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DESIGN AND MANUFACTURE A MODEL CONVERTING THE KINETIC ENERGY COLLECTED FROM THE MOVEMENT OF VEHICLES INTO ELECTRICITY

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ABSTRACT

This paper proposed a novel kinetic energy harvesting model that is installed under the speed bumps to harvest power wasted by vehicles when they pass over the speed bumps. The model consists of three main parts: drivetrain-pump-storage system, generator module, and control module. Acting as an energy input, the drivetrain-pump system harvests kinetic energy to produce compressed air. The storage system then stores this air so it is ready to discharge to the generator system. When compressed air is discharged into the generator module, this module will generate electrical energy which can be charged to a battery. The control module can automatically monitor and adjust the amount of compressed air and power in the battery. Tests have shown that the system is capable of storing a compressed air volume below 50 psi. This energy allows generating 14.8VDC power to charge the 12VDC battery. The initial results allow further research for a new energy source in the future.

Keywords: Speed bump, energy harvesting, kinetic energy, renewable energy.

Thiết kế và chế tạo mô hình chuyển động năng thu được từ chuyển động của xe thành điện năng

TÓM TẮT

Bài báo này đề xuất một mô hình thu năng lượng động học được lắp đặt dưới gờ giảm tốc để thu năng lượng bị lãng phí do các phương tiện đi qua gờ giảm tốc. Mô hình bao gồm ba phần chính: hệ thống truyền động - bơm - hệ thống lưu trữ, mô-đun máy phát điện, mô-đun điều khiển. Hoạt động như một đầu vào năng lượng, hệ thống truyền động - bơm thu năng lượng động năng để tạo ra khí nén. Sau đó, hệ thống lưu trữ sẽ lưu trữ lượng không khí này để nó sẵn sàng xả khí tới hệ thống máy phát điện. Khi khí nén được xả vào mô-đun máy phát điện, mô-đun này sẽ tạo ra năng lượng điện có thể được sạc cho ắc quy. Mô-đun điều khiển có thể tự động giám sát và điều chỉnh lượng khí nén cũng như năng lượng trong ắc quy. Các thử nghiệm được đưa ra cho thấy hệ thống có khả năng tích trữ một lượng khí nén dưới 50psi. Năng lượng này cho phép tạo ra điện năng một chiều 14,8VDC để nạp vào ắc quy 12VDC. Kết quả ban đầu cho phép tiến hành những nghiên cứu sâu hơn về một nguồn năng lượng mới trong tương lai.

Từ khóa: Gờ giảm tốc, thu năng lượng, động năng, năng lượng tái tạo.

1. INTRODUCTION

Global energy demand is increasing dramatically and it is forecast to grow by almost 30% by 2040. Therefore, countries are actively researching and applying multiple clean energy sources to replace fossil energy sources. Major hydroelectricity, solar power, and wind power projects are being built, and they have had great success in reducing the use of fossil fuels. However, besides natural energy sources, there are some very useful energy sources that do not come from nature that aren’t currently being utilized. The kinetic energy recovery system through speed humps is one of them.

The speed bump has been used to regulate traffic since the late 1970s o in Western countries. In Vietnam, they started to be applied in 2000 when the Department of Roads identified this as a solution to decrease traffic accidents on many major highways. According to Khorshid *et al.* (2007), the speed bump is an elevated profile placed across the road, usually 7.5-12.5cm high and in various lengths. The speed reduction of a vehicle while encountering speed bumps not only affects the comfort of drivers/passengers but also results in huge kinetic energy loss at the same time (Todaria, 2015).

Ahmad & Masood (2014) developed the idea that there is a possibility of generating power by using mechanical motion mechanisms to convert translational movement into generator rotation, such as rack pinion and crankshaft. They can convert the energy which is being wasted every day on the roads by the moving vehicles, into electricity and store it in batteries. In addition, some research have been focusing on ways to recover this energy such as Todaria *et al.* (2015) and Wang *et al.* (2016) with a novel speed bump energy harvester (SBEH). It can generate large-scale electrical energy up to several hundred watts when the vehicle drives on SBEH. A unique design of the motion mechanism allows the up-and-down pulse motion to drive the generator into the unidirectional rotation, delivering more power than the traditional design. However, this system only produces electricity through the drivetrain for direct use, it cannot store electricity.

A type of piezoelectric pads installed under the road surface for energy harvesting has been developed by Li *et al.* (2013). In particular, Gholikhani *et al.* (2019) studied an electromagnetic speed bump energy harvester (ESE) prototype that was developed to harvest energy from the kinetic energy of passing vehicles, and to simultaneously control vehicles' speed. The ESE absorbs the deflection generated by a passing vehicle and converts it to a rotating shaft that triggers an embedded generator. Azam *et al.* (2020) designed, and manufactured a movable speed bump, which is integrated into a rack and gear mechanism with a combination of one-way clutches for application on the road. All of these systems have the drivetrain to generate electricity, but they only generate electricity when vehicles impact them. However, the electricity generated is not available to use immediately. Thus, it is necessary to store the electrical energy and use when needed.

