International Journal of the Physical Sciences Vol. 6(4), pp. 768-776, 18 February, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS10.656
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

A novel design of lower vehicle arm based on optimization technique

Wafaa Mahdi Salih

Centre of Training and Workshops, University of Technology, Baghdad, Iraq. E-mail: drwafaa_ir@yahoo.com.

Accepted 19 January, 2011

In the automotive industry, the riding comfort and handling qualities of an automobile are greatly affected by the suspension system. The scenario of this paper presents the Robust Design of suspension arm using a technique Stochastic Design Improvement (SDI) based on Monte Carlo Simulation (MCS) then also to identify the critical location and to find optimum result and suitable materials for the suspension arm. The structural model of the suspension arm was utilizing the Solid works and aluminum alloys (AA7075-T6) as the selected suspension arm materials. The finite element model and analysis were performed utilizing the finite element analysis code. The TET10 mesh and maximum principal stress were considered in the linear static stress analysis, and the critical location was considered at node (96080). SDI has been performed to the design. A target output behavior is selected from the output variables available in the analysis. The result shows that the lower arm design has a higher capability to stand a higher pressure as 9.18 MPa with the stress acted on the lower arm is 41 MPa.

Key words: Robust design, SDI, aluminum alloy, lower arm.

INTRODUCTION

The suspension system is one of the most important parts of the vehicle; it should provide ride comfort to the driver by isolating irregular vibrations from the road surface effectively and must secure the maneuverability. The finite element method (FEM) has become an indispensable engineering tool in design processes of comments for automotive industry. Designing a robust suspension lower arm is crucial to the success of building the car and requires that suspension components have to be well engineered in aspects of both compactness and crashworthiness, which is defined as a measure of the whole vehicles or its components structural ability to plastically deform and yet maintain a sufficient survival space for its occupants in crashes involving reasonable deceleration loads (Seo et al., 2007). Conle and Mousseau (1991) used vehicle simulation and the finite element results to generate the fatigue life contours for the chassis components using automotive proving ground load history results combined with the computational techniques; They concluded that the combination of the vehicle dynamics modeling, finite-element analysis, and fatigue analysis are the viable techniques for the fatigue design of the automotive components. Kim et al. (2002) studied a method for simulating vehicles dynamic loads, but they add durability assessment, for their multibody dynamic analysis they use DADS and a flexible body model. Dynamic stress analysis was performed using MSC. NASTRAN. Bharatendra et al. (2004) has studied robust design of an interior hard trim to improve occupant safety in a vehicle crash, they used orthogonal arrays and compound noise factors to cut down on the number of experimental runs originally needed to address all the control and noise factors of interest and to achieve a robust interior hard trim design. The study used separate analyses to identify control factors affecting mean and variability. From a technical standpoint, the Statistical process control (SPC) and Statistical experimental design (SED) are two methods which has been used as a robust design of an automotive suspension arm to improve quality and productivity (Sreeram, 1994).

In automotive industry, aluminum (Al) alloy has limited usage due to their higher cost and less developed manufacturing process compared to steels. However, Al alloy has the advantage of lower weight, therefore, has

