Faculty of Mechanical Engineering

LABORATORY-SCALE AND REAL EXPERIMENTAL STUDY ON THE PERFORMANCE OF ENERGY REGENERATIVE SUSPENSION SYSTEM

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AHMED ESMAEL MOHAN

A dissertation submitted
in fulfillment of the requirements for the degree of Master of Mechanical Engineering
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DECLARATION

I declare that this dissertation entitled "Laboratory-scale and real experimental study on the performance of energy regenerative suspension system" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this dissertation and in my opinion this dissertation is sufficient in terms of scope and quality as a partial fulfillment of Master of Mechanical Engineering (Applied Mechanics).

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DEDICATION

In the name of Allah, The most Gracious, The most Merciful

All of praise for Allah, glorified and exalted be He. Praise the God for Abundant blessings which given to me, and the determination that he gave me to complete this search.

To the great teachers and educator, My Prophet Mohammad (Allah blessings and peace be upon him and his family), which is the light and guidance for world.

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بســــــــــم الله الرحمـــــن الرحيـــــم

كل الثناء لله سبحانه وتعالى، والحمد له على جزيل نعمه وعلى القوة التي منحني لاتمام هذه الر سالة.

الى معلمي ورسولي العظيم محمد (صل الله عليه وعلى آله اجمعين)، الذي هو نور وضياء للعالمين

لوالدي الحبيبين، العظيمين والمضحيين.....والدي الغالي الذي لم يدخر ابدا اي جهد في سبيلنا, اطمح لان اجعله فخورا بي بقدر فخري به وبكرم نفسه....امي الحبيبة بوابتي الى الجنة التي تضيء بدعواتها وحبها وتطرد بابتسامتها كل همومي. تعجز الكلمات عن وصف حبها وتضحيتها. لم اكن اصل الى ما انا عليه الان بدون حبهما وتضحياتهما واهتمامهما. لن استطيع اوفيهما جزاءهما ما حييت لكني اسأل الله عز وجل ان يحفظهما ويطيل في عمريهما ويجزيهما الجنة.

الى زوجتي الحبيبة, الغالية ورفيقة عمري, لصبرها و مساندتها ودعمها وعطائها الدائم لي. والى ابني الحبيب قرة عيني حسين. اسال الله ان يحفظهما ويوفقهما ويطول في عمرهما.

الى اخوتي واخواتي الاعزاء, حبهم ودعمهم ودعواتهم وتشجيعهم يعنون الكثير بالنسبة لي. اسأل الله ان يحفظهم.

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لجميع الناس من قريب وبعيد على تشجيعهم ودعواتهم . شكرا لهم جميعا

ABSTRACT

Nowadays, getting more efficient vehicle to investigate the improvement in renewable energy is highly crucial for the automotive industry. The operation of most vehicles is with fossil fuel. However, there are some vehicles which apply varying energy resources. The previous EReSS using the magnetic coil does not show satisfying performance in term of the voltage output. Therefore, the goal of this research is to investigate the improvement of the energy regenerative suspension system (EReSS) to obtain energy efficient vehicle (EEV) from the vibration of vehicle suspension system. The study began with the observation of the potential vibrations created by a vehicle running on a route that has been selected. The designed system has been put to the test on a test rig for the laboratory scale experimentation procedure to monitor its reliability and harvesting potential. At the laboratory, the EReSS test produces the maximum output voltage of 32.76 V at 400 windings. Additionally, the test is carried out to test the function of the EReSS system on real vehicle. In the next step, the device is installed on a passenger vehicle with minor modification on the suspension system. The vehicle works on the same route to observe the electrical voltage harvested during ordinary driving on the actual traffic. The EReSS recorded that the maximum voltage at the real car test was 17.6 V at 400 winding. The tests are done with the help of the Data Acquisition (DAQ) system to record the reading of voltage produced by the EReSS system. The material improvement can boost the output voltage. According to the obtained results, it is observed that, the proposed system can lead to minimal energy wastage because of the vibration and it produces an effective vehicle in terms of electrical and electronic utilization. To add, the output voltage of the EReSS can be affected by the number of windings of the coil and its diameter. The study shows that with higher number of coil winding, higher output voltage is achieved. There is evidence that the EReSS harvests energy therefore, it can be used on hybrid and electric vehicles to develop the vehicle, in terms of the efficiency and it will further reduce the fuel consumption.

