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DESIGN AND DEVELOPMENT OF ACTUATION PART OF PIEZOELECTRIC GENERATOR PROTOTYPING FOR ALTERNATIVE POWER GENERATION

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ABSTRACT

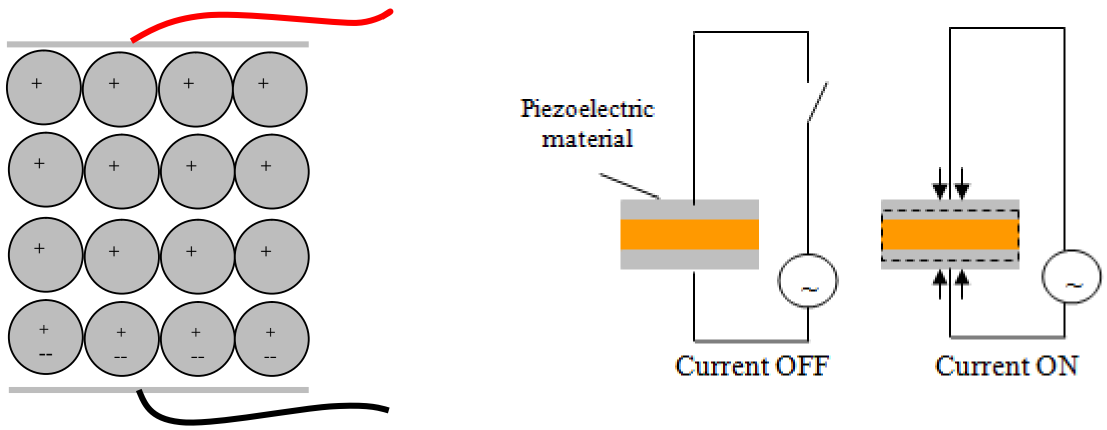
Piezoelectric materials were known as smart materials due to the ability to produce electric potential in response to applied mechanical actions. The materials are expected to become another advantage for automotive industry and also in alternative power generation field. New opportunities for innovative design and development of becoming generation low-cost and high performance piezoelectric application on the latest technologies will be illustrated in the following segments. The complete steps for designing and developing an innovative piezoelectric generator prototype by using 4-axis machine including the factors considered for the best design will be presented. The process consist of designing the model refer to generator working principal and some new fabrication methods for the small thickness plate to be used for the piezoelectric generator.

Keywords: Piezoelectric generator, actuation, power harvesting, prototyping, thin work pieces

INTRODUCTION

Piezoelectric materials have unique ability where it can produce electric potential in response to the applied mechanical actions. Nowadays, these materials can be seen in many applications for the new technologies especially in automotive industry. The concepts of power harvesting by using piezoelectric materials can produce low-cost and high performance products for the consumers.

In piezoelectricity phenomenon, the energy is converted between mechanical and electrical forms. This conversion can explain the effects of piezoelectricity that can be divided into two terms called converse piezoelectric effect and reverse piezoelectric effect. Specifically, when a compression is applied on polarized crystal, the opposite mechanical action will be deformed in an electrical charge. Alternatively, when an electrical charge is applied to a polarized crystal, the crystal will have mechanical deformation which can create an acoustical compression back. Figure 1 shows the structure and the charge position in polarized crystal and the effect of piezoelectricity. Common well-known piezoelectric materials are such as quartz (SiO2), piezo-ceramic barium titanate (BaTi03), zirconate titinate (PZT), some polyceramics and etc. Effective concepts of mechanical actions that applied to the piezoelectric material can contribute to some innovations for new technology appliances in the future. It will surely become new advantages for consumer in the aspect of effective power consumption and cost saving.



(i) Internal structure of polarized crystal (ii) Piezoelectric effect

Figure 1: Structure of piezoelectric material and the effect of piezoelectric

BACKGROUND

Piezoelectricity concept was found as a benefit in power harvesting. This technique is quite effective because it use the ambient energy for power generation. It is an alternative method to generate power and therefore it contributes to the achievement of minimizing the using of natural source and reducing the cost. This method of power harvesting is actually about converting mechanical energy from the environment to usable electrical energy for consumer uses. The conversion between the mechanical and electrical energy is the key to develop self-powered systems. It also means that by implementing power harvesting into appliances, portable systems that do not depend on traditional methods for providing power, such as battery, which has limited operating life can be developed. Describing how the power is harvested, the piezoelectric materials form transducers that are able to interchange electrical energy and mechanical action or force. These materials therefore can be used as mechanism to transfer ambient motion such as vibration into electrical energy that then will be stored and used to supply power for any device. Figure 2 illustrates the mechanism of power harvesting by using piezoelectric materials.

