Design of Regenerative Suspension System using Spiral Drive Mechanism

Kazeem Pasha S B [1][a] and Champa V [1][b]

[1]Department of Electrical and Electronics Engineering, B.M.S. College of Engineering, Bengaluru, India

Keywords: Spiral Drive Mechanism (SDM), Electronic Control Unit (ECU).

Abstract: In the present research, a unique spiral drive mechanism (SDM) which is able to generate green energy from the vibration energy has been presented. The proposed model is able to capture the kinetic energy that decelerating automobiles lose as vibrations when they collide with a speed bump on the road or on the road roughness and any other disturbances which creates oscillations in the suspension system of the vehicle under loaded and unloaded situations. The linear motion of the SDM is converted into rotational movement, A DC generator transforms the mechanical energy into electrical power, which can then be stepped up using boost converter and power can be stored in the batteries. The power generated can be utilized during turning on of the electronic control units (ECU) and other vehicle modes which requires the electronic units to power up even before the cranking of the engines . The harvested power which is otherwise lost in the form of heat can be effectively utilized using the mechanism proposed in this paper. The paper focuses more on the reliability, effectiveness of the mechanism and cheaper cost in producing the power.

1 INTRODUCTION

Numerous mechanisms that use regenerative suspension systems to capture energy from road disturbances have been described at conferences and in academic journals. An explanation of the most recent development will be provided by the literature review on this subject. some of the prominent being as stated, (Sorrentino et al., 2022) Brushless permanent magnet devices often use field-oriented control. However, when a vehicle travels over bumps or potholes at high speed, the suspension is subjected to impulsive forces. Therefore, a field-weakening approach is necessary to ensure steady and effective operation under the aforementioned circumstances. The application of a field-oriented control method with field weakening is demonstrated in this work. An electro-hydrostatic shock absorber's three-phase permanent-magnet synchronous motor is tested in a lab. (Hua et al., 2022) the emerging electromagnetic damper cum energy harvester (EMDEH), which has the ability to both control vibration and harvest energy, was used in this study to develop a novel energy-regenerative semiactive secondary suspension system of HSTs and the corresponding control strategy. By semiactively regulating the duty cycle of an energy harvesting circuit, the created EMDEH can offer constantly variable damping coefficients. A full-scale EMDEH prototype's mechanical behaviour and energy efficiency were experimentally studied using cyclic tests. Through comparison with the outcomes of experiments, an EMDEH simulation model was created and validated. (Azam et al., 2021) this study presents the design, fabrication, and testing of a novel mechanical energy harvester (MEH) that utilizes a moveable speed hump integrated into a rack and gear mechanism, incorporating a mixture of one-way clutches. The intended application of this harvester is on the road. The gadget has the ability to extract the kinetic energy that automobiles release as vibrations when they decelerate upon encountering a speed bump on the road, both while the vehicles are loaded and during the subsequent restoration phase. The harvester that has been presented comprises four distinct modules, including the energy input module, transmission module, energy conversion module, and storage module. The vertical input movement of the bump is

[a] https://orcid.org/0009-0003-6953-4799
[b] https://orcid.org/0000-0002-2341-0278

B., K. and V., C.
Design of Regenerative Suspension System Using Spiral Drive Mechanism.
DOI: 10.5220/0012530100003808

In *Proceedings of the 1st International Conference on Intelligent and Sustainable Power and Energy Systems (ISPES 2023)*, pages 144-149
ISBN: 978-989-758-689-7

translated into rotational motion in both directions by the transmission module. This rotational motion is then further transformed into unidirectional rotation of the generator shaft through the continual engagement and disengagement of a one-way mechanism.(Chen et al., 2020) the present study explores the development and analysis of a novel energy-regenerative vibration absorber (ERVA) that incorporates a ball-screw mechanism. The ERVA system is founded upon a rotating electromagnetic generator with a modifiable nonlinear rotational inertia. This characteristic allows for the passive augmentation of the moment of inertia in tandem with the escalation of vibration amplitude. The aforementioned construction demonstrates efficacy in both energy harvesting and vibration control, while maintaining the original suspension size. Moreover, the system utilizes a nonlinear model predictive controller (NMPC) to boost performance. This controller leverages road profile information as a preview. The efficacy of NMPC-based ERVA is illustrated through several simulations, highlighting its superior performance.

