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SUSPENSION OPTIMIZATION USING DESIGN OF EXPERIMENT (DOE) METHOD ON MSC/ADAMS-INSIGHT

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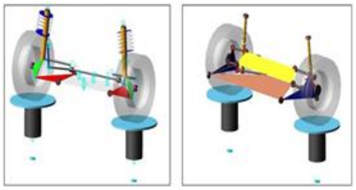
Graphical abstract



Abstract

In this paper, the optimum setting for suspension hard points was determined from a half vehicle suspension system. These optimized values were obtained by considering the Kinematic and Compliance (K&C) effects of a verified PROTON WRM 44 P0-34 suspension model developed using MSC/ADAMS/CAR. For optimization process, multi body dynamic software, MSC/ADAMS/INSIGHT and Design of Experiment (DoE) method was employed. There were total of 60 hard points (factors) in x, y and z axis-direction for both front and rear suspension while toe, camber and caster change were selected as the objective function (responses) to be minimized. The values of 5 mm, 10 mm and 15 mm were used as relative values of factor setting to determine the factor range during optimization process. The hard point axis-direction that has the most effects on the responses was identified using the Pareto chart to optimize while the rests were eliminated. As expected result, a new set of suspension system model with a selected of Kinematic and Compliance (K&C) data set were obtained, and compared with the verified simulation data when subjected to the vertical parallel movement simulation test to determine the best setting and optimum suspension hard points configuration.

Keywords: Suspension modelling, MSC/ADAMS Insight, design of experiment (DoE), Pareto chart

1.0 INTRODUCTION

Suspension system is an important and main role in the overall vehicle system to give a better handling stability and ride comfort during maneuvering. It used to support the load, and protect the passenger in the car by absorbing the shock and vibration from road [1]. Generally, Suspension system consists of springs, shock absorbers or strut and linkages that connect a vehicle to its wheels [2].Traditionally, to develop or modify suspension component system, suspension test rig were being used. This method is time consuming, costly, required a number of workmanship and might have an error due to human factor and machine setting [3]. Thus, a virtually suspension model simulation and analysis is employed nowadays among researchers.

In this paper, the aim of this study is to optimize and find tune the best configuration setting of suspension hard points in order to improve the kinematic and compliance (K&C) characteristic using Design of Experiment approach. Previously, N.Ikhsan et al. has developed a model of half car suspension system of PROTON WRM 44 P0-34 using MSC/ADAMS Car and verify the analysis and simulation data with the experimental data on the same K&C analysis test (Figure 1) [3]. The verified suspension model could be used for optimization to reduce the overall time, cost and workmanship. The same suspension models, which are, McPherson and Multilink suspension system for front and rear respectively, will be use on this research. Generally, the McPherson suspension is the system that currently employed in the most of small and medium-sized cars [4]. The main advantage of the McPherson is that all parts on the suspension and wheel control are combined into one assembly [2]. It is simplest and allocated more space for other vehicle's components and usually use for front suspension system. Different with Multilink suspension type, uses several links to attach the hub carrier to the car's body and consist of a high number of links (as few as three links) and bearings, therefore making more complex and [5].

In the following section, the methodology for this study is discussed including the selection of optimization process characteristic, screening the factors using Pareto chart and objective target for optimization process. Finally, a detail discussion on the result and conclusion is present.