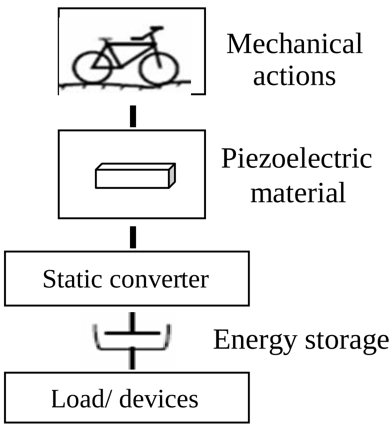


Figure 2: General diagram of generator based vibrations energy harvesting using piezoelectric material

Looking at the present technology implemented, the concept of piezoelectricity had begun to be explored by some researchers for power generation. As examples, the polyvinylidene fluoride (PVDF) films had been used by Kendall and Kymissis et al. in 1998, Shenck in 1999, Shenck and Paradiso in 2001 and Starner and Paradiso in 2004 to harvest electric power from human moving action. Roundy et al. also had presented a piezoelectric cantilever beam to harvest maximum electrical power from vibration source in 2004.

This paper will present one more innovative way of power harvesting by using piezoelectric material. By utilizing the waste energy from vibration produced in suspension as the input power, a piezoelectric generator was designed with the complete innovative concept of mechanical actions. The concept consists of stack actuator which is a multilayer construction that can be used to produce linear motion. These layers are sandwiched by piezoelectric materials and the piezoelectric effects will be occurred when the piezoelectric layers bended. The basic concept comes from the theory shown in Figure 3 where each stack is composed of several piezoelectric layers. The required dimensions of the stack can be easily determined from the requirements of the application. The height is determined in respect to the desired movement and the cross sectional area in respect to the desired force.

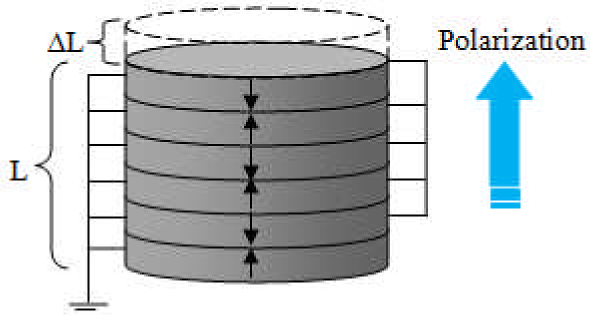


Figure 3: Structure of a piezoelectric stack

The concept also applied the implementation of an electric field across two layers of a bender where one layer expands and the other contracts. When a piezoelectric bender is used, relatively high displacements can be achieved within the force and speed. Multilayer benders can be built into one or two types that are in series or parallel arrangement. Figure 4 shows the chosen type of serial bender is where there are two piezoelectric layers with an anti-parallel polarization connected to each other and two surface electrodes. One of the electrodes is connected to the ground and the other to the output of the amplifier.

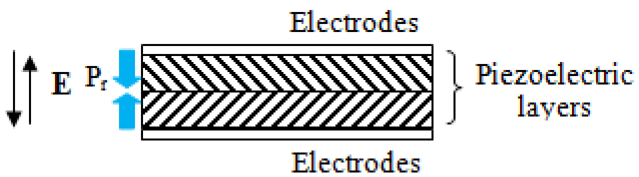


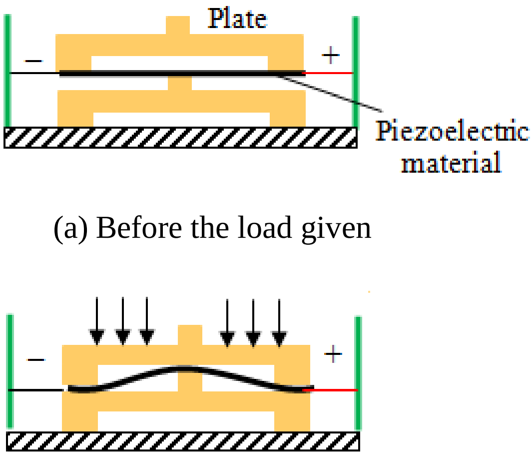
Figure 4: Serial bender arrangement with an anti-parallel polarization in piezoelectric layers