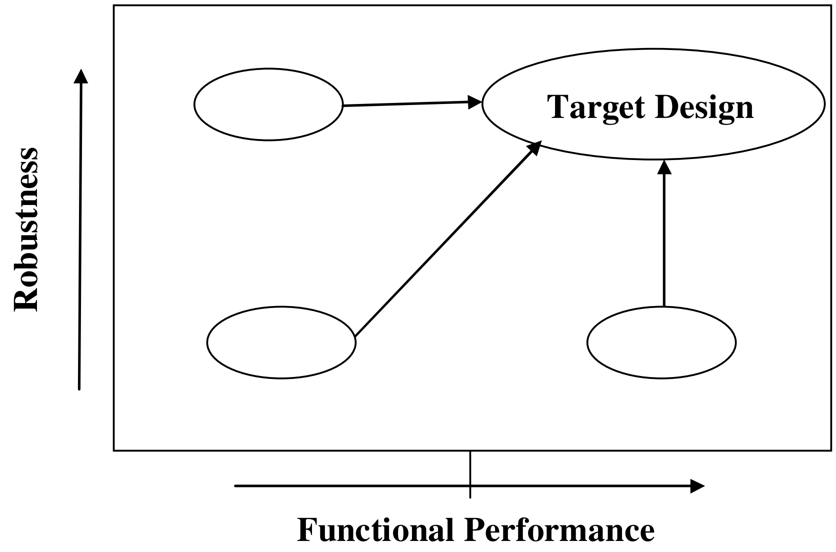


Figure 1. Robust optimization.

been used increasingly in car industry for the last 30 years, mainly as engine block, engine parts, brake components, steering components and suspension arms with significant weight can be achieved (Rahman et al., 2009). From a technical standpoint (Sreeram, 1994) the Statistical Process Control (SPC) and Statistical Experimental Design (SED) are two methods which has been used as a robust design of an automotive suspension arm to improve quality and productivity.

In this paper, MSC.NASTRAN finite element techniques have been used as a tool to model the mechanical properties of the suspension arm. Three-dimensional linear tetrahedron solid elements (TET10) used for the initial analysis based on the loading conditions. Convergence of stress energy was considered as the criteria to select the mesh size; SDI has been performed to the design using MSC. Robust Design. A target output behavior is selected from the output variables available in the FEM. In the optimization process for the design all the parameters have been set as a hardtarget for stress and design variable for material.

ROBUST DESIGN

The robust design technique is very important in creating or developing a better product for the automotive industry such as a lower suspension arm. Rakesh et al. (2002) was using robust design method for developing and minimizing variability of products and processes in order to improve their quality and reliability for the spindle motor. The method of robust design is used to make sure that a light weight, low cost and better safety component can be made at the final, gives us a better performance and market value in the automotive industry.

The used substructure was made in Aluminum, but the adopted technique can be applied also to cases where lightweight materials are used and where the effects of the scatter of manufacturing parameters can be still more relevant. Figure 1 is the goal of Robust Design to evaluate and find suitable design of any modal. RD is a tool for conducting stochastic analysis, that is, to evaluate and understand the behaviour of systems in the presence of uncertainty.

This work deals with linear response investigation carried out in the study of the linear behaviour of Lower arm located in the suspension part of a vehicle and which makes use of a new stochastic methodology, Stochastic Design Improvement (SDI), as implemented in the commercial code MSC. Robust design, which can be coupled with specialized FEM codes as MSC. Nastran for the deterministic structural part of the process.

OPTIMIZATION TECHNIQUE

Optimization problems in practice depend mostly on several model parameters, noise factors, uncontrollable parameters, etc., which are not given fixed quantities at the planning stage. Due to several types of stochastic uncertainties (physical uncertainty, economic uncertainty, statistical uncertainty, and model uncertainty) these parameters are modeled by random variables having a certain probability distribution. In most cases at least certain moments of this distribution are known. Robust Design provides the means to quickly sort through this information and indicate the variables that have the most significant correlations, and therefore, most impact the product's performance. Correlation is a concept different from that of sensitivity in that collective changes in variable values are considered. Correlation between two variables expresses the strength of the relationship between these variables by taking into account the scatter in all the other variables in a system. It is possible to compute correlations between any pair of variables (input-output, output-output, etc.). Knowledge of the correlations in a system is equivalent to the understanding of how that system works. The above correlations are used in Robust Design for results interpretation and are labeled as linear and non-linear correlations on output plots. Pearson's correlation coefficient measures the linear correlation between variables. For two stochastic variables, x and y, their Pearson, or linear correlation is expressed as follows.

