Measurement of Turbine RPM with Hall Effect Principle

Bennett Terrill
Mechanical Engineering Program
SUNY New Paltz, NY
New Paltz, NY, USA
terrillb1@newpaltz.edu

Rachmadian Wulandana
Mechanical Engineering Program
SUNY New Paltz, NY
New Paltz, NY, USA
wulandar@newpaltz.edu

***Abstract** -- Hall effect sensory devices, invented by Edwin Hall introduced new techniques to obtain measurements wirelessly. Through the presence of a changing magnetic field, an induced current in principle gave off a corresponding voltage value. Stemming from demand for more portable and eco-friendly power generative devices, one of the current engineering solutions shifted towards bladeless turbines. The application of Hall effect sensors shown in these experiments did attempt to produce rpm measurements for bladeless turbine prototypes. With a freedom for geometric design, bladeless technologies are argued to be more cost efficient and quieter than their bladed counterpart. New challenges rose to obtain a sensor that maintained consistent data collection and robustness for both complex geometries and more importantly, environmental settings. A repurposed water flow meter (with Hall effect sensor) was connected externally to bladed and non-bladed prototypes. Under the Hall effect principle, between each revolution created voltage spikes which were analyzed through Arduino as step response signals, to continue, the rate of step impulses could then be calculated to rpm. Under various flow regions, prototypes were observed for autorotative behavior mainly in the vertical orientation. Primarily, results focused on analyzation of rate of revolutions per minute and in cases of bidirectionality and motion halt. To compare results from Hall effect experimentation, the wireless water flow meter was compared to a commercial, wired rotation sensor.*

Keywords—Bladeless Turbines, Autorotation, Renewable Energy, Fluid Dynamics

I. INTRODUCTION

The main consideration concerning RPM values was sensor behavior during or without oscillation. 3 turbine models made with PLA were 3-D printed identically in dimension (5x5x5) cm^3, in addition, models were printed with 40% infill settings. Tests were primarily done in a vertical configuration supported by low friction roller bearings. A cross cylinder, cross cylinder (dimpled), and tri-curve turbine prototypes were created to record various RPM behaviors. In a systematic study carried by many researchers has shown that the orientational dynamics become even more interesting in the unsteady regime, vortex shedding effects become significant and gives rise to oscillations of the body [1]. To replicate an unsteady regime, a horizontal water tunnel was to be created that provided characteristics of turbulent flow. Supplemented with a study conducted of the same water tunnel and dimensioned models, the given Reynold's number spanned between 13,258-48,595 [2]. Calculations were made with the respective equation:

$$Re = \frac{\rho D V}{\mu}$$

Where ρ is the density of the fluid, D was the model diameter, V the speed of fluid, and μ was the dynamic viscosity of the fluid. The speed of the fluid correlated to the frequency of the AC motor provided in the calibration equation:

$$V = 0.0128F$$

Where F is the set frequency of the motor.
To better describe the behavior of prototype behavior submerged in fluid flow -- [1] indicated behaviors of particles having periodic oscillations (P), where the particle oscillates periodically, and steady orientation (S) where the particle position remains steady over time. A third case (iii) autorotation was noted as a non-oscillatory state where the particle revolved by an angle of 2π. Transition states between P and S was recorded to having aperiodic oscillatory behavior. The behaviors described above are naturally occur and would continue to prevent a continuous auto-rotative state.
While previous papers have explored rotational behavior with commercial reflective tape tachometers, we see a potential drawback in measurement accuracy in cases where P and S states occur. Under rigid sensor calculation, laser tachometers solely rely on the reflective reference tape to output RPM data. An alternative approach shown with Hall effect sensory, provide electrical analog to digital conversion to provide more flexibility while connected other user-controlled appliances such as Arduino.

In applicable scenarios, Hall effect can become a new method of recording rotation data of turbines, with studies that aim to showcase improved efficiency and reliability factors in vibratory environments [4, 5].

II. EXPERIMENTAL DESIGN AND ANALYSIS

We designed an experiment where a bladeless turbine prototype was suspended in a flow tank, allowing it one degree of freedom.

