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Development of an Optimization Framework for Suspension Parameters in Automotive Vehicles Using Genetic Algorithms

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Summary

Introduction

Numerical Model

- *Quarter Car Model and Equations of motion*
- *Step-Road Excitation*
- *Sinusoidal Excitation*

Optimization With Genetic Algorithms

- *Objective functions and Selection Process*
- *GA Operators and Parameters*

Results and Discussions

Conclusions

Introduction

Suspension Systems

- Importance
  - Enhance ride comfort and handling
- Optimization
  - Improves ride comfort and handling
- Background
  - Previous studies demonstrate the potential of GA's in handling non-linear optimization tasks [1].

Numerical Model

The quarter-car model, shown in Figure 1, simplifies the vehicle dynamics by representing the suspension as a single mass-spring-damper system.

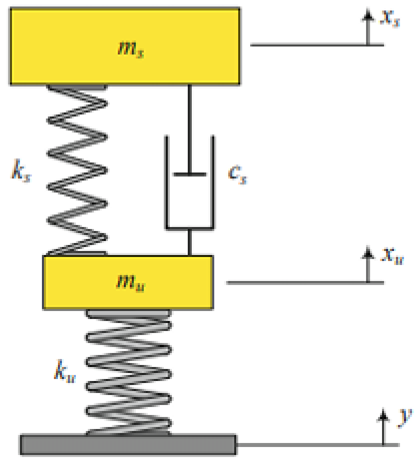

Fig. 1 Quarter car model [2]

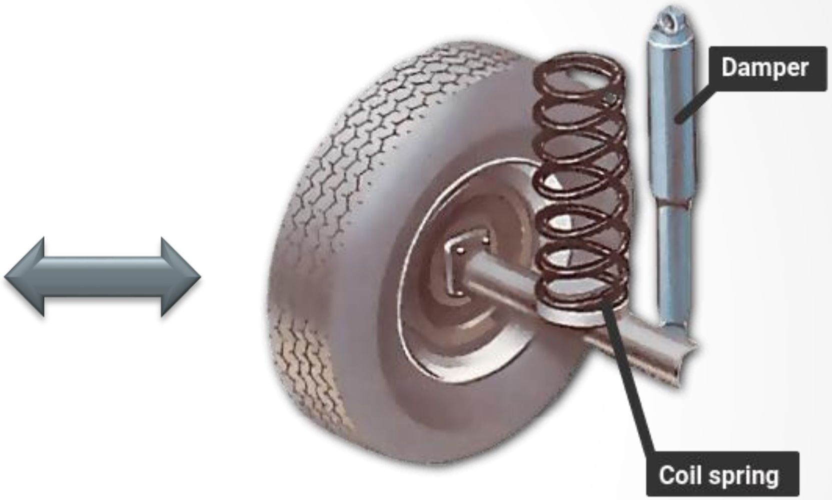

Fig. 2 Spring and damper [3]

Equations of motion as referenced by Jazar and Marzbani [2]:

$$m_s\ddot{x}_s = -k_s(x_s - x_u) - c_s(\dot{x}_s - \dot{x}_u) \quad (1)$$

$$m_u\ddot{x}_u = k_s(x_s - x_u) + c_s(\dot{x}_s - \dot{x}_u) - k_u(x_u - y) \quad (2)$$

Numerical Model – Properties and excitations

The properties of the quarter car model chosen are presented in Table 1, and refer to a real car, a Mercedes-Benz AMG SLC43, adapted to a quarter car model [4].

Table 1. Quarter car model properties

Propriedade	Simbologia	Valor
Sprung mass	m_s	395 kg
Unsprung mass	m_u	38 kg
Spring stiffness	k_s	29300 N/m
Damping coefficient	c_s	3000 Ns/m
Tire stiffness	k_t	290000 N/m

Excitations:

1. Step-road with a pulse of 0,05 m, Fig. 3.

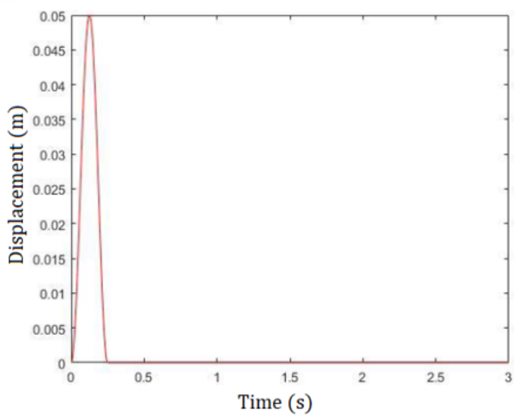

Fig. 3. Step-road profile from Simulink

2. Sinusoidal function with A=0,01 m and λ=5 m.

$$y = A * \sin\left(\frac{v_{car}/3{,}6}{\lambda} \cdot 2\pi \cdot t\right) \quad [m]$$