The basic conceptual design has shown the potential of implementing piezoelectric material to harvest power and providing fully self-powered system for the industry. While this field had seen a number of schemes for harvesting ambient energy sources, piezoelectric materials can be easily applied into many systems that are subjected to alternative energy generation. It will then be followed by some new methods in power storage for the complete systems.

DESIGN OF THE ACTUATION PART OF PIEZOELECTRIC GENERATOR

The design for the piezoelectric generator is developed by considering some factors including the ability of free vertically movements, easy for maintenance, maximum output power achievement, standard component sizes and etc. Some designs have been developed until the last suitable design achieved. The edges of the shape need to be minimized to produce smooth movement between the layers in the piezoelectric generator. Geometry of the model is among the most significant aspects to be considered to get the best design with maximum output.

. The inner components such as shown in Figure 5 were detailed due to the concept of the mechanical actuation that had been decided in the conceptual design of the piezoelectric generator. The final design developed was considered as the most effective and suitable design and it will be applied to make the prototyping of the new piezoelectric generator.



(a) Before the load given

(b) After the load given

Figure 5: Illustration of the inner parts movement and harvesting methods of the piezoelectric generator

The plates between the piezoelectric materials were designed with minimum thickness in about five millimeters and the shape is quit suitable for the harvesting method. The sandwiched piezoelectric material will bends when the arranged plates become close during the load is given. The mechanism then will be applied in multilayer segments to get more output power. For the prototyping process, surely some constraints were found because of the dimension aspect. The way how the constraints handled will be discussed in the following paragraph.

CONSTRAINTS IN PROTOTYPING

After confirmed the conceptual and model full design, the next process will be proceed to develop the prototype. This segment will elaborate the steps in achieving the first product for the design done. Figure 6 shows the fabricated plate that had been produced by using 4-axis modular machine.

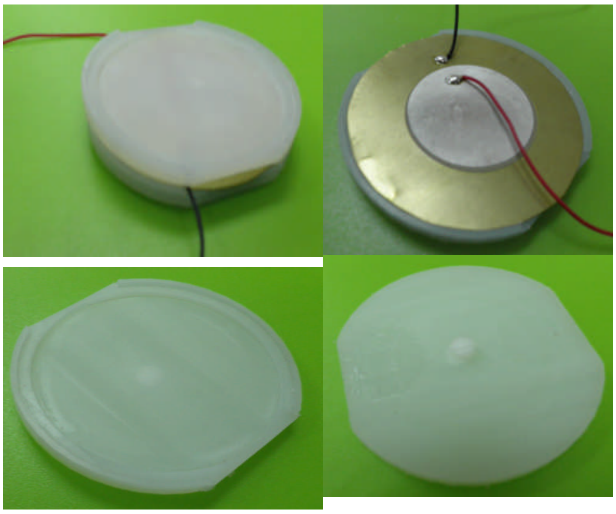


Figure 6: Developed prototype of the plates for the inner part in the piezoelectric generator

Actually for the common methodology, this kind of small plates can be produced by using injection molding. For the prototyping purpose, it requires only about 30 pieces of plates. Injection molding process will need a complicated process with extra costs and it is more suitable for mass production. This project proposed an alternative conventional way to fabricate such things by using 4-axis modular machine and it can be considered as an innovation according to the new practical ideas in handling the fabrication. The dimension and the geometry of the plates become main constraint during the prototyping. The steps of fabricating the plates are:

