame. Divots that secure the bearing to the frame can be observed around the circumference of the bearing.

Steel plate that is 1 ½ inches wide, ¼ inch thick, and 7 inches long was selected for the front portion of the frame (Figure. 5). The housing was constructed from 16 gage aluminum (Figure 6). The housing was fastened to the front frame with number 4 screws. Two tabs extended down from the front frame that allowed for mounting the front axle and wheels (Figure 7). A box frame was mounted to the front of the frame to allow for weights to be easily mounted to the frame (Figures 6 & 7).

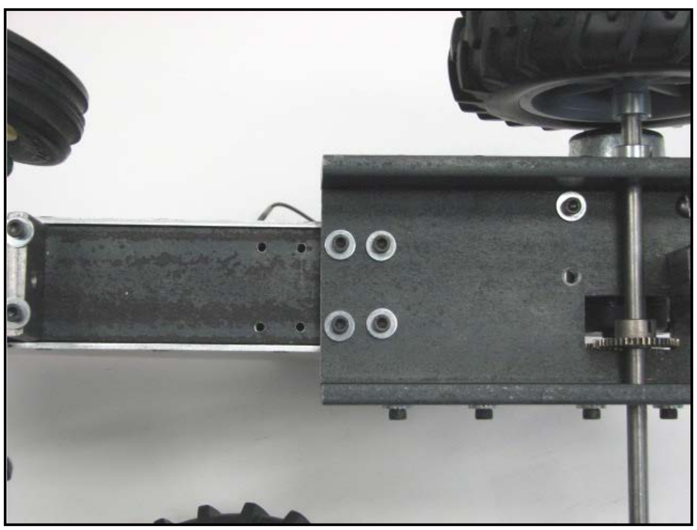

Figure 5. Front and rear portions of the frame.
The front frame is mounted to the rear part via Allen screws.

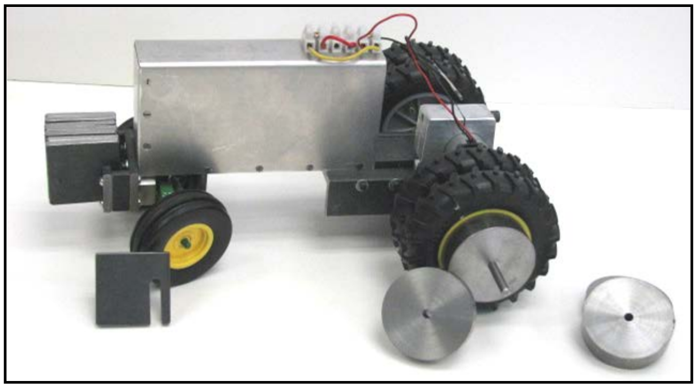

Figure 6. Tractor with front and rear weights.

Weights were fabricated from steel to act as front end and wheel ballast. The front end weights were cut with a slot so that they would slide in place as shown in Figure 6. The rear wheel weights were machined to slide onto the rear drive axle. These weights were machined to the same size for uniform loading. These weights were designed to be slide on and off with no fastening mechanism. The rear wheel speed was slow enough that the weights stayed in place as the tractor was moving.

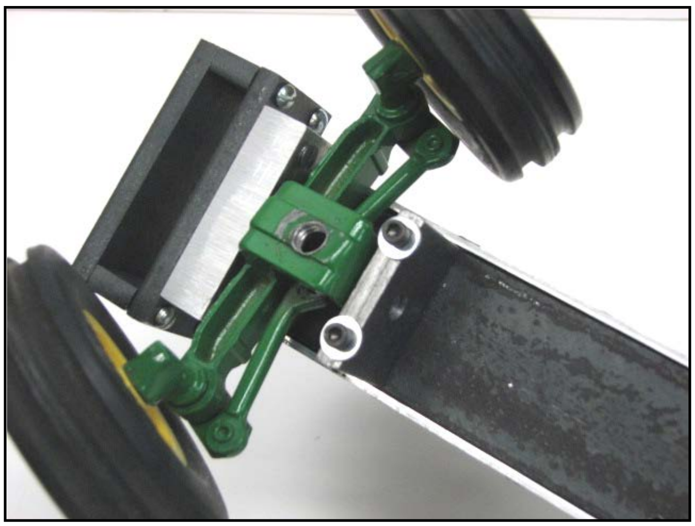

Figure 7. Front axle and box assembly for mounting weights.