Note: The vehicle test speed used was 50 km/h

Optimization

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Optimization Problem

Objective Function #1

$$\min_{k_s, c_s} RMS(\ddot{x}_s)$$

$$s.t. \begin{cases} 10000 \text{ N/m} \leq k_s \leq 200000 \text{ N/m} \\ 500 \text{ Ns/m} \leq c_s \leq 10000 \text{ Ns/m} \end{cases}$$

Objective Function #2

$$\min_{k_s, c_s} RMS(x_s)$$

$$s.t. \begin{cases} 10000 \text{ N/m} \leq k_s \leq 200000 \text{ N/m} \\ 500 \text{ Ns/m} \leq c_s \leq 10000 \text{ Ns/m} \end{cases}$$

The genetic algorithm (GA) employed in this study includes a population of individuals, each representing a unique configuration of k_s and c_s .Through iterative generations, individuals are selected based on a fitness function, where the best performers are selected to reproduce and pass on their genes via crossover and mutation, leading to better solutions over time.

Genetic Algorithm – Operators and Parameters

Operators

Selection
Crossover
Mutation
Replacement Techniques

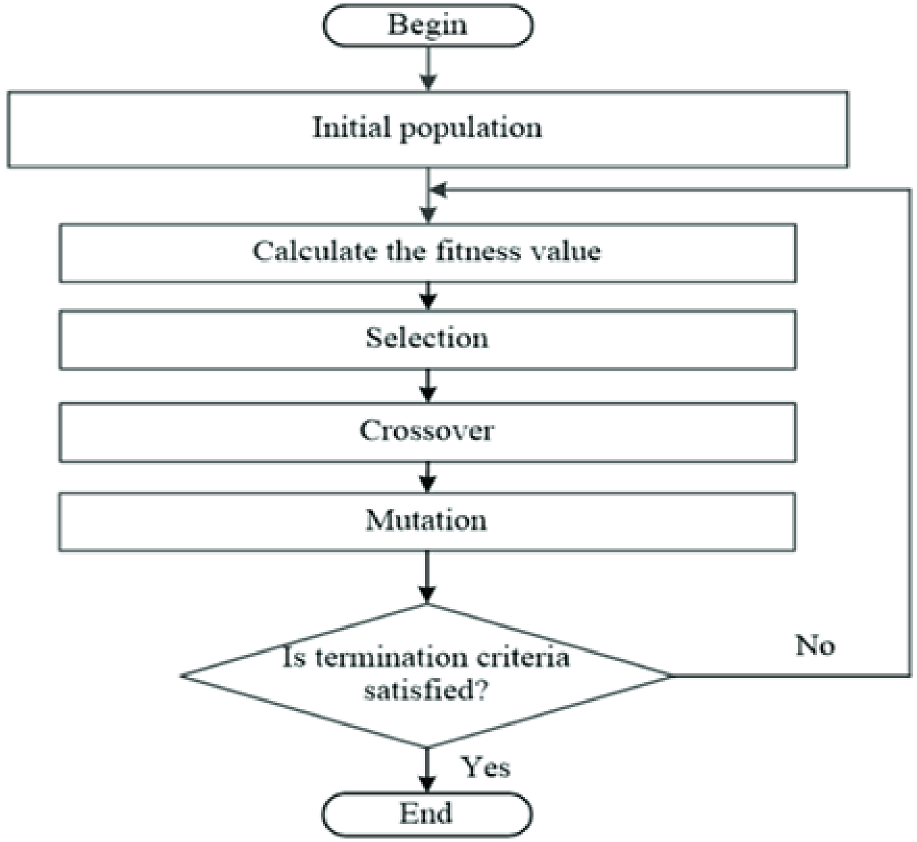
Parameters

Table 2. Genetic Algorithm Parameters

Property	Value
Population size	80
Crossover	70 %
Mutation	10 %
Máx number of generations	100
Tolerance	0,0001 $[m \text{ or } m/s^2]$

Genetic Algorithm

Flow chart of the Genetic Algorithm used in this study:



GA Flow chart [1]

Genetic Algorithm

A script was created in MATLAB®, which utilized the software's own native libraries "Global optimization Toolbox", to solve the problem with genetic algorithm. A Simulink model representative of the numerical problem was also created in Simulink, a tool inside MATLAB® software.