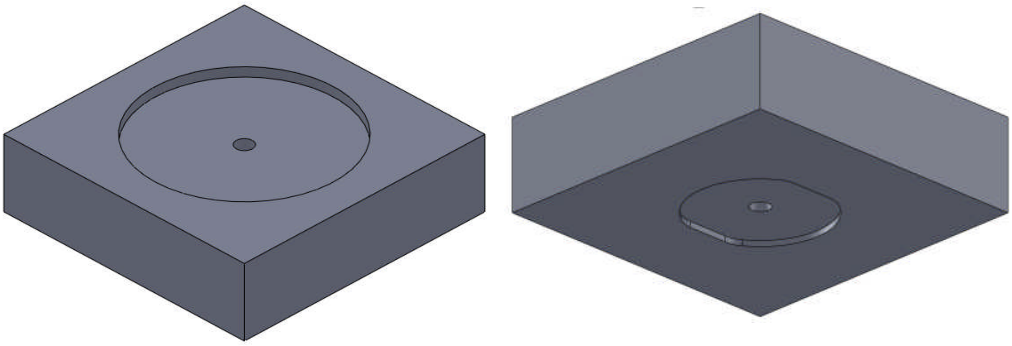
Prepare the 3-D Drawings

The first requirement for the nylon piece prototyping is making the drawings. The machining process will be done layer by layer. So the drawing is not exactly same like what the piece is look like but it is according to the shape after divided into layers. The drawing files then are converted into STL file and open through SRP Player software that can be read by 4-axis Modula Machine system.

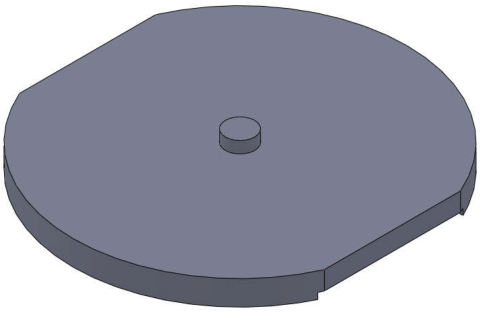
In the drawings, any sharp edge is avoided to make sure the machining can be done smoothly. The plate can be produced exactly like the drawing ask but the right and suitable parameter must be determined according to the ability of the machine itself.

Material Preparation

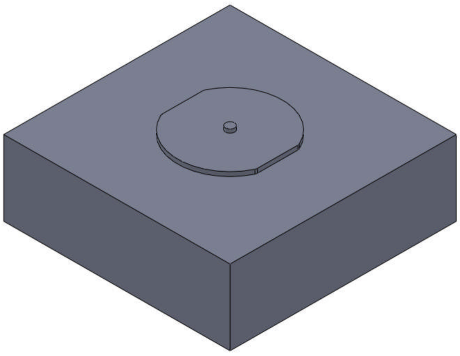
Figure 7 shows the nylon pieces which have about 65mm diameter and only 8mm thickness. There are some offset from the exact values because the fabrication process may need some work piece surface finishing. Figure 8 shows the Polyethylene (PE) block that will be used as the holder of the nylon pieces for machining. Nylon material is harder than PE and quite suitable to secure the piezoelectric part during the harvesting happen.



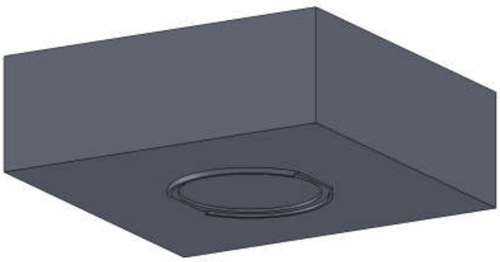
(i) Drawing of the PE holder



(ii) Drawing of the nylon piece



(iii) Drawing for the upper layer machining



(iv) Drawing for the bottom layer machining

Figure 7: Drawings for the prototyping process in Solidworks

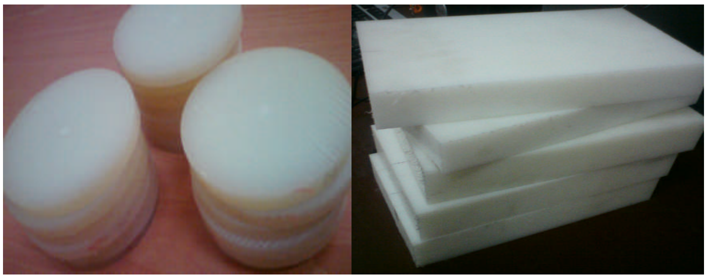


Figure 8: Nylon pieces that will be used to make the plates and the PE block for machining purpose

Holder Part Fabrication

Holder part mentioned here is the PE block. The nylon pieces need the holder because of the small thickness they have. In order to get good machining, the process must be done layer by layer such as shown in the following Figure 9.