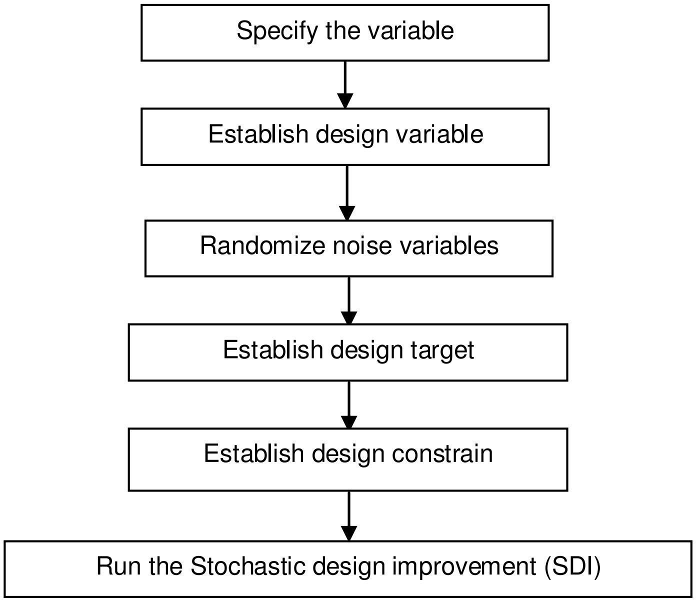


Figure 2. Flow chart of steps in SDI.

$$r = \frac{\sum_i (x_i - u_x)(y_i - u_y)}{\sqrt{\sum_i (x_i - u_x)^2}\sqrt{\sum_i (y_i - u_y)^2}} \tag{1}$$

Where u is the mean value, the values of the Pearson correlation range from –1 to 1. A value close to either 1 or –1 indicates a strong linear correlation. Values close to zero indicate the variables are uncorrelated.

The Spearman rank correlation coefficient rs, is then computed as the linear correlation coefficient between the ranks Ri of the xis and the ranks Si of the yis, the rs is expressed as follows.

$$r_s = \frac{\sum_i (R_i - u_r)(S_i - u_s)}{\sqrt{\sum_i (R_i - u_R)^2}\sqrt{\sum_i (S_i - u_S)^2}} \tag{2}$$

For the design of the lower arm suspension, the application of Stochastic Design Improvement (SDI) will be use, which is in the MSC.Robust Design software. SDI is a fast and efficient capability to improve a system design so that its most probable behavior coincides with specified target values.

This process continues until either the target value or a physical limit for the design variable is reached. This is normally accomplished with 4 to 6 sets of 15 analysis runs. The key feature of SDI is that it operates on a full FE model, which incorporates tolerances, and not on a simplified surrogate. SDI surpasses classical optimization techniques in terms of performance and computational cost. Figure 2 shows the flows of steps that will be done in the SDI for the lower arm suspension design.

MODEL DESCRIPTION

Vehicle suspension is a mechanism locating between the sprung mass (vehicle body) and the unsprung masses (wheels) of the vehicle. The suspension provides forces between these two masses of the vehicle according to certain state variables of the vehicle. A good car suspension system should have a satisfactoryroad holding ability, while still providing comfort when riding over bumps and holes in the road. When the bus is experiencing any road disturbance the bus body should not have large oscillations, and the oscillations should dissipate quickly. A simple three-dimensional model of suspension arm was modelled by using Solid Works software as shown in Figure 3.

