A Cost-effective Laboratory Setup for Engine and Chassis-Dynamometer

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Abstract:

Trine University's Mechanical Engineering program has seen frequent requests in surveys from graduating seniors and alumni to focus on hands-on experience in the undergraduate program. Along with that, there has also been a focus on participating in competitions such as Shell-Eco Marathon by seniors for their capstone project. An opportunity arose to address both these issues by building an engine/chassis dynamometer.

A funding request has been granted by a robotics company paving the way for design and build of an engine/chassis dynamometer. The dynamometer, in its first iteration, cost about $10,000 but a revised design costs under $8,000. The dynamometer has been designed for Shell Eco Marathon competition but has found its uses in multiple projects over the past year, including a summer toboggan redesign for a local state park. The dynamometer is being used in courses such as senior design, system dynamics and controls, and mechanics of machinery, mostly to teach concepts such as energy accounting, gear/drive trains etc...

The design of the dynamometer and a list of the components are presented in this paper. The cost of each component is also presented along with suggestions to reduce cost for more cost-effective designs. It is hoped that this design will result in undergraduate institutions building dynamometers for use in their engineering programs, and even improve the design to make it more cost-effective.

Introduction:

Trine University's Mechanical engineering program uses graduating seniors' survey and alumni survey to improve the program on a continual basis. One of the consistent themes of the feedback has been to incorporate more hands-on experience/experiments in the program.

The Mechanical Engineering program's senior design includes participating in design competitions like Shell-Eco Marathon. Students have been participating in the competition for more than a decade and there has been a consistent handicap in terms of quantifying losses. Design teams have been perpetually hampered by lack of insight into the proportion of losses in different components, most importantly, the ever-elusive drivetrain losses.

Other design teams with similar requirements had to be content with guessing the losses during the design process and hence fell short of meeting the requirements in the build-phase during the second semester of senior-design.

To address all these issues, an opportunity arose when a grant for funding senior-design projects was approved by Denso Foundation, associated with its eponymous company whose expertise lies in robotics. A funding of $50,000 was approved for various senior-design projects and a funding of $10,000 was allocated for the senior-design team tasked with designing and building a Chassis/Engine/Motor dynamometer with track simulation. The design team was originally composed of three mechanical engineering seniors but after one member dropped due to health reasons later in the first semester, the senior-design team consisted of two mechanical engineers.

At the outset, the team lacked experience in motors, variable frequency drives (VFDs), and data acquisition but overcame the obstacles to produce a working dynamometer that met the requirements set for the project. The requirements were to design a chassis/engine/motor dynamometer to:

- Be able to test a 2HP, Honda GX 50 engine, through its power and torque range.
- Be able to test a 1.5 kW, 6000 RPM brushed DC motor through its power and torque range.
- Be able to test chassis of vehicle running using the engine/motor mentioned above.
- Be able to provide track-simulation and obtain real-life efficiency of a vehicle.
- Validate obtained measurements.

This dynamometer was designed and built during the academic year 2016-2017. During the ASEE conference 2018 in Salt Lake City, one of the authors attended a presentation [1], which inspired the author to publish the functional design achieved at Trine university. The authors also investigated an Engine dynamometer design [2] (published in 2002) which lacked focus on powertrain, which was priced at around $3000 (in 2002 dollars). Another paper published in 2003 [3] also focused on engine dynamometer but the cost was not provided.

Description of Design:

The design of the dynamometer can be broken down into the following significant components:

1. An absorbing (inverter-duty) AC motor
2. A VFD to regulate energy flow
3. A resistor to dissipate energy (as heat) from engine, when it exceeds AC motor's dissipative capacity
4. A roller to test chassis. Engines/motors can be tested by disengaging the roller.
5. A data-acquisition (DAQ) system for ease of use/control and for further addition of functionality.

The VFD and the motor are selected to meet the torque/speed requirements for a Honda GX 50 and a 1.5kW, 6000 RPM brushed DC motor. Gearing is included in the design to meet such a wide range of torque and speed. The motor is selected to be inverter-duty so that it can provide assistance torque (during track simulation) and resistance torque.

The dynamometer needs to provide both assistance torque and resistance torque to meet the track-simulation requirement. A brake resistor is needed to provide resistance torque as the VFD diverts power to the resistor when the motor is providing resistance torque. The brake-resistor can be avoided if the energy produced during resistance-phase of VFD is diverted to the grid by the VFD by purchasing an accessory or using a regenerative drive instead.

The following Table 1 provides the parts list used for the design. **Figure 1** shows a picture of dynamometer as built by the students.