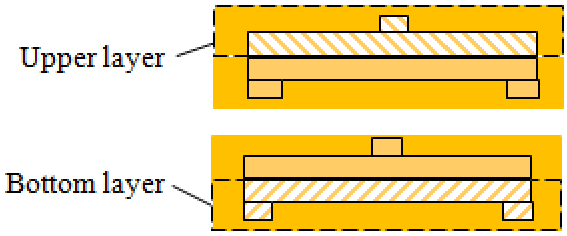


Figure 9: Upper and bottom layer of the nylon pieces that will be fabricated separately

Before the nylon part can be machined, the PE block as the holder is fabricated first. Figure 10 shows the drawing of the PE holder and from the figure there is a hollow made in the middle of the work piece. This hollow will be used to take out back the nylon pieces from the holder after the machining done.

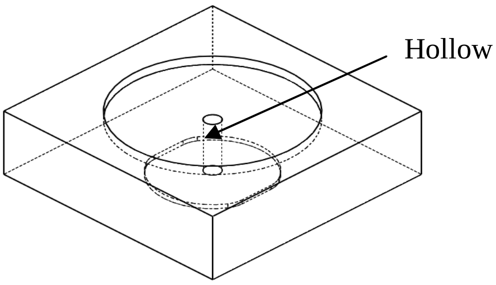
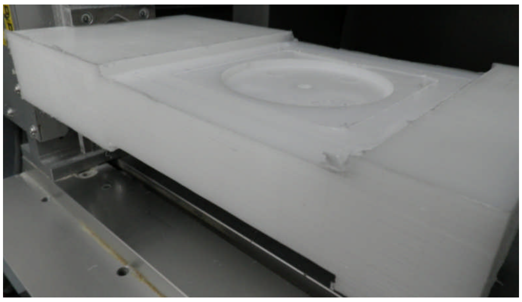
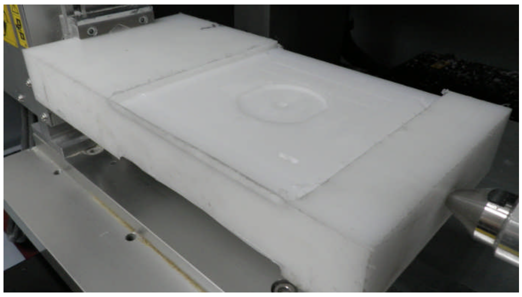


Figure 10**:** Transparent view of the PE holder drawing

For the roughing process, 10 mm tool is used with cutting in amount about 0.2 mm and path interval 2 mm. The cutting speed set is about 600 rpm. For the finishing process, 4 mm tool is used with the same cutting in amount and 0.2 mm path interval. The following Figure 11 shows the fabricated PE holder. The PE holder cannot be removed until the machining process for the whole pieces are done. The origin value must be the same for each piece.



