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From: Team D - Generator Dynamometer

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Date: 2/17/2017

Re: ***Background Report***

1. Background

1.1 Introduction

The purpose of our capstone project is to design and build a hobby-scale dynamometer (dyno) capable of accurately measuring relevant outputs of a small-scale wind turbine generator. Once completed, this dyno will help future Northern Arizona University (NAU) wind turbine teams to accurately test designs under different scenarios to create the most efficient designs possible. This dyno will build upon and replace the previous dyno completed by a capstone team of electrical engineering students in May 2016. With demand for renewable energy sources increasing, this dyno could help to design wind turbines capable of generating clean electricity for a more sustainable future.

1.2 Project Description

The main sponsor/client of this capstone project is David Willy from the mechanical engineering department of NAU. The project description stated by Mr. Willy reads "design, build, and test a hobby scale (~50-500W, ~200-2000KV rating) generator dynamometer. This dyno will be used for all future hobby scale generator characterization for designs in areas such as renewable energy conversion and energy harvesting."

1.3 Original System

The original dyno was designed and built in the 2015-2016 academic year. The dyno was successful, but improvements must be implemented in order to have more satisfactory testing of future generators. The previous design used a Rimfire .32 AC outrunner motor with an output of 1480 Watts and a KV rating of 380. KV ratings refer to the number of revolutions per minute the motor can sustain when 1 Volt is applied [1]. Figure 1 below shows the motor-motor electric generator dyno created by the previous capstone team. The far left of the picture shows the Arduino controller as well as the three-phase AC power supply, which is attached to the AC generator. The generator and motor being tested, on the right side, share a shaft that runs through a coupler to reduce misalignment of concentricity. The generator is wired to a "dumb" resistance load(not shown in the picture). The motor and generator are attached to an

Aluminum T-bar frame by machined motor mounts specific to each motor. A solid metal shield covers the system while testing to reduce the risk of injury.

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Figure 1: Previous Dyno

2. Requirements

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The team gathered the customer needs through meetings with our client, Mr. Willy, and developed the House of Quality (HoQ). For this report we were tasked with creating the customer requirements as well as weighting them. This is the first step to creating a HoQ, the team's process is detailed in this section.

2.1 Customer Requirements

After meeting with our client, we formed a list of customer needs. Mr. Willy made it clear that his top priority was to get torq ©ı†ue measurements from the dyno, as the current one has no way of measuring mechanical torque. To do this, our team has to get an accurate torque sensor and add it to the dyno. The current dyno measures RPM through an infrared sensor, which is accurate enough for the purposes of the dyno, but our team would like to make sure that we are getting accurate readings for RPM for the tested motor. Another need that Mr. Willy expressed was getting a DC motor, for its low KV rating. These DC motors come in much larger sizes than AC so our mounting system will have to change to accompany this larger motor. Along with these needs we created a few more from the information provided, such as safety, reliability and easily accessible. These needs are essential to the project because we need to be able to count on this to receive accurate measurements from the wind turbines. Low cost was added because at the time we didn't have a known budget and we needed to create this dyno for as cheap as possible. With all of this knowledge we started to build the HoQ, by turning our customer's needs into requirements.

2.2 House of Quality

The first step of the HoQ is to gather customer needs and then translate them into customer requirements(CRs) with weights. Our team completed this and created table 1 below, which shows the CRs and the corresponding weights. Our weighting system is 1,3,5 with 1 being lowest priority and 5 being highest.

Table 1: Customer Requirements and weight

Customer Requirements	**Weight**
1. Accurate Torque reading	5
2. Accurate RPM reading	5

3. Capable driving motor	5
4. Adjustability for motor size	3
5. DC variable load	1
6. Adjustable power supply	1
7. Safety	5
8. Easily accessible	3
9. Low cost	3
10. Reliability	3

Originally, our HoQ had safety with a weight of 3, but after sending that list to our client, he said that safety should be rated higher, and so we changed that weight to a 5. The most important requirements of this project would be accurate torque and RPM readings, as those are essential for a dyno to operate. Safety and having a driving motor capable of our load are also very important to the design, as the design would fail if we do not meet these requirements. Adjustability, accessibility, cost, and reliability are all weighed at 3 because they are fairly important to the design but are not the most important factors of the dyno. DC variable load and adjustable power supply are rated lowest, and although they would be helpful to the dyno our team decided to focus on key functions before worrying about power supplies. The client has stated that he has a dumb load that we can use, but our results would be more realistic with a variable load. With these requirements in mind, our team began researching the state-of-the-art behind dynos.

3. Existing Designs

To gather background information, the team set up a shared document with sections dedicated to certain parts of the design including: Types of dynos, torque sensors, RPM sensors, driving motor, motor controllers, etc. Each team member was tasked to insert info that he gathered into relevant sections. This helped us gather information much faster and have it all in one collective location for the group to look at.