ABSTRAK

Dewasa ini, usaha memperolehi kenderaan yang efisien dalam mengkaji penambahbaikan dalam tenaga yang boleh diperbaharui adalah sangat penting untuk industri automotif. Pengoperasian kebanyakan kenderaan dijalankan menggunakan bahanapi fosil. Namun demikian, ada beberapa buah kenderaan yang menggunakan sumber tenaga yang berbeza-beza. Tujuan kajian ini ialah untuk mengkaji penambahbaikan sistem suspensi jana semula tenaga (EReSS) untuk memperolehi kenderaan yang efisien dari segi tenaga (EEV) dari getaran sistem jana tenaga tersebut. Kajian ini bermula dengan pemerhatian getaran potensi dicipta oleh berjalan kenderaan di laluan yang telah dipilih. Sistem yang direka diuji di atas satu rig ujian untuk prosedur eksperimen berskala makmal untuk meninjau potensi keboleh-percayaan dan pemanehan. Di makmal, ujian EReSS mengeluarkan voltan output maksima 32.76 V pada 400 belitan. Tambahan pula, ujian ini dijalankan untuk mengkaji kefungsian sistem EReSS ke atas kenderaan yang sebenarnya. Dalam langkah seterusnya, alat itu dipasang kepada kenderaan dengan sedikit pengubahsuaian dibuat ke atas sistem suspensi. Kenderaan tersebut berjalan di atas laluan yang sama untuk memerhatikan voltan elektrik yang dipanehkan dalam pemanduan biasa pada trafik sebenar. EReSS merekodkan voltan maksima pada ujian kereta sebenar ialah 17.6V pada 400 belitan. Ujian dilakukan dengan menggunakan sistem Perolehan data (DAQ) untuk merekodkan bacaan voltan yang dikeluarkan oleh sistem EReSS berkenaan. Penambahbaikan bahan boleh meningkatkan lagi voltan output. Menurut keputusan yang diperolehi, diperbatikan bahawa Sistem Perolehann Data yang disarankan boleh membawa kepada pembuangan tenaga yang minimal yang disebabkan oleh getaran dan ia menghasilkan kenderaan yang efektif dari aspek penggunaan elektrikal dan elektronik. Sebagai tambahan, voltan output EReSS boleh dijejaskan oleh bilangan belitan lingkaran dan diameternya. Kajian ini menunjukkan bahawa dengan bilangan belitan wayar yang tinggi, voltan output yang lebih tinggi dicapai. Terdapat bukti bahawa EReSS memaneh tenaga, maka itu ia boleh digunakan untuk kenderaan hibrid dan elektrik untuk menguatkan lagi kenderaan, dari sudut keberkesanan dan ia akan lebih membangunkan lagi penggunaan bahan api.

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LIST OF ABBREVIATIONS

EReSS	Energy Regenerative Suspension System
HESA	Hydraulic Energy Shock Absorber
LRESA	Linear Regenerative Shock Absorber
MMR	Mechanical Motion Rectifier
EMS	Electromagnetic Suspension
RER	Rotational Electromagnetic Regenerative
EMI	Electromagnetic Induction
R&D	Research and Development
LETs	Linear Electromagnetic Transducers
CrNiMoVA	Chromium Nickel Molybdenum Vanadium
NdFeB	Neodymium Ferrite Boron
PZT	Piezoelectric
MR	Magnetorheological
AWG	American Wire Gauge
DOF	Degrees of Freedom
RMS	Root Mean Square
EMS	Electromagnetic Suspension
CAD	Computer Aided Drafting