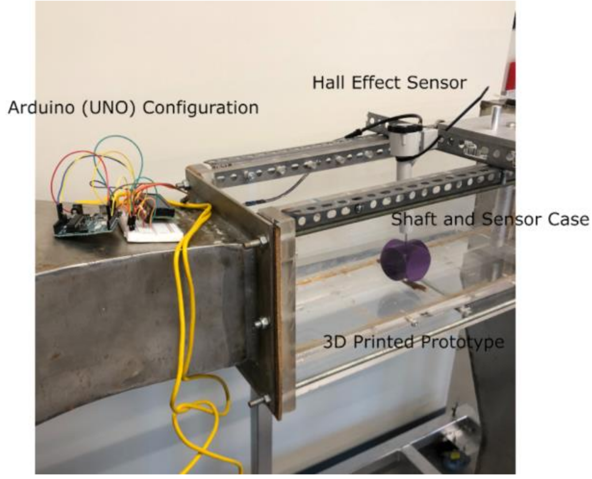

Figure 1: Experimental setup for RPM measurements within fluid chamber. Flow speeds were controlled via a controller which connected to an AC centrifugal water pump.

Based off previous measurements of the fluid tank, the cross-sectional area of the flow chamber was 15x15cm^2, and an overall test length of 75cm. In addition, a manifold in the shape of a converging chamber was constructed to reduce turbulence and complex characteristics [6].

A. Experimental Procedure

Supplied by the State University of New York (SUNY) New Paltz campus, the utilized fluid chamber was closed loop provided with power with a centrifugal pump with a maximum flow rate of 1200 gallons per hour (gph). The speed of the pump can be controlled using a Variable Frequency Drive (VFD), a frequency range of 30-55Hz was used for the experiments. The average water flow speed was be calibrated at the following pump frequencies: 30, 35, 40, 45, and 50Hz: . The observation chamber has a cross sectional area of 15x15 cm^2 and is 50cm long. The fixture was minimally designed to withstand maximum lateral forces from the fluid. To achieve an ideal autorotative state, 2, 2mm roller bearings were inserted on both ends of the shaft case. The hall sensor was extracted from a YF-s201 flow sensor. Included with the fluid flow sensor was the annular 2-pole magnet surrounding the metal shaft. Primarily, Arduino code was used in finding the measurements of rate of oscillation and RPM. Over several iterations of programming, an optimal way of RPM values was obtained when detection values (labelled Hall count) reached a set threshold. RPM values are outputted based on the following equation:

$$RPM = \frac{Hall\ Count}{Time\ Passed} * 60$$

The code was set that when the Hall sensor was triggered 5 times, there was a returned RPM. After a return, the Hall count and time passed would reset. Rate of oscillation returned step outputs (0 or C) where 1 indicates oscillatory detection. When the number of outputs reaches a threshold value, an RPM value would be returned. All respective outputs were recorded with Excel software. Reflective tachometer experimentation was best compared when procedures mirrored hall sensor procedures. Reflective tape covered a single face of each prototype. RPM values were recorded and averages per each flow speed.

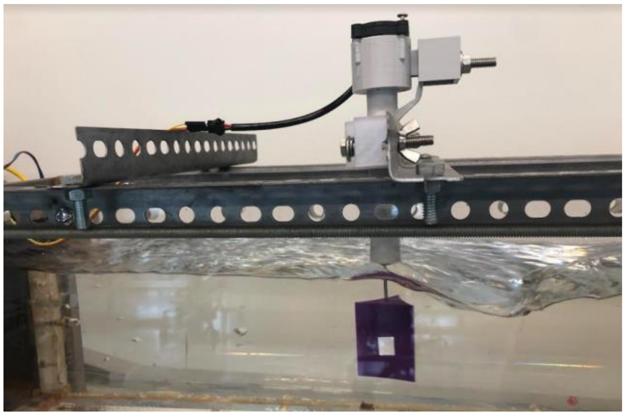

Figure 2: Tri-curve experimental setup for RPM measurements within fluid chamber. The commercial tachometers utilized the white, reflective tape as shown.

