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EXPERIMENTAL DESIGN OF ADD-ON REGENERATIVE SYSTEM FOR PASSIVE ENGINE MOUNT IN DIESEL ENGINE

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ABSTRACT

This paper proposes an add-on regenerative system for engine mounting. Vibration on engine mounting is an energy mechanic outage that has just wasted. Piezoelectriccan change the wave on the engine mounting into electrical energy. Regenerative system design that plug and play become the essential concept to facilitate its application. The purpose of this project is to get the performance of the add-on regeneration system in reducing vibration and determine the electrical energy generated by the regenerative operation The system's add-on regenerative design can dampen vibration at each engine on engine mounting at several variable. The most substantial voltage is generated by the regenerative system at 500 RPM, thickness 0,398 mm, and 8,1 m/s^2generated the optimum respone (vibration result: 7, 200 m/s^2, voltage: 2, 878V, power: 0,029 Watt).

Keywords: engine mount, vibration, piezoelectric, add-on regenerative system.

1. INTRODUCTION

Engine mount acts as a vibration damper generated by the engine. Engine mount can reduce the noise level of 5dBand suppress the shock level by one-third of the fixed portion to keep the idle vibrations constant [1]-[2]. The waves generated by engine lies on 30 Hz [3]. On the engine mount, the wave of the engine at low frequency (1-50 Hz) has an amplitude of more than 0.3 mm, while the high frequency (50-200 Hz) has a magnitude of less than 0.3 mm [4]-[5]. Vibration on the engine can be reduced using engine mounting that used on the engine vehiclesuch aselastomer mount, passive hydraulic mounting, semi-active mounting an active mounting [6]-[11].

The passive mount more widely used in designing a vehicle as a solution for dampening engine vibration because it is more economical [12]. The resulting vibration mounting engine converted to electricity by utilizing fluid flow as a piezoelectric cracker placed on the driver mounting decoupler diaphragm. Piezoelectric can generate electricity as the fluid moves to press from both sides of the liquid chamber on the engine mounting [13].

Hydraulic engine mount (HEM) engine system is mainly designed to have dual mode vibration isolation performance so as to reduce engine vibration transmission to the chassis and vehicle body in addition to its role to support a static load of engine weight [14]. Engine mounting on vehicles can divide into dynamic and static components. It consists of engine, mass, and torque. This load usually exceeds the dynamicpressure, which is most significant regarding comfort chiefly the result of the combustion process as well as force inertia. Static charges have no effect on vibrations on the vehicle body [15].

Energy harvesting systems using piezoelectric tend to increase in development of the automotive industry. With the advantages of simple design and construction, piezoelectric also serves to generate electricity from the wasted mechanical energies (dissipated energy) [16]. However, due to restriction piezoelectric placed inside decoupler of passive engine mount are challenging to be installed. While on the other hand, harvesting energy on the vibration of the engine by using a piezoelectric cantilever bending type outside the engine mounting system has been done [17]-[18]. However, it is just to generate electricity, not to reduce vibration on the engine. In this paper, presented a merelydesign a regenerative systemforinstalling above engine mount by plug and play model.Harvesting system outside the engine mountsmore accessible to beestablished and maintained than inside. By using piezoelectric bending type design, a regenerative system on engine mounting can save space on low chance chambers. The main contributions are (1) to propose a prototype add-on regenerative system on engine mount with a simple design and (2) to analyze regenerative experimental results when mounted on engine mounting.

The paper is structured as follows, The design of a regenerative system on an engine mount presented in Part 2.1, while piezoelectric generator systems and cantilever rigidity beam discussed in Section 2.2 and 2.3Continued in section 2.4 describes the design of a regenerative system mounted on the engine mount. For the experimental design used in this project are shown in section 2.5. Followed by an analysis of the regenerative method described in Section 3.Statistical analysis of regenerative systems Add-on engine mounts to be one of the objectives of this project For static analysis performed using the software shown in Section 3.1; Experimental-Design isanalyzed for vibrations and voltages on the installation of the add-on regenerative show in Section 3.2 respectively. Finally, conclusions summarised in Section 4.

2. MATERIAL AND METHODE

2.1 Design of regenerative system

Unbalance mass in the active engine mounting system [15], can be a reference as passive regenerative system design. Figure-1 illustrates thedesign of the regenerative system lies in the inactive mounting engine.