Table 1: Bill of Material for original design

Component	Part Description/#	Price
Motor+ Encoder	3HP BALDOR 1750RPM 184TC TENV 3PH MOTOR IDNM3661T	$1,193.40
Brake Resistor	PowerOhm braking resistor R2-5A10	$449.00
Data Acquisition (NI + Labview)	cDAQ 9178, NI 9263, NI 9402, NI 9472, NI 9216, Labview	$4,335.67
Roller	Custom Made	$525.00
Frame Material	80/20 Extruded aluminum	$799.89
VFD	3 HP ABB ACS880-01-10A6-2+B056 Wall Mount Variable Frequency Drive with Basic Keypad	$1,300.07
Torque Transducer	Rotary Torque sensor, Lorenz Messtechnik gmbh, DR-2	$450.00
Misc	Couplers, wiring, brackets	$1,000.00
Total		**$10,053.03**

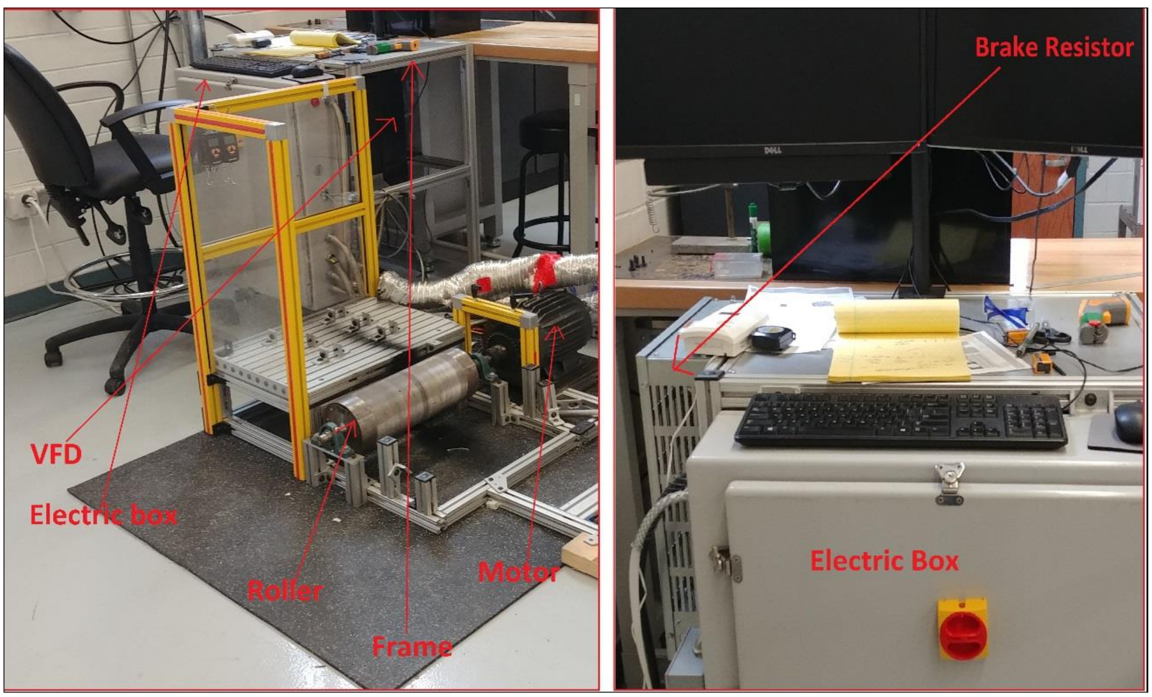

Figure 1: The dynamometer, as built by students

Validation of Measurements:

The VFD provides measurements of torque and speed (RPM) which is used to characterize a motor/engine. The measurements, however, needed to be validated.

The manual for ABB drive claims a dynamic speed error under 0.4% of the measured value. A hand-held Omega tachometer was used to validate the speed measured by the VFD, which turned out to be accurate as stated.

The manual provided by the manufacturer of the VFD (ABB) claims that the torque measurement is accurate to within 3% when the encoder feedback is available, which it is, in this case. The reported torque by the VFD has been validated against the in-line torque sensor (Lorenz DR-2, 0.1% accuracy class) and the torque reading has been verified to be within the error band.

More cost-effective design options:

After the system has been built and tested, an effort has been made to investigate the design and provide alternate designs which provide similar or slightly reduced functionality for a significant reduction in cost. Different versions of the design of the dynamometer with their functionalities and costs have been presented in **Table 2**. From left to right, the functionality and the cost increase.