Section of the MATLAB® script regarding GA implementation

```
problem.solver  = 'ga()';
problem.fitnessfcn = @(x)V1_quarter_car_funcao([x(1) x(2)]);
problem.nvars = 2;
problem.lb=[10000,500];
problem.ub=[200000,10000];
problem.options = optimoptions('ga','PopulationSize',...
  popsz,'MaxGenerations',maxgen, 'FunctionTolerance',...
  tol, 'CrossoverFraction',xfrac, 'EliteCount',...
  mutfrac*popsz,'SelectionFcn',...
  ,{@selectiontournament,2},'PlotFcn',...
  {@gaplotbestf, @gaplotstopping});
```

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Results and discussions – Road Step

Table 3. Quarter car model optimization through step-road excitation

	OEM	$RMS\ (\ddot{x})$	$RMS\ (x)$
$RMS\ (\ddot{x})\ [m/s^2]$	1,1032	0,3728	-
$RMS\ (x)\ [m]$	0,00987	-	0,00762
$k_s\ [N/m]$	29300	10000	10194
$c_s\ [Ns/m]$	3000	516	2461
Improvement [%]	-	**66,21**	**22,79**

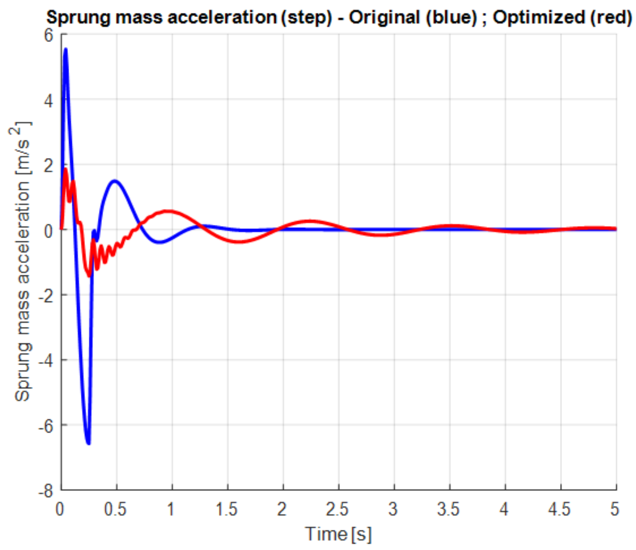

Fig. 4. Comparison of the acceleration OEM vs Optimized (step)

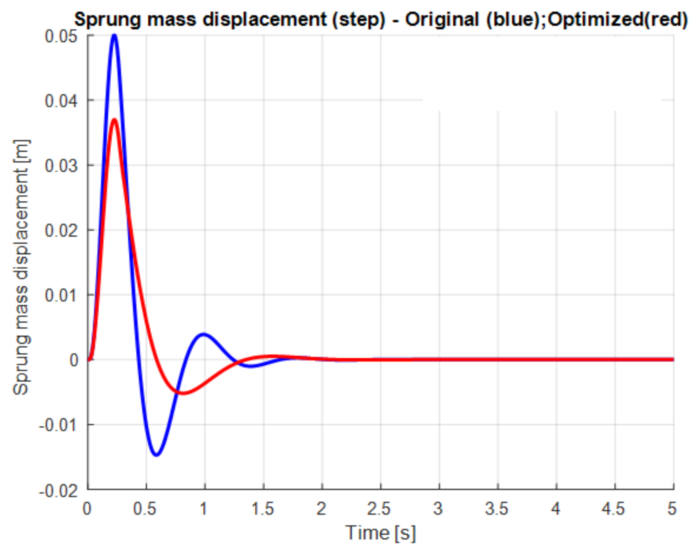

Fig. 5. Comparison of the displacement OEM vs Optimized (step)

