Design Analyses of a Hybrid Suspension System for Scooter Application

Cheng-Tsung Liu[1], Wei-Ping Lin[1], and Chang-Chou Hwang[2]
[1]Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung, 80424, TAIWAN
[2]Department of Electrical Engineering, Feng Chia University, Taichung, 40724, TAIWAN
ctliu@ieee.org

***Abstract*—To effectively harvest the inherent vibration energies, feasibility of replacing those common mechanical shock absorbers that are mounted between the wheels and bogie of a scooter with electromagnetic motion device will be assessed. Instead of consuming additional energy to control the vibration pattern, the main design objectives are to convert the mechanical vibration to electric energy directly, and to produce the suspension forces to meet the maximum force specifications. Based on proper emulation designs and electric output controls, the operational fluxes and dynamic characteristics of this hybrid suspension system at various operational conditions will be thoroughly investigated, and the satisfactory performances of the proposed system can then be systematically validated.**

***Index Terms*—Damping, magnetic flux, power generation, suspensions, vibrations.**

I. INTRODUCTION

To alleviate the uncomfortable car sick effects that will be resulted onto passengers from the motions of vehicles, the mechanical bogie oscillation/vibration frequencies between 2 to 5 Hz must be properly damped. As the active suspension system can provide adjustable damping coefficients to appropriately absorb the tires' shock forces when driving through the rough road, more advanced designs that can replace the traditional suspension systems by the active ones are certainly desired. Though different types of active suspension systems have been proposed to meet the market requirements [1]-[3], most of these designs are based on adopting some motor structures to produce controllable force patterns to absorb the shocks applied onto the tires. Consequently, even some regenerative operation modes can be implemented to increase the overall system efficiency, extra electric energy are still required to realize these oscillation/vibration force pattern control objectives [4]-[6].

With their mass volumes that being commuted among the urban areas in third world countries, major efforts to improve the performances of scooters have been focused on designing energy-efficient/low-emission combustion engines or developing even hybrid/full electric driven motorbikes. Alternatively, the major design concern of this research is to seek feasible arrangement that can both generate the maximum required damping force and convert the mechanical vibration to electric energy directly [7], [8]. A hybrid suspension system, which consists of a permanent magnet (PM) shock absorber for providing the maximum suspension force and a slotless permanent magnet linear generator (PMLG) for generating both the electricity and the controllable damping, is designed to fulfill the system requirements. For a scooter application, four hybrid systems can be installed to its two wheels, and the specific design is aimed to supply a total of about 35 W for the headlight power requirement and to counter the entire system mass of about 2800 N during the oscillation/vibration motions.

II. THE HYBRID SUSPENSION SYSTEM

Fig. 1 depicts the conceptual arrangement of the simple hybrid suspension system. The PM shock absorber consists of two PMs with same polarities facing each other to produce the repulsive force, and the single-phase, 4-pole, 6-coil PMLG is integrated with the shock absorber longitudinally to generate the controllable power outputs to meet the equivalent damping and electric energy requirements. In addition to the desired electrical and mechanical output specifications, with a length of 300 mm and a diameter of 60 mm, the physical dimensions of common suspension system are selected. With an allowable operational stoke, the process for determining the optimal physical composition between the PM shock absorber and the PMLG is illustrated in Fig. 2.

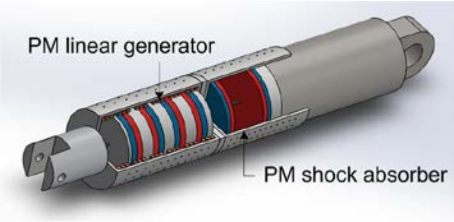

Fig. 1. Conceptual arrangement of the hybrid suspension system.

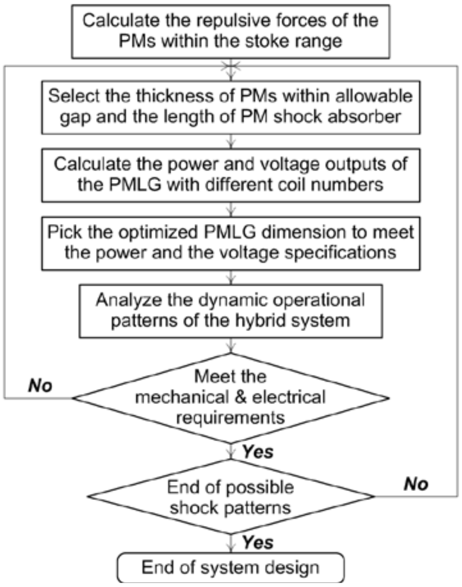

Fig. 2. Design process for the optimized hybrid suspension system.