(a) Holder for upper layer machining part

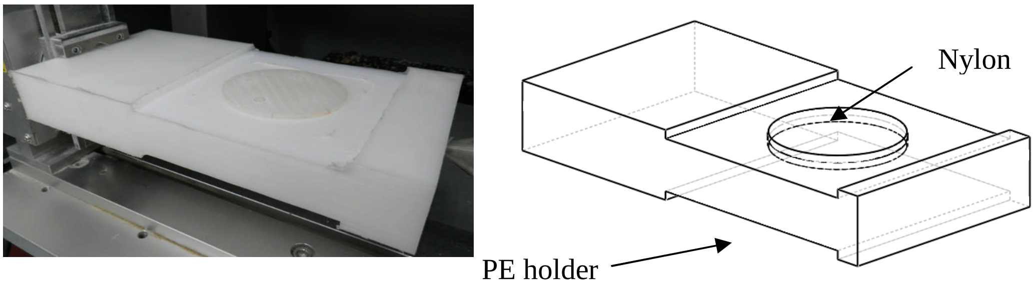


(b) Holder for bottom layer machining part

Figure 11: Finish PE holder work piece of the nylon pieces

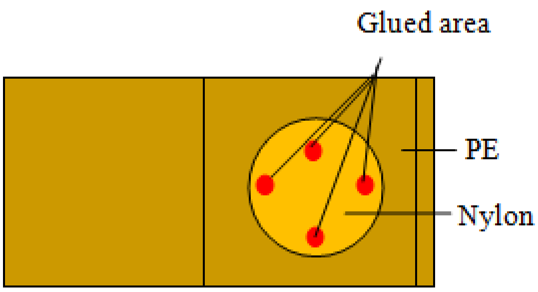
Attachment Between Nylon and PE

This attachment is done by using adhesive glue. Both of the work pieces must be attached tightly so then the nylon pieces will not spin out from the holder during the machining. Figure 12 shows the process described and the glue used.

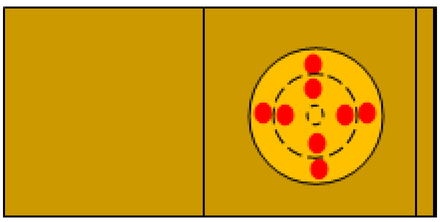


(a) Attached work piece

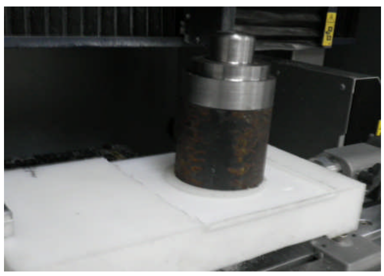
(b) Adhesive glue



(c) Points of glued area at the upper layer



(d) Points of glued area at the bottom layer



(e) Glue area is weighed

Figure 12: Work piece setup before the machining

The adhesive glue is suitable for most plastics. The glued area is weighed to make sure the surfaces are attached uniformly. For this prototyping, only glue is used as the medium for attachment because the contacted area is just temporary where the nylon pieces will be moved outwards from the holder just after the machining for the next process.

Machining of the Upper Layer

The nylon part must be machined layer by layer because of the dimension factor. The 4-axis modular machine cannot operate such thin and small work piece. So in this situation, the PE holder and the nylon will be considered as a work piece by the machine. In the first machining stage, the half thickness of the nylon part will be operated and the rest half will be continued in other process. Figure 13 shows the machined upper layer of the nylon piece. For the upper layer machining, 10 mm end mill tool is used for the roughing with 0.1mm cutting in and 3.0mm path interval value. Then for the finishing, 4.0 mm tool is used with 0.2mm for cutting in and path interval values. The time taken for each upper layer of the nylon piece machining is about 2.4 hours. Anyway, this time range can be minimized by adjusting the cutting speed and the overrides on the MDX-540 (RML-1) VPanel that represent the machine operation system.

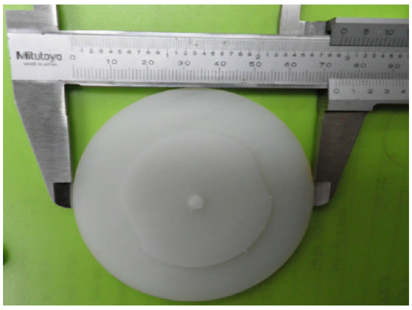
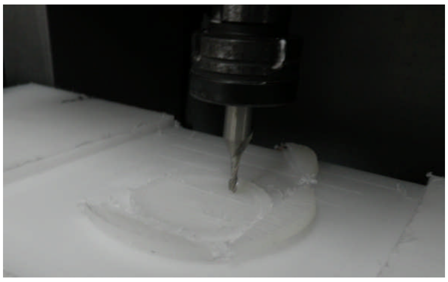


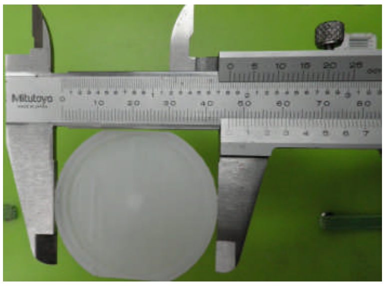
Figure.13**:** Machined upper layer of the nylon piece

Machining of the Bottom Layer

After finished the upper layer machining of the nylon pieces, the process will be continued by operating the bottom layer. The clamped PE holder cannot be removed from the clamped unit except after the origin value is noted. In this project, the upper layers of all nylon pieces are done before the next step is proceed. For the bottom layer, the machined upper layer will then be attached into the PE holder also by using adhesive glue. Same with the process done to the upper layer, the glued area is weighed to make sure both of nylon and PE materials are attached properly. Figure 14 shows the machining process done and the finished product produced.