Results and discussions – Road Step

Table 3. Acceleration optimization through Step-road excitation

	OEM	*Optimized*
$RMS\ (\ddot{x})\ [m/s^2]$	1,1032	0,3728
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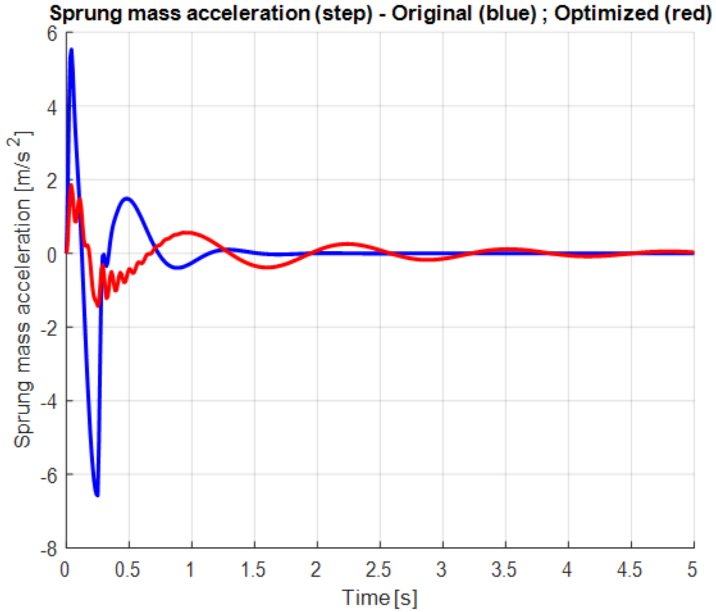

Fig. 4. Comparison of the acceleration OEM vs Optimized (step)

Results and discussions – Road Step

Table 4. Displacement optimization through Step-road excitation

	OEM	*Optimized*
$RMS\ (x)\ [m]$	0,00987	0,00762
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$\mathbf{c}_s\ [Ns/m]$	3000	2461
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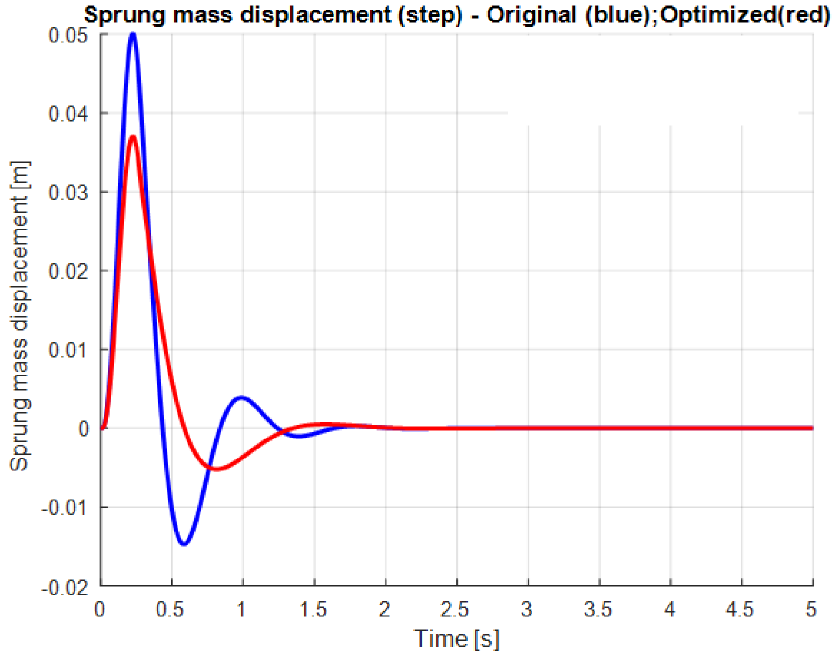

Fig. 5. Comparison of the displacement OEM vs Optimized (step)

Results and discussions - Sinusoidal

Table 4. Quarter car model optimization through sinusoidal excitation

	OEM	$RMS\ (\ddot{x})$	$RMS\ (x)$
$RMS\ (\ddot{x})\ [m/s^2]$	0,07294	0,06885	-
$RMS\ (x)\ [m]$	0,007808	-	0,007172
$k_s\ [N/m]$	29300	10000	199994
$c_s\ [Ns/m]$	3000	4836	8936
Improvement [%]	-	**5,61**	**8,14**