The voltage management for kinetic energy capture systems has been studied by Chen *et al.* (2017) and Hyun *et al.* (2018). They designed a start-up circuit for a power management circuit to save energy during periods of system downtime. This start-up circuit also realizes the self-start and self-powered functions, when the rechargeable battery is empty, but the power management circuit can still transfer energy to the load side. However, this management circuit does not have a monitoring function for the system, which is essential for the following tasks when designing smart transport systems.

Utilizing this previous research, we designed a system that can recover the kinetic energy of passing vehicles through the speed bumps. The system can convert kinetic energy into compressed air that is then used to generate electricity. The generated electricity is stored in the batteries for later use. The whole system is controlled and monitored automatically.

2. METHODS

2.1. Model structure

Drivetrain - pump - storage of compressed air system is composed of a transmission mechanism, a pneumatic pump system, and a gas accumulator (Figure 1). In this study, we do not go into detail about the structure of the speed hump so a pump arm was built instead. The transmission mechanism is made of circular joints and the spring compression jet system to transmit the compressive force to the pump system when force is exerted on the pump arm.

The pump system consists of two pumps responsible for pumping compressed air into the gas accumulator. The system of gas accumulators includes 4 gas accumulators with manufacturing dimensions as shown in Figure 2.

The generator module is composed of a gas turbine blade system and a closed air path that rotates the generator, the dimensions are shown in Figure 3.

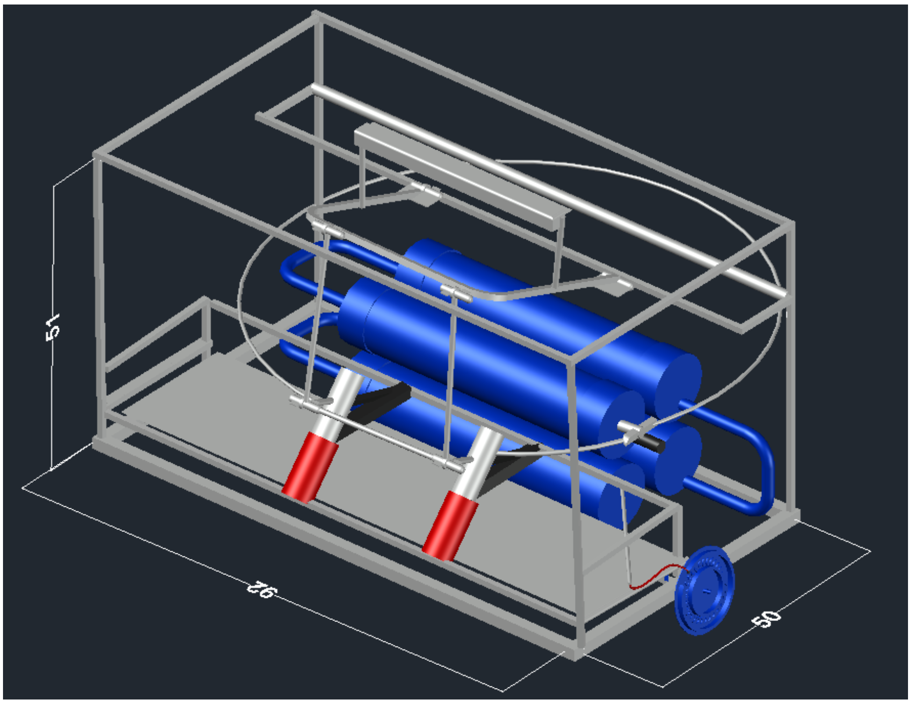

Figure 1. Drivetrain - pump - storage of compressed air system and generator module
(Units measured in centimeter (cm))

