

Experimental Study on the Effect of Coil Spring Reaction Force Vector on McPherson Strut Suspension Characteristics

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ABSTRACT

In McPherson strut applications for automotive suspension systems, the desired coil spring reaction force vector (FLP: force line position) that minimizes damper friction and king pin moment is typically determined by Statics/Kinematics calculations. There is not a device available on the open market today which can mimic the coil spring reaction force vector within the suspension system.

Such a programmable coil spring reaction force vector generator, named "Universal Spring", was developed in 2003 (USPG2003), and was then improved in 2013 (USPG2013) from the standpoint of accuracy, durability and reliability. The device is actuated by six hydraulic cylinders constructing a Stewart platform type parallel mechanism. Accuracy of FLP generated by USPG2013 is 1.1mm at maximum in $\phi 80\text{mm}$ area around strut axis. Using this modified device, the relationship between the spring reaction force vector and damper friction, as well as spring reaction force vector and king pin moment, can be experimentally studied to confirm vehicle characteristics without actually producing any prototype coil springs. These studies will be discussed in this paper with showing actual measured data. Furthermore, it was found that approximately 70% of moment generated by upper bearing friction was transferred to king pin moment for the suspension system used in this experiment. The validity of this device was proven by comparing to actual coil spring based testing data.

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INTRODUCTION

In McPherson strut applications for automotive suspension systems, the desired coil spring reaction force vector (FLP: force line position) that minimizes damper friction and king pin moment is typically determined by Statics/Kinematics calculations^{1,2}). There is not a device available on the open market today which can mimic the coil spring FLP within the suspension system.

Such a programmable coil spring FLP generator, named "Universal Spring (USPG)", was developed in 2003 (USPG2003)^{3,4}), and was then improved in 2013 (USPG2013) from the standpoint of accuracy, durability and reliability. This paper introduces the improvements for the USPG2013 with its accuracy at first, and then discusses strut suspension characteristics by showing actual data measured with this device. We focus on riding comfort (damper friction) and self steer torque (king pin moment (KPM)) as the suspension characteristics in this paper.

Furthermore, an effect of an upper bearing friction on king pin moment is also studied. A validity of this device was proven by comparing to actual coil spring based testing data.

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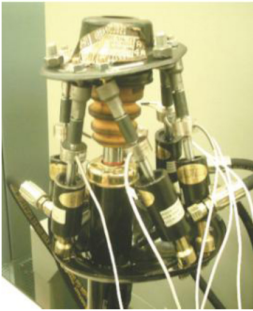
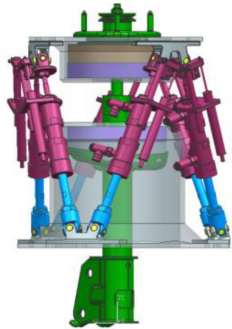
Improvements

Table 1 shows the difference in specification between USPG2003 and USPG2013.

The device is actuated by six hydraulic cylinders mounted between upper and lower spring mounting seats with universal joints, with a formation of Stewart platform type parallel mechanism. The use of two universal joints per cylinder allows for an additional 6 degrees of freedom for the whole mechanism. These additional 6 degrees of freedom are present as the non-constrained rotational motion of the cylinder along each axis. These allowable rotations have no influence to generating force between the two spring mounting seats. For

practical use of this mechanism, this freedom is rather convenient; for example, it allows arrangement of all twelve hydraulic hoses from each cylinder in an organized manner. The length of each leg can be adjusted using extension rods installed between the universal joint and the cylinder element.

Table 1. Difference in USPG2013/2013 Specifications

	USPG2003	USPG2013
Stroke	24 mm	40 mm
Max Load	12,000 N	12,000 N
FLP	Φ25 around strut axis	Φ40 around strut axis
Sensor	6 axial load cells	2 multi-axial load cells
Feedback	6 axial forces	FLP, vertical reaction force, Mz (moment around strut axis).
Appearance		

The desired FLP can be programmatically controlled by adjusting axial force of each cylinder. In USPG2003, axial force was measured by axial load cell mounted on each cylinder axis. Because of that, accuracy of the resultant FLP was not

guaranteed due to friction of the universal joints and seat deformation due to point loading. To improve the FLP accuracy in USPG2013, the FLP is directly measured by two multi-axial load cells mounted inside the device, constructing a closed PI control loop to achieve the target FLP. Furthermore, for the USPG2013, hydraulic cylinders are mounted between hat-shape fixtures rather than between the lower seat and the upper mount. This contributes to increasing in cylinder stroke and adjustable FLP range.