Table 2:Dynamometer design with different options and their capabilities and comparison with best Dynamometer available in the market in 2016.

	Engine/Motor Dyno	**Chassis Dyno**	**Chassis Dyno with Track Simulation**
	Option 1	**Option 2**	**Option 3**
Components			
Motor+ Encoder	$1,193.40	$1,193.40	$1,193.40
Brake Resistor	$449.00	$449.00	$449.00
Data Acquisition (NI)			$2,863.16
Roller		$525.00	$525.00
Frame Material		$799.89	$799.89
VFD	$1,300.07	$1,300.07	$1,300.07
Torque Transducer (FUTEK)	$1225 (optional)	$1225 (optional)	$1225 (optional)
Misc	$500.00	$500.00	$500.00
COST	**$3,442.47**	**$4,767.36**	**$7,630.52**
Comparison with DYNOmite[4]	**$12,950**	**$18,945**	**$18,945**
Functionality			
Engine/Motor Dyno	X	X	X
Chassis Dyno		X	X
Track Simulation			X

Table 2 assumes that there is an existing license for LabVIEW Full Development System. The table provides a comparison of the design with what was available in the market in 2016 from DYNOmite[4]. The comparison provided here is with 5Hp dynamometer from DYNOmite, since that's the dynamometer available with lowest power. DYNOmite's torque transducer's accuracy is 0.5% (of full-

scale output) whereas the torque provided by the VFD in the proposed design has an accuracy of 3%. For the proposed design, an optional torque transducer (FUTEK [5]) can be added for $2000 which has an accuracy under 0.5% (of full-scale output). The proposed design includes a VFD, which provides a torque reading with accuracy of 3%. This can be used for obtaining the torque in the absence of the separate torque transducer.

As can be seen from the comparison, the proposed design is cost-effective compared to the closest match available in the market. However, the proposed design requires expertise in LabVIEW programming-to make the dynamometer work.

Sample Applications/Results:

The following experiments and their results are published here; the list is not complete. The experiments were performed by a student (an author of this paper) for his Capstone design to demonstrate the effect of different variables on fuel economy. The student is part of a team participating in Shell-Eco Marathon competition.

1. Effect of lubrication on bearing losses
2. Effect of tire pressure on losses due to rolling resistance
3. Determination of losses due to the free-wheel mechanism

The purpose of the first experiment is to determine the effect of lubrication on bearing losses. The design team has pondered whether the presence of grease or WD-40 will affect the energy losses in the bearing. A wheel has been tested to determine the losses. The results are shown below in Figure 2.

Data is plotted only for speeds between 10 mph and 22 mph since, according to the team’s driving strategy, the speed is supposed to remain in this interval for the entire race, except at the beginning of the race and at the end of the race.

It can be clearly seen that running the race with dry bearings will save the team about 1-2 W per wheel. This is significant since the average power loss during the race is around 125W for last year’s team. So, running the wheels dry is expected to reduce the losses by up to 6W (three wheels) or 4.8%.

The disadvantage of running dry is reduced bearing life but the bearings are inexpensive and help the team determine where to spend their money to maximize fuel economy within their budgetary constraints.