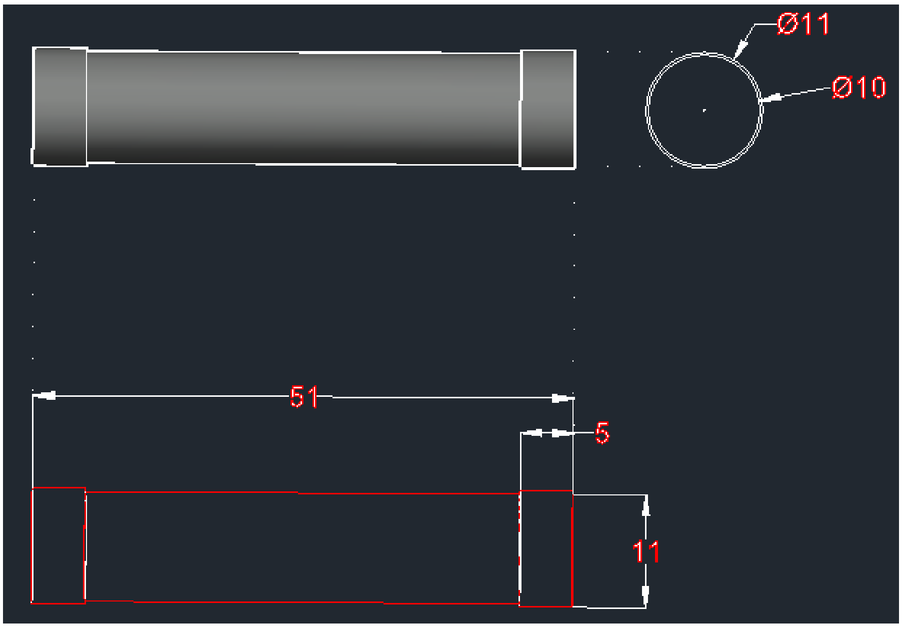

Figure 2. The size of the gas accumulator (Units measured in centimeter (cm))

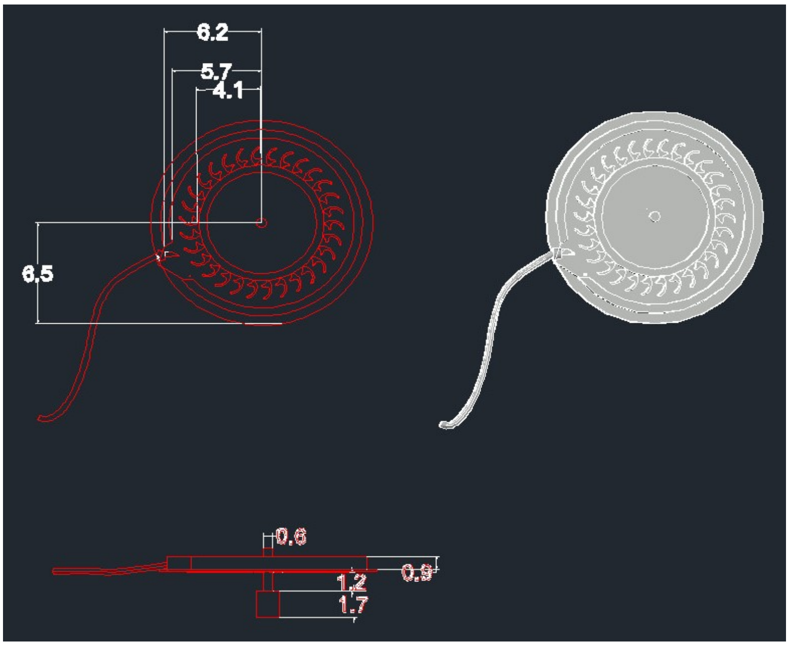

Figure 3. The size of the gas turbine system (Units measured in centimeter (cm))

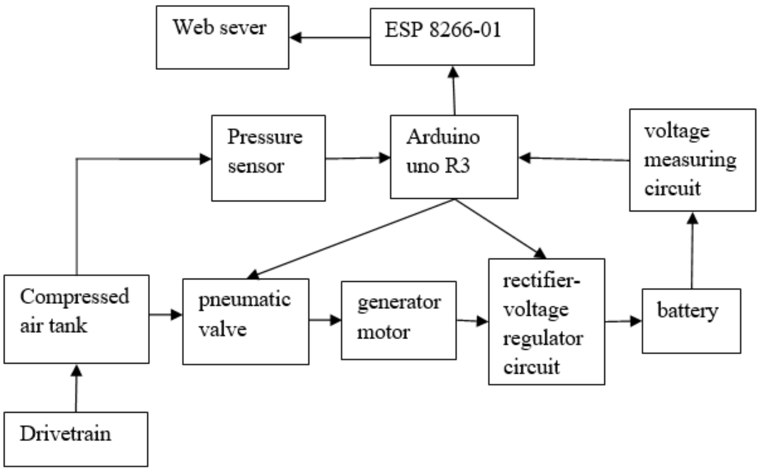

Figure 4. Block diagram of an automatic monitor and gas-electric control system

2.2. Monitor and control system

A pressure sensor measures the pressure in the compressed air tank and sends data to Arduino UNO R3 to activate the pneumatic valve when the set threshold is reached.

