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Research Article

INVESTIGATION THE MODELING OF GENETIC ALGORITHM BASED VEHICLE POWERTRAIN SYSTEM OPTIMIZATION

Mehmet Onur GENÇ*[1], Alper KARADUMAN[2]

[1]*Valeo Automotive Systems, BURSA;* ORCID: 0000-0003-0332-1785
[2]*Valeo Automotive Systems, BURSA;* ORCID: 0000-0001-6723-5136

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ABSTRACT

Vehicle powertrain system has many key parameters to obtain optimum system dynamics under real vehicle condition. In parallel to new technological developments, driving comfort is investigated with the new methodologies to provide passenger satisfaction. The clutch system is of the importance for vehicle powertrain system with torque transmission controlling and vibration damping properties. A vehicle clutch system is subjected to high dynamic loads and vibrations under operational conditions that need further system analysis. Optimization algorithms are the cost and time effective methodologies during system analysis prior to real production phases. In this study, the medium segment vehicle powertrain system is analyzed with the genetic algorithm methodology integrated with 1-D modeling. The powertrain system was modeled with 1-D set-up, then the genetic algorithm was run with multiple loops to provide optimum vibration level with the clutch damper spring stiffness and clutch disc inertia. In conclusion, the results give an assumption of using the genetic algorithm in the 1-D vehicle system modeling. Inertia and stiffness parameters are the key factor in using vibration analysis for system dynamics. In the study, optimum analysis outputs of clutch damper inertia and stiffness values have illustrated the effects and feasibility of the genetic algorithm integrated 1-D modeling with the eliminating of many real vehicle road testing.
Keywords: Clutch damper system, powertrain system, system optimization, genetic algorithm, 1-D modeling, vibration analysis.

1. INTRODUCTION

Powertrain system is one of the most important structures of the vehicle with comfort, endurance and performance tasks. The clutch damper system in the powertrain system has high importance in automobiles and provides torque transmission. Under driving conditions between engine and transmission relative motions occur between engine and transmission due to dynamic variables. Torque transmission T(t) [Nm] is proportional to clamp load F [N], friction coefficient μ, the number of friction faces N and mean radius Rm (Eq. 1).

$$T = F * \mu * N * Rm \quad (1)$$

[*] Corresponding Author: e-mail: mehmetonurgenc@gmail.com, tel: (507) 432 67 16

Vibration damp is provided with the clutch damper disc in the conventional clutch system. Helical metallic springs and hy steresis components are the key components of the clutch damper disc (Fig. 1).

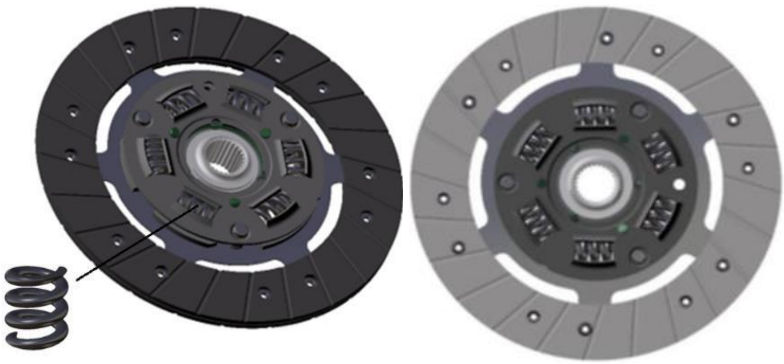

Figure 1. Modeled clutch damper disc in the study

Figure 2 shows the image of vibrations generated in the engine and its flow throughout the powertrain system. As shown, a clutch system has the task to damp the vibrations to preserve any possible damages on the mechanic components and provide the desired driving comfort level. The vibrations generated in the engine were transmitted mainly through the clutch, gearbox, propeller shaft, wheels. Therefore, the vibration damping efficiency of the clutch damper system can be tested by taking a measurement from the gearbox. The measured value on the gearbox should be lower than the engine through the clutch damping system.

