Designing an Inexpensive Automotive Dynamometer

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Abstract

This purpose of this project is to design, machine, assemble and test an economical automotive chassis dynamometer. The dynamometer will be used to measure the power output of the automobiles that belong to Northeastern University’s Society of Automotive Engineers (SAE) Club. The primary goal is a dynamometer that is significantly less expensive and more compact than those commercially available. After researching existing technologies and initial design options, the team has decided to base the final design on self-energizing brakes. Key concepts investigated and discussed are load absorption, heat dissipation, material selection, and user constraints. Major challenges included machining costs and time, accessory component research, and safe operating procedures.

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The Camaro model in the above image belongs to GrabCAD.com.
The Need for Project

A cost efficient means of measuring the horsepower and torque output of a car. The Northeastern Chapter of the Society of Automotive Engineers does not currently have a method to measure engine torque and power output in the shop. The club has recently purchased a 1984 Camaro and had begun replacing the engine. The club has plans to add a supercharger and race the car on a drag strip. A dynamometer is needed to measure and optimize the performance enhancements that the group makes to the car.

The Design Project Objectives and Requirements

The objective of this project is to develop a dynamometer that is inexpensive, robust, reusable, compact, and safe. The objective of this project is to provide the Northeastern Chapter of the Society of Automotive Engineers with a means to measure the power and wheel torque output of their cars in the shop. The design must meet the dimensional and performance specifications of a 1984 Camaro. It must also be inexpensive and compact in order to be stored and operated in limited space.

Design Requirements

In order to construct an affordable, safe chassis dynamometer various design requirements and challenges need to be considered. The assembly must absorb close to 500 horsepower for a period of about 30 seconds each run. In order to do this safely and effectively, the interface between the automobile and the dynamometer is critical. This can be done either by rolling the wheels onto a set of rollers, or by removing the wheels and attaching the load absorption assembly to the wheel hubs. As energy is absorbed, heat dissipation and control will be a main concern. The system will be designed so that no metal part will exceed 660 degrees Fahrenheit. A fan will be used to cool the engine during runs and assist in ventilating the testing space as the engine will be redlining without cooling-air flowing rapidly through the grill. Lastly, all operators (besides the driver) will be a safe distance away from any rotating parts and wearing eye and ear protection. The final deliverable of the dynamometer system will be the generation of a power curve displaying engine output torque and horsepower against engine RPM – an example of which is shown at left.
Design Concepts Considered

Four candidate design concepts were developed, one of which best met the requirements of the project. After meeting with SAE and seeing their available space, the team decided a chassis dynamometer system would be more beneficial to SAE than an engine dynamometer. A chassis system would be easier to use as the engine does not need to be removed from the vehicle in order to perform a run. After researching existing technology, the group developed and modeled in Solid Works several potential system solutions.

**Inertia Dynamometer Direction Hub Connection**

This design features a direct attachment to the wheel hub — requiring the driving wheels to be removed from the car — where the engine accelerates a large inertia wheel. A tachometer and DAQ system will record the angular acceleration of the flywheel and calculate the torque that was driving the system. This system did not advance past the first design review as an inertia wheel alone would have to weigh over 2,000 lbs to absorb 500 HP in 30 seconds during its acceleration to 1,700 rpm. In addition, the acceleration time would be altered by engine power. Refer to report section 4.2.2 for a more detailed explanation.

**Inertia Dynamometer with Rollers**

This design is also based on an inertia flywheel, but instead of a direct hub connection the driving tires remain on the vehicle and drive a roller. This design also failed as the amount of material and the space required were not conducive for a compact and inexpensive solution.

**Self-Energizing & Capstan Brake**

The third system was developed to integrate the concepts of self-energizing and capstan brakes and was one of two designs to advance into the next development stage. A self-energizing brake (SEB) is a positive feedback braking system that is designed to proportionally increase resistance to an input torque as angular acceleration increases. This principle will give the dynamometer the ability to dynamically absorb the input torque from the car. The capstan brake principle enables the dynamometer to absorb a large input torque with a much smaller load torque through the friction applied to a shaft by several loops of material. Although this design has many merits, the group decided to move in a different direction after the designed components proved too expensive to manufacture and too sensitive to changing...
input torques and RPM. This design, modeled on disk pack brakes, is discussed in detail in the following section.