A Mass on a regenerative system serves as potential energy to counter the vibrational motion of diesel engine that has transferred through the engine mount. The energy potential can set in motion cantilever beam up and down on a regenerative system with a particular stiffness. Also as a vibration damping system in passive simple mounting engines.

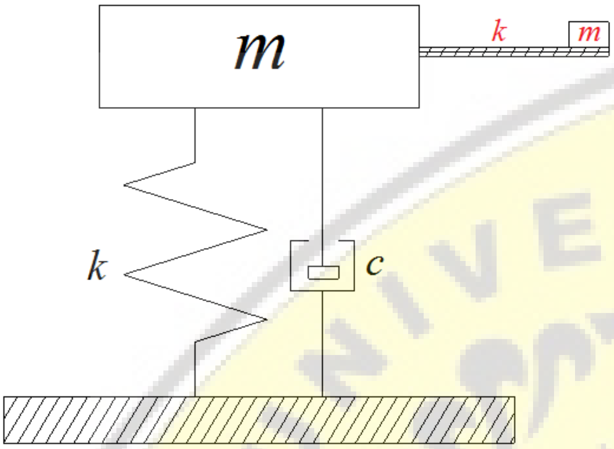

Figure-1. Simple add-on regenerative on the installation of inactive damping engine with regenerative function and vibration reduction.

2.2 Piezoelectric generator system

Figure-2. Piezoelectric cantilever without mass.

In Figure-2 piezoelectric cantilever beams of MEAS type are more accessible to apply in add-on regenerative system design, due to piezoelectric type bending produce the highest output per strain unit when the film is elongated. It is also very suitable for use in high fidelity transducers [18]. Table 1 shows the properties and advantages of MEAS piezoelectrictype that it has avoltage value limit of 15 mV / με up to 1% strain. Its dimensions also become considerable because of its portable size andhave an operating temperature -40° C to 70° C which relatively suitable to be placed in a heat-induced environment of an engine with high enough temperature. This type of Piezoelectric has a function as a transducer; sothe accuracy is quite significant with a value of approximately 20%.

Table-1. Specification of Piezoelectric Meas Type.

Type	Flexible film, adhesive mount
Range	15 mV/με up to 1% strain
Accuracy	±20% (Typical)
Operating Temp.	-40°C to 70°C
Dimensions (mm)	12 mm x 30 mm

There are two types of modes to generate an electrical voltage on the piezoelectric, “Mode 31” and “Mode 33”. In this prototype regenerative system, “Mode 31” has been chosen, because the force that occurs perpendicular to the direction of polarisation. Subscribe 31 the used in an electric field that happens along the 3 axes, but the voltage happening on axis 1 is perpendicular to the axis 3 as seen in Figure-3.

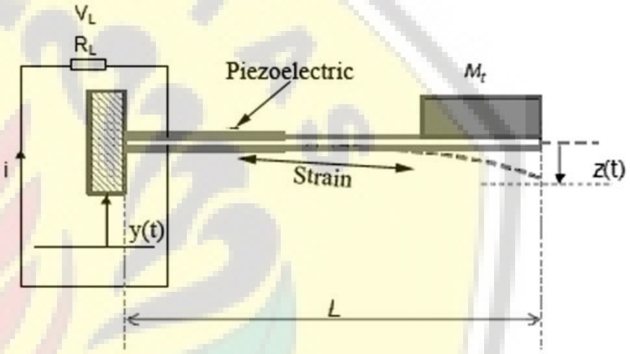

Figure-3. Prototype of the piezoelectric power generator mode 31.

Cantilever mode 31 presented in both types of regenerative systems. The stiffness of 1000 N/m has two cantilever beam generators modes 31 on the regenerative system, and the stiffness of 2000 N/m has four cantilever beam generator modes 31 on the regenerative operation. The regenerative system moves up and down when receiving vibrations from the engine mounting. The load placed on the wild disc circle, the regenerative process swinging up and down, as an effect was cantilever can move and generate electricity.