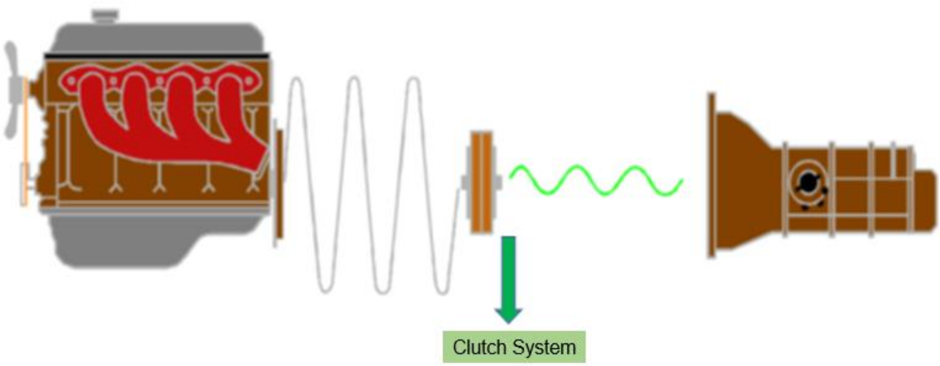

Figure 2. Clutch system in a vehicle powertrain structure

In the literature, some studies have been conducted related to the vibration and optimization for vehicle systems. Verdonck et al. [1] investigated hybrid vehicle powertrain systems by using 1-D modeling. They used Forward Dynamic Model (FDM) and defined some contrasts for the power system parameters. Genc and Kaya [2] have investigated the clutch damper stiffness effect on truck driving comfort by using AMESim 1-D modeling software. In the study, simulation and real test results have been compared and correlated. Genc et al. [3] studied the modal analysis for truck powertrain systems and determined related parameters that have the most effective and contribute to modal shape of the system. Macor et al. [4] have investigated hydro-mechanical hybrid powertrain system by using 1-D modeling with AMESi m software. In their study, hybrid and traditional mechanical systems have been compared in terms of energy savings. Hwang et al. [5] investigated the modeling of powertrain system including automated transmission by making torsional mode analysis. Smith [6] investigated the natural frequency of vehicle components and made assumptions on optimal weight values. Sofian et al. [7] examined the frequency of the gearbox vibrations on different gearbox types. Brandt et al. [8] studied an engine vibration at the frequency level by FFT method.

Optimization algorithms are of high importance in system design for vehicle engineering. Afifi et al. [9] examined the SA algorithm for the optimizing of machine tool movement during production cycles. Leng et al. [10] investigated the constrained and unconstrained shape optimization of cold-formed steel columns. Xin et. al. [11] investigated the using of genetic algorithm optimization in using the autonomous vehicle driving system. In this study, the navigation and communication system in the vehicles has been investigated using genetic algırithm coding.

This study provides a novel methodology for system optimization for the vehicle system. The powertrain system is composed of the different parts which have specific inertia, stiffness, mod level, etc. In this study, the system optimization is aimed by using a clutch damper design change at the optimum level. The system vibration is measured with the real vehicle test with the many variations and the instrumentations. So, numerous trials result in high cost and time-consuming. In order to overcome this issue, the new methodology was investigated and tried. The genetic algorithm is investigated and integrate into the 1-D model in AMESim to obtain optimum vibration values for driving comfort and mechanical endurance. Results indicate the cost and time-saving in the engineering design phase, and give assumptions for vehicle system engineering.

2. POWERTRAIN SYSTEM 1-D MODELING

1-D modeling is simulating the systems that consist of real physical components using a representative approach. Each block on the model corresponds to physical elements, for example gearbox, engine, mass, springs, etc. These blocks are joined by lines corresponding to the physical connections. With this approach the physical behavior of system is simulated, then the possible behavior of the system is assumed to predict real driving conditions (Figure 3).

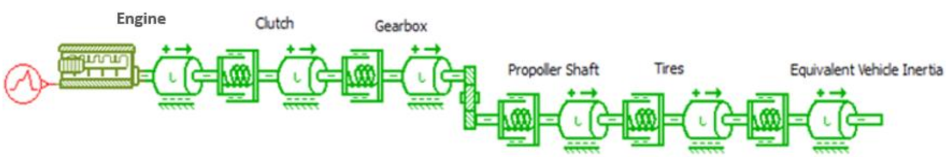

Figure 3. 1-D model of the powertrain system for target vehicle model

In this study, to provide system dynamic behavior, the Gearbox model was investigated to see the effects of the clutch system parameter effects. Gearbox model consists of the mass and spring system with the real data from the modeled vehicle. Generated torque in the engine creates oscillations that need to be damped to provide mechanical endurance and driving comfort. Therefore, the clutch system is well designed to have sufficient damping prior to Gearbox in the vehicle. Measured vibration on the Gearbox model is the optimum way to evaluate clutch system damping ability in the vehicle.

