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Energy Recovery from a Yamaha Mio Aerox 155 Motorcycle Using Turbine-Driven DC Generator with an Integrated Electrostatic Coarse Particulate Filter

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Abstract. The worsening traffic conditions in the Philippines have increased the demand for motorcycles. This becomes a reason for more air pollution. One component of air pollution is particulate matter. Motorcycles emit more PM than passenger vehicles per vehicle-mile traveled [2]. PM kills more than five-hundred-thousand people annually through cardiac and respiratory damage [1]. In addition to air pollution, there is also wasted wind energy coming from motorcycle exhaust. Both the pollutant and the wasted energy are found in the exhaust wind emissions. The problem was addressed through an energy harvesting device with an integrated electrostatic coarse particulate filter. The harvesting device was comprised of a turbine, a generator, and an exterior. These components were fabricated using aluminum. On the other hand, the filter was made of aluminum plates and a 3D-printed exterior. With these two components attached to the motorcycle's exhaust, the wind energy was converted into electrical power, and the coarse particulate matter levels were decreased from the emissions. The generator reached max power generated at 5500 rpm, sitting at 858.97 mW. The linear regression analysis gave an R-value of approximately 0.94 which shows that there is a strong relationship between the rpm of the engine and the power generated by the generator. Meanwhile, in order to analyze the difference between the concentration of PM10 before and after the application of the electrostatic coarse particulate filter, the researchers used a t-test on the data. The two-tailed test resulted in a p-value<0.001 for Case 0 which shows that there is a statistically significant difference between the concentrations of the PM10 before and after the application of the filter. Moreover, Cases 1, 2, and 3 also had a p-value<0.001, which implies the same conclusion. A formula was used to calculate the efficiency of the filter. The average of all the peak efficiencies of the cases sits at 74.25%. These findings show that the prototype is feasible against air pollution and energy harvesting. Hence, the expansion of the research is imperative.

Keywords: energy harvesting, renewable energy, motorcycle exhaust, electrostatic filter, particulate matter, air pollution

1. Introduction

Air pollution from motor vehicles has long been a major issue in most countries. One integral ingredient of air pollution is particulate matter. It was known to kill more than 500,000 people annually through cardiac and respiratory damage [1]. The worsening traffic conditions in the country have led to an increased demand for motorcycles, which emit more particulate matter than passenger vehicles per vehicle-mile traveled [2]. Furthermore, according to [3], modern internal combustion engines used in motorcycles only have a thermal efficiency of around 40%. This is with respect to the energy stored in the fuel versus the useful work done by the vehicle, as most of the energy is wasted as heat that is pumped out of the vehicle's exhaust. Harnessing this wasted energy and converting it to electricity can produce practical benefits. The problem with the gas emissions of motorcycles is the air pollution and wasted energy caused by the vehicle. These can be addressed by using the knowledge already known about renewable energy and will further help the progress of integrating renewable energy sources into our regular consumption.

The main objective of the study is to develop an energy recovery system from a Yamaha Mio Aerox 155 motorcycle exhaust using a turbine-driven DC generator with an integrated electrostatic coarse particulate filter. The specific objectives of this study are: (a) to fabricate a prototype that can harness energy through

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motorcycle exhaust, (b) to make a filtration system powered by the DC generator, (c) to calculate the power generated by the generator and the efficiency of the filter.

The scope of this study is to convert the air pressure coming out from the exhaust of a Yamaha Mio Aerox motorcycle with a 4-stroke, 155 cc engine into useful electrical energy. The energy harnessed is only intended to charge a battery and power the electrostatic filter. The filtration system is only limited to the reduction of coarse particles ejected from the motorcycle exhaust.