3.1 General Information

The purpose of a dynamometer is to test various characteristics of a motor. Based on measurements taken of inputs and outputs to and from the motor, attributes can be directly or mathematically obtained. A typical dyno will measure torque at a given rpm, then based upon the voltage and current input from an electric drive, torque and efficiency curves can be mapped along with characteristics such as dynamic and static drag. For the purposes of our project, we will need to do this process in reverse, since we are concerned with how the motors that are tested function as a generator. While any electric 'motor' can function as both a generator, where mechanical energy is converted to electrical, or a motor, where electrical energy is converted to mechanical, the efficiency will be slightly different due to back emf (electromagnetic force). When an electric motor functions as a 'motor', rotation of the armature through the magnetic field induces a counter field that opposes the rotational motion. Functioning as a generator, the e.m.f. produced is essentially what drives the rotation, so there is no back e.m.f. This difference, although slight, could affect the characterization of a motor to be used as a generator or vice versa [2].

3.2 System Level

Dynamometers come in various forms, including motor-motor electric generator, inertial, or a variety of braking such as friction, hydraulic or fan. While our client has made it apparent that for this project, an electric generator dyno will likely be the best option, we give an overview of the types of dynamometers below. We also considered the possibility of constructing a small wind tunnel for testing turbine efficiencies, however it wouldn't be practical due to the size required. In order to produce an uniform airstream as would be experienced in the open air, the wind tunnel diameter would have to be several times larger than the turbine blade diameter because of fluid drag (no-slip) on the tunnel walls.

3.2.1 Electric Generator Dyno

Motor-motor or electric generator dynos function by coupling the shaft of two motors together. The 'driving' motor is electrically powered, in turn mechanically powering the motor to be tested. The resulting electricity produced by the testee can then be measured to interpret its characteristics. In order to determine the magnitude of mechanical energy the testee is receiving, input rpm and torque must be known. This can be accomplished either through electrical input monitoring and electrical calculations with a known driving motor efficiency, or through a torque sensor (aka torque transducer) as well as a rpm measuring device. Generally, the latter method is easier and more accurate due to changes in efficiency of the driving motor as a result of torque, rpm, or temperature during extended test periods.

3.2.2 Inertial Dyno

Inertial dynos work on the principle of rotating a relatively heavy cylindrical mass. With the moment of inertia of the mass known, motor characteristics can be interpreted based upon the rotational acceleration and deceleration of the mass from a given electrical input. An appropriate mass is selected based upon the operating range of the motor(s) to be tested. A couple of the most important benefits of an inertial dyno is that tests can be conducted within a matter of seconds, and are very repeatable due to design simplicity [3]. Figure 2 below shows a diagram of an inertial dyno.

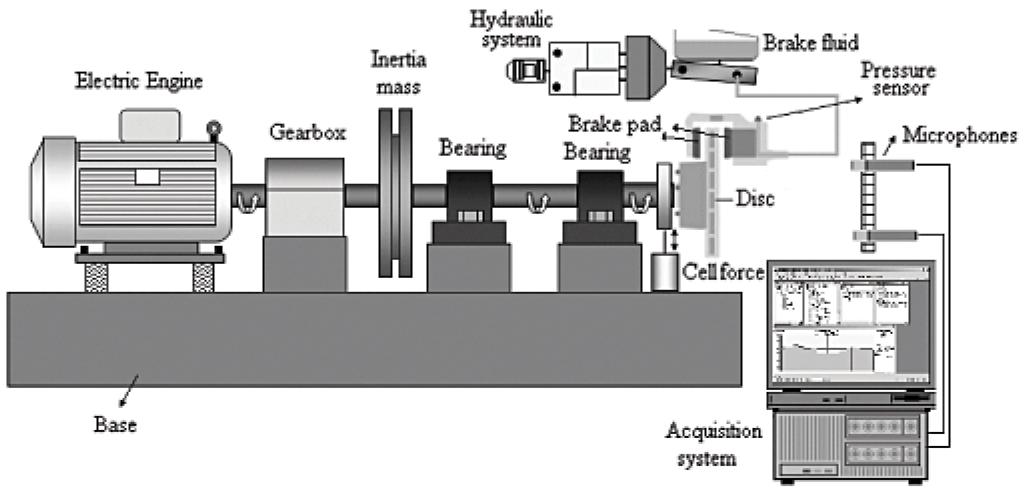

Figure 2. Components of an inertial dynamometer.