Measured vibration values are read on the Gearbox model which shows the maximum amplitude (Figure 4). Gearbox structure has an effective vibration range in real using condition, then the lower and higher vibration levels on the transmission create the uncomfortable using in addition to the possibility of mechanical damages. In real vehicle testing, the measurement was taken the sensors which have measured the relative motions within the time. The sensors were fitted to the engine and the gearbox, then the vibration ability of the clutch damper is measured after the post-processing via the related measurement software. In this study, the torsional vibration is taken from the 1-D model run. The clutch system and the other parts of the model were defined by the torsional parameters, then the system output will be the torsional base. The torsional vibration measurement technique is the base of the clutch damping efficiency. The damper springs, in the clutch disc, works in torsional operation condition, therefore the torsional vibration test was done to validate the clutch damper system.

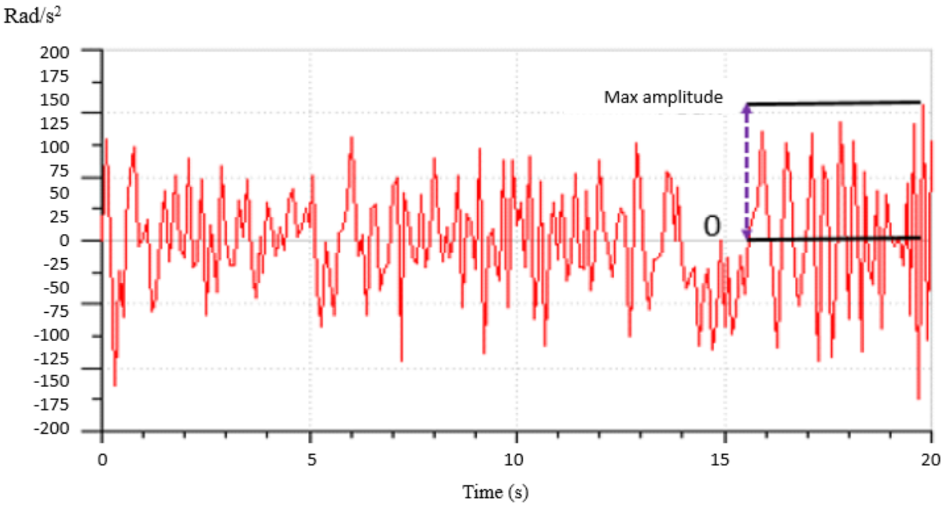

Figure 4. Vibration values measured on the Gearbox model

Table 1 is the real values of the modeled vehicle using in the 1-D model. In the clutch model, the inertia and stiffness parameters are selected with a useful range. This range is determined with the real design ability from the design team with respect to necessary geometries and envelopes. Clutch damper stiffness is accepted between the 9.5 and 10.5 Nm / °, in parallel the inertia of the clutch damper disc is accepted between the 0.0060 – 0.0085 Kg.m^2. Inertia and stiffness are aimed to be selected at the optimum level to provide an optimized vibration level measured on the Gearbox model.

Table 1. Assigned values for the 1-D modeling in the powertrain system

Powertrain system sub-group	Stiffness (Nm / °)	Inertia (Kg.m^2)
Engine	-	1
Clutch	9.5 – 10.5	0.0060 – 0.0085
Gearbox	2800	0.6
Propoller Shaft	2200	0.8
Equivalent Vehicle	-	38

3. SYSTEM OPTIMIZATION

In this study, the genetic algorithm is used for system optimization. This study investigates the optimization algorithm integration to the vehicle system. For this reason, the genetic algorithm was selected because of the high success ratio of the evolutionary algorithms in this kind of high iterative runs. The genetic algorithm (GA) is a global optimization method for solving optimization problems and is based on natural selection represented with biological evolution. The genetic algorithm modifies a population of individual solutions at each step and produces the children for the next generation. It is selected because it is not trapped in a local optimum. This algorithm is available in AMESim software for optimization. As design parameters, the variables which have major effect on the system outputs such as vibration are defined with constraints. The main flow of the genetic algorithm is shown in Table 2. This flow in the genetic algorithm provides the loop between the 1-D model and the algorithm in order to best solution can be found. The best solution is expressed with the vibration level with the constraints clutch disc inertia and the damper stiffness which have high importance in vibration dampening in the dynamic systems. Table 3 is the selected factors in the algorithm. Each parameter has high importance on the solutions, however the indicated factors in Table 3 gave the best solution with the optimum duration.

