National Conference in Mechanical Engineering Research and Postgraduate Studies (2nd NCMER 2010)
3-4 December 2010, Faculty of Mechanical Engineering, UMP Pekan, Kuantan, Pahang, Malaysia; pp. 603-613
ISBN: 978-967-0120-04-1; Editors: M.M. Rahman, M.Y. Taib, A.R. Ismail, A.R. Yusoff, and M.A.M. Romlay

EXPERIMENTAL PERFORMANCE TESTING OF THE ACTUATION PART OF PIEZOELECTRIC GENERATOR FOR ALTERNATIVE POWER GENERATION

S.N.S Jamaludin, Rosli A. Bakar and L.M. Gan

Faculty of Mechanical Engineering
University Malaysia Pahang, LebuhrayaTun Razak
26000, Kuantan Pahang, Malaysia. Tel : 09-4242202/2225
E-mail :snursakinah@gmail.com, rosli@ump.edu.my, ming@ump.edu.my

ABSTRACT

Piezoelectricity was noticed as a new potential in the alternative power generation field. A new design of piezoelectric generator prototype was developed in this project within an innovation idea on the actuation concept of the inner part that makes the system working. This paper will show the experimental testing procedure to reach the performance of the new system developed. The independent variables used for the experiment are magnitude, speed and durations and they come in some different values. These values show different results and explain the performance of the actuation part developed.

Keywords: Experimental testing, actuation part, magnitude, speed, durations

INTRODUCTION

Mostly, the terms of energy scavenging and harvesting are related to research and engineering activities that targeted at generating energy in electric form from various ambient energy. Generally the ambient energy cannot be scaled up for full-size and power plant energy generation schemes but it usually can be activated in micro or miniature scale to make it transform into usable electric energy. There are much ambient energies that could be exploited by low power generators such as waste heat, vibrations, electromagnetic field, air movement, human movement and etc. In addition, former century resource of renewable energy like water flow, wind energy or sun radiation can also be used at the miniature scale for micro energy harvesting. Nowadays, it can be seen that there is the increasing of MEMS implementation in the industry and it challenges manufacturer and researchers to find the techniques of powering such devices. The issue of energy, integration and miniaturization occur when these kinds of devices become free standing systems without tethered to any plug and all of them must be addressed on the basis of compatibility of the components. Self-sustainable or self-powered generator is one of the alternative methods to overcome such problems. Piezoelectric materials have been extensively utilized because of their unique capability of converting mechanical energy into electrical energy. So that, in this project the idea on using piezoelectric materials on a series of stack actuator is proposed to become one of the alternative self-powered generator to be used independent power supply devices in the industry.

BACKGROUND

The main idea is a power system that is able not only for power generation for load applications but also self-replenishing. The system is composed of a piezoelectric stack in series with a suspension that contain spring factor and damper unit. Piezoelectricity is a special behaviour of certain materials that have the ability to transform mechanical stress and strain into electrical potential. Suspension that is used in the system acts like a power conversion system delivering the waste energy from the vibrations to be used as the input energy for the generator developed. In this project, the waste energy from vibrations is used as the input for the self-sustainable system.

According to Inman D.J.(2001), vibration is evident everywhere and in many cases greatly affects the nature of engineering devices. He said that every structure has its own natural frequency and because of that, power harvesting devices have almost always some kind of ambient mechanical vibration available around themselves as an energy source for power generation. Sodanoet. al.(2005) then said that to use mechanical vibration to apply strain energy to the piezoelectric material, one of the most effective ways is by implementing a power harvesting system to convert the mechanical energy from vibrations into useful electrical energy to power other devices. Previous researches had done many kinds of experimental testing on devices developed using piezoelectric material as the energy source medium. For example, in Xi et al. (2004) had achieved peak voltage which approximately 0.45V for each hybrid device with the dimensions 1mm length, 50µm width and 10µm thickness from their self-assembled muscle piezoelectric micro generator. They had done a testing by fixing the poled devices were fixed on a petri dish and followed by the addition of the cell culture medium mixed with the neonatal cardiac myocytes.