III. RESULTS

Experimentation in recording rate of oscillation can clearly show lapses in time when the models are in a rotative state. Gaps within time intervals spanned longer in models with a larger perimeter, and smoother surfaces. In contrast to models with curvature and features that create turbulent boundary layers. Dimples were an outstanding feature chosen studied in [3] that promoted drag forces compared to smoother surfaces. In addition to prototype features, flow speed contributed to the amount of detected oscillation in the Hall sensor. In a case such as the dimpled cross cylindrical design, as pump frequency went higher, there are regions of sustained rotation. However, the notion that a bladeless turbine model transforms into a continual state of autorotation can be disproved with output response illustrations.

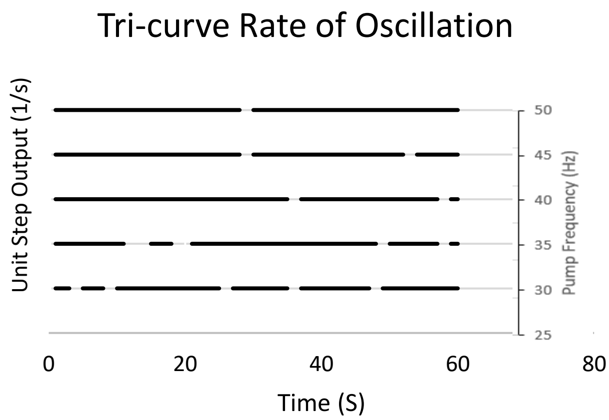

Figure 3: Rate of Oscillation of Tri-Curve bladeless turbine. From Bottom to Top are the corresponding motor

frequencies (30, 35, 40, 45, and 50Hz). Output sample rate (1/s).

The tri-curve output response with an increase of pump frequency shows consistent data output during experiment duration. In addition, the rate of oscillation as frequency of increases indicates a continual response to rotation whether it be auto-rotation or periodic rotation.

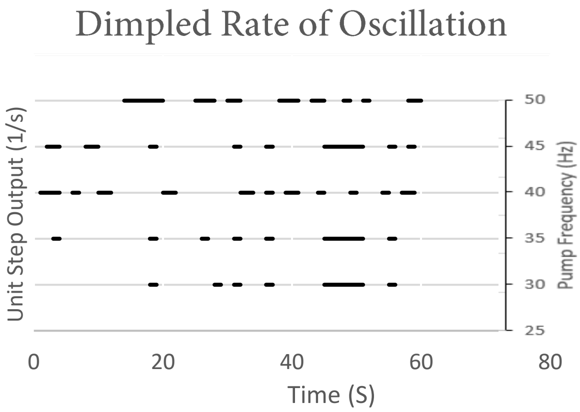

Figure 4: Rate of Oscillation of Cross Cylinder Dimpled bladeless turbine. From Bottom to Top are the corresponding motor frequencies (30, 35, 40, 45, and 50Hz). Output sample rate (1/s).

On an ascending order of pump frequency, the noticeable behavior shown are the frequency of data output. From a 50Hz standpoint, the increments of output are more closely spaced and are often lumped without separation. In contrast to 30Hz measurements, the trend was unpredictable and experienced larger gaps between outputs.

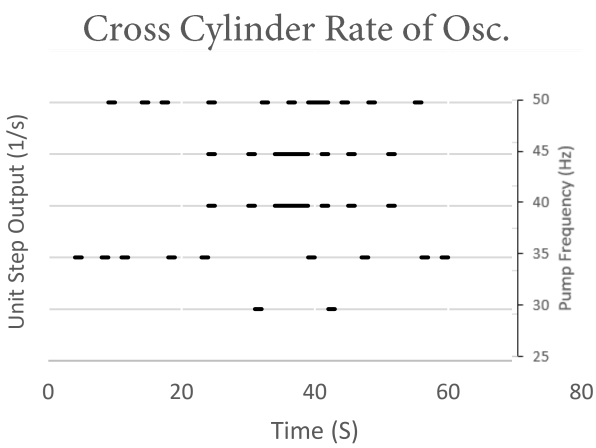

Figure 5: Rate of Oscillation of Cross Cylinder bladeless turbine. From Bottom to Top are the corresponding motor frequencies (30, 35, 40, 45, and 50Hz). Output sample rate (1/s).