2 DESIGN METHODOLOGY

The block diagram illustrates the utilization of power derived from the vehicle suspension system, which predominantly consists of mechanisms that convert linear motion into rotational motion. The suggested spiral drive mechanism is expected to operate within the same framework. The selection of a generator plays a crucial part in ensuring the efficient generation of power, necessitating the consideration of appropriate rotational speed. When the motor turns counter clockwise, it functions as a motor, and when it rotates clockwise, it operates as a generator. The power generated is inadequate for battery charging purposes, necessitating the utilization of a DC-DC boost converter to elevate the voltage to the necessary levels for the lithium-ion battery.

The spiral driving system bears resemblance to the household 360-degree cleaning mop. The device comprises a spiral spring that constitutes the sturdy central peripheral component, as depicted in Figure 2. Additionally, it incorporates an interlocking gear mechanism that remains in a locked state when force is exerted on the stick, and transitions to an unlocked position when the stick is removed.

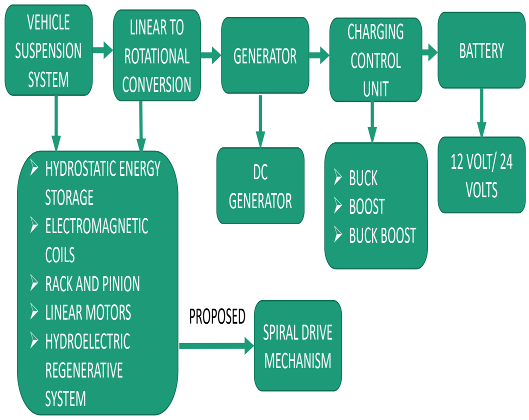

Figure 1: Block Diagram for the Proposed Mechanism.

The proposed structure is a vertical cylindrical object that measures 60 centimeters in length. It has the capability to stretch up to 90 centimeters during vertical upward movement. Furthermore, it is characterized by its strong construction. The mechanism consists of a rod that is twisted in a spiral form, enabling it to function as a support for reciprocal motion and hence the name Spiral Drive Mechanism.

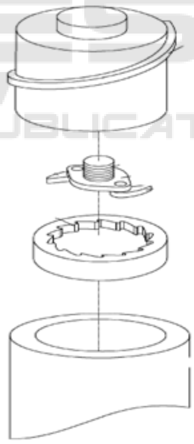

Figure 2: Spiral Drive Mechanism (Inventor:-Yi-Pin Lin).

The integration of the spiral drive mechanism and the DC generator, facilitated by the use of connectors, enables the generation of electricity.

3 TWO DEGREE QUARTER CAR DESIGN

Two-degree quarter car design is explained in the below section.

3.1 Quarter Car Model

In order to ascertain the dynamics of the system, it is important to comprehend the system's behaviour, which can be achieved by a thorough analysis of the system. In the context of vehicle dynamics, two often employed models are the quarter car model and the full car model. Due to the increased complexity associated with the full car model, the decision has been made to utilize the quarter car model, which offers a simplified representation with two degrees of freedom.

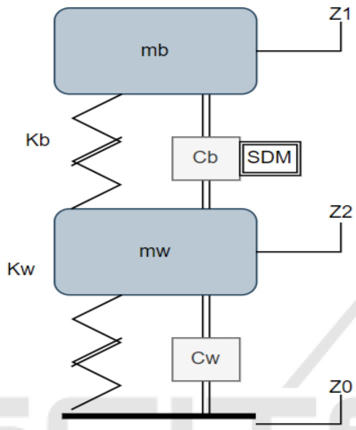

Figure 3: Quarter Car Model with 2^0 Freedom.

Where m_b is the sprung mass, m_w is the unsprung mass, K_b; K_t are the spring constants the spring and tire, C_b; C_t are the damping coefficient of the shock absorber and the tire, lastly Z_1;Z_2;Z_0 is the position of the sprung mass, unsprung mass and tire respectively. The dynamic equations have been defined based on the utilization of Newton's second law of motion.

$$m_b \ddot{z_1} + c_b (\dot{z}_1 - \dot{z}_2) + K_b(Z_1 - Z_2) = 0 \quad (1)$$

$$m_w \ddot{z_2} - c_b (\dot{z}_1 - \dot{z}_2) + K_b(Z_1 - Z_2) + c_w (\dot{z}_2 - \dot{z}_0) + K_w(Z_2 - Z_0) = 0 \quad (2)$$

In the equation, the double dot notation is used to denote acceleration, while the single dot notation represents velocity. Single variables are used to signify displacements.

The equations 1 and 2 can be represented using differential equation methodology and have been implemented utilizing control block techniques to replicate the outcomes in the MATLAB simulation software.

The equations of the model have been formulated within a control block, and the response of the vehicle's suspension to vibrations or irregularities is represented as an oscillating wave that gradually diminishes when the suspension reaches its resting state.