Zylka (2009) had designed a piezoelectric energy scavenger model that consists of two M-8557-P1 type MFC transducers fixed to a phosphor bronze flat beam using DP460 epoxy adhesive and connected in parallel to increase magnitude of the generated current. The maximum voltage amplitude noted was about 150V and even higher for high resistive loads. Zylka had achieved ambient energy harvesting using piezoelectric materials and electroactive polymers. Discenzoet. al (2006) also had developed a power conversion circuit to rectify the sinusoidal voltage from the piezoelectric generator. They scaled the voltage for charging the super-capacitor bank before convert power from batteries for pre-charging the capacitor bank to provide a voltage signal for monitoring the generated power and the capacitor state of charge and regulate the power going to the processor and radio.

Lewandowski B.E et. al (2007) used a software model to predict the output power by varying the system parameters within their constraints. They applied mechanical forces that mimic muscle forces experimentally to a piezoelectric generator to verify the accuracy of the simulations and to explore losses due to mechanical coupling.

Leffeuvreet. al(2005) hadcompared the maximization of the harvested power produced by the piezoelectric structure constructed with impedance adaptation principle and new synchronous electric charge extraction approach. It reached 4.6mW with a 10kΩ optimal load resistance and 2mm displacement amplitude at 60Hz. It achieved 12.3mW useful power, Pout within 70% maximum efficiency.

DEVICE TESTING SETUP

The performance of the piezoelectric generator system developed in this project will be tested at ambient conditions. The purpose of the testing is to determine the performance of the generator itself in terms of power output under some independent variables given on the system and to determine if the power output is adequate for commercial in micro or miniature applications.

The test rig structure is designed to be convenience for many layers testing. In this case, the test rig must be able to be adjusted for different kinds of input variables in terms of magnitude, speed and duration. It will be started with one sandwiched piezoelectric stack, continue until the complete set used for the generator. From this method, the performance of the generator within the number of piezoelectric stack can be seen. So for that purpose, the upper parts of the test rig that consist of actuator casing, acrylic upper holder, the acrylic itself and the stud are designed within bolts and nuts for adjustment. Figure 1(a) shows the parts we have on the test rig structure and Figure 1(b) shows the method of adjusting the upper parts of the testing rig for the testing purpose. Materials used for the test rig structure were chosen by considering the function of each part. For the test rig frame, metal is considered as the most suitable to be used because it is fixed part of the test rig and should be strong enough. Beside that, in order to show the harvesting phenomenon happen on the inner part of actuation part of the piezoelectric generator, the transparent acrylic is used for the cylinder part.During the testing procedure, the acrylic cylinder will be adjusted many times. So, nylon material is used for the acrylic holder to protect the part from jagged.

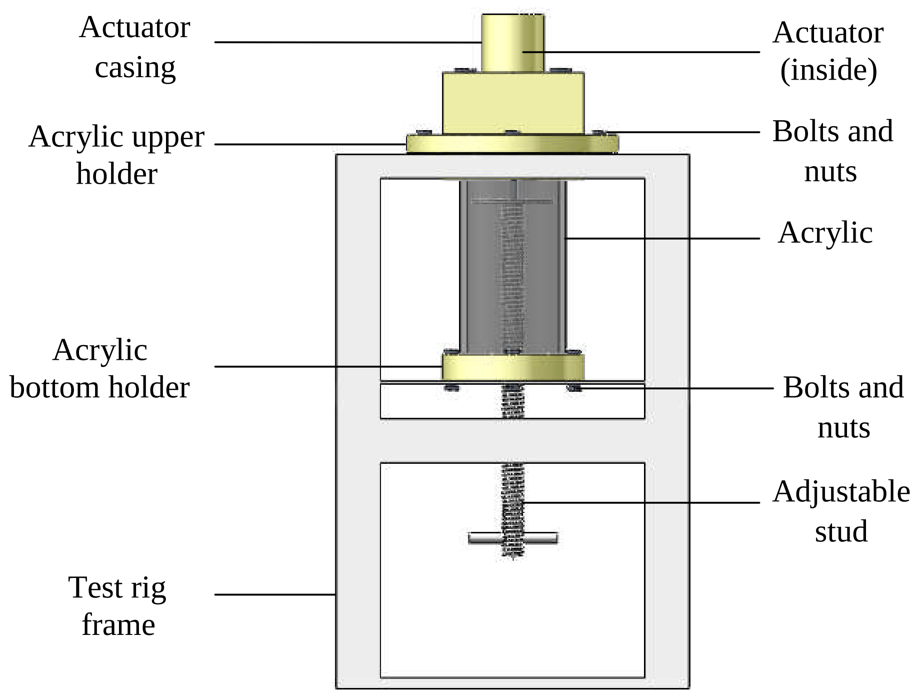

Figure 1(a):Test rig structure designed for the piezoelectric generator performance testing