The generator is connected to a gas turbine system. The release of compressed air rotates the turbine generating alternating current. This AC goes into the rectifier-voltage regulator circuit to get 14.8VDC voltage to charge the 12VDC battery.

Arduino UNO R3 receives a signal from the pressure sensor and receives a voltage signal from voltage measuring circuit. The Arduino output is used to control the pneumatic valve and the battery charging circuit. Moreover, it is transmitted to the ESP8266 to send to the server.

2.2.1. Arduino and Arduino IDE software

This is a processor board that is used to program interactively with hardware devices such as sensors, motors, and expansion modules.

The core part of the Arduino UNO R3 is built on the ATmega328P microcontroller which uses quartz with an oscillation period of 16MHz.

In this study, we used Arduino IDE software to write a control program for the Arduino UNO R3. Arduino integrated development environment IDE is an application platform of Windows, MacOS, and Linux which is written in the Java Runtime Environment. The Arduino IDE uses the avrdude program to convert the executable to a text file in hexadecimal encoding. It is loaded on the Arduino board by a loader in the motherboard firmware.

2.2.2. Pressure sensor

A pneumatic pressure sensor is responsible for receiving pressure signals and sending them to the central controller. It helps monitor the pressure system steadily in a certain pressure range, and allows the system to automatically read the value to stop the gas filling at a preset pressure level. Additionally, the system can also automatically reopen the compressed air filling when the pressure changes to a set value.

2.2.3. Solenoid valve 3V210-08

3V210-08 solenoid valve is a 3/2 pneumatic valve. The way the valve works is to continuously switch and close to direct compressed air into the generator's turbine.

2.2.4. Generator

A brushless motor (LA034-040NN08A) is used as a generator through the action of the compressed air system in the model. It has an engine diameter of 36.5 mm, length 61 mm, shaft diameter 5 mm. A rectifier circuit is built-in with the generator to provide a DC voltage at the output. The maximum speed of 10,000 rpm corresponds to 230VDC and other parameters are given in Table 1.

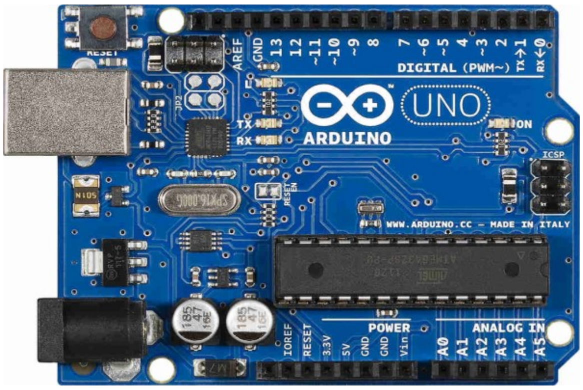

Figure 5. Arduino UNO R3

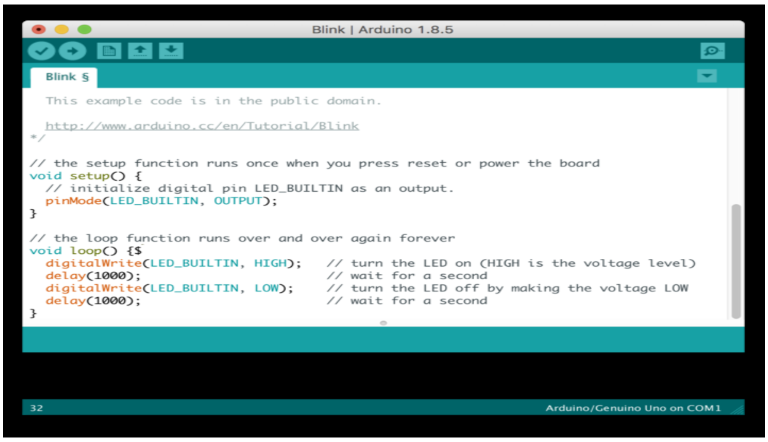

Figure 6. Programming interface

Figure 7. Pneumatic pressure sensor with signal feedback

Figure 8. Solenoid valve 3V210-08

Figure 9. Generator

Table 1. Relationship between speed and generated voltage of LA034-040NN08A

Revolutions Per Minute (rpm)	Generated voltage (V)
1,000	23
2,000	46
3,000	68
5,000	112
10,000	230

Figure 10. Arduino ESP8266-01

2.2.5. ESP 8266-01 module

The ESP8266 Uart ESP-01 Wifi transceiver module uses Espressif's ESP8266 SoC Wifi IC. It is used to connect to a microcontroller that performs data transmission functions over Wifi. The ESP-01 can connect to the network and send data to website in a certain cycle by connecting to a wifi signal and a pre-installed website.