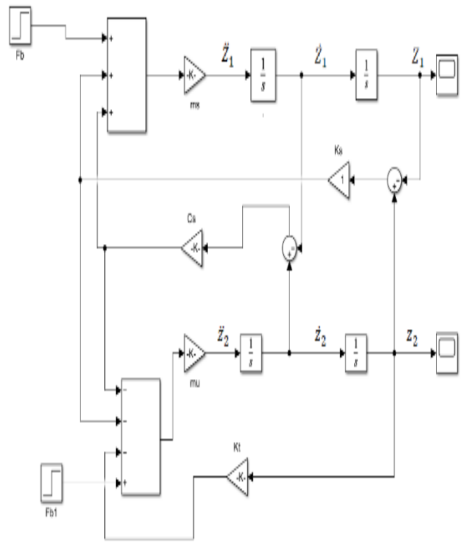

Figure 4: Quarter Car Model MATLAB simulation.

The spring mass response graph shows how the suspension behave for any disturbances in the form of road humps. The frequency of oscillation as shown in between the two measurement cursors is 1.138 Hz as shown in Fig 5. This shows the potential to harness the power.

3.2 ISO 8608 Road Profile

The road profile is commonly regarded as a stochastic process denoted by y(d), where y represents the road height and d represents the distance along the road. As the car moves with a velocity v along the road, the random process y(d) undergoes a conversion to a random process y(t), which is then fed into the vehicle suspension system through the tire. The stochastic process y(d) is commonly characterized by its power spectral density with respect to frequency, expressed in either radians or cycles per unit distance. Nevertheless, the existence of multiple definitions for power spectrum density poses a challenge when attempting to compare published data, as a clear understanding of how the power spectral density has been established is necessary.

The control blocks have incorporated the governing equations of power spectrum density for the four wheels simultaneously. The graph visually represents the power spectral density for each individual wheel. The first and third graphs exhibit a phase relationship, as do the other two wheels.

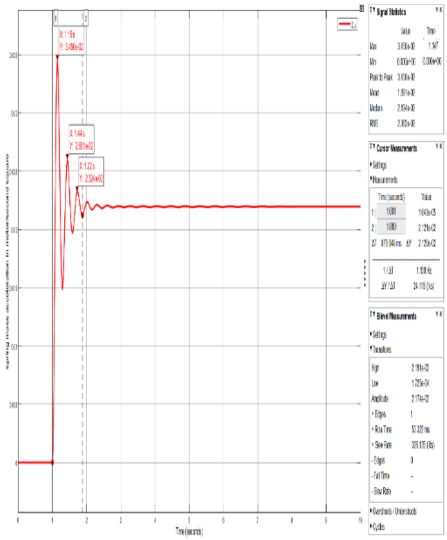

Figure 5: Spring Mass Acceleration Vs Time Graph.

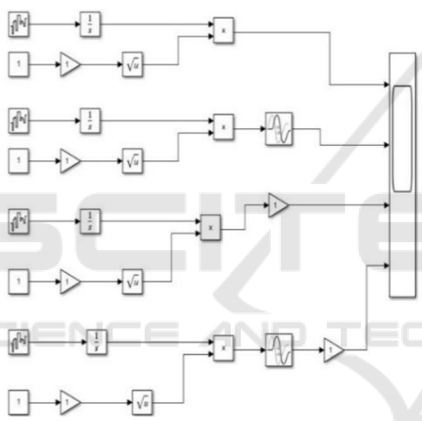

Figure 6: Road Profile Simulation using MATLAB.

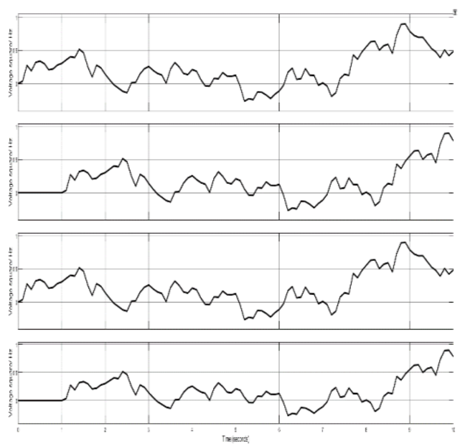

Figure 7: Roughness of the Road Vs Time for Individual Car Tires.

In the aforementioned simulation, we conducted a drive on a road with class C conditions, utilizing the ISO settings, and subsequently generated power spectral density (PSD) graphs. This provides an insight into the variability of power harnessing across varied road conditions, whereby the suspension system demonstrates an increased capacity for generating power in rougher terrains.