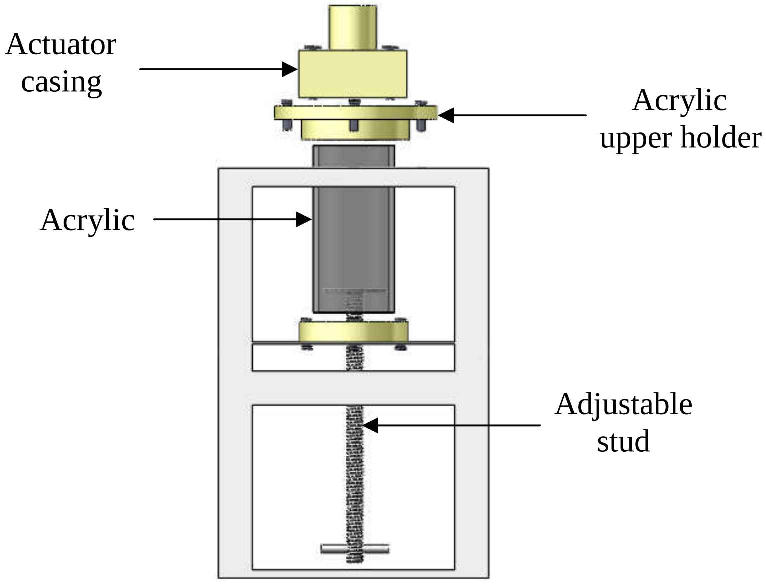

Figure 1(b): Adjustable parts of the test rig structure

For the input variables medium, tubular push linear solenoid actuator is utilized within some electronics integration. The electronics part may contain of IC Timer 555 circuit for the input variable adjustment, rectifier and regulator circuit, storage circuit and voltage controller circuit. The last result will be the output power achieved by the generator from the mechanical system developed and this value will show the ability of the system as the alternative power supply for micro and miniature scale devices. Figure 2 below shows the dimension of the actuator used for the testing purpose and Figure 3 shows the graph that can explain the stroke amounts of the actuator on flat face within different speeds and forces given on it.

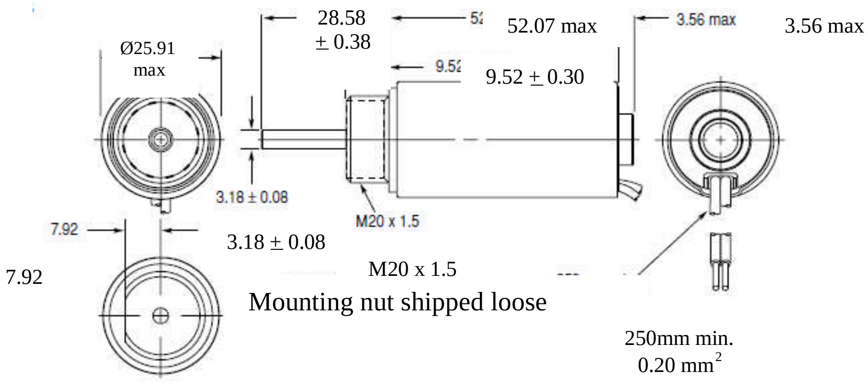

Figure 2: Dimension of the tubular push linear solenoid actuator used as the input variable medium for the testing