2.3 Prototype design regenerative system

The mass in this regenerative system is designed such as a disc to provide an even distribution of the regenerative system; there are two parts of the top and bottom disks connected with the bolts. With a total weight of discs is 2500 N. In the stiffness section using cantilever beam system placed a piezoelectric as shown in Figure-4 and Figure-5.

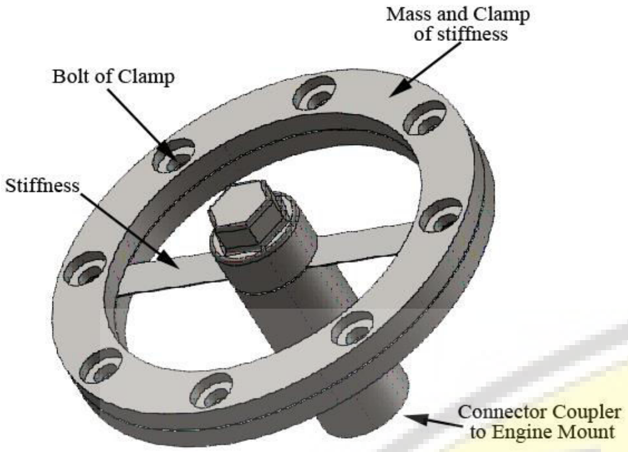

Figure-4. Prototype an add-on regenerative system with two cantilever beams.

Design in Figure-4 using two cantilever beams, and in Figure-5 using four cantilever beams. Each cantilever beam has a stiffness of 500 N / m, so in Figure-4 it has a stiffness of 2 x 500 N / m with a stiffness value of 1000 N / m, while in Figure-5 has a stiffness of 4 x 500 N / m with a stiffness value of 2000 N / m.

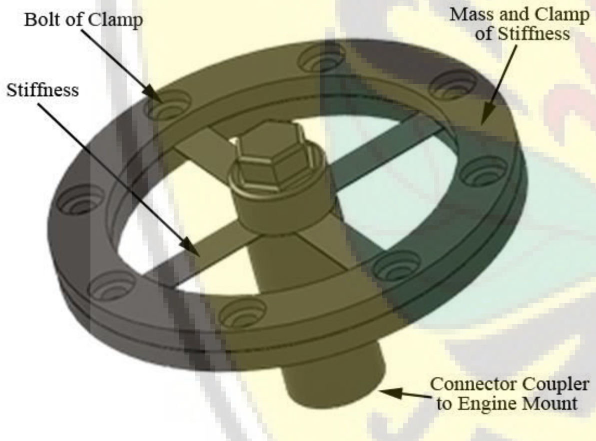

Figure-5. Prototype an add-on regenerative system with four cantilever beams.

The cantilever beam is coupled using a bolt clamp on each side in the middle of the regenerative system. The clamp is connected directly to the adapter coupling holder that attaches the regenerate system to the engine mount. The design of the prototype add-on regenerative system implements inertia generators that more flexible than direct-mode device changes because it requires only one point of attachment to a moving structure, allowing for a possible increase in shape optimization. Figure-6 Cottone, 2012 [19].

2.4 Experimental set-up of an add-on regenerative system

The diesel engine is use in this project because it produces a stronger vibration than a gasoline engine to regenerate the system on a mounting machine. The big waves caused by the diesel engine's compression ratio are quite high above the gasoline engine [20]. The reliability of the diesel engine is the reason it is widely used in small vehicles to heavy vehicles as well as minimal maintenance allowing diesel engine long way mileage and long durability time.With these conditions, the regenerative system in the engine mounting can be a possible energy harvesting system in a vehicle. Diesel engine to be tested using 4D56 medium duty diesel engine type. Regenerative system testing is done in a static state to facilitate the retrieval of experimental data. Specification of a diesel engine as shown in Table-2.

For experimental data retrieval, installing on the engine mounting system is placed on only 1/3 of the overall engine mounting section. Installation is set on the left side of the engine mounting on the 4D56 diesel engine because this position has an ample enough space. Although in a static state the conditions have been conditioned according to the actual requirementsof the vehicle.

As seen in Figure-6 (a) the position of installing engine mounting system is above the remaining mounting bolts on the stock engine mounting. The remaining bolts on engine mounting stock become the main holder of the regenerative system. Installation of the regenerative system on the engine holder mounted with bolts. When installed on the engine mount installation, the position of the regenerative system show at Figure-6 (b). The position of the regenerative system on the left side of the engine has its advantages during testing and experimental because the position of the regenerative system is adjacent to the rotary distribution fuel pump.