4 DC-DC BOOST CONVERTER

The power provided by the prototype is insufficient to adequately power the arrangement, necessitating the use of a boost converter to increase the voltage to a level suitable with the battery voltage. The MATLAB simulation of the closed-loop boost converter has been conducted.

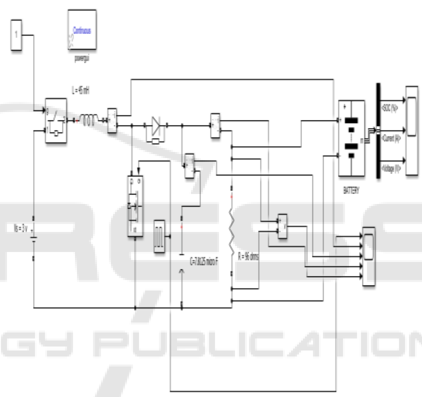

Figure 8: Open loop DC-DC Boost Converter.

The design equations have been used to calculate the values of the parameter, the input voltage being 3volts and the output voltage is 12 volts. The designed value of inductor is 45 mH and the capacitor value being 7.8125 microF the value of resistor is 96 ohms. The state of charge(SoC) has been kept at 48% , which means if the charge of the battery goes below the threshold, the boost converter starts charging. If the battery reaches its full charged capacity it will start discharge as shown in the Fig 9 and 10 respectively.

When the voltage has been dropped to certain limit and the SoC of the battery is below 48%, the battery starts to charge as shown in figure 9.

Similarly, when the battery is fully charged the switch is kept to zero so that the circuit is totally disconnected and the battery slowly starts to discharge till it reaches 48%.

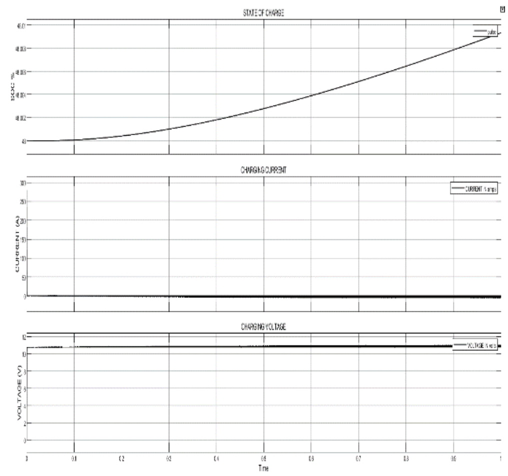

Figure 9: MATLAB Simulation Battery Charging.

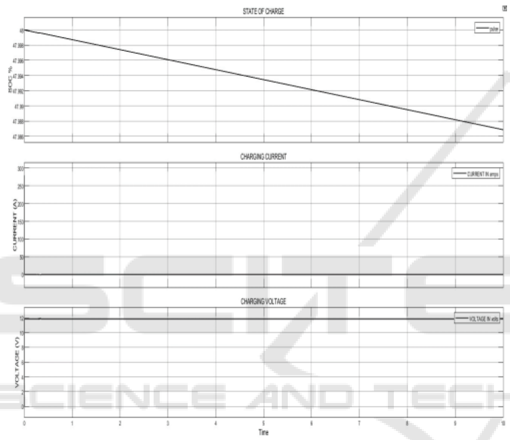

Figure 10: MATLAB Simulation Battery Discharging.

The current is in 260 mA which is sufficient to charge the battery of 12 volts and 2600 mAh. The battery discharge rate is kept at 30 seconds.

5 HARDWARE PROTOTYPE

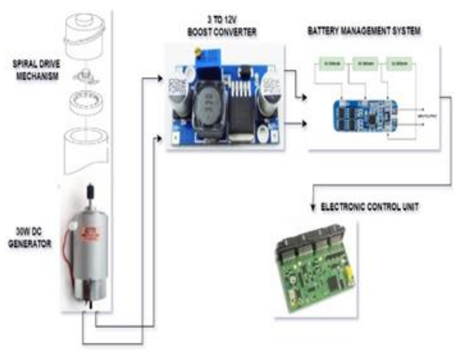

Figure 11: Hardware Connection Diagram.

The spiral drive mechanism is coupled to 30 watts DC generator. The output of the generator is connected to boost converter which raises the voltage to 12 volts. The potentiometer is used to adjust the voltage levels.

The output of the converter is fed to the 12-volt Battery which is protected with the help of Battery Management System (BMS) for any fault or short circuit protection.