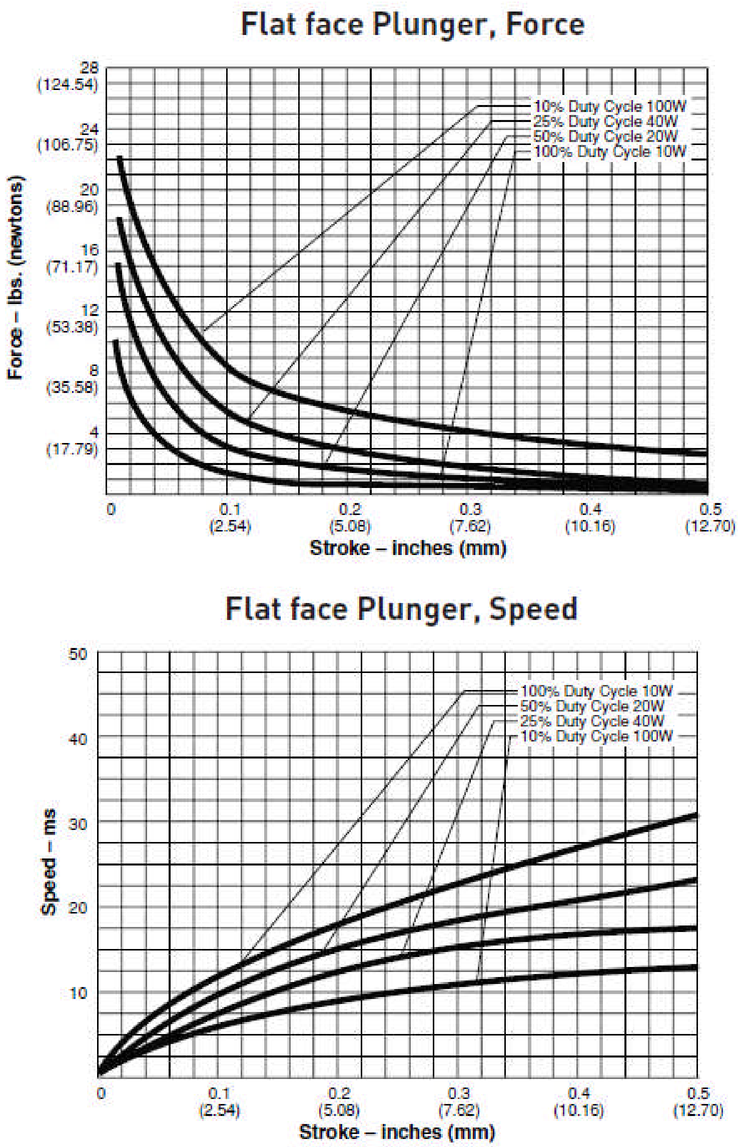

Figure 3: The ability of the push actuator in terms of different speeds and forces [Tubular solenoid push actuator, 2010]

The force at nominal stroke of the actuator is about 2.2 until 3.3N at 100% duty cycle. The value is quite small but enough for the testing. There is no push and pull in combination actuator available in the industry. Therefore, a pull back system that consists of a PVC piece layer was designed to make sure the testing can be done smoothly. For the pull back system, the spring factor, k that belongs to the PVC piece is considered. As long as the PVC piece able to back to its original shape after bend, it is suitable for the system. Figure 3(a) and (b) illustrate the push actuator pull back system designed. The actuator is connected to an IC Timer 555 circuit that functions as the input variable adjustment centre. From the circuit, the values of R1, R2 and C1 can be controlled according to our requirement for the testing. The whole integrated parts will be explained afterwards.