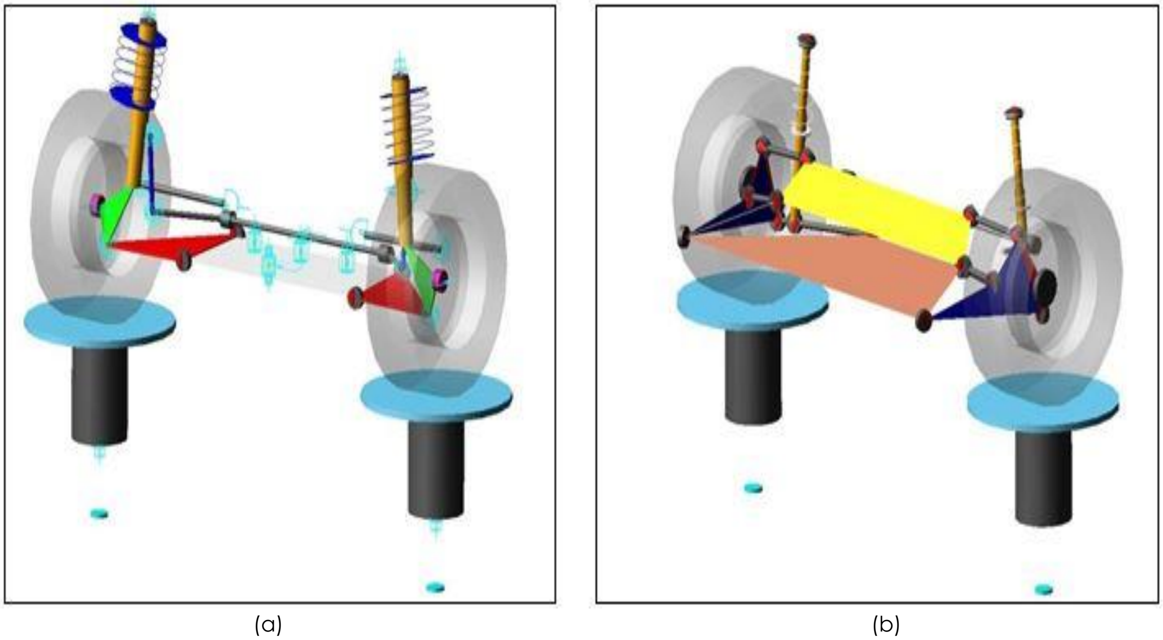

(a) (b)

Figure 1 Verified suspension assembly model of PROTON WRM 44 P0-34 on MSC/ADAMS Car test rig (a) McPherson strut suspension (b) Multilink suspension

2.0 METHODOLOGY

The process for this study involved several important steps. It starts with a selection of the design objective for optimization, factors setting, screening the factors using Pareto chart and optimize the factors to meet with the design target.

The verified PROTON WRM 44 P0-34 consist of 10 components hard point in x, y, z direction for both front and rear suspension models with specific joining type and orientation [3], make it the suspension model consist of 60 hard points in total. The components are considering only at one side of a car (left/right) since it is on symmetry All the hard point is selected as factors (known as factors afterwards) on optimization process and selected Kinematic and Compliance (K&C) characteristic such as toe, camber and caster as responses (known as responses afterwards). Since the number of factors is greater than 5, Partial factorial is suitable as a design type for Design of Experiment (DoE). The design specification to optimize the suspension model MSC/ADAMS Insight is depicted in the Table 1.

Table 1 Design specification for optimization

Design specification	Type
Investigation strategy	DOE screening (2 level)
Model	Linear
DOE design type	Partial factorial

Factors setting are another step need to consider. This process allows specifying the range of factors based on nominal value before executing the analysis and optimization process. For this research, a relative value of 5mm, 10mm and 15mm factor setting were selected with moderate ease of adjustment. It means the range would be 10mm, 20mm and 30mm range respectively. Equation 1 shows the equation of relative factor setting type.

$$\begin{aligned}\text{Factor setting (Range)}\\ &= \text{Nominal value} - \text{setting value AND}\\ &= \text{Nominal value} + \text{setting value}\end{aligned} \quad (1)$$

The target or design objective for this research is to find the optimum factors value of hard point location and axis-direction when the responses value of toe, camber and caster change is minimized. To do so, screening process is employed to identify of any factors that not contribute or effect the response change by using Pareto chart. Only factors that have most effect on the response are taken and will be optimized.

Once a new sets of optimum hard point is collected, the suspension system will be re-modeled by replacing the current x, y and z location value with an optimized value and then, will be simulated with the vertical parallel movement test to ensure it meet the design target by comparing with verified simulation data

3.0 RESULTS AND DISCUSSION

The simulation running on MSC/ADAMS Insight provides the Pareto chart (see figure 2-4). The chart is used to reduce and screen the number of factors that significantly have no effects on the responses, thus only factors that has most effect on responses are considered to optimize. Based on the figure 2, most of the factors of front suspension were reacting sensitively with the toe change compared to camber and caster change when the factors is set with 5 mm relative value. This indicates that a slight change on the value of hard points will have a profound effect on toe change, followed by camber change and caster change. The summary of the direction of the hard points that had the most effects on the responses is shown in Table 2 - 4. The selected factors had been identified and the number of total factors that will be optimized is tabulated on table 5. The maximum percentage reduction of factors number after screening process was 46.7% on 5 mm relative value of factor setting for both front and rear suspension, followed by 43.4% on 10 mm relative value of factor setting for front and rear suspension and 15 mm relative value of factor setting for front suspension. The 10 mm relative value of factor setting recorded as the lowest percentage reduction of 40.0% on rear suspension.