In this application, the ESP8266 team programmed the ESP8266 to display a web interface that displays the device's data and configuration information, as well as the device controls. Therefore, the first step was to design the interface and data structure of the Webserver. To design the webserver interface for the ESP8266, the authors applied online tools to test HTML commands until they were complete. Then the authors copyiedthe tested HTML commands and saved them to the ESP8266 program on the Arduino IDE.

When users want to use it, they can turn on the Wifi setting on the smartphone and connect to the Wifi network which is operated by ESP8266. After successful connection, the user can open any web browser and access the IP address 192.168.4.1 which is the default IP address of the ESP8266 Webserver. The user can see the web interface that has been designed and can interact with the ESP8266 such as configuration settings, read sensor current value as well as a list of previous values, and so on. They can copy the contents of the sensor value and save it as a text file ending in .csv. They can then open it in Excel to plot graphs, analyze data, and more.

3. RESULTS AND DISCUSSION

3.1. The results of manufacturing drivetrain - pump - storage of compressed air system and generator module

Each impact on the pump arm will create a force. This forces the drivetrain to act on the pump system, helping to pump compressed air into the gas accumulator. In addition, this system can limit the number of jolts inflicted on vehicles, thereby reducing the level of discomfort for the vehicle used when passing through the real speed bump.

The structure of a gas turbine is shown in Figure 12. The blades of the turbine are designed to help optimize the air discharge from the gas accumulator. The generator has a compact structure suitable for the model.

3.2. Control circuit fabrication results

The principle circuits and printed circuits were designed on Proteus 8.7 software. The principle circuit includes: control block, power block, voltage measuring unit, display unit, ESP8266 block, gas valve relay power on and off a block, which has been divided into separate parts in the circuit. Figure 14 is the actual circuit when tested.