(a) Bottom layer of the nylon part



(b) Finished product of the nylon pieces

Figure 14: Bottom nylon part layer during and after the machining

The bottom layer machining consists of three levels that are inner area roughing, outer area roughing and finishing. For the roughing process, 3.0 mm end mill tool is used with 0.1 mm cutting in value and 2.0 path interval. For the finishing process, 4.0 mm tool is used with 0.2 mm for both path interval and cutting in values. For this bottom layer machining, the lower cutting speed at about 540 rpm must be used to avoid the nylon piece spin out from the holder. Total time taken for each bottom layer of the nylon piece machining is about 2.8 hours. Anyway, same like upper layer machining, this time range can be minimized by adjusting the cutting speed and the overrides on the machine panel. After this bottom layer machining, finished product such as shown in Figure 15, it can be seen right after the nylon part is apart from the PE holder.

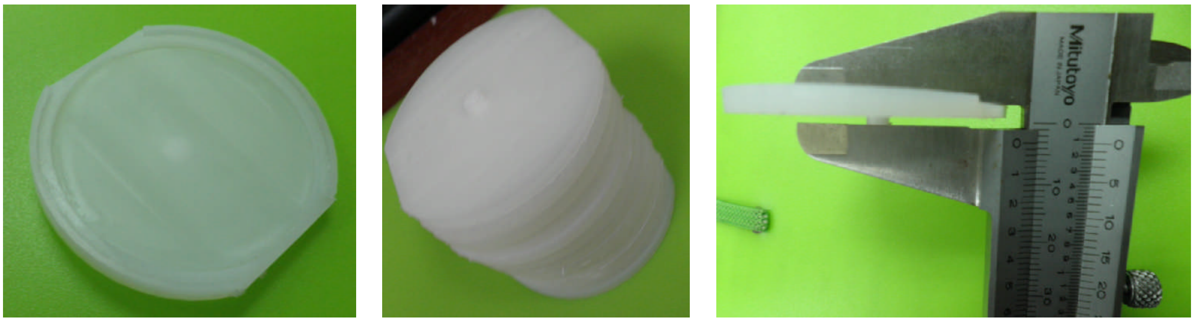


Figure 15: Finished nylon pieces product

The PE holder can be removed from the clamp units after the machining for all pieces are done. After the fabrication, the function of the plates as actuation medium can be observed by doing just a preliminary testing. For this purpose, the piezoelectric buzzer plate is sandwiched between two nylon plates and load is given manually to the system. Figure 16 explains how the testing done. From the figure, it can be seen that the piezoelectric plate suit the nylon size. The ability of the nylon pieces to produce electric potential finally proved when there is an output value on the ammeter screen. The system able to generate vary kinds of negative and positive values such as shown in Figure 17. It shows the maximum value about -19.65V and the minimum value at about -0.50. These positive and negative values show the electric potential generated by the systems. The values will be regulated to be a direct current with some electronic setup after the mechanical part prototyping done.