2. Methodology

The process started with the two inputs, the engine speed, and the exhaust gas with coarse particles, which could be increased or decreased by rolling the throttle. Using a DC generator, the kinetic energy of the exhaust gas spun the turbine attached to the shaft of the generator, inducing a voltage in the conductor. This voltage was measured using an Arduino microcontroller with a voltage/current sensor, and a data logging module to record the voltage values in uncontrolled testing. To move on to the next process, the voltage reading must be at least 2V to meet the minimum voltage requirement of the boost converter, otherwise, the generator must be modified or changed. Next, the current was measured using the same microcontroller. Then, the voltage was regulated by the boost converter to a constant voltage of 8.4V which charged the two lithium-ion batteries connected in series. A battery management system was used for the protection of the batteries. The input terminals of the high voltage boost converter were connected in parallel with the BMS to increase the voltage to 400V, which were utilized to power the electrostatic filter. Using an Arduino microcontroller with PM10 sensor, and a real-time clock and data logging modules, the concentration of PM10 from the exhaust pipe was measured before and after the filtration. According to the Environmental Protection Agency, the level of the national primary and secondary 24-hour ambient air quality standards for particulate matter is 150 µg/m3, 24-hour average concentration [4]. Thus, the reading from the air quality meter must not exceed 150 µg/m3 otherwise, the design of the electrostatic filter must be modified. To end, the output of these processes was the electrical power converted by the generator and the PM10 emission reduced by the electrostatic filter, along with the measured parameter values.

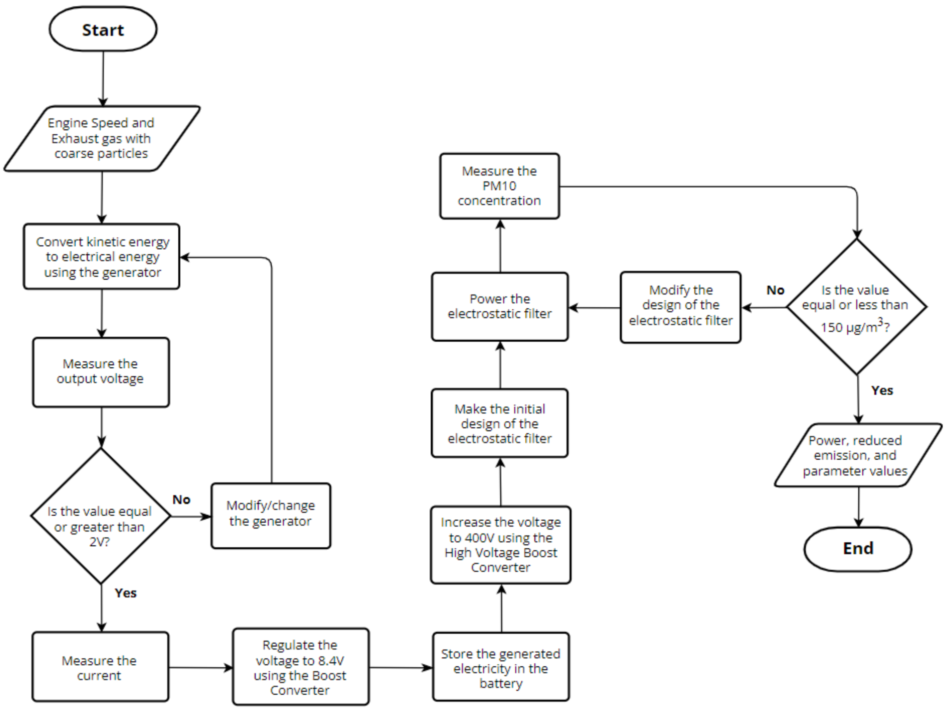

Fig. 1: Process Flow Chart

2.1. System design

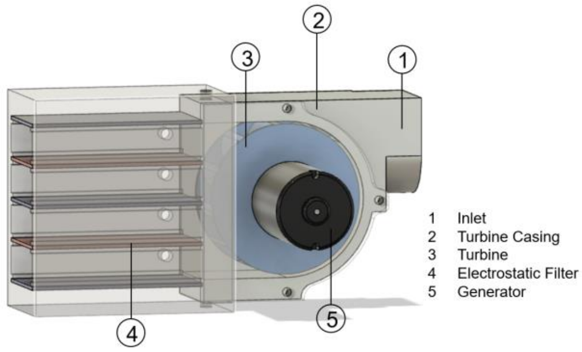

Fig. 2: Turbine, Generator, and Filter

Figure 2 shows the 3D designs of the system showing the major hardware parts: the turbine, the casing, the filter, and the generator. The type of turbine used in this study was a crossflow turbine, composed of a central rotor surrounded by a cage of 12 blades. The next part was the casing, which encloses the turbine. Its inlet will be directly connected to the tailpipe of the motorcycle exhaust. Fixed to the casing was the generator which was driven by the turbine as the exhaust gas hits the blades perpendicularly. Lastly, the electrostatic filter was made of aluminum plates, consisting of anodes and cathodes. This was placed at the outlet to filter out coarse particles from the exhaust gas before it is released into the environment.