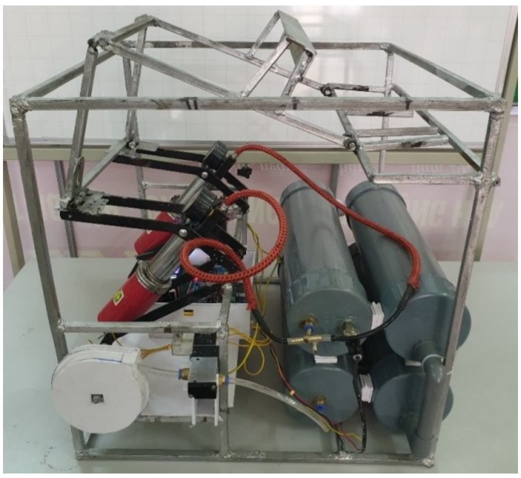

Figure 11. The designed real system

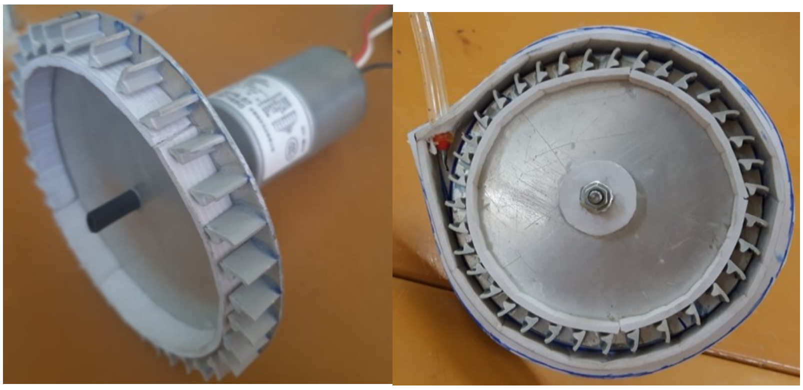

Figure 12. Generator module

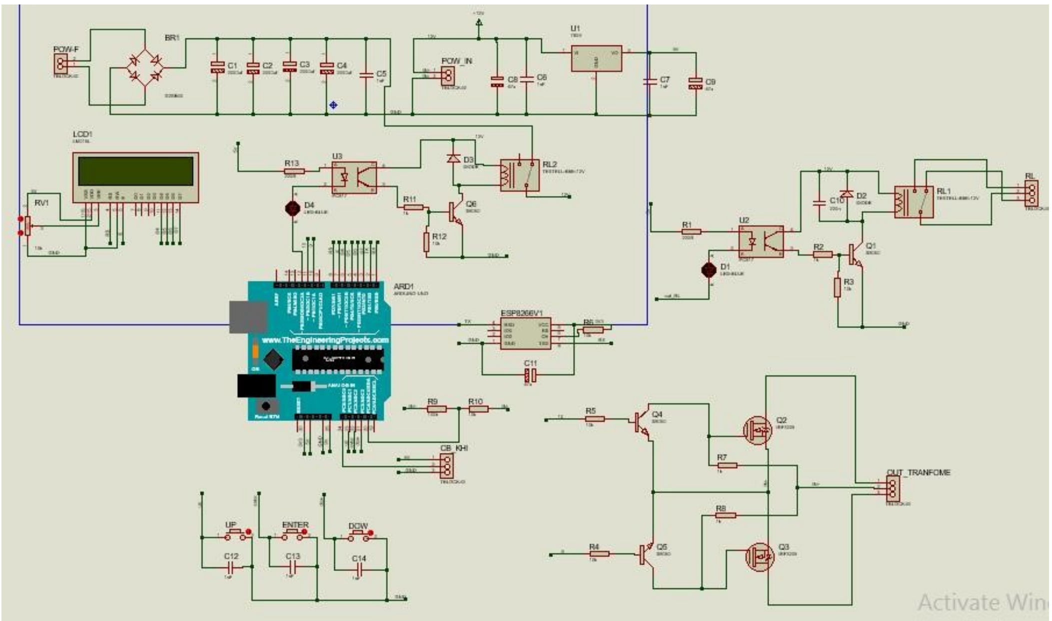

Figure 13. Principle circuit

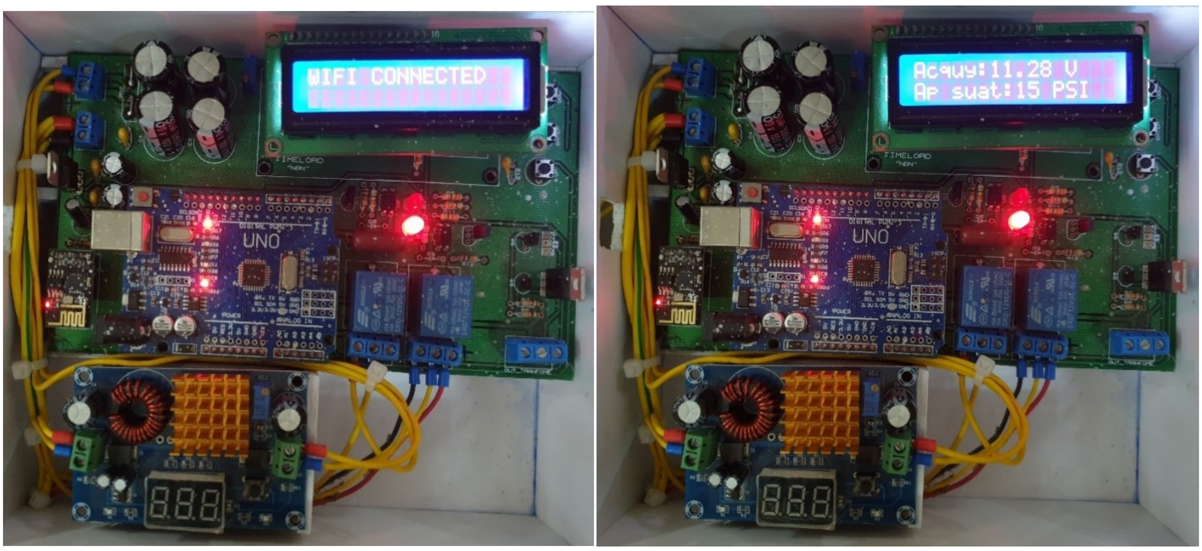

Figure 14. The control module

Figure 14 indicates information on the control module in action. Initially, the module was connected to wifi to send data to the Web Server. Then the parameters: the pressure limit in the gas accumulator, the electric limit in the battery can be set via the LCD. In addition, the LCD helps to monitor the battery voltage status and the pressure inside the gas accumulator.

3.3. Test results

3.3.1. Testing the drivetrain - pump - storage of compressed air system and generator module

a. Full system testing

To test the drivetrain - pump - storage of the compressed air system and generator module, the authors performed an experiment that exerted a force on the pump arm. At that time, a certain amount of air was compressed into the gas accumulator. When it reached the specified threshold, the pneumatic valve allowed air discharge to rotate the generator module. Experiments to determine if the pneumatic discharge thresholds were enough to rotate the generator module which created a larger DC voltage 14V. It was intended to charge the battery. Pressure levels were given to consider system stability at different pressure levels.