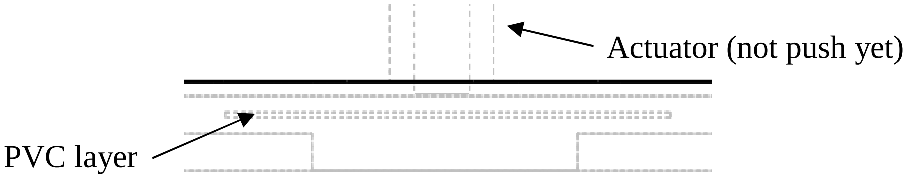

Figure 4(a): Original shape of the PVC piece layer

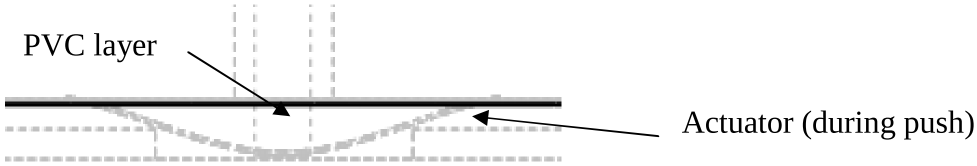

Figure 4(b): Shape of the PVC layer under bend of the actuator stroke

VARIABLE DC PULSE GENERATION

Battery is one of the electric source that commonly used by the appliances available in the industry. It provides constant DC power supply to the micro and miniature scale devices. In order to adapt the instantaneous energy supplied within variables input for testing purpose, a mechanism is required to transform the constant DC power into DC pulse supply. The basic idea to generate DC pulse voltage potential is illustrated in Figure 5.

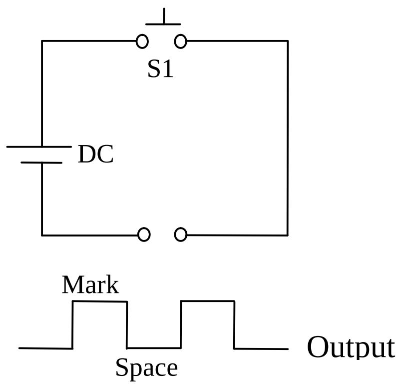

Figure 5: Basic concept of generate DC pulse voltage potential

From the figure, as the switch button S1 is pull and push repetitively, the output will be spitted into Mark (high potential) and Space (low potential) form. For the consistent control of Mark time and Space time, a control mechanism is required to replace S1. In the Stanley Meyer (1992), original patent, semiconductor called thyristor or SCRs (silicon controlled rectifier) to switch the DC signal into pulse signal. One major problem associated with SCRs is that they are not fully controllable switches. In high frequency applications, thyristor are poor candidates due to large switching times arising from bipolar conductor. As the invention of MOSFET (metal oxide semiconductor FET), SCRs have almost been replaced. MOSFETs have much faster switching capability because of their unipolar conduction. In recent development, Naohiro S. et. al. (2006), makes some improvement by using static induction thyristor (SIThy) with FET (field effect transistor) to introduce ultra-short pulse for his project on water electrolysis. For the testing purpose in this project, a variable DC pulsed generator was designed and developed using Timer IC rather than thyristor since it allow fine tuning on various aspects including DC pulse with different input variables and adjustable constant voltage. Instead of using thyristor, SCRs or MOSFET, Timer IC would produce a much precise DC pulsed voltage potential. By different combination of resistance and capacitance value, the Mark time and Space time for the input voltage is controlled. Combined with LM338T, voltage amplitude is adjusted accordingly. Some of the important characteristic of the Timer IC is listed in Table 1.

Table 1: Specification of Timer IC [555_timer_IC, 2010]

Supply voltage (V_{cc})	4.5 to 15V
Supply current (V_{cc} = +5 V)	3 to 6 mA
Supply current (V_{cc}= +15V)	10 to 15 mA
Output current (maximum)	200 mA
Power dissipation	600 mW
Operating temperature	0 to 70^0C

Basically, the IC Timer IC could be grouped into three operating modes which are monostable, astable and bistable or Schmitt trigger. In stable mode, the Timer IC outputs a show a continuous stream of rectangular pulses having a specific frequency which operate as an oscillator. The circuit symbol and the actual pin arrangement of the Timer IC is shown in Figure 6 and the proposed astable circuit diagram for the DC pulsed voltage supply is indicated in Figure 7.