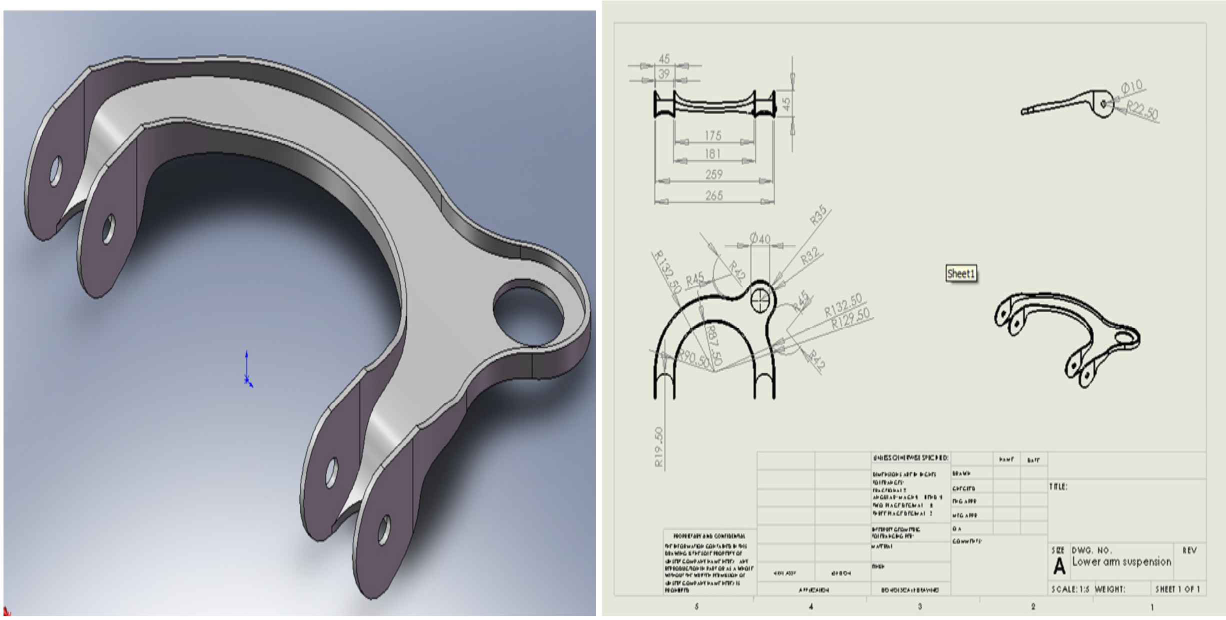
MECHANICAL PROPERTIES

Material model and material properties play an important role in the result of FE method. The material properties are one of the major inputs, which is the definition of how the material behaves under the cyclic loading conditions. The materials parameters required to depend on the analysis methodology being used. The mechanical properties of 7075-T6 aluminum alloy are shown in Table 1.

RESULTS AND DISCUSSION

Modeling and simulation

The lower arm suspension is one of the important parts in the suspension system. A specific area of constraint has been set into the design in order to get a precise result. TET10 has been used in the finite element modeling using MSC. PATRAN. These analyses were preformed iterative at different mesh global length until the appropriate accuracy was obtained. The convergence of the stresses was studied as the mesh global length was refined in the analysis. The mesh global length of 0.1-1.5 mm was chosen and the pressure of 8 MPa was applied at the end of the bushing that connected to the tire. The other two bushing that connected to the body of the car are a constraint. The pressure that has been applied is based on Al-Asady et al. (2008). The three-dimensional FE model, loading and constraints of suspension arm are shown in Figure 4.



(a) Structural model

(b) Overall dimension

Figure 3. Structural mode.

Table 1. Mechanical properties of aluminum alloy 7079-T6.

Material	Young's modulus (GPa)	Poisson's ratio	Tensile strength (MPa)	Yield strength (MPa)
Aluminum alloy AA7079-T6	72	0.33	503	572

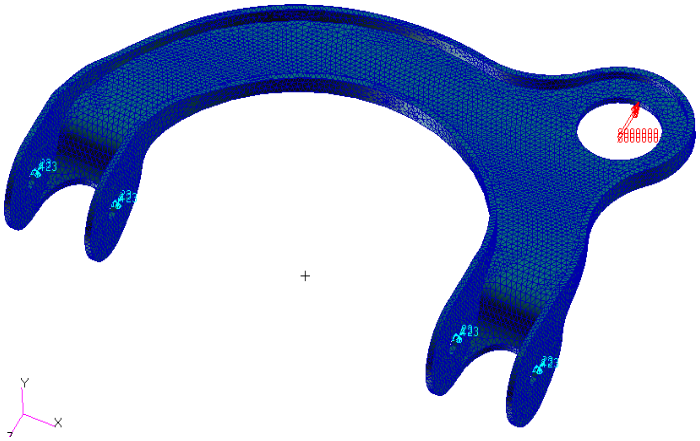


Figure 4. Three-dimensional FE model, loading and constraints.