[4]

3.2.3 Water Brake Dyno

Water brake dynos (also know as water brake absorbers) work of the rotational resistance of a pump full of water. A typical water brake dyno has one or more vaned rotors that spin between stators. The amount of load output by the dyno is controlled by the amount of water inside and the size of the inlets and outlets. When more water is added to the system, more resistance is applied to the motor being tested. The water within the dyno becomes extremely hot during use. This clean, hot water can either be discarded or cooled and recirculated back into the dyno. Manual or automatic controls are available to control RPM and load experienced by the motor being tested. A major market where water brake dynos are used is the gokart industry. Many manufacturers and race teams prefer to use these types of dynos because of their "power capacity versus size." These dynos can be fitted directly onto the output shaft of the motor being tested for quick and easy setup. Water dynos are used for testing motors from about 10 horsepower to over 2,000 horsepower. Because the motors we will be testing will be of a much smaller scale, water brake dynos are not a feasible option for use on our project [5]. Figure 3 shows a simplified version of a water brake dyno.

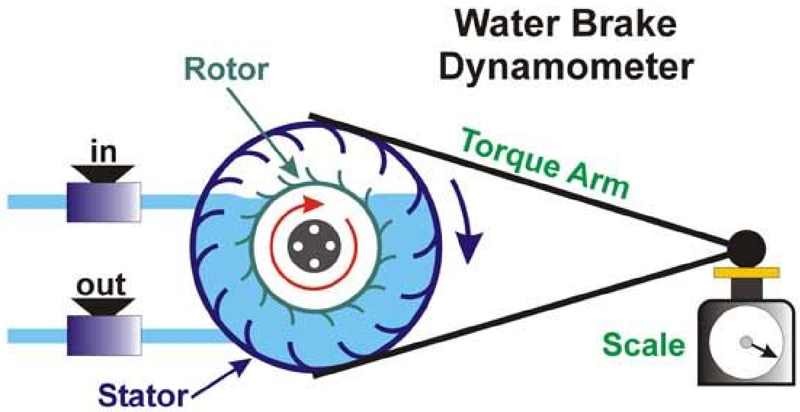

Figure 3: Water Brake Dynamometer [6]

3.3 Subsystem Level

The client requested we create an electric generator dynamometer, therefore we focused our research into this type of dyno. The main functions the client desires are a torque sensor and swapping the AC (Alternating Current) motor for a DC (Direct Current) one. These were our main two subsystems as they were most important to the design. The final load subsystem describes how a variable load functions in a motor-motor dyno.

3.3.1 Torque Sensor

There are many different types of torque transducers (sensors) , such as reaction, slip ring, and various rotary sensors. Reaction sensors measure torque through a linear strain gage attached to an arm. While they are simple and have a long working life, they are less accurate than other in-line torque sensors and have reduced dynamic response time. Slip ring style sensors use metal brushes to measure torque output. While they are relatively inexpensive, they may have issues with accurate torque readings and require maintenance. There are a variety of rotary torque sensors which rely on a strain gauge to interpret shaft torques. While expensive, digital telemetry torque sensors are considered the most accurate and widely used type. [7]

3.3.2 DC Driving Motor

It is important that the driving motor be powerful enough to handle a range of hobby motor output capabilities. Our client has specified that we should look for a driving motor in the range of 1000-1500W if we are to construct an electric generator dyno. Also, because we are likely to use an Arduino as the motor controller for this type of dyno system, it will be easier to use a DC input motor. Most electric motors listed for sale advertise the torque specifications rather than wattage. Calculations to approximate the max torque, shown in Appendix A, were made to find us a suitable motor.

3.3.3 Load

An electrical load is a part of an electrical circuit that consumes generated electrical power. When used in a motor-motor dyno, the load absorbs the power created by the generator and releases this energy through heat. A “dumb” load is essentially a resistor that is able to dissipate all the energy. Advantages of a dumb load are that they are simple and relatively cheap to construct. They are a good choice for testing motors of the same size where is is not necessary to change the amount of load. A variable load is able to change its level of resistance instantaneously through the use of multiple resistors. Variable loads can be used to test motors with different outputs under different load conditions quickly and efficiently. A major disadvantage of variable loads is a high cost. For a hobby scale, price can range from $600-$1,500. Although variable loads provide more adaptability to the system being used, our team will have to factor in cost if it is decided to design a motor-motor dyno. [8]

Appendix A - Calculations for approximate max torque [9]

Requirements:
0-6000rpm
DC, 1000-1500W=2HP
24/40V

E - Motor efficiency (guess 50%)
Pout - Power output from motor (Watts)
PIn - Power input to motor
τ - torque (Newton*Meters)
I - current (Amps)
V - Voltage (Volts)
ω - rad/s

Pout = Pin * E

E = Pout / Pin

$\tau * \omega = I * V * E$

$\tau * rpm * 2\pi / 60 = I * V * E$

$\tau = (I * V * E * 60) / (rpm * 2\pi)$

$\tau = (1500W * 0.5 * 60)/(6000rpm * 2\pi)$

Approximate max torque = 1.19N-m ~ 1 N-m = 0.75 ft-lb = 144 oz-in = 9 in-lb

References

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