UTeM	Universiti Tecknical Malaysia Melaka
FKM	Faculty of Mechanical Engineering
DAQ	Data Acquisition
EV3	Third generation of the LEGO® MINDSTORMS® platform and the "EV" stands for evolution, hence EV3.
COG	Center Of Gravity
Ni	Nickel
DC	Direct Current
AC	Alternating Current
ECU	Electronic Control Unit
EEV	Energy Efficient Vehicle
PID	Proportional Integral Derivation
VMB	Volume Modification Bridge
LER	Linear Electromagnetic Regenerative
PM	Permanent Magnet
ATV	All-Terrain Vehicle

LIST OF SYMBOLS

B	Magnetic flux density
R	Resistance
V	Induced voltage generated
Do	Outer diameter of spring
Di	inner diameter of spring
d	Diameter of coil wire
N	Number of turns
W	Watt
T	Tesla
Ω	Ohm
MΩ	Mega ohm
kΩ	Kilo ohm
km/h	Kilometer per hour
mi/h	Mile per hour
s	Second
milli-g	milli gravity
milli degree/sec	milli degree per second
Hz	Hertz
ms^{-1}	meter per second

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Ahmed Esmael Mohan, Mohd Azman Abdullah and Jazli Firdaus Jamil. "The Improvement and Laboratory Testing of Regenerative Suspension System," *Proceedings of Postgraduate Research Symposium in Mechanical Engineering*, 2016, Melaka, Malaysia, pp. 1-2, Paper ID: 12.

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CHAPTER 1

INTRODUCTION

1.1 Background

Vehicles have gained importance and are widely used globally, automatically steadily causing a lot of energy and environmental issues. In the United States, transportation represents over 70% of oil consumption (Department of Energy, 2010); that said, only 10%–16% fuel energy in the vehicles is utilized for driving to overcome resistance stemming from road friction and air drag (Fueleconomy, 2014). Vehicle exhausts brings about more air pollution than anything else (Legasse, 2007). Recently, it has also been shown in research that vehicle suspensions have a substantial influence on the fuel efficiency (Efatpenahet al, 2000).

Suspension is a system comprising of a spring, damper and linkage that connect the sprung and un-sprung vehicle mass that enables the vehicle and the wheel to move separately from each other (Martins et al., 1999). Damper in tandem with the suspension springs, have been widely used to mitigate the vibration by dissipating the vibration energy into heat waste, when the vibration is produced from irregular road surface (Sharp and Crolla, 1987). The green technology manufacturing is essential for the vehicle industry in the future because the suspension system carries an important source of energy dissipation and the energy is wasted. The wasted energy can be harvested and converted to regenerative energy and this enhances the vehicle's fuel efficiency. The harvested energy can also be converted to electricity and kept for hybrid vehicle usage. The stored electricity

can well function as the power for the vehicle electronics (Patil and Gawade, 2012). Vehicle manufacturers have had to suffer from costly development to improve the fuel economy and car designers also worked hard to reduce the wind drag and to further lessen the fuel consumption of a vehicle. The regenerative shock absorber can lower the fuel consumption as the harvested energy can charge the vehicle's battery and help to charge the battery instead of using the alternator on the vehicle (Gysen, et al., 2011). Gradually, what happens is that it will reduce air pollution by lesser emission of pollutant gases. Several ways of converting kinetic energy from vibrating structures to form a more usable energy have been suggested. One method is to use the hydraulic and electro-chemical regenerative suspension. The research on the system has been carried out with a designed shock absorber (Zhen and Wei, 2010). The most workable method is the electromagnetic regenerative suspension system. The harvested energy from the vibration is deemed adequate to complete the requirement in the consumption process for the system (Tonoli et al., 2013). Latest research has dwelt into the use of electromagnetic suspension. In order to absorb vibration in the vehicle suspension system as an acceptable alternative, and to harvest the wasted energy from the vertical vibration on the vehicle suspension system. The system found to be appropriate for converting the kinetic energy to electricity to use on the electric vehicle and stored for high-performance vehicle electronics (Abdullah et al., 2015b). In addition, there is a need to obtain an increase of fuel efficiency by reducing the electrical demand to the car alternators and, thus, lessen the engine's workload. Therefore, this study seeks to work on the regenerative suspension system to reach the power required. In this way, it will enhance the final desirable output demand.