Table 2. The main principle of the Genetic algorithm (GA)

input a set of chromosomes
Generate the initial population
Initialize the crossover and mutation probabilities
Y: Evaluate the fitness function of each individual
Selection of the current best for the next generation
Reproduction by crossover and mutation
Z: Update t = t + 1
Repeat (Y) → (Z) if t < Max number of generations or Stopping criteria is met
Display the best solution → X

Table 3. Selected parameters in analysis in the simulation

Population size	100
Reproduction Ratio (%)	85
Max.Number of Generation	20
Mutation Probability (%)	12
Mutation Amplitude	0.2
Seed	1

Figure 5 shows the general flow of the 1-D model integrated with the GA. The model is the main part of the flow because the input parameters are managed from the 1-D model. AMESim software presents the ability to genetic algorithm database and the aimed vibration level can be selected as an objective function from the system. This system provides multiple runs with the integration of the GA and 1-D model. In case the aimed vibration level is obtained, the constrained parameters are indicated as best solutions, otherwise the loops are re-performed till the best solution is acquired.

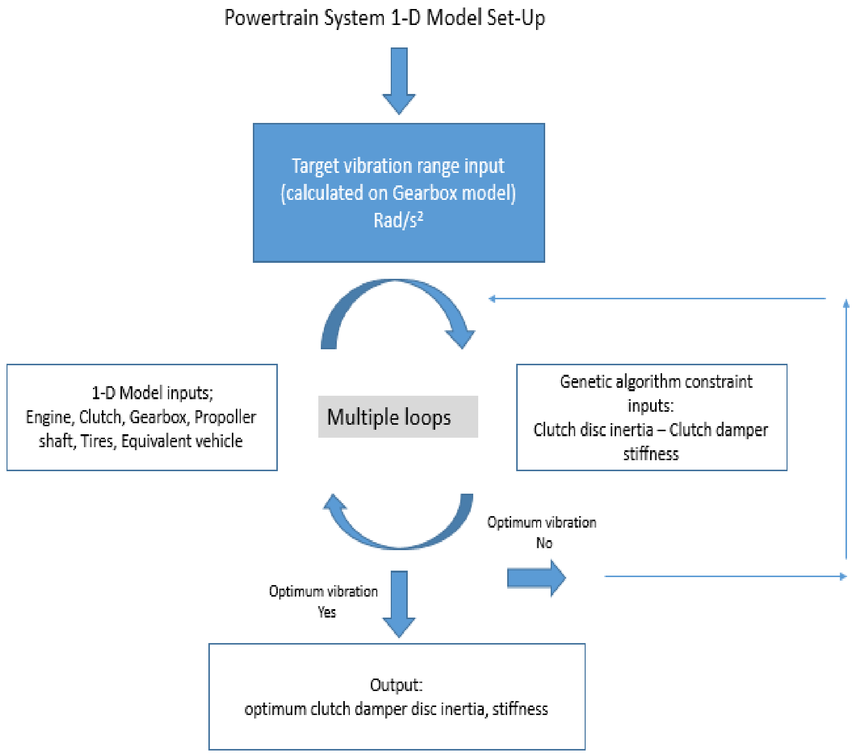

Figure 5. Genetic algorithm integrated 1-D modeling running methodology

The flowchart of the genetic algorithm integrated 1-D modeling is given in Figure 6. In the genetic algorithm, evolution from random individuals begins and evolves in the next generation. Every generation of various individuals is selected from the current population to create a new population. By doing so, the best solutions will be figured out and the process is completed. In Figure 6, the initial population is started to meet the criteria which represent the objective function. In case the objective function is obtained, the algorithm will stop and the best solution is found. Conversely, in case the results are not met the target range, the process tries to repeat the loop. In this study, the objective function is selected as vibration range, the constraints are selected as the clutch disc inertia and clutch damper disc.