To aid in this effort the device was designed in a universal manner for any strut application by only requiring the replacement of strut-dependent seat adapters.

Controller Design and System Response

Fig.1 shows a SIMULINK model of the USPG2013 system. Three feedback loops with PI controller can be observed for FLP, vertical load, and Mz (moment about strut axis on the upper spring plane). A zero regulator for Mz is necessary to avoid entire device body rotation induced by the upper bearing. Because of this control scheme, error of these parameters in steady state is theoretically zero. After confirming the system behavior in the SIMULINK model, C++ code for the controller and other calculations is generated and embedded into INTime real-time operating system with 1ms of system sampling time.

The step response of the system measured by the lower multi-axis load cell is shown in Fig.2. The setting time to the target FLP is approximately 2 sec.

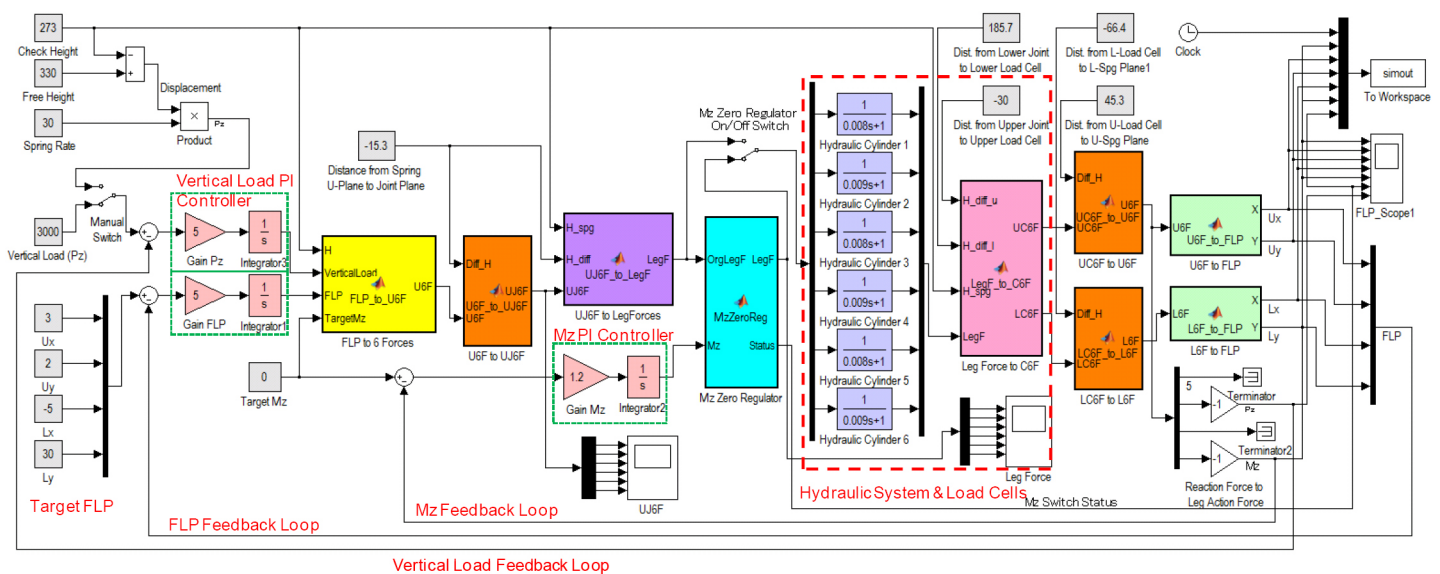


Fig. 1. USPG2013 Control System Model in SIMULINK