III. PRELIMINARY DESIGN INVESTIGATIONS

Based on the design process as described in Fig. 2, by using 3-dimensional (3-D) finite element analyses (FEA), the repulsive forces generated by two PMs at different gaps with various thicknesses can be calculated as shown in Fig. 3. Apparently, with a minimum gap setting of 5 mm for safety consideration, all the PMs under investigations can fulfill the objective of supplying a force larger than 700 N. Hence the smallest PM with thickness of 15 mm is selected. While for the single-phase PMLG, it is certain that longer dimension can implement more PM poles and stator windings to produce larger power and higher voltage outputs. The evaluated output results of the PMLG based on a total length of 300 mm for the entire hybrid suspension system is shown in Fig. 4. Clearly it can be seen that if the length is longer than 65% of the entire hybrid suspension system, the desired output power and voltage levels for the operational objectives can be achieved.

From the separate fundamental analyses about the PM shock absorber and the PMLG, preliminary design about the physical dimensions of a hybrid suspension system can be provided. The overall system dynamic 3-D FEA field distribution at one operational time instance is illustrated in Fig. 5. With controllable electrical loads connected to the PMLG terminals, the summarized system composition assessments based on the dynamic analyses are provided in Fig. 6. Based on the design objectives and operational constraints, it can be seen that the 700 N repulsive force and 8.75 W power output objectives cannot be achieved simultaneously. However, by selecting the PMLG length to be 60% of the entire system, the compromised results can still provide quite promising performances with such preliminary structural designs. It is thus confident that the desired hybrid suspension system can be achieved if finer designs and controls can be implemented.

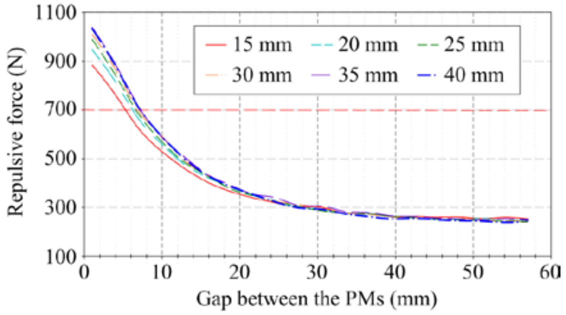

Fig. 3. Generated repulsive forces by two PMs with different thicknesses.

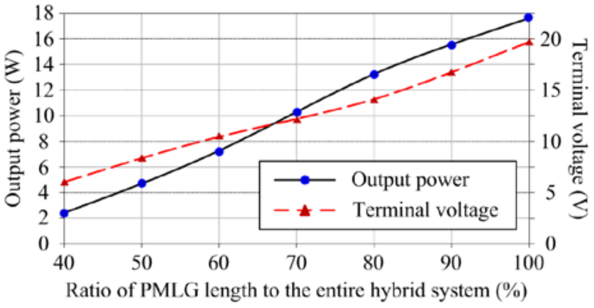

Fig. 4. Generated terminal voltages and output powers of the PMLG with different lengths.

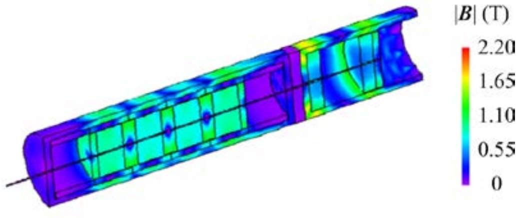

Fig. 5. 3-D magnetic flux density distribution inside the hybrid system at one operational time instance.

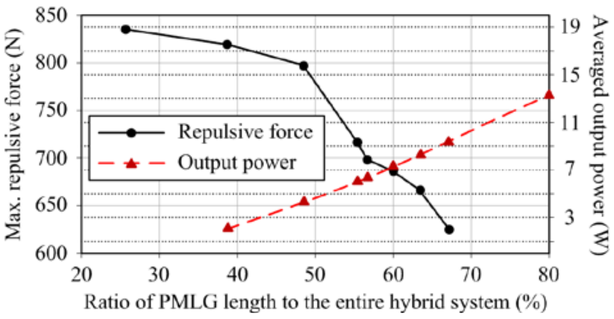

Fig. 6. Output performance of the hybrid suspension system with different PMLG length ratios to the entire system.

IV. CONCLUSION

A hybrid suspension system that can both absorb the motion/vibration shocks and generate electric power, has been investigated for its feasibility for scooter application. Within the specified physical constraints, preliminary designs showed that the maximum shock force and the minimum power generation objectives can be easily met separately. Supported by detailed dynamic assessments, the compromised results indicated that it is realistic to develop such a hybrid system to fulfill the integrated system operational requirements.

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