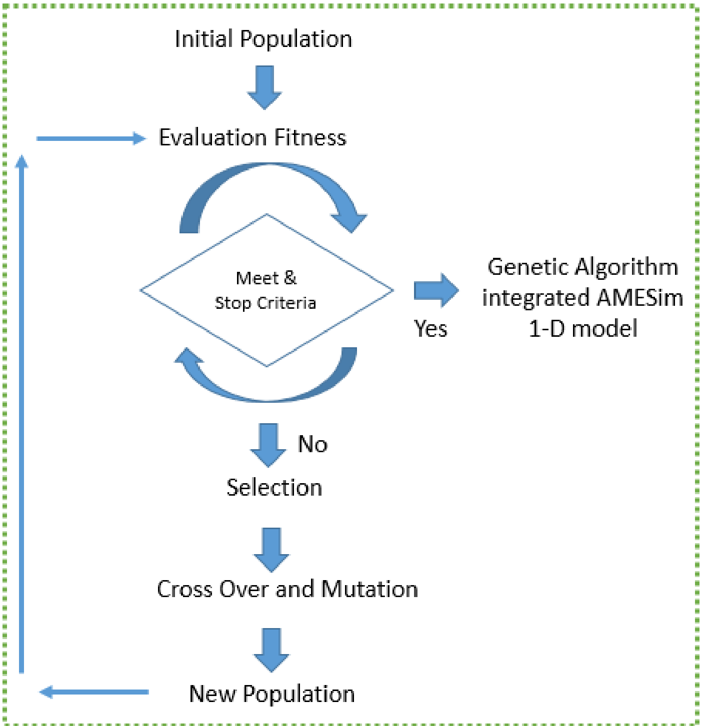

Figure 6. Genetic algorithm flow in 1-D modeling

4. ANALYSIS AND DISCUSSIONS

In this section, the analyzed simulation results are observed and the results are discussed. In order to achieve this target, the objective function, and the constraints are defined. GA integrated 1-D modeling was run in AMESim software. The objective function and the constraints are shown in Equation 2;

Objective function: ± 175 Rad/s^2 (Desired level of vibration measured on the Gearbox model) (2)
Constraint 1: 0.0060 – 0.0085 Kg.m^2 (Clutch disc inertia constraints)
Constraint 2: 9.5 – 10.5 Nm / ° (Clutch damper disc stiffness constraints)

Figure 7 is the objective function iteration graph. Totally, 1600 steps were conducted and the best vibration value was found simultaneously with the constraints inertia and stiffness. The best amplitude is found as 56 Rad/s^2 at the end of the iterations in parallel to optimum constraints.

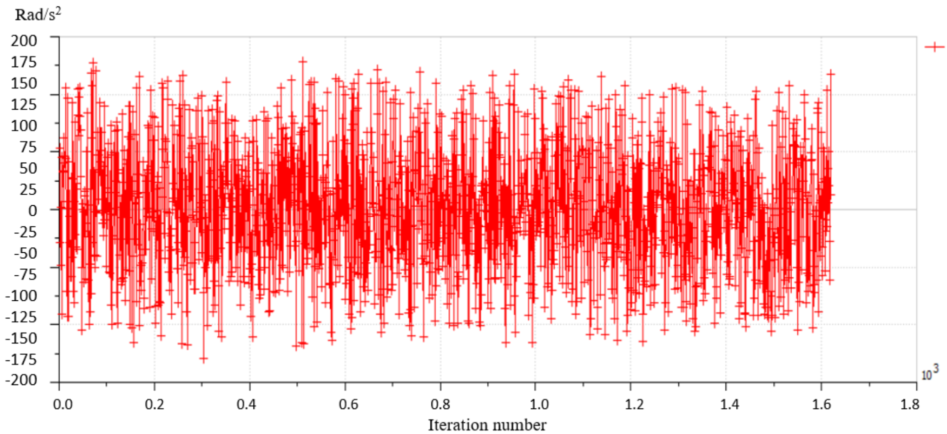

Figure 7. Iteration phases for the vibration on the Gearbox model (Objective function)

Figure 8 is the results graph of the first constraint which is clutch disc inertia with the range of 0.0060 – 0.0085 Kg.m^2. The model provides the stabilization and found the best solution after the 1600 iteration which was resulted near the 0.00678 Kg.m^2 inertia value as the best solution.