Figure-6. DieselEngine forgenerating a regenerative system.

Diesel engine configuration four-cylinderinline SOHC (Single overhead camshaft) in this experiment all in a state of all stock with a volume of 2.5 liters. Including the air intake system maintains a state of factory standardnaturally aspirated. So as the ignition system with a fuel system with Rotary distribution injection pump stock, without changing the angle of the injection. The compression ratio on the engine is maintained in a stock 21: 1.

This add-on regenerative system has installed above the engine mount. With plug and play installing it is possible to experiment in regenerative systems with different stiffness to achieve damping and voltage performance even with the same mass. Shown in Figure-7(a) a regenerative system with the rigidity of 1000 N/m and 2000 N/m stiffness for the regenerative system in Figure-7(b). Experiments using two types of stiffness were performed to understand the correlation between stiffness and vibration damping on the engine mount. Both types of regenerative systems tested above engine mounting on a diesel engine coupled to the engine mount.

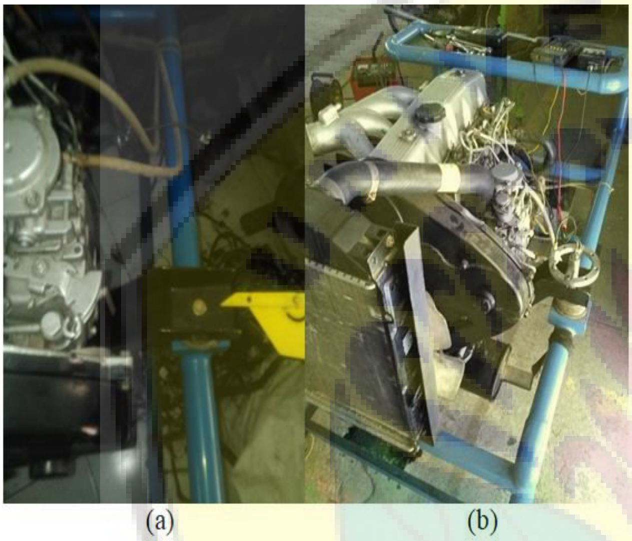

Figure-7. (a) Position installed regenerative system on engine mounting (b) system regenerative position has been installed.

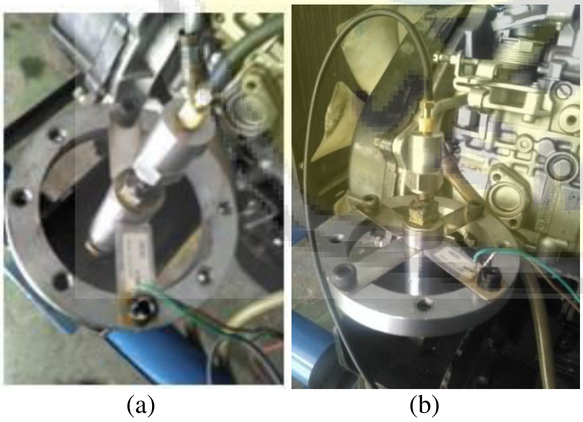

Figure-8. (a) 10.000 N/m Two Cantilever Beam (b) 20.000 N/m Four Cantilever Beam.

Table-2. The Specification of Diesel Engine of use.

Displacement	**2.5 L (2,476 cc)**
Bore	91.1 mm
Stroke	95.0 mm
Fuel type	Diesel
Air Intake	Non-Turbo (Naturally Aspirated)
Power	55 kW (74 hp) at 4,200 rpm
Torque	142 N.m (105 lb·ft) at 2,500 rpm
Engine type	Inline 4-cylinder SOHC
Fuel system	Rotary distribution injection pump
Compression ratio	21:1

2.5 Experimental design of an add-on regenerative system

The central composite design and Design of Expert was employed to determine optimum condition on regerative system. The variable were engine speed (500 - 2000 rpm), engine vibration (8,1-19,8 m/s^2), and thickness of regenerative system (0,2-0,4 mm) and each variable has three level ranging from low (-1), medium (0), and high (+1). The respone are vibration result, voltage, and power were observed and predicted to optimum operated. The central composite design gave 20 runs, for experiments add-on regenrative system.