The compressed air discharge thresholds were tested at 1.38 bar, 2.07 bar, 2.76 bar, and 3.45 bar in compressed air bottles. The results in Table 2 shows that if the average impact was 19 times on the pump arm, the pressure in the gas accumulator reached 1.38 bar, with a pressure of 2.07 bar required an average of 42 times, the pressure of 2.76 bar required an average of 70 times and 96 times at 3.45 bar pressure. The number of actions on this pump arm corresponded to the figure of the wheel rolls over the speed hump. It reached the compressed air discharge threshold was installed in the control circuit. The lower threshold for closing the exhaust valve was set to 0.83 bar during the tests. This is the minimum pressure level that helped the generator module generate a voltage greater than 14VDC to be loaded into the battery. Besides, discharge times from the test pressure levels down to 0.83 bar can also be observed in Table 2.

b. Experiment without load

Experiment without load was measured with the generator running but not connected load behind. The test used a multimeter to measure the generator output voltage as it passed through the rectifier. This test has illustrated that when the pressure in the compressed air tank reached the set threshold (1.38bar, 2.07bar, 2.76bar, 3.45bar), the pneumatic valve opened to turn the generator. The generated voltage levels are shown in Table 3.

Table 2. Results of the testing system

N^0	Number of times on pump hand (times)				Exhaust time (s)			
	1.38 (bar)	2.07 (bar)	2.76 (bar)	3.45 (bar)	1.38 to 0.83 (bar)	2.07 to 0.83 (bar)	2.76 to 0.83 (bar)	3.45 to 0.83 (bar)
1	18	42	70	95	15	28	39	50
2	19	43	71	96	17	29	39	51
3	18	42	69	95	16	28	40	51
4	20	41	70	96	16	28	40	50
5	18	42	70	97	15	30	39	51
6	19	42	71	95	15	29	38	50
7	19	43	70	96	16	29	39	50
8	19	43	69	96	15	28	39	51
9	18	42	70	96	16	28	40	50
10	19	42	70	95	15	28	39	51

Table 3. The generated voltage at different pressures

Pressure (bar)	Voltage (VDC)	
1.38	Umin	6.54
	Umax	44.1
2.07	Umin	8.57
	Umax	82.6
2.76	Umin	9.78
	Umax	119.5
3.45	Umin	11.66
	Umax	141.3

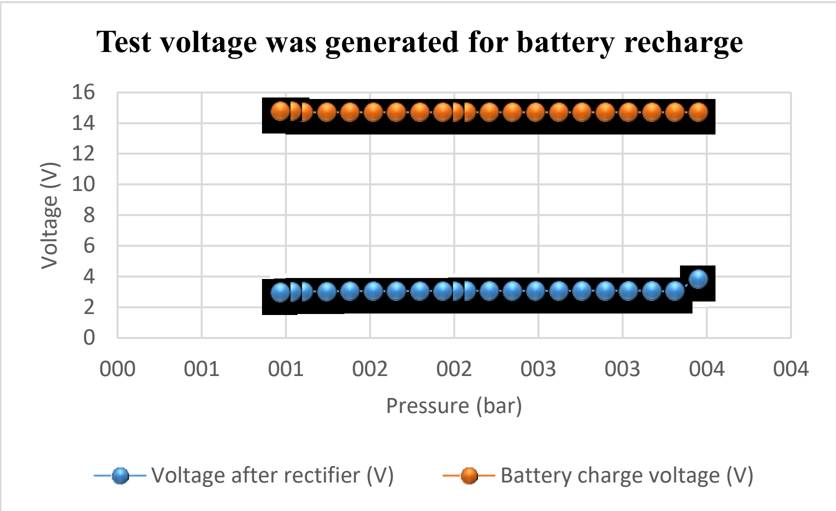

Figure 15. The voltage for battery charge

Table 3 illustrates the results of the test with the generator idling. The maximum pressure level of the test was 3.45 bar and the minimum was 1.38 bar. When the pressure in the compressed air tank reached 3.45 bar, 11.66VDC was the minimum voltage generated and the maximum voltage generated at 141.3VDC. When the pressure reached 1.38 bar, the minimum voltage and maximum voltage were generated at 6.54VDC and 44.1VDC, respectively.

c. A test of generated voltage for battery recharge

With the results obtained in the no-load test, we used a voltage regulator circuit to stabilize the output voltage at 14.8V to charge the battery, while the input range was 3VDC - 45VDC. When the load (battery) was connected to the generator, the output voltage fell to 3VDC as the blue marked line in Figure 15. This was explained by the fact that the load was too large, so there was a demagnetized horizontal armature reaction, and at the same time causes magnetic disturbance. This is the reason why the generator voltage has dropped so sharply.

By using the voltage regulator, we can achieve the stabilized voltage of 14.8VDC at the output to charge the battery, which was shown by the orange marked line in Figure 15. In this study, we stopped at building a system with a chargeable output voltage for the 12VDC battery. However, the issue of the battery charging process should be more analyzed in future researches.