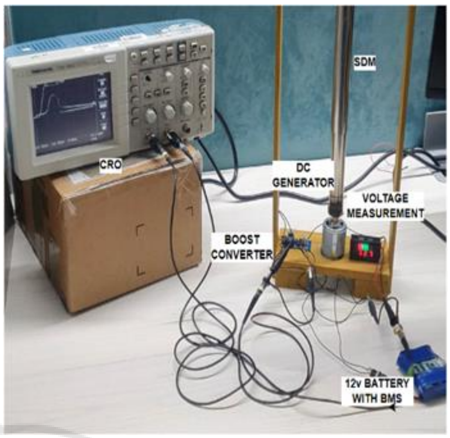

Figure 12: Hardware Setup of SDM.

The proposed mechanism can be able to generate about 12 volts and 0.2 amps of current which is enough to power up the battery packs. Oscilloscope has been used to show the power generated waveforms for a larger time division settings.

6 CONCLUSION

The primary objective of the project was to demonstrate the potential utilization of the spiral drive mechanism in converting the inherent vibrational energy of the suspension system into a viable power source. The system's capacity to respond to external perturbations, such as uneven road surfaces or bumps, is exemplified by the simulation of the road profile and the quarter-car model. The non-isolated DC-DC converter is employed to enhance the generated power. A comparison is made between the hardware prototype and the MATLAB simulation model. The calculated results were deemed satisfactory based on the obtained values.

REFERENCES

Sorrentino, G., Circosta, S., Galluzzi, R., Amati, N., & Tonoli, A. (2022). Implementation of a Field-Oriented Control Strategy for Electromagnetic Shock Absorbers. *International Symposium on Electromobility (ISEM) IEEE conference.*

Hua, Y., Cai, Q., & Zhu, S. (2022). Energy-Regenerative Semiactive Lateral Suspension Control in High-Speed Trains Using Electromagnetic Damper Cum Energy Harvester. *IEEE Transactions on Vehicular Technology*, *71*(5), 4801–4812.

Azam, A., Ahmed, A., Hayat, N., Ali, S., Khan, A.S., Murtaza, G. and Aslam, T. (2021). Design, fabrication, modelling and analyses of a movable speed bump-based mechanical energy harvester (MEH) for application on road. *Energy*, 214, p.118894.

Chen, K., Li, Z., Tai, W.-C., Wu, K., & Wang, Y. (2020). MPC-based Vibration Control and Energy Harvesting Using an Electromagnetic Vibration Absorber With Inertia Nonlinearity. *ArXiv (Cornell University)*.

Hamza, A., & Ben Yahia, N. (2020). Heavy trucks with intelligent control of active suspension based on artificial neural networks. *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering*, *235*(6),952–969.

Wang, Z., Zhang, T., Zhang, Z., Yuan, Y., & Liu, Y. (2020). A high-efficiency regenerative shock absorber considering twin ball screws transmissions for application in range-extended electric vehicles. *Energy and Built Environment*, *1*(1), 36–49. https://doi.org/10.1016/j.enbenv.2019.09.004

Casavola, A., Tedesco, F., & Vaglica, P. (2020). H 2 and H ∞ Optimal Control Strategies for Energy Harvesting by Regenerative Shock Absorbers in Cars †. *Vibration*, *3*(2), 99–115.

Kopylov, S., Chen, Z., & Abdelkareem, M. A. A. (2020). Implementation of an Electromagnetic Regenerative Tuned Mass Damper in a Vehicle Suspension System. *IEEE Access*, *8*, 110153–110163.

Xie, L., Cai, S., Huang, G., Huang, L., Li, J. and Li, X. (2020). On Energy Harvesting From a Vehicle Damper. *IEEE/ASME Transactions on chatronics*, 25(1), pp.108–117.

Gillespie, T. D., Saied Taheri, Sandu, C., & Duprey, B. L. (2021). *Fundamentals of vehicle dynamics*. Sae International.

Donahue, M.D., & Hedrick, J.K. (2002). Implementation of an Active Suspension, Preview Controller for Improved Ride Comfort.

Demetgul, M., & Guney, I. (2017). Design of the Hybrid Regenerative Shock Absorber and Energy Harvesting from Linear Movement. *Journal of Clean Energy Technologies*, *5*(1), 81–84.

Zheng, P., Gao, J., Wang, R., Dong, J., & Diao Jincheng. (2018). Review on the Research of Regenerative Shock Absorber.

Hurtado, G., Romero, J.A,. and Carlos,S.(2016) Energy Harvesting Simulator *IEEE*