3. RESULTS AND DISCUSSIONS

3.1 Optimisation of an add-on regenerative system

The optimisation based on statistical methode central composite design established a complete design, using both the predicted and experimental value obtained for the respone are vibration result, voltage, and power by the design are shown in Table-3.

Vibration result obtained range from 7,2 mm to 23,8 mm, voltage obtained from 0,4 V to 3,4 V, and power obtained from 0,0004 V to 0,034 V. The analysis optimum operating identifying and suggested by Design-Expert software which is selected on the basis of sewuential model sum of square, the best model was selected based on the higher polynomial. The model equation based on coded values A, B, C as engine vibration, engine speed, and thickness of beam on regenerating system for vibration result, voltage, and power on regenerative system was expressed on equal 1, equal 2, and equal 3.

$$\text{Vibration result} = 11,83 - 4,55A + 6,04B - 9,73C \quad (1)$$

$$\text{Voltage} = 1,865 + 0,100286A - 0,780286B + 1,035C \quad (2)$$

$$\text{Power} = -0,017975+0,00551571A-0,0115957B+0,014805C \quad (3)$$

Table-3. Design experiment of an add-on regenerative system.

		Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3
Std	Run	A:engine vibration	B:engine speed	C:thickness	vibration result	Voltage	Power
		m/s^2	RPM	mm	m/s^2	Volt	Watt
10	1	15,7	1250	0,3	12,6	1,6	0,016
9	2	15,7	1250	0,3	12,6	1,6	0,016
2	3	8,1	500	0,2	22,5	0,8	0,0008
16	4	15,7	1250	0,3	12,6	1,6	0,016
13	5	15,7	1250	0,2	23,8	0,9	0,0009
15	6	15,7	1250	0,3	12,6	1,6	0,016
6	7	8,1	500	0,4	7,2	3	0,03
18	8	15,7	1250	0,3	12,6	1,6	0,016
17	9	15,7	1250	0,3	12,6	1,6	0,016
4	10	19,8	2000	0,2	23,1	0,4	0,0004
12	11	19,8	2000	0,3	13,4	1	0,01
11	12	8,1	500	0,3	8,5	3,4	0,034
20	13	15,7	1250	0,3	12,6	1,6	0,016
3	14	19,8	2000	0,2	23,1	0,4	0,0004
19	15	15,7	1250	0,3	12,6	1,6	0,016
8	16	19,8	2000	0,4	11,6	1,2	0,012
14	17	15,7	1250	0,4	12,5	1,8	0,018
5	18	8,1	500	0,4	7,2	3	0,03
1	19	8,1	500	0,2	22,5	0,8	0,0008
7	20	19,8	2000	0,4	11,6	1,2	0,012

On experimental design process, Design Expert software suggested quadratic model as the best model which is selected on the basis of sequential model sum of squares, the best model was selected based on the highest order polynomial where the additional terms were significant and the model was not aliased [21]. The operating conditions solutions offered by Design-Expert software reach 76 solutions, with the best solution offered having a desirability value of 0.836 shown on Table-4 and Figure-8. The solution on shown is optimum conditions with some desired respone parameter conditions, there are: minimum vibration result, maximum voltage value, and maximum power value.