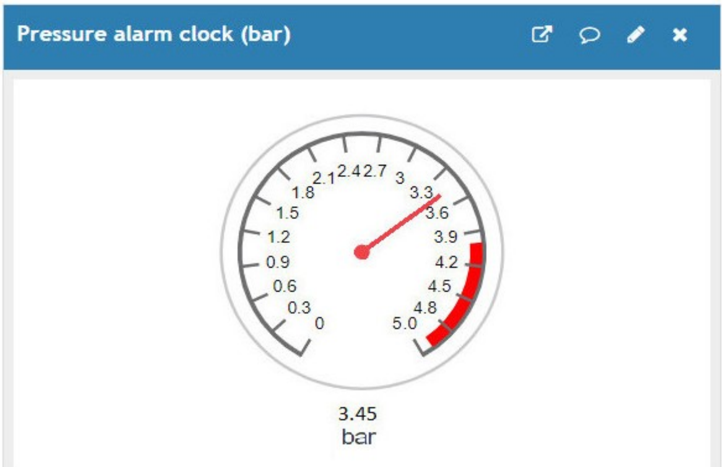

Figure 16. The pressure inside the compressor tank

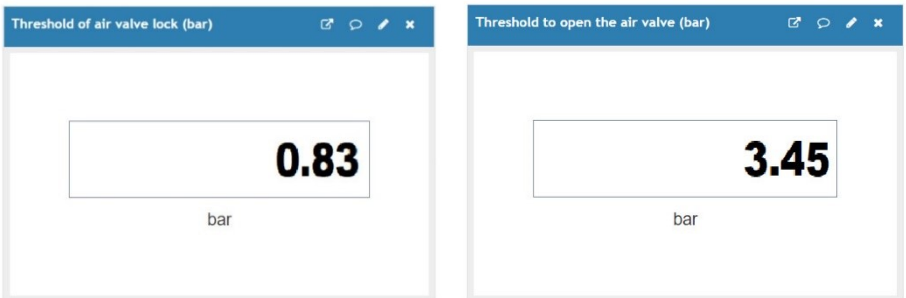

Figure 17. Threshold of locking and opening the air valve

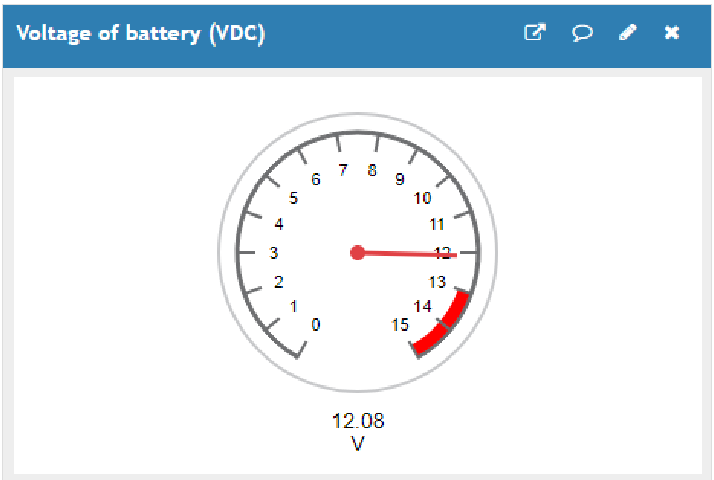

Figure 18. The battery voltage

3.3.2. A test of monitor and control module

This section addresses the results of a test of the monitor and control module. Figure 16 provides information on the pressure level contained in the gas accumulator sent up from the pressure gauge sensor. The discharge threshold and the air valve lockout threshold for different tests were executed. During this test, the authors checked the gas discharge threshold at 1.38 bar, 2.76 bar, and 3.45 bar. Figure 17 shows the threshold to open the air valve

(3.45bar) and the threshold of the air valve lock (0.83bar). The battery voltage was addressed in Figure 18. When the battery was full, the system did not charge the battery.

3.4. Discussion

From the above results, the model has initially demonstrated the ability to store compressed air so that it can generate DC power within the permissible range for charging the battery. The experiments without load are executed to show the reliability of the system before proceeding to the load test. A voltage regulator circuit is used to stabilize the output voltage at 14.8VDC to charge the battery. The information on the pressure, the air threshold, charging voltage, … can be monitored and stored on the network. However, some issues on designing a generator system that suits for charging the battery, as well as the battery charging process should be clarified in future researches.

4. CONCLUSIONS

This paper presents a system of capturing kinetic energy wasted when vehicles pass over the speed bumps, and then to convert that energy into compressed air, which is used to generate electricity. The generated voltage can be chargeable for the 12VDC battery. The whole system is controlled and monitored automatically. Although there exist some problems in designing the generator system, the voltage regulator, as well as the battery charging process, this construction of the system is the first step for further researches in the future.

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