**Recommended Design Concept**

A disk pack brake solution is compact, easy to manufacture and will dynamically adjust to varying input torque.

**Design Description**

The group will employ two identical disk pack brake systems – one attached to the hub of each driving wheel. Each assembly will fit into a 2’ diameter by 1’ cylindrical package and will weigh close to 250 lbs, including a 95 lb flywheel. The system receives torque from the car’s driving axle by attaching a designed part called the hub connector directly to the 5 lugs on the hub. The disk pack portion itself will consist of 6 stator plates alternating with 6 rotor plates which will be pressed together to absorb most of the engine torque through friction. Lever arms will extend 6’ from the system frame to prevent rotation of the frame and stators and press on a load cell which will record the torque applied by the car. The flywheel is designed to receive up to 5% of the maximum input torque and its acceleration will be recorded using a strobo-tach system for wheel RPM calculation. Instantaneous engine horsepower will be calculated from the RPM and torque measurements and will be plotted via Matlab after each run.

**Analytical Investigations**

Each designed component is made from AISI 1018 CR steel in order to withstand the input torque from the car and the bending experienced by cantilevering off the hub connector. Solid Works FEA passed every component with a minimum factor of safety greater than 2. All sharp edges have been filleted for reduced stress concentrations.

**Key Advantages of Recommended Concept**

The key advantages of the disk pack system are its manufacturability, compact size, and decreased sensitivity to varying input torque. Most designed components were designed in house and outside vendors were used only because tight tolerances had to be held on the central bore of 24” diameter pieces – this is ideal for water jetting. Besides special orders for the right and left hand ball screws that the flywheel sit on and the one way rotary clutches, most hardware was purchased cheaply from McMaster Carr. The system’s small package and its ability to quickly adapt to varying input torque while maintaining constant acceleration make it a practical solution.
Financial Issues

Prototype cost: $2,400 for two units. Manufacturing processes can be streamlined.

Since the main purpose of this project was to design an inexpensive dynamometer, financial issues were a top priority. The team went through many design iterations on many of the parts in order to reduce material and manufacturing costs. A large amount of the manufacturing was done at Northeastern in order to save money. The only parts that were manufactured by an external vendor were the disc rotors, stators, and backing plate. The team decided against manufacturing these parts in-house due to their complexity, tight tolerances and the number required for the final product.

The final cost for the prototype was $2,400, which is less than the group’s initial low-end estimate of $3,300. This means, even at a 100% markup, this dynamometer unit would sell for about $5,000 per system. This is well under the cheapest commercial chassis dynamometer solution on the market today at around $20,000 per system. However, the large amount of labor involved in manufacturing the in-house parts pose an issue if the proposed solution were to be mass produced. External vendors with advanced CNC machines could be an option for quicker manufacturing of the complex components although high quantities would have to be produced in order to make this a cost effective approach.

Recommended Improvements

Design of a frame for portability; investigate braking material and lubrication for improved life of disk pack.

One key improvement that could be made to the design is portability. Currently, the dynamometer prototype has no easy way of being transported as it weighs over 200 lbs per side and is cantilevered 12 inches off the wheel hub. Adding a simple frame with lockable caster wheels would solve this problem as long as all absorbed torque is transferred from the case, through the lever arms to the load cell.

Another improvement would be to investigate friction brake material to line the rotors and add an enclosure around the disk pack to contain a lubricant. Adhering to all rubbing surfaces an appropriate RPM-rated braking material could reduce the anticipated wear and operating noise of the dry friction system. Turning the disk pack from a dry brake into a wet brake will also reduce wear on the rubbing components and help absorb the generated heat. Both additions contribute to longer system life.