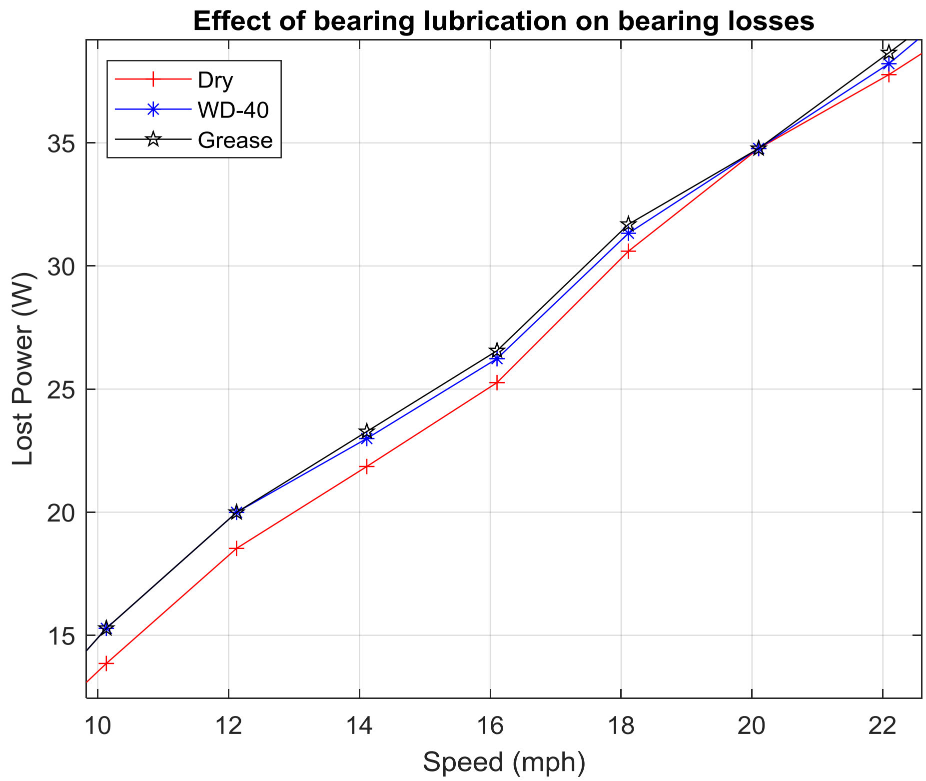

Figure 2: Effect of lubrication on bearing losses

The purpose of the second experiment is to determine power loss due to rolling resistance as a function of tire pressure. The team knew that tire pressure affects fuel-economy performance but wanted to quantify the losses, so the team could spend their resources intelligently. The tire is rated to 50 psi, but the team knows they can inflate the tire to higher pressures. Tests with higher pressures will be conducted closer to the competition to determine the limit to which the tires can be pressurized.

As can be seen from Figure 3, tire inflation pressure has significant impact on the power loss due to rolling resistance. At 20 mph, a tire inflated to 50 psi pressure (rated tire pressure) has 27W lower power loss compared to a tire inflated to 25 psi.

The purpose of the third experiment is to determine whether a freewheel mechanism on the vehicle would cause any losses, a manual clutch being the best alternative. Including the freewheel to make the wheel spin during coasting, when the motor/engine is turned off, has its own disadvantage since the freewheel mechanism itself will consume some power.

Figure 4 demonstrates the loss of power due to freewheel. This is achieved by running the experiment with just a wheel at first and then running the same wheel with the free wheel mechanism attached. The difference computed is the power loss due to the freewheel. The power loss is around 2W for most of the range of speeds of interest.