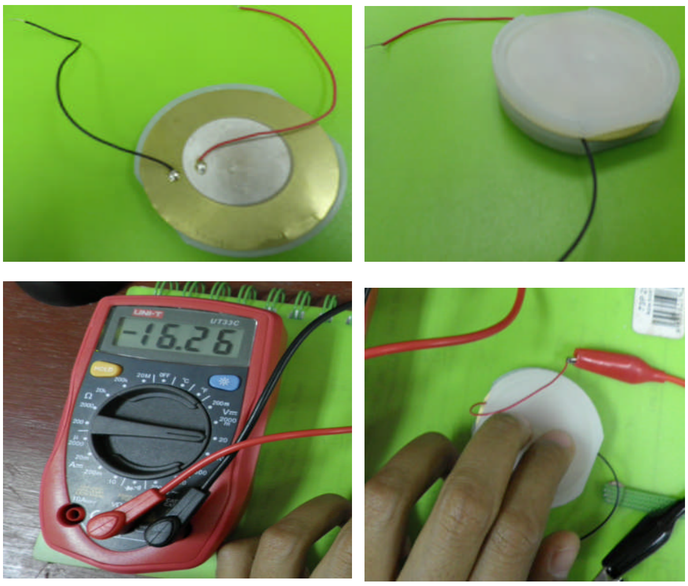


Figure 16: Preliminary experiment setup to test the actuation system output

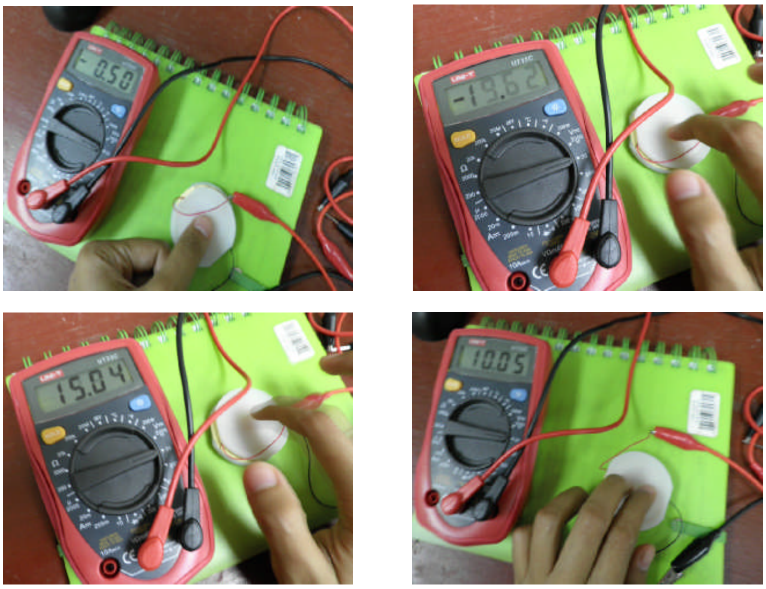


Figure 17: Output positive and negative values of the system created

INNOVATIONS IN THE PROTOTYPNG METHODOLOGY

Some innovations can be highlighted from the steps of making the prototyping in this project such as:

The PE holder

Basically this work piece is used as the holder of the thin nylon pieces. Such small thickness nylon pieces need a medium that can hold it in its place along the fabrication time. The fabrication done on the PE work piece suits the nylon pieces and they can be attached together before the machining. A hollow in the middle of the PE holder also facilitate the process when the nylon can be moved outwards from the holder after the machining.

Adhesive glue as the attachment temporary medium

For the attachment, the work pieces required not too hard stick medium. The adhesive glue was determined as a suitable medium for that temporary attachment besides the use of different kinds of materials for the plates and holder. These materials have different mechanical properties so that they can be separated easier.

Layer by layer fabrication

Looking at the small thickness of the nylon work pieces, the machining must be done carefully. For this purpose, some layer by layer machining programs were created. Starting from the inner area machining that operate the real required plate shapes and continued by the outer part machining that separate the real nylon plate required and the waste nylon part. This step by step machining procedure can helps the 4-axis machine to be able to fabricate such thin materials without any problem. The procedure created for the prototyping process can be considered as an innovation because it introduce new ability of the 4-axis Modula Machine to operate such thin work piece with some acceptable ideas. It varies the expediency of the machine besides human intelligence control. As long as the program created suit the ability of the machine, any kind of thing can be operated.

CONCLUSION

Finally as the conclusion, an innovative method for the product prototyping for this project had been achieved successfully. This alternative method of fabricating the 8mm thickness nylon plates by using 4-axis Modula Machine exposed the ability of that machine to operate such thin work piece. So in the future, the innovation prototyping methodology can be applied for other similar project.

FUTURE WORKS

After this prototyping task, the product will be integrated to the electronic part. The electronic part consists of the charge regulation circuit, charge storing circuit and followed by output control panel part. After all, the integrated system will be tested on a mini scooter to find the real output from the developed piezoelectric generator.

ACKNOWLEDGEMENT

Thank to God for His bless in this life. Special thank goes to the supervisor, Prof. Dr. Rosli Bin Abu Bakar, for the guidance and knowledge sharing. Also appreciations to all members who ever help and give advice for this project. Hopefully this project can be a new potential in alternative energy field in the future and can be used by all citizens specifically.

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