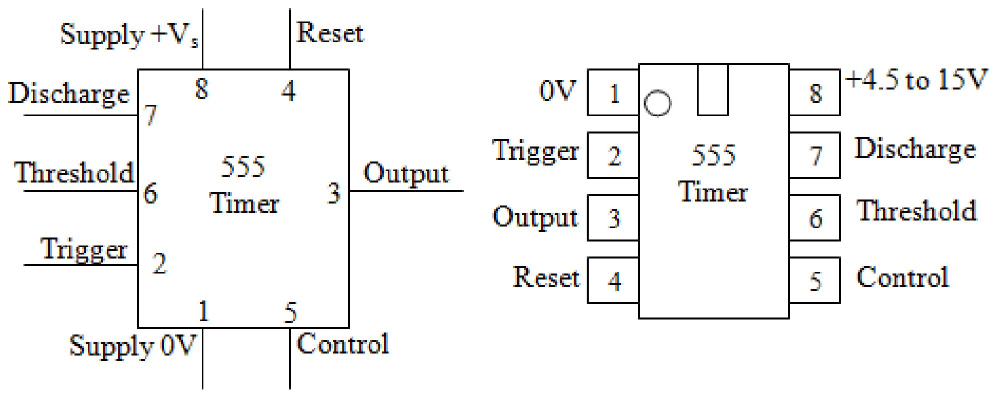

Figure 6: Timer IC circuit symbol and Timer IC actual pin arrangement

Refer to the circuit diagram, VR1 and VR2 is variable resistor used to control the Mark time, T_m and Space time, $T_s$of a pulse which will determine the duty cycle, % of the voltage pulse. The time period of the pulse is the time for one complete cycle, but it is usually better to consider as frequency *f* which is the pulse e number of number of cycles per second.

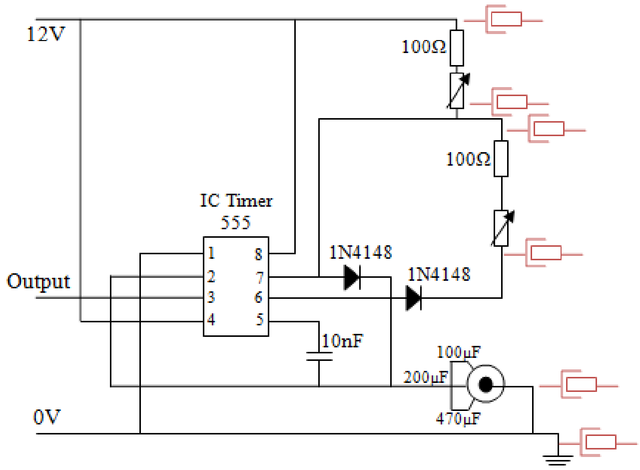

Figure 7: DC Pulsed voltage supply circuit

In this circuit, the output voltage frequency range, *f* is set by capacitor C1. Trigger gate is a selection switch between Gated pulse and Pulsed voltage output depends on the output requirement. The output from the IC2 could be used directly as Out 1 or rectify by MOSFET as Out 2. The control parameters and related calculation is listed as follow:

$$\text{Mark time, } T_m = \ln(2)\, VR_1 C_1 \quad (1)$$

$$\text{Space time, } T_s = \ln(2)\, VR_2 C_1 \quad (2)$$

$$\text{Duty cycle} = \frac{T_m}{T_m + T_s} = \frac{VR_1}{VR_1 + VR_2}\% \quad (3)$$

$$\text{Pulse time, } T_p = T_m + T_s$$

$$Tp = \ln(2)\,(VR_1 + VR_2)\, C_1 \quad (4)$$

$$\text{Pulse frequency, } f_P = \frac{1}{T_P} = \frac{1}{\ln(2)(VR_1 + VR_2)C_1} \quad (5)$$

The main different between Out 1 and Out 2 would be the current supply at Out 2 capable to withstand higher current limit than Out 1. Although Timer IC shows significant advantage compare to SCRs, the main constraint of the Timer IC would be the current limit. In order to use Out 1 directly in hydrogen fracturing process without broken the IC2, a precision current limiter is installed between power supply and V_{cc} as illustrated in Figure 8.

The output current of the circuit in Figure 8 is calculated as follow:

$$I_{out} = \frac{V_{ref}}{VR} \quad (6)$$

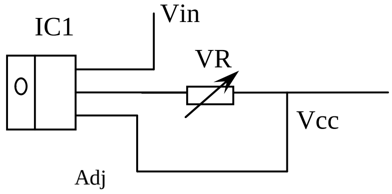

Figure 8: Precision current limiter for circuit IC2

OUTPUT VOLTAGE STORAGE

The outputs in term of voltage value from the piezoelectric generator system may need storage area before it can be benefited for usage. In this project, a 12V battery charger is proposed as the storage medium for the output. As well as we know, the output voltage from the actuation system is regulated at 12V in the regulator circuit. So, the 12V battery charger is required and enough for the storage purpose. The 12V voltage then can be adjusted by using the voltage controller developed in the next segment of the electronics part. Figure 9 illustrates the circuit diagram of the proposed battery charger.