Figure 3 (a) to (f) show a simulation result of a optimized front and rear suspension setting for relative value of factor setting 5 mm, 10 mm and 15 mm when subjected to the vertical parallel movement test. Each simulation test is compared with the verified PROTON WRM 44 P0-34 suspension model simulation data on toe, camber and caster change effect. As mention previously, the target of this study is to determine the best setting of optimized suspension system to minimize the toe, camber and caster change. For front suspension system, it shows 15 mm relative value of factor setting give a minimum simulation data for toe and caster change while minimum camber change is when the factors are set to 10 mm of relative value, (Figure (a) to (c)). Different with the rear suspension system, minimum simulation data for camber and caster change is happened when the factors are set to 15 mm of relative value while 10 mm relative value of factor setting effect only for the toe change, (Figure (d) to (f)). However, the relative value of 5 mm of factor setting was not reflect to give a minimum simulation data for toe, camber and caster change on front and rear suspension. Based on this result and analysis, it showed there are conflicts between relative values of factor setting of 10 mm and 15 mm for both front and rear suspensions system, since there are no single factors setting values capable to meet all objective targets (Table (6)).

Figure 2 Example of Pareto chart for front suspension with factor setting of 5mm for Toe change

e: toe_change_left

Factor	From	To	Effect
.hpl_tierod_inner.z	8.0000e+01	1.1000e+02	-4.0227e-01
.hpl_tierod_outer.z	9.2850e+01	1.2285e+02	2.1498e-01
.hpl_lower_ball_joint_centre.z	-5.2680e+01	-2.2680e+01	-2.0939e-01
.hpl_lower_control_arm_front.z	-5.3000e+01	-2.3000e+01	1.8710e-01
.hpl_tierod_outer.x	1.1327e+02	1.4327e+02	-1.7707e-01
.hpl_strut_top.x	1.4600e+01	4.4600e+01	1.5047e-01
.hpl_spring_center_upper.y	-5.7890e+02	-5.4890e+02	1.1602e-01
.hpl_lower_ball_joint_centre.y	-7.1355e+02	-6.8355e+02	1.0818e-01
.hpl_strut_top.y	-5.6187e+02	-5.3187e+02	-1.0415e-01
.hpl_lower_ball_joint_centre.x	-2.0450e+01	9.5500	9.5346e-02
.hpl_strutslider_axis_point.y	-6.0664e+02	-5.7664e+02	8.9222e-02
.hpl_strut_top.z	5.5379e+02	5.8379e+02	8.0448e-02
.hpl_spring_center_upper.x	1.2740e+01	4.2740e+01	6.1788e-02
.hpl_strutslider_axis_point.x	-1.0600e+01	1.9400e+01	-5.9609e-02
.hpl_spring_center_lower.x	2.8500	3.2850e+01	4.4799e-02
.hpl_lower_control_arm_front.y	-3.8830e+02	-3.5830e+02	-4.2262e-02
.hpl_lower_control_arm_rear.z	-4.2500e+01	-1.2500e+01	3.6140e-02
.hpl_lower_control_arm_front.x	-8.0000	2.2000e+01	-3.5992e-02
.hpl_tierod_outer.y	-6.6730e+02	-6.3730e+02	2.2749e-02
.hpl_lower_control_arm_rear.x	3.0200e+02	3.3200e+02	-1.1646e-02
.hpl_tierod_inner.y	-3.2300e+02	-2.9300e+02	9.9165e-03
.hpl_wheel_centre.y	-7.4219e+02	-7.1219e+02	8.9367e-03
.hpl_spring_center_upper.z	5.1842e+02	5.4842e+02	-7.4553e-03
.hpl_spring_center_lower.y	-6.1895e+02	-5.8895e+02	6.7180e-03
.hpl_lower_control_arm_rear.y	-3.7150e+02	-3.4150e+02	-6.1625e-03
.hpl_strutslider_axis_point.z	1.1814e+02	1.4814e+02	-5.5066e-03
.hpl_spring_center_lower.z	3.5043e+02	3.8043e+02	-3.6837e-03
.hpl_wheel_centre.z	4.4000e+01	7.4000e+01	2.5981e-03
.hpl_wheel_centre.x	-1.4840e+01	1.5160e+01	2.3704e-03
.hpl_tierod_inner.x	1.4500e+02	1.7500e+02	-2.5455e-04