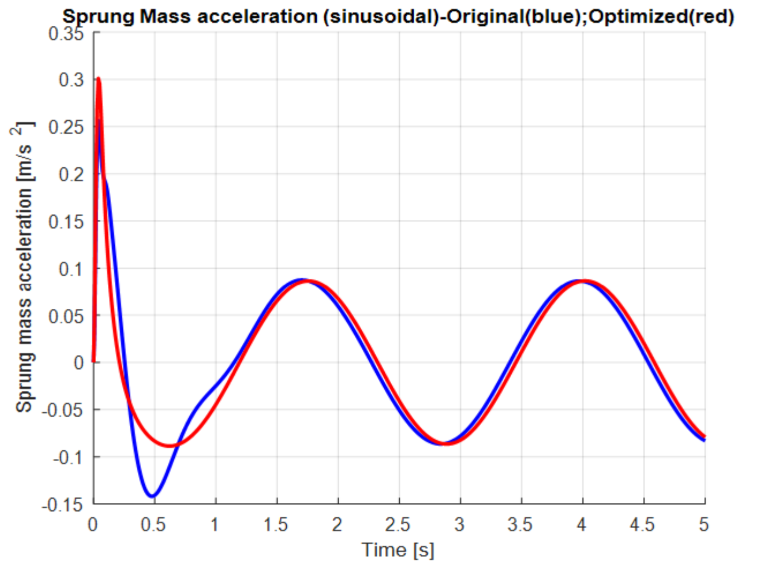

Fig. 6. Comparison of the acceleration OEM vs Optimized (sinusoidal)

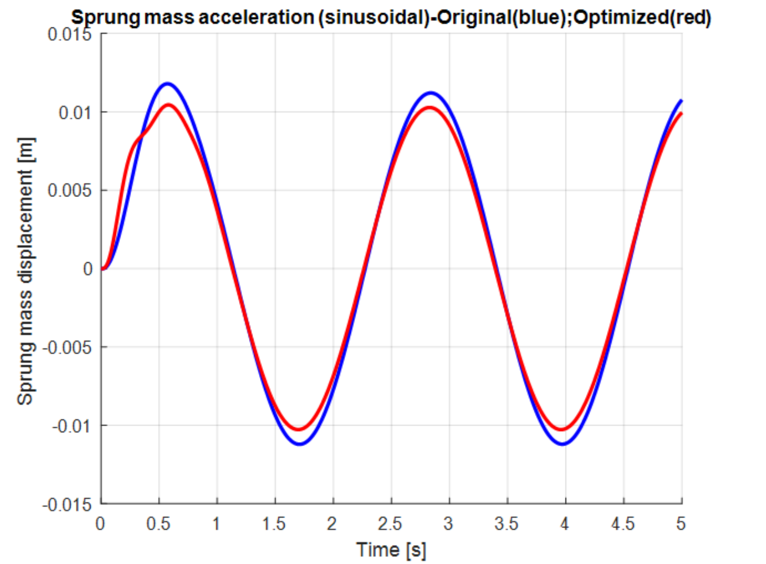

Fig. 7. Comparison of the displacement OEM vs Optimized (sinusoidal)

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Results and discussions - Sinusoidal

Table 5. Acceleration optimization through sinusoidal excitation

	OEM	*Optimized*
$RMS\ (\ddot{x})\ [m/s^2]$	0,07294	0,06885
$k_s\ [N/m]$	29300	10000
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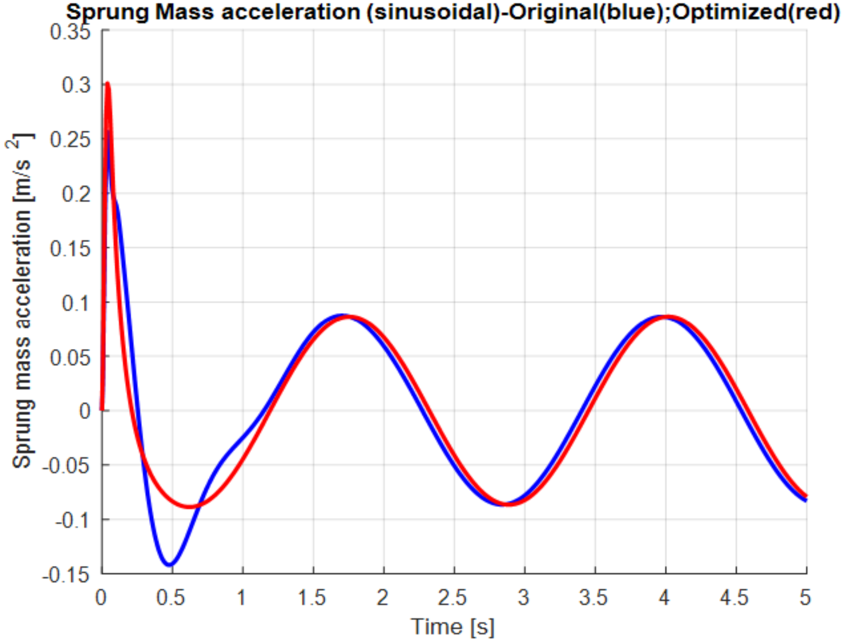