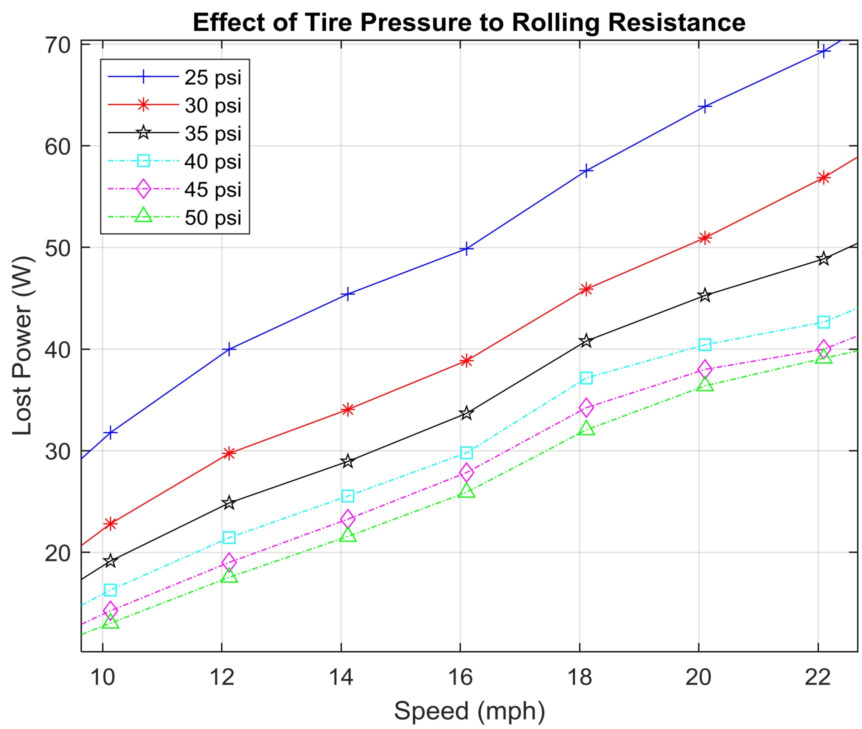

Figure 3: Effect of tire pressure on rolling resistance

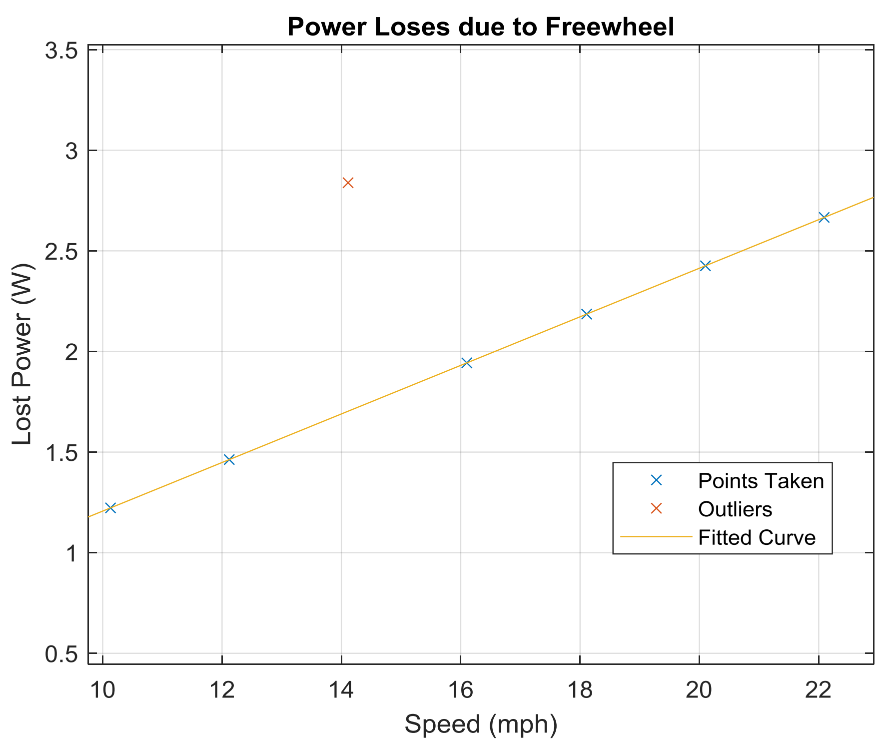

Figure 4: Power loss due to freewheel

Potential Other Applications:

The experiments described above are only three of numerous applications of the dynamometer put to use so far. Some of the other applications for the dynamometer, for use in classroom use, for use in capstone project, and for explaining different concepts are listed below.

Table 3: Potential application using the proposed design

Concept/Experiment	Relevant course/project
Quantification of torque loss due to different components in a drivetrain	Dynamic of machinery, Mechanical measurements, certain capstone projects
Conservation of energy	Dynamics, Thermodynamics, Mechanical Measurements
Quantification of effect of changing the compression ratio of an engine (by modification)	IC Engines, certain capstone projects
Performance of a DC/AC motor	Electric Motors
Determining the life of bearing/wheels under loading	Certain capstone projects

Conclusions:

Description of a design of a dynamometer at Trine University has been presented in this paper. Based on the experience of building the dynamometer, three simpler designs, which are more cost-effective, have been proposed. A comparison has been provided with closest match available in the market; an explanation is provided about why the proposed design is cost-effective. Results from selected applications using the dynamometer have been presented. Potential other applications for the dynamometer have been proposed. It is hoped that this paper will help other engineering educators build their own dynamometer using the designs described in this paper.

Acknowledgements:

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References:

[1]. Harding, G. L., & Prygoski, M., & Burns, J., & Carmichael, B. J., & Engstrom, M. S. (2018, June), A Portable Engine Dynamometer Test Cell for Studying Spark-ignition Engine Performance and Technical-Electrical-Thermodynamic Energy Conversion Paper presented at 2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah. https://peer.asee.org/29712

[2]. Cooley, T. (2002, June), Portable Engine Dynamometer Paper presented at 2002 Annual Conference, Montreal, Canada. https://peer.asee.org/11176.

[3]. Fotouhi, K., & Yilmaz, E. (2003, June), Engine and Dynamometer Service And Fuel Consumption Measurements Paper presented at 2003 Annual Conference, Nashville, Tennessee. https://peer.asee.org/12236.

[4]. “DYNOmite AC Dynamometer prices,” DYNO Mite. [Online]. Available: https://www.dynomitedynamometer.com/ac_dynamometer/ac-dynamometer-price.htm. [Accessed: 27-Jan-2019]

[5]. “FUTEK TDD400 Reaction Torque Sensor,” FUTEK. [Online]. Available: http://www.futek.com/product.aspx?stock=FSH04373. [Accessed: 27-Jan-2019]