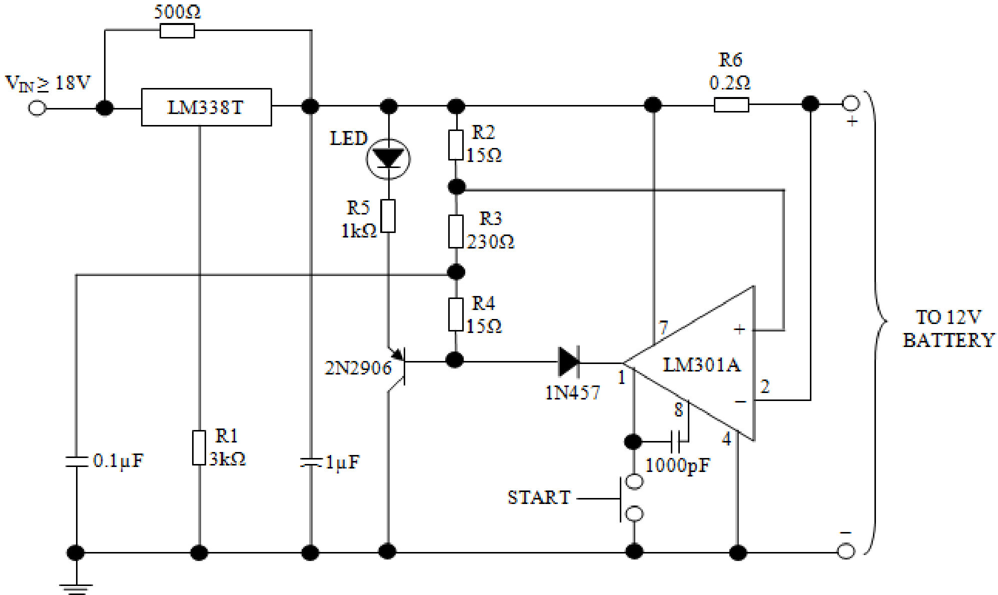

Figure 9: Circuit diagram for output voltage storage

ADJUSTABLE CONSTANT VOLTAGE

An adjustable constant voltage circuit is used to control the output power that will be used as power supply to the miniature appliances. 12V DC power supply is regulated using LM338T 5 Amp Adjustable regulator IC. The details of the circuit diagram are shown in Figure 10.

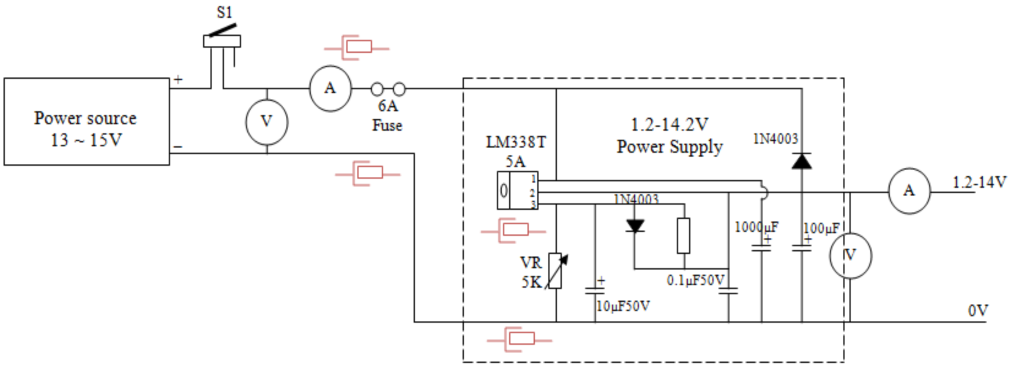

Figure 10: Circuit diagram for constant voltage regulation

In the circuit diagram, VR (Variable resistor) play the main role to tune the output voltage to the desired value while diode D is serves as the protecting component from any short circuiting. From the theory, power (P) is equal to voltage (V) times current (I). In this project, in order to get more current, we used to adjust the value of voltage (V). So the constant voltage is adjusted using the circuit shown above.