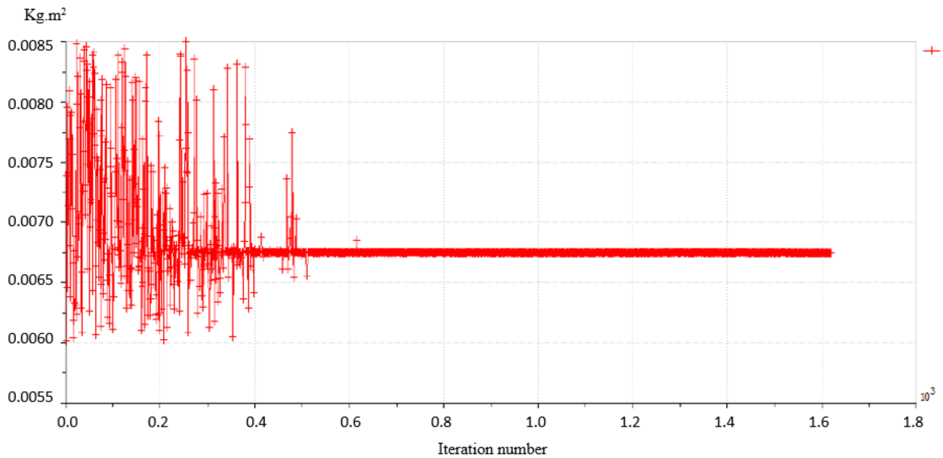

Figure 8. Iteration phases for the clutch disc inertia (Constraint-1)

Figure 9 shows the optimization process for the clutch disc damper stiffness. The selected stiffness range (9.5 – 10.5 Nm / °) had been defined with respect to the design envelope and production capacity (Figure 10). Figure 10 is the damper torque graph of the minimum, maximum and the nominal stiffness values in order; 9.5 Nm/° - 10 Nm/° - 10.5 Nm / °. Also, this graph means that in case this stiffness range values are selected, the clutch damper withstands the generated torque 150 Nm to 170 Nm. As shown in Figure 10, the best stiffness result (Constraint-2) is found as 9.8 Nm/° after the 1600 iteration. In parallel to constraint 1, simultaneously the objective function is searched within the loop between the genetic algorithm and the 1-D modeling. Figure 11 is the damper torque graph of the optimized stiffness value of 9.8 Nm / °.

This damper characteristic shows the best damping parameter for stiffness in powertrain system dynamics in the clutch damper component.

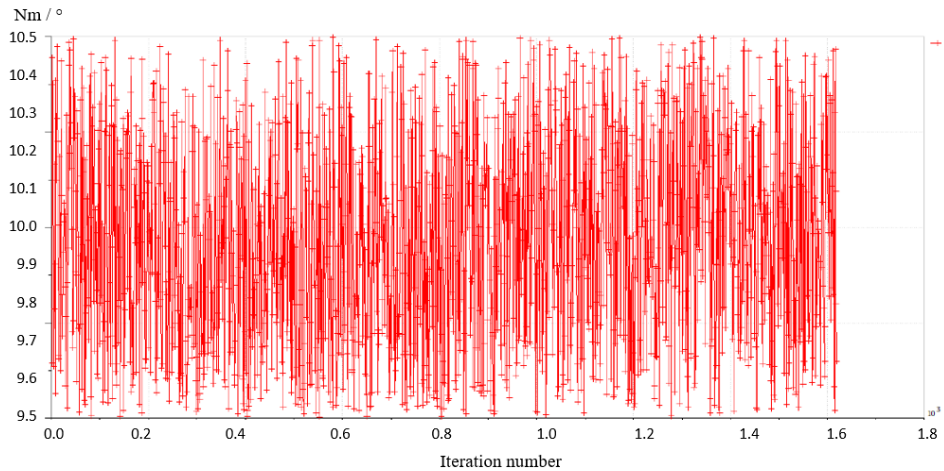

Figure 9. Iteration phases for the clutch damper stiffness (Constraint-2)