In order to demonstrate slip and power usage, a means of loading the tractor had to be provided. A sled was constructed of ½ thick, 4 inch by 12 inch piece of steel (Figure 8). The front edge of the sled was beveled to allow it to slide easily on a test surface. A pin was welded to the front of the sled to attach a spring scale. Additional weights were constructed from flat metal that were 4 inches by 4 inches and ½ inch thick. These weights were used to provide additional loading as required.

Figure 8. Sled, weights and spring scale.

Amperage is measured by placing an ammeter in series between the motor and the power supply (Figure 1 & 9). A second multimeter that is set to measure voltage was connected in parallel with the motor. Approximate power consumption in Watts can be determined by multiplying voltage by amps (See the example calculations below.).

Wiring

An electric motor was selected for this model for several reasons. The motor is quiet and it allows for better verbal communication during the lab. Electric motors are readily available. The motor can be wired to start and stop remotely. It is convenient and easy to compute power consumption. It should be noted that Figure 1 shows an AC to DC power supply. This is perhaps more convenient to use because it can be plugged into the wall and the DC output voltage can be adjusted to control the model speed. Special care must be taken to make sure that no one trips on the extension cord. Figure 9 illustrates the wiring diagram for this model.

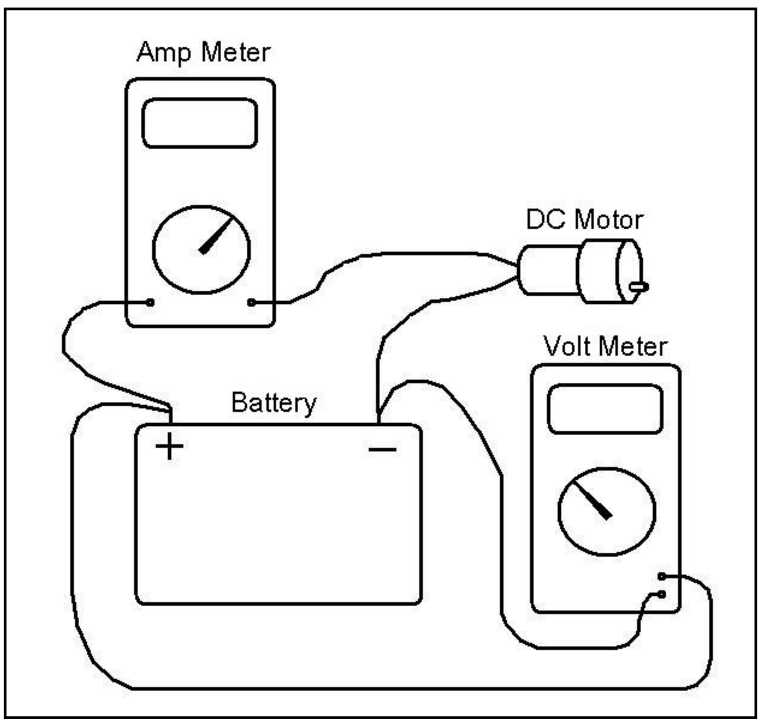

Figure 9. Wiring diagram of the power measuring circuit.

Teaching Methods

The Model Tractor utilization methods described below engage students and hold their attention throughout the lab. Several students are given tasks that everyone within the team relies on. With one model tractor, one lab activity could involve up to 12 students.

(1)	Student running the power supply		
(2a)	Student reading pull on the scale	(2b)	student recording
(3a)	Student counting wheel revolutions	(3b)	student recording
(4a)	Student reading volt meter	(4b)	student recording
(5a)	Student reading current meter	(5b)	student recording
(6a)	Student running the stop watch	(6b)	student recording.
(7)	Student directing the tractor		

Power Output

Power output was determined by first measuring the time it took the tractor to travel a specific distance while pulling the weighted sled. A person was required to take pull readings while the tractor was moving. The tractor moved slowly enough that it was not difficult to take readings from the spring scale. Example calculations of power output are shown below.