CONCLUSION

A low cost adjustable multi input variablestest rig is proposed and serves as an important equipment to test the performance of the developed piezoelectric generator. The most important thing that needs to be achieved from the project is the practical and acceptable concept for the harvesting method in the actuation part that builds the generator itself. So that, the idea of alternative power generation method can be applied for the industrial application especially for micro and miniature scale devices within some future recommendation from this project.

FUTURE WORKS

The development of the working model is continue with the prototyping process where all the proposed circuit diagram and the integrated model will be transform into actual model. The finished model will conduct series of test using the complete testing rig. For the actual application and performance test, a mini scooter that we have in our laboratory will be used by attaching the piezoelectric generator next to the scooter suspension. The test rig is important to gather the performance data of the generator actuation part within different input variables.

ACKNOWLEDGEMENT

Special thanks are indicated to the project supervisor Prof. Dr.Hj. Rosli Abu Bakarand co-supervisor, Mr.Gan Leong Ming for their detail guidance, advice and support to conduct an alternative energy harvesting method according to the increasing of energy demand for green energy in industrial sector nowadays.

REFERENCES

555 timer IC *http://en.wikipedia.org/wiki/555*timer IC accessed on 17-02-2010

F. M. Discenzo, D. Chung and K. A. Loparo, 2006, *"Pump Condition Monitoring Using Self-Powered Wireless Sensors"*, Sound and Vibration/ May.

Inman D.J., 2001, Engineering Vibration, Prentice-Hall Inc., Upper Saddle River, NJ.

J. Xi, E. Dy, M.T. Hung and C. Montemagno, 2004, *"Development of a Self-Assembled Muscle-Powered Piezoelectric Microgenerator"*, ISBN 0-9728422-7-6 Vol. 1.

Lefeuvre E., Badel A., Richard C., and Guyomar D., 2005, *"Piezoelectric Energy Harvesting Device Optimization by Synchronous Electric Charge Extraction"*, Journal of Intelligent Material System and Structures.

Lewandowski B.E, Kilgore K.L and Gustafson K.J, 2007, *"Design Considerations for an Implantable, Muscle Powered Piezoelectric System for Generating Electric Power"*, Ann Biomed Eng., 35(4): 631-41.

Naohiro S., Souzaburo H et. al., 2006, *"A Novel Method of Hydrogen Generation by Water Electrolysis using an Ultra Short Pulse Power Supply"* Elsevier: Journal of Applied Electrochemistry (2006) 36: 419-423.92/07861 – A Control and Driver Circuit for a Hydrogen Gas Fuel Producing Cell" http://www.waterfuelcarengine.com/patent-a-control-and-driver-circuit-for-a-hydrogen-gas-fuel-producing-cell.html accessed on 20-11-2009.

P. Zylka, 2009, *"Current Progress in Ambient Energy Harvesting using Piezoelectric Materials and Electroactive Polymers"*, Institute of Electrical Engineering Fundamentals, NN510 2117 33.

Sodano H.A., Inman D.J., and Park G., 2005, *"Generation and Storage of Electricity from Power Harvesting Devices"*, Journal of Intelligent Material Systems and Structures, 16(1):67-75.

Tubular solenoid push actuator, *www.saia.burgess.com*, Preferred Product: 195225-229, P:109 accessed on 20-10-2010.

NOMENCLATURE

T_m	Mark time in s
T_s	Space time in s
T	Cycle time in s
f_p	Pulsed frequency in Hz
f_G	Gated frequency in Hz
VR_1	Resistance in Ω with minimum 100Ω
VR_2	Resistance in Ω with minimum 100Ω
VR_3	Resistance in Ω with minimum 100Ω
VR_4	Resistance in Ω with minimum 100Ω
C_1	Capacitance in *F* with variable range
C_3	Capacitance in *F* with variable range
V_{ref}	Reference voltage in V
VR	Resistance in Ω
I_{out}	Output current in A