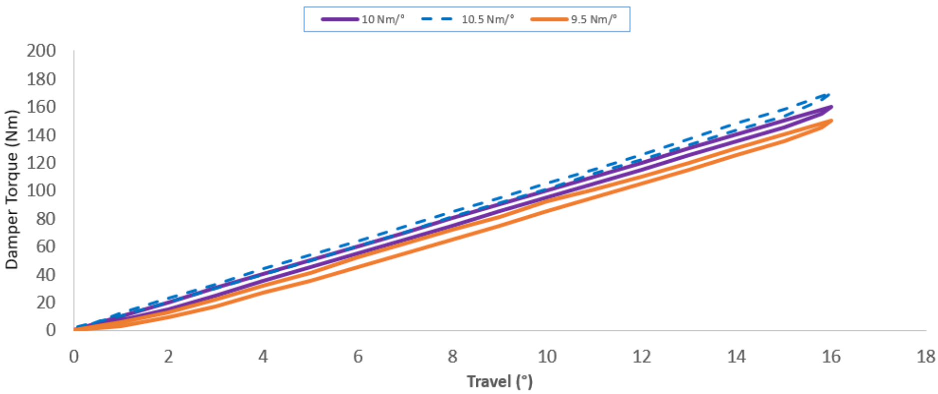

Figure 10. Clutch damper torque graphs for the stiffness constraints

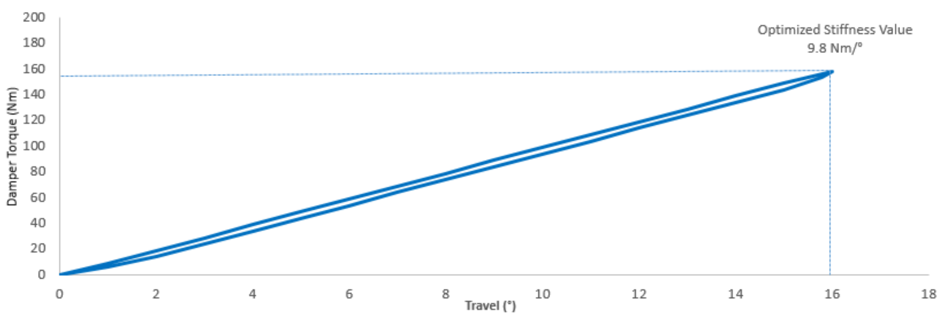

Figure 11. Clutch damper torque graph having optimized stiffness

Table 4 explains the optimum parameters which were found after the algorithm run. According to obtained results, the GA can be approached to optimum solutions in 1-D modeling and provides system optimization. Results show that the obtained values create a prominent vibration reduction on the gearbox, then the driving comfort is expected to increase by system optimization. This methodology prevents overdesign studies and accelerates the system engineering phase in the desired accuracy. The production tolerances for the clutch system inertia and the stiffness have to be within the range, therefore the sensitive production limits are needed to realize this methodology in real production conditions.

Table 4. Optimized values vs. Initial design parameters

Inertia Kg.m^2	0.0060 – 0.0085 Kg.m^2	0.00678 Kg.m^2
Stiffness Nm / °	9.5 – 10.5 Nm / °	9.8 Nm / °
Optimum vibration value Rad.s^2	± 175 Rad/s^2	56 Rad/s^2

5. CONCLUSIONS

The clutch system is of the importance for driving comfort and mechanical endurance in case the desired level of vibration is damped. In this study, GA optimization usage and integration to vehicle system engineering is observed with the real vehicle input data. The powertrain system of medium level passenger vehicles was investigated with the genetic algorithm integrated 1-D modeling in terms of vibration optimization. Firstly, related 1-D modeling was set in AMESim software, then the genetic algorithm database was integrated into multiple runs with the related constraints of the key parameters in order clutch disc inertia and clutch damper stiffness. According to results, the genetic algorithm has success to approach to optimum vibration level with the use of selected parameters. The results of the study give an idea to reduce the vibration damping within the powertrain system by using the genetic algorithm integrated methodology. The results of the analysis show that the optimization of the clutch system inertia and the damper stiffness level reduces the measured peak vibration level dramatically. The reduction in the gearbox is expected up to the %47 level by this methodology. This paper presents the novel methodology in using the vibration dampening optimization for powertrain system dynamics by using the GA.

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