Ballasting and Slip

Ballasting and slip measures are determined by first running the tractor with a load and counting 10 wheel revolutions (Leviticus et al. 1996). While the tractor is travelling this distance a person must record the time that it takes for the tractor to travel this distance. The distance must also be recorded. The tractor is then unloaded and run the same distance. The wheel revolutions must also be counted to the nearest ¼ turn. If the number of wheel revolutions for the unloaded test was 8.25, wheel slip can be determined from the following relationship.

$$Slip = 100 \times \frac{10 - \#\ revolutions\ without\ load}{10}$$

$$Slip = 100 \times \frac{10 - 8.25}{10} = 17.5\%$$

The model tractor is designed so that wheel weights and weights can be added and removed quickly and easily so that students can change the weights and test the tractor under different ballasting conditions.

Power Measurement and Calculations

Power consumption is straight forward to determine because the model uses a DC motor. Two digital multimeters are required so that voltage and current readings can be taken while the tractor is operated. The ammeter must be connected in series between the power source and the motor. The voltage meter must be connected between the hot and neutral connections of the motor. A terminal block was mounted on the tractor to facilitate connecting the voltage and amperage meters (Figures 1 & 6).

For example 20.9 VDC and 0.08 amps were measured for one test. At the same time the tractor travelled 9.5 feet in 27.24 seconds and a pull of 2.8 pounds was recorded from the spring scale. The power consumption calculations are as follows:

Power in HP = $\frac{V \times A}{746\, watts/HP} = \frac{20.9 \times 0.08}{746} = 0.0022\, HP$

Power out HP = $\frac{S \times P}{550\, lb\, ft/\sec HP} = \frac{(9.5/_{27.24}) \times 2.8}{550} = 0.0018\, HP$

It is important that the students also have an understanding of efficiency. The calculation is also easy to determine.

Efficiency Eff = $\frac{Power\ Out}{Power\ In} \times 100\% = \frac{0.0018}{0.0022} \times 100 = 81.8\%$

These numbers may vary depending on test surface, tractor weight, motor efficiency, and measurement error. Hunt (2007) estimated that drawbar efficiency for a properly ballasted tractor should be around 80%. The experimental data used here validates this, but it may not be for other tractor models.

Conclusions

This tractor model and described lab help show that there are always losses due to inefficiencies in the machine. The data from this experiment can be used to discuss the reasons why there are losses in the system. Losses in motor efficiency can be attributed to friction in the bearings and losses in the motor windings. There are also losses in the drive gears between the motor and the drive axle. The drive axle main bearings will also have losses. Finally, there are losses at the wheels due to slip.

Even though the losses have been demonstrated on a model tractor, the instructor can draw comparisons to a full size tractor. A full size tractor has bearings in the motor as well as gears in the drive system, and bearings in the drive system. A full size tractor will also have losses due to wheel slip. One loss that is not covered in this lab is the heat energy loss that happens with an internal combustion engine. Over 50% of the fuel that is consumed by an internal combustion engine is lost in heat energy (Goering and Hansen, 2008). Some comparisons may be drawn between heat energy loss and electric motor winding loss.

There is an additional benefit to using a model for lab instruction. Because there are several students that are involved in the lab, there is a high possibility that one of the students will make a mistake in taking a reading. Using the model makes it very easy to simply conduct the test again. This helps to make sure that the test data is valid for the data analysis and lab write-up.

After the weights are added to the tractor model and the traction/power test is conducted again, the students could observe how ballasting affects power and efficiency. The students will be able to see that there is less wheel spin as weights are added to the tractor. In addition, the data analysis shows the effects of ballasting on wheel slip.

Upon use of the tractor model, the instructor explained calculations to the students (*n = 16*). Only one student made a small mathematical error. Two students failed to give a reasonable explanation about how ballasting reduced slip and increased efficiency. Reflecting on the overall efforts of these students, it is believed that they did not want to put the effort in to explaining this.

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