A. Hall Effect vs Reflective Tachometer

RPM values are relatively achieved the same way. The results do show that extreme differences do arise between Hall and reflective tachometer measurements.

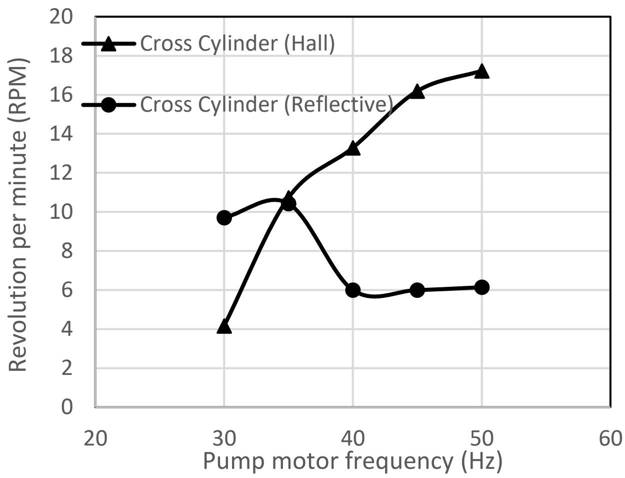

Figure 6: RPM comparison of tachometer and Hall effect sensor of a cross cylinder device.

Shown in figure 6, RPM results indicate accuracy within the frequency range. A difference however can be seen as the RPM trend continued to increase in the Hall experiment. Tachometer measurements however provide a trend that decreased momentarily after an increase of flow speed.

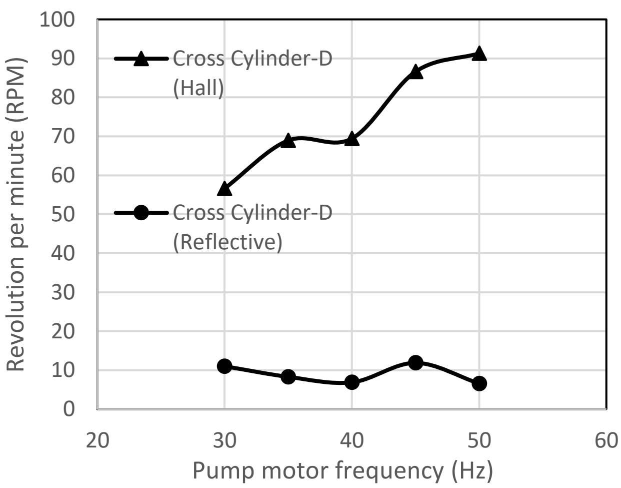

Figure 7: RPM comparison of tachometer and Hall effect sensor of cross cylinder (dimpled).

The trend provided in figure 7 start to show dissimilarity between each measurement. The Hall measurements have clearly stepped over the range of tachometer measurements. A maximum difference 66-80% difference can be seen in this trend.

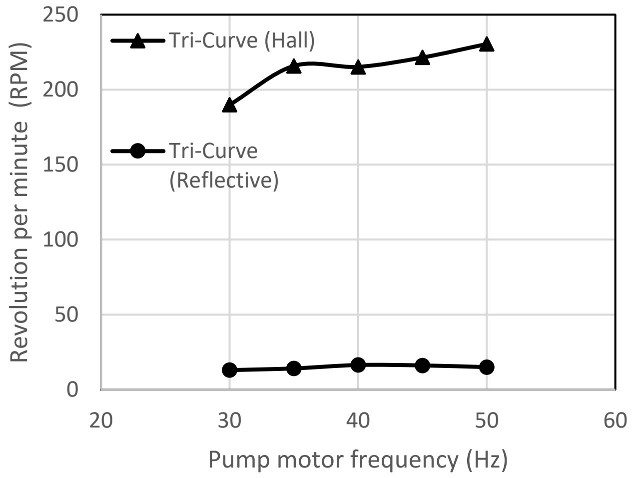

Figure 8: RPM comparison of tachometer and Hall effect sensor of Tri-curve design.

The trend shown in figure 8 show a large marginal gap of rotation data between measurement methods. The Hall effect sensor picked up rotational data at a more continuous and rapid interval than the reflective method. Based off of figure 3, most of the rotation indicated were not in a autorotative state.

