

To: Dr. David Willy

From: Nathaniel Holguin – HCC26

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Re: Individual Analysis – Prony Brake Uncertainty/Design

Introduction:

For my individual analysis, I will be looking at the design of our Prony Brake and its corresponding uncertainties. My team HCC26 plan to build and test a Prony brake system to collect data on a scaled down version of our Stream diver turbine. Before being able to dive into the uncertainty of the data collection we must first determine at least the rough design of this experiment to understand all the different variables that will go into this process. With instruments decided upon and general measurements known, uncertainties can be collected and calculated.

Design:

This experiments will be taking place in the 495 (thermal fluids) Lab so we will need to plan the experiment around that fact. The work bench is not huge so the turbine will likely have to stay around or under 60 cm and have a diameter around 10-15 cm. The shaft will be extended directly to the Prony brake to collect data so that will add some extra length as well. The water can be shot out of a small nozzle about 1 cm in diameter up to almost 1 L/s which will provide enough velocity to generate 40+ Watts of theoretical power. The Prony brake will use a variation known as the Rope brake where a flexible coord will be wrapped around the drum to read force measurements.

With the main setup/scale understood we can look into the ideal components of the system:

- Aluminum Brake Drum (Lathe Job)
 - Diameter ~ 40 mm
 - Width ~ 30 mm
 - Bore ~ 8 mm
- Wooden Frame/Body (Bought and Assembled) < \$15
 - 2x4 Wood Boards (in)
 - Board up middle to connect frame, drum, and turbine

- Two 50 lb (23 kg) digital fish scales
- Paracord or some string/line connected to tower
- Dead weight on the bottom end
- Neiko 20713A Digital Laser Tachometer (< \$30)
- Turbine:
 - 8mm Ground Stainless Steel Shaft
 - 3D printed fins, 100% infill, ASA filament
 - Center hole of 8.1 mm
 - Two 608-2RS Ball Bearings

With these components, a functional operation can proceed to collect power output values [4].

Uncertainty:

When looking for power using a String Prony brake system, power is given by four variables as seen in equation 1 [2]. In this equation: N = Rotational Speed (RPM), r = Radius of the Aluminum Drum (meters), F_{scale} = Force reading from the Digital Scale (Newtons), W_{dead} = The hanging dead weight (Newtons), and lastly P = theoretical power generated (Watts).

$$P = \frac{2\pi \cdot N \cdot r \cdot (F_{\text{scale}} - W_{\text{dead}})}{60}$$

Figure 1: Equation 1 – Theoretical Power [2]

Now that the variables and their measurement tools have been outlined, the uncertainties of each portion can be analyzed. The resolution of the fish scales are .01 kg [6] but will fluctuate so will be considered ± 0.05 kg ($\sim \pm 0.05$ N). Standard caliper error (for measuring the radius) is ± 0.05 mm. The dead weight measured on a precision scale one time will yield an uncertainty of ± 0.001 kg or 0.01 N. The Neiko tachometer is stated to have an accuracy of $\pm 0.05\%$ + 1 digit according to the manufacturer specifications [5]. With a speed around 1,000 RPM * .05% the uncertainty is .5 RPM plus 1 digit for a total uncertainty of ± 1.5 RPM. Now with all the variable uncertainties known, error propagation can begin with equation 2 [1].

$$w_P = \left[\left(\frac{\partial P}{\partial N} w_N \right)^2 + \left(\frac{\partial P}{\partial r} w_r \right)^2 + \left(\frac{\partial P}{\partial F_S} w_{F_S} \right)^2 \right]^{1/2}$$

Figure 2: Equation 2 – Error Propagation [1]

To find the total uncertainty in the calculated power, the partial derivative of each variable with respect to the power function must be multiplied by that variable's corresponding uncertainty [1]. Once that is done for each variable, the sum of square roots is used to find the total uncertainty of the calculated theoretical power.

$$\frac{w_P}{P} = \sqrt{\left(\frac{w_N}{N} \right)^2 + \left(\frac{w_r}{r} \right)^2 + \left(\frac{w_{F_S}}{F_S - W} \right)^2}$$

Figure 3: Updated Error Propagation [3]

Taking those partial derivatives, each term of the equation becomes the uncertainty of a variable over the real value of that variable [3]. Given everything that has been set up, a likely speed is **1,000 RPM** and a likely net force is **5 N**. With a radius of **0.02 m**, each term can be solved for:

- Speed: $1.5 \text{ RPM} / 1000 \text{ RPM} = 0.0015 \rightarrow 0.15\%$
- Radius: $0.00005 \text{ m} / 0.02 \text{ m} = 0.0025 \rightarrow 0.25\%$
- Force: $0.49 \text{ N} / 5 \text{ N} = 0.098 \rightarrow 9.8\%$

With each term found all that needs to be done is taking the sum of square roots. That will yield a total uncertainty of about **9.8%** which is pretty high and is due practically entirely to the force uncertainty. Due to the fish scale not being able to read accurately, the total error shoots up quite a bit. A way to counteract this is to use a more accurate force scale to get our readings. “Digital Push Pull Force Gauge AMF-50N for Precision Measurement” can be purchased for \$50 with a much finer and precise resolution of $\pm 0.01 \text{ N}$ [7]. With this new instrument, the uncertainty drops significantly: $0.01 \text{ N} / 5 \text{ N} = 0.002 \rightarrow 0.2\%$

With this the total uncertainty can be re-calculated to a much more satisfying number:
Sum of square roots $\rightarrow 0.0015, 0.0025, \text{ and } 0.002 = 0.0035355 \rightarrow 0.354\%$

Conclusion:

With this design proposal, a Prony brake system can be bought for ~ \$100 and built with relative ease. It can withstand and collect valuable readings from our scaled down Stream diver turbine with a total uncertainty of only **0.35%**. This should for all intents and purposes work efficiently for our project. Now the next steps are to purchase each of the required tools and equipment alongside machining or 3D printing any and all parts needed. Once that is done, the assembly can begin and the process to actually collect results can begin. The thermal fluids lab can be reserved, and with some testing the experiment can begin and used to collect valuable data for the project to be used in the future. This data will help give us an understanding of how well our turbine will collect power on a larger scale.

References

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