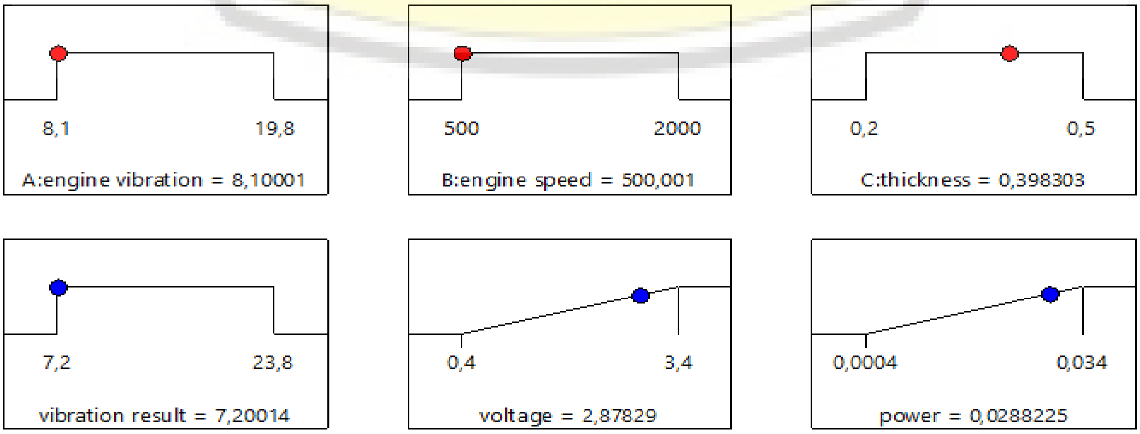

Figure-9. Optimum solutions of Central Composite Design by Design Expert.

Table-4. Solution offered by Design-Expert.

No	Engine vibration	Engine speed	Thickness	Vibration result	Voltage	Power	Desirability	
	m/s^2	RPM	mm	m/s^2	V	Watt		
1	8,100	500,005	0,398	7,200	2,878	0,029	0,836	Selected
2	8,100	505,341	0,399	7,200	2,877	0,029	0,836	
3	8,148	500,011	0,398	7,202	2,875	0,029	0,835	
4	8,110	519,911	0,401	7,200	2,874	0,029	0,834	
5	8,100	553,943	0,405	7,200	2,868	0,029	0,832	
6	8,429	500,036	0,394	7,200	2,857	0,029	0,831	
7	8,100	561,565	0,406	7,200	2,867	0,029	0,831	
8	8,100	500,000	0,396	7,342	2,863	0,029	0,830	
9	8,100	574,067	0,407	7,200	2,865	0,029	0,830	
10	8,631	500,003	0,392	7,200	2,844	0,029	0,828	
11	8,100	600,200	0,411	7,200	2,860	0,028	0,828	
12	8,100	588,415	0,409	7,235	2,858	0,028	0,828	
13	8,694	500,006	0,391	7,200	2,839	0,029	0,827	
14	8,100	609,283	0,412	7,204	2,858	0,028	0,827	
15	8,100	551,138	0,403	7,334	2,855	0,028	0,827	
Etc until								
76	13,899	1880,025	0,500	7,200	2,244	0,023	0,643	

3.2 Analysis of experimental design

As shown on Figure 9 to get the desiret optimum respone, then the operating conditions that must be carried out must not have a range that is too far as suggested. The recommended operating conditions have been calculated using a quadratic system with the highest polynominal value called desirability. The three desired response are influenced by three factors that are linear and mutually influential. The influence of factors on response is multilinier, in other words each factor has an interrelated role and cannot be separated from the response received.

On Table-4 the value of the solution offered by Design-Expert software at number 1 and number 2 shows the same desirability value of 0.836, but the number 1 solution is chosen because the value of the generated respone voltage is greater than the voltage generated of solution option at number 2.

4. CONCLUSIONS

Damping Vibration on engine mounting has improved with regenerative system prototype. Additional systems by utilizing ease of installation and limited space utilization have achieved. The development of a simple and practical design without changing the function and performance of engine mounting base to accomplish the primary goal of this paper.

Static analysis of the regenerative system on engine mounting has been done, with the first capability as the engine vibration damping as well as to harvest energy. The system's add-on regenerative design can dampen vibration at each engine on engine mounting at 2000 RPM. Moreover, can be a booster of passive engine mounting to dampen vibration. The most substantial voltage is generated by the regenerative system at 500 RPM, thickness 0,398 mm, and 8,1m/s^2.

The regenerative prototype of the system in this project has not yet been studied further the relationship between damping force and electrical resistance during power storage process. Therefore, the electrical charge on the regenerative system can be manipulated to produce resistance to the piezoelectric to obtain a significant damping result against the engine vibration force.

Based on the experimental design that has been carried out, the purpose of this study has fulfilled the desired criteria, where the aim of this research is to harvest energy as much as possible without reducing the function and performance of the engine, which has been shown by the vibration value after the smaller add-on regerative system and the value of energy that is loaded in a maximum voltage and power.

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