Table 2 The summary of the Pareto chart for 5mm relative value of factor setting

Suspension geometry hard points	Direction and responses most affected	
	Front suspension	Rear suspension
Tierod inner	z (toe, camber), x (caster)	x (caster), z (toe, camber)
Tierod outer	z (toe, camber caster)	z (toe, camber, caster)
Lower control arm outer	z (toe, camber), x (caster)	x (caster), y (toe, camber)
Lower control arm front	z (toe, camber, caster)	y (toe, camber, caster)
Lower control arm rear	z (toe, camber, caster)	x (toe), y (camber), z (caster)
Strut upper	x (toe, caster), y (camber)	y (toe, camber), z (caster)
Strut lower	y (toe, camber), x (caster)	y (toe, camber, caster)
Spring upper	x (toe), y (caster, camber)	x (toe, camber), z (caster)
Spring lower	y (toe, camber, caster)	x (toe, camber), z(caster)
Wheel center	y (toe, camber), x (caster)	y (toe, camber, caster)

Table 3 The summary of the Pareto chart for 10mm relative value of factor setting

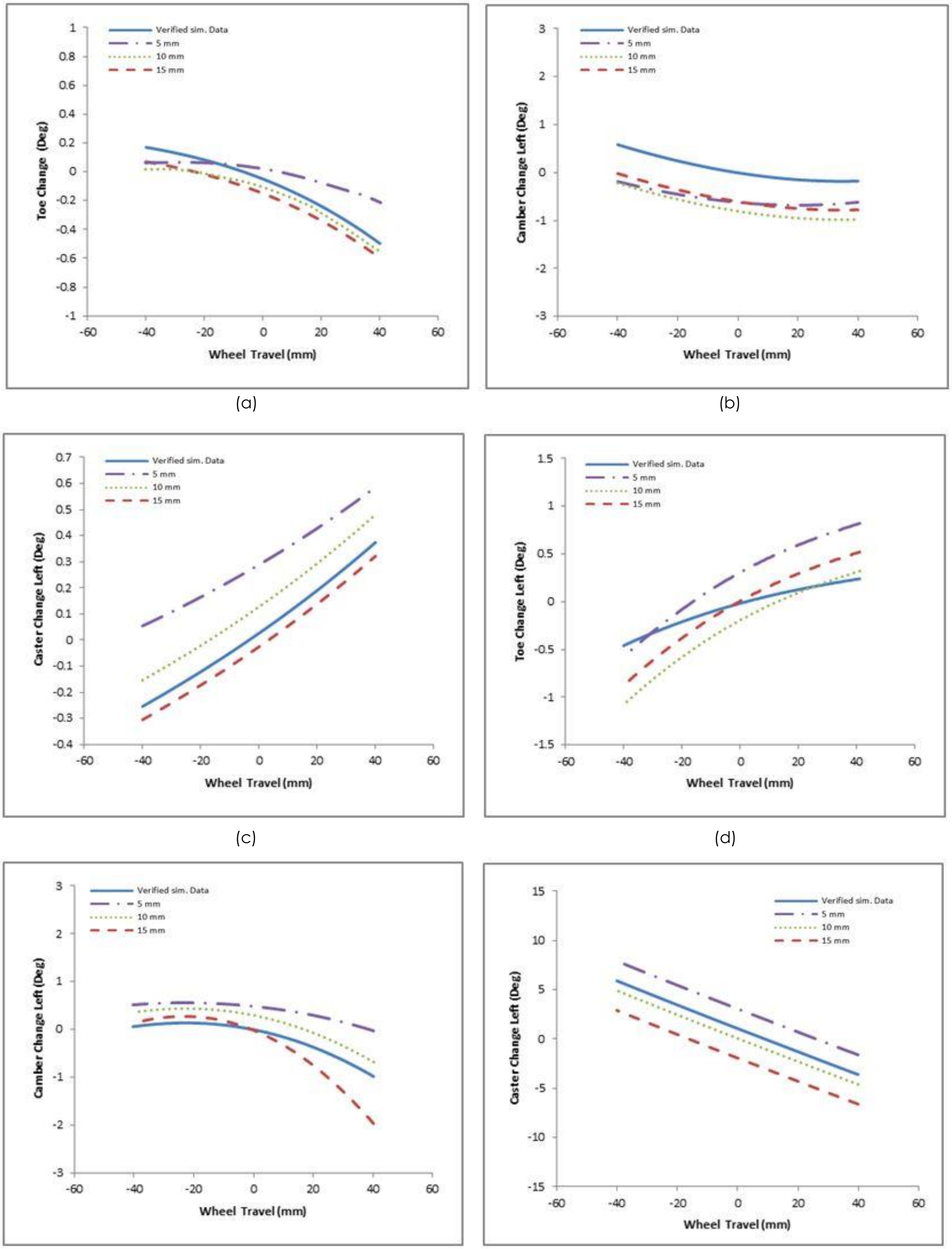
Suspension geometry hard points	Direction and responses most affected	
	Front suspension	Rear suspension
Tierod inner	z (toe, camber), x (caster)	z (toe, camber, caster)
Tierod outer	z (toe, camber caster)	y (toe, camber, caster)
Lower control arm outer	z (toe, camber), x (caster)	x (caster), y (toe camber)
Lower control arm front	z (toe, camber, caster)	y (toe, camber), z (caster)
Lower control arm rear	z (toe, camber, caster)	y (toe, camber), z (caster)
Strut upper	y (toe, camber), x (caster)	y (toe), z (camber, caster)
Strut lower	y (toe, camber), x (caster)	x (caster), y (toe, camber)
Spring upper	x (toe), y (caster), z (camber)	x (toe, camber), z (caster)
Spring lower	y (toe, camber, caster)	x (toe, camber), z (caster)
Wheel center	y (toe, camber), x (caster)	y (toe, camber, caster)