IV. Conclusion

From the experimentations carried out between rate of oscillation and RPM, there was a clear indication of major variability in rotative behavior. The behavior shown in figure 3-5 however do show that oscillatory behavior occurs more frequently when fluid flow increases. Concerning RPM measurements, the data provided show that while the Hall effect sensor was detecting oscillations during aperiodic oscillatory regions , the tachometer recorded at a slower rate, and not without the taped surface to reflect light back. In higher and more turbulent regions, the Hall effect trend consistently increased which showcased accuracy improvements when under a threshold measurement method. A possible reason as to why the tachometer produced lower than expected values would be in part to the conflict between aperiodic oscillations and reflective tape placement. In higher turbulent regions, as clarified by [1, 8], aperiodic behavior appears more frequently in Re < 5000, and autorotative behavior was expected with Re values exceeding 3000. The results indicate a constant variable behavior that while not having consistent behavior have exhibited every form of expected rotational behaviors.

For future Hall effect case studies, enabling a larger threshold may further cut outlier measurements, but will be incapable of differentiating each type of rotation. Proposed in [9], a T-method for measuring velocity, and comparing pulse and system clock time intervals periods along a change in magnet polarity. In short, an ability to filter out velocities typical in aperiodic/periodic rotations. Mechanical factors that may have influenced measurements can be caused from deflection of the connected metal shaft and frictional forces of the roller bearings.

Based off RPM trends of both devices, there is indication that while the tachometer proved to lack sensitivity due to having 1 location of measurement, the Hall effect sensor has shown to become prone to hypersensitivity and difficulty in distinguishing autorotative behavior from other forms of rotative behavior. Due to the unpredictability factor in bladeless turbine behavior, a possible solution to obtain and filter consistent RPM measurements was not found in this paper, however; as mentioned, the given flexibility in Hall effect programming and possible route towards feedback systems may provide more reliable, and consistent data outputs in future bladeless turbine concepts.

References

[1] Camassa, Roberto & Chung, Bongjae & Howard, Philip & McLaughlin, Richard & Vaidya, Ashwin. (2010). Vortex Induced Oscillations of Cylinders at Low and Intermediate Reynolds Numbers. 10.1007/978-3-642-04068-9_8.

[2] N. Ilyayev, Creative Commons, Poughkeepsie, NY, rep., 2020.

[3] Chowdhury, Harun & Loganathan, Bavin & Wang, Yujie & Mustary, Israt & Alam, Firoz. (2016). A Study of Dimple Characteristics on Golf Ball Drag. Procedia Engineering. 147. 87-91. 10.1016/j.proeng.2016.06.194.

[4] Sriratana, Witsarut & Murayama, Riichi. (2013). Application of Hall Effect sensor: A study on the influences of sensor placement. IEEE International Symposium on Industrial Electronics. 1-5. 10.1109/ISIE.2013.6563781.

[5] Kathirvelan J, Babu Varghese,Ubaid A Ponnary,Fajas Kamar,Renju Thomas Jacob. "Hall Effect Sensor Based Portable Tachometer for RPM Measurement." International Journal of Computer Science and Engineering Communications 2.1 (2014): 100-105.

[6] Open Water Flume for Fluid Mechanics Lab," Fluids, vol. 6, pp 242, 2021

[7] Jeong-Hoi Gu, Chi-Young Song and Sang-Yeal Lee, "A new velocity measurement method using linear type Hall-effect sensor for an electro-mechanical fin actuator," SICE Annual Conference 2007, 2007, pp. 2179-2183, doi: 10.1109/SICE.2007.4421349.

[8] Chung, B., Cohrs, M., Ernst, W. et al. Wake–cylinder interactions of a hinged cylinder at low and intermediate Reynolds numbers. Arch Appl Mech 86, 627–641 (2016). https://doi.org/10.1007/s00419-015-1051-2

[9] Jeong-Hoi Gu, Chi-Young Song and Sang-Yeal Lee, "A new velocity measurement method using linear type Hall-effect sensor for an electro-mechanical fin actuator," SICE Annual Conference 2007, 2007, pp. 2179-2183, doi: 10.1109/SICE.2007.4421349.