2.2. Results and discussion

The researchers conducted seven trials, each for thirty seconds, in a plain and straight road. The voltage and current data logger remotely recorded the voltage and current values generated by the DC generator with respect to the motorcycle engine's RPM and stored them in the micro-SD card. The electrical power produced by the generator, with respect to the rpm, was plotted in the graph below.

The PM10 data logger remotely recorded the PM10 concentration of the exhaust gas with respect to time and recorded them on a micro-SD card. In the first test, the concentration of coarse particles in the exhaust gas was measured with the electrostatic filter turned off while in the second test, the concentration of coarse particles in the exhaust gas was measured with the electrostatic filter turned on. Using acquired values of the filtered and unfiltered exhaust gas PM10, the filter efficiency was calculated and plotted in the graph below:

The voltage gathered by the prototype without a load increases along with the engine speed. The same trend was also observed from the with load voltage and the current. Therefore, the power increases with the engine speed as well.

In all three cases, the concentration of PM10 before and after filtration had a difference in favour of the filter. The PM10 concentration was significantly lower after filtration.

The efficiency of the filter generally followed a downward trend. However, the volatility of the values increased in the presence of uphill and downhill landscapes, as seen in cases 2 and 3.

Table 1: Summary of Power Generated

RPM	No Load Voltage (V)	With Load Voltage (V)	Current (mA)	Power (mW)
2500	3.9±0.64	2.99±0.54	34.78±2.90	103.81
3000	4.21±0.47	3.26±0.52	41.73±3.94	135.90
3500	4.74±0.58	4.28±0.74	46.82±5.13	200.56
4000	6.18±0.63	5.4±0.66	52.35±5.17	282.58
4500	6.92±0.46	5.89±0.73	64.95±5.69	382.43
5000	8.28±0.78	6.29±0.63	85.79±5.63	539.82
5500	8.8±0.78	6.46±0.77	132.91±5.23	858.97

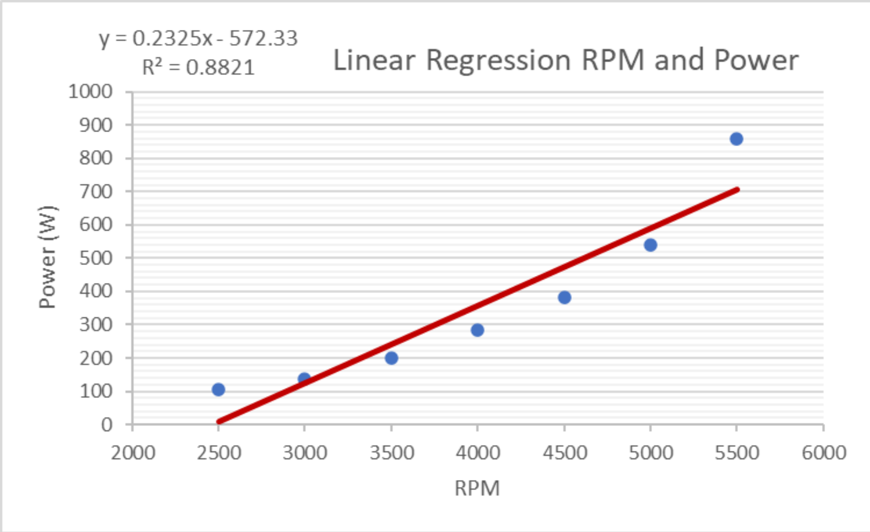

Fig. 3: Linear Regression of RPM and Power

Table 2: PM10 Readings of Cases 1, 2, and 3 Summary

Measurement Time (minutes)	Coarse Particle, C (μg/m³)					
	Case 1		Case 2		Case 3	
	C_1V_0	C_1V_1	C_2V_0	C_2V_1	C_3V_0	C_3V_1
5	243	58	257	73	264	66
10	245	62	264	93	268	74
15	244	61	261	72	269	70
20	248	66	255	80	265	76
25	250	62	253	75	273	77
30	245	61	268	84	264	74
35	242	63	261	79	264	75
40	244	62	254	76	267	70
45	241	63	259	93	269	73
50	238	63	260	85	265	75
55	248	57	255	77	269	64
60	249	70	261	82	271	72