Effects of the mesh types

The stress histories calculated using the linear static analysis method are usually the most accurate and are commonly used by members of the finite element community as a reference to evaluate the accuracy of the stochastic design improvement. The linear static stress analysis was performed utilizing MSC.NASTRAN to determine the stresses result from the finite element model. The material models utilized elastic and isotropic

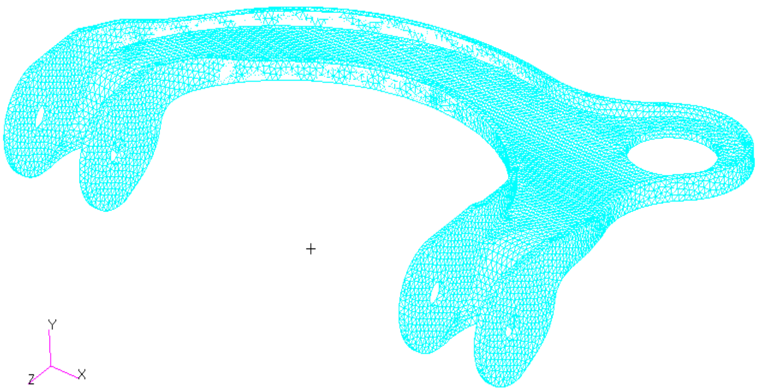


Figure 5. TET10, 54178 elements and 96080 nodes.

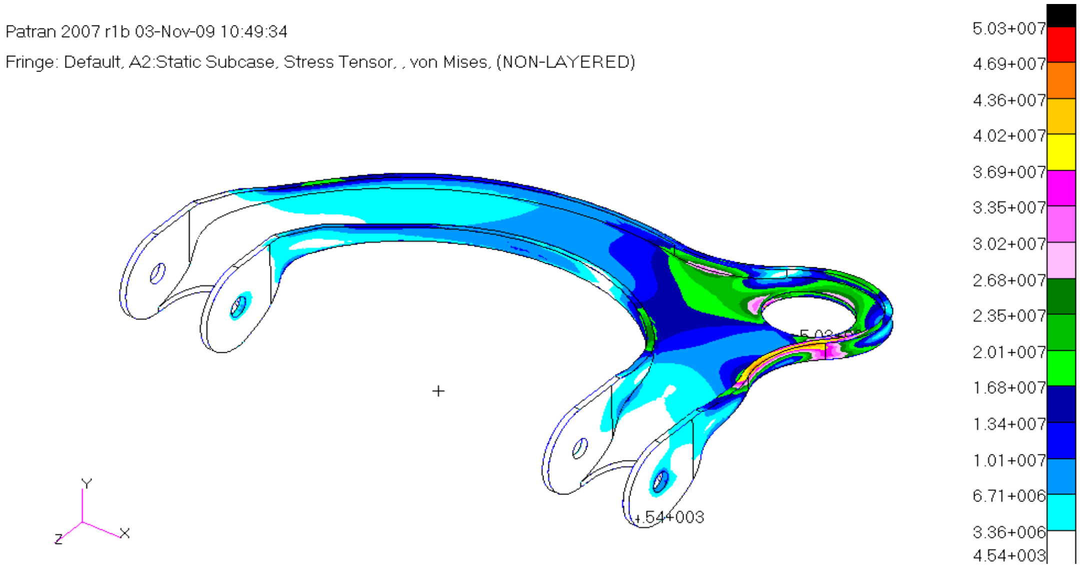


Figure 6. von Mises stresses contour for TET10.

Table 2. Variation of stresses concentration at the critical location of the suspension arm for TET10 mesh.