Fig. 6. Comparison of the acceleration OEM vs Optimized (sinusoidal)

Results and discussions - Sinusoidal

Table 6. Displacement optimization through Step-road excitation

	OEM	*Optimized*
$RMS\ (x)\ [m]$	0,007808	0,007172
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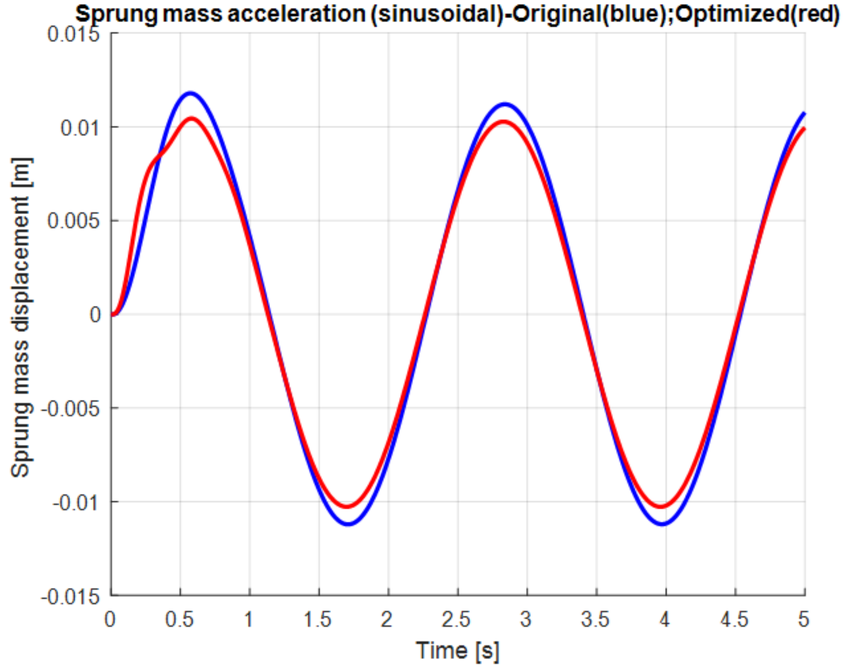

Fig. 7. Comparison of the displacement OEM vs Optimized (sinusoidal)

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Conclusions

A quarter car model representing a vehicle suspension system was successfully optimized with genetic algorithms. Significant improvements in the performance were presented in response to the proposed excitations.

For the step road excitation, the spring stiffness had more direct impact to minimize both RMS responses on acceleration and displacement. For the sinusoidal function excitation both parameters had impact on the optimization. Although the spring stiffness had a greater variation in the optimized models in relation to the original characteristics, the increase of damping coefficient also impacted the optimization of the system.

It is important to keep in mind that, although the parameter values in the optimized systems can coincide with the constraint values and better solutions could exist, some mechanical elements for suspension systems with that characteristics might not exist in real life.

Future work will focus on the development of more complex models and consider multi-objective optimization of the system. Analysis of other types of excitations, such as optimizing suspension parameters in the context of motorsport can be possible as well.

References

[1] M. A. Albadr, S. Tiun, M. Ayob, and F. Al-Dhief, “Genetic algorithm based on natural selection theory for optimization problems,” Symmetry (Basel), vol. 12, no. 11, pp. 1–31, Nov. 2020, doi: 10.3390/sym12111758.

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[3] How car springs and dampers work | How a Car Works. (n.d.). Retrieved November 10, 2024, from https://www.howacarworks.com/basics/how-car-springs-and-dampers-work

[4] S. Ebrahimi-Nejad, M. Kheybari, and S. V. N. Borujerd, “Multi-objective optimization of a sports car suspension system using simplified quarter-car models,” Mechanics and Industry, vol. 21, no. 4, 2020, doi: 10.1051/meca/2020039.

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Thank You!