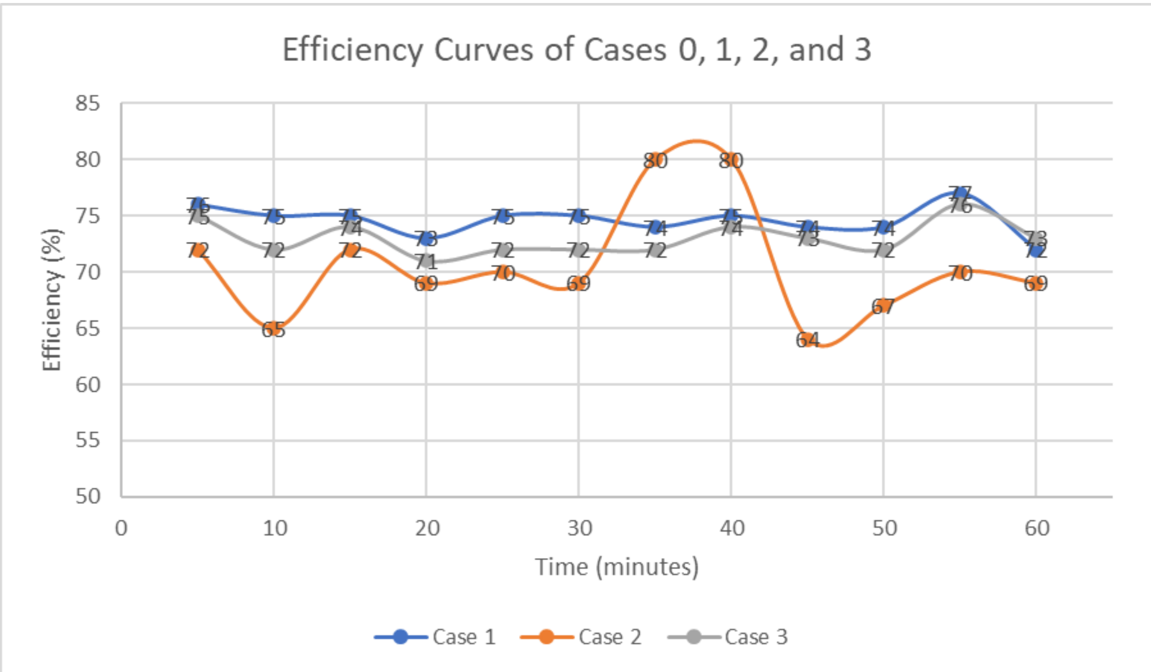

Fig. 4: Case 1, 2, and 3 Efficiency Trend

2.3. Conclusions

The energy recovery system prototype installed in a Yamaha Mio Aerox 155 motorcycle was successfully designed and developed along with the integrated electrostatic filter. The group fabricated the design through a machine shop and showed that it could harness energy from the motorcycle's exhaust through the data gathered by the microcontrollers. Moreover, the filtration system, which was electrostatic, was integrated into the prototype and was able to remove PM10 particles from the exhaust gas. Lastly, the data was calculated accordingly using linear regression, t-test, and efficiency formula. The generated power showed a directly proportional relationship with the engine speed, and the data showed a positive slope. Moreover, the highest power output of the generator was at 5500 RPM, which was 858.97 mW. The filter had a peak efficiency of 72% in Case 0, 77% in Case 1, 72% in Case 2, and 76% in Case 3. The PM10 concentrations before and after adding the filter had a statistically significant difference, indicating a decrease in PM10 concentration upon filtering in all Cases.

3. Acknowledgements

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4. References

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