Table 4 The summary of the Pareto chart for 15mm relative value of factor setting

Suspension geometry hard points	Direction and responses most affected	
	Front suspension	Rear suspension
Tierod inner	z (toe, camber), y (caster)	x (caster), z (toe, camber)
Tierod outer	z (toe), y (camber, caster)	z (toe, camber, caster)
Lower control arm outer	y (toe), z (camber), x (caster)	y (toe, camber, caster)
Lower control arm front	z (toe, camber, caster)	y (toe, camber, caster)
Lower control arm rear	y (toe), z (camber, caster)	y (caster), z (toe, camber)
Strut upper	y (toe, camber), z (caster)	y (toe), z (camber, caster)
Strut lower	y (toe, camber), x (caster)	y (toe, camber), z (caster)
Spring upper	y (toe, camber, caster)	y (toe), z (camber, caster)
Spring lower	y (toe, camber, caster)	x (toe, camber), z (caster)
Wheel center	y (toe, camber, caster)	x (camber), y (toe,) z (caster)

Table 5 The summary of the number of hard point that will be optimized

	Factor setting		
	5mm	10mm	15mm
Front suspension	16	17	17
Rear suspension	16	17	18



(a) (b)

(c) (d)

(e) (f)

Figure 3 The front and rear suspension system for vertical parallel wheel movement test comparison between verified simulation data and optimized setting (5 mm, 10 mm and 15 mm of relative value) using (a) MSC/ADAMS CAR for front toe change; (b) front camber change; (c) front caster change; (d) rear toe change (e) rear camber change (f) and rear caster change.

Table 6 The summary of the factors setting values in respect to minimum responses

	Factor setting		
	5mm	**10mm**	**15mm**
Front suspension	-	camber	Toe, caster
Rear suspension	-	toe	Caster, camber

4.0 CONCLUSION

The optimization of front and rear suspension systems of PROTON WRM 44 P0-34 had been done using Design of Experiment (DoE) method through MSC/ADAMS Insight software. It was found, new set of front and rear suspension systems hard point configuration using relative value of 10 mm and 15 mm as factor setting, achieved the objective targets which were to minimize the value of toe, camber and caster change when subjected to vertical parallel movement test. As a recommendation for future work, a relative value of factor setting should be increased considering allowable space on suspension system. Hence finally, only one value of factor setting are to be chosen to satisfy all objective targets.

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