Mesh size (mm)	Total nodes	Total elements	Von Mises (MPa)	Tresca (MPa)	Max principal stress (MPa)
0.1	96080	54178	50.3	52.2	56.3
0.3	10041	4676	50.2	51.3	54.2
0.6	5889	2665	48.9	50.6	52.2
1.0	5436	2465	47.4	48.2	50.7
1.5	3186	1409	45.3	35.7	49.9

material. The tetrahedral element TET10 used for the mesh analysis is shown in Figure 5. The convergence of the finite element model of the structure was tested for TET10 and 5 different mesh sizes. Figure 6 shows the von Mises stress contour for TET10 element. The linear elastic analysis results, including maximum principal stress, von Mises stress, and Tresca stress are tabulated in Table 2. The convergence of the stress was considered as the main criteria to select the mesh type. The finite element mesh was generated using TET10 for various meshes global length. From the stress analysis, the result shows that the white area of the design is the

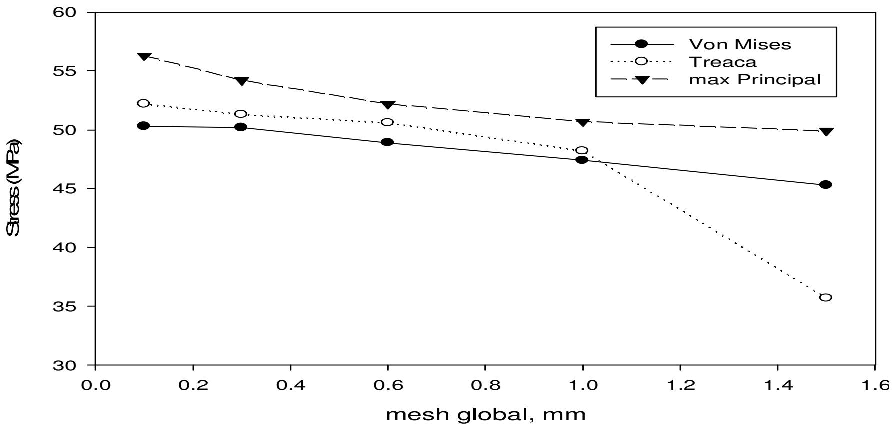


Figure 7. stress contour for TET10.

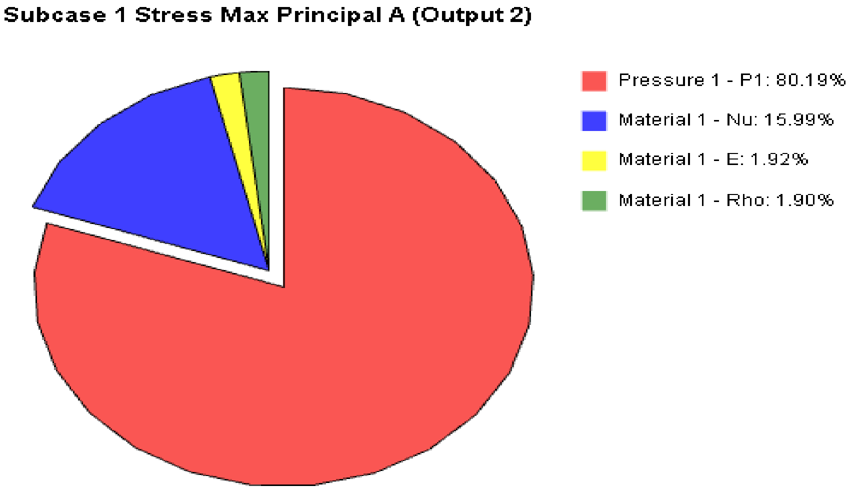


Figure 8. Pie chart of factors that influence to the stress value in the design.

lowest predicted stress acting on the lower arm suspension design. Therefore, the area can be made as a guide in the future processes of modifying or optimizing the design. It is also important to make sure that the critical points on the design which have the highest predicted stress should be looked carefully in the process of modifying and optimizing the design in order to avoid any failure in the future usage of the lower arm design.

Figure 7 shows the predicted results of stresses at the critical location of the suspension arm. It can be seen that the smaller the mesh size capture the higher predicted stresses. It is also observed that mesh size of 0.1 mm (54178 elements) has obtained the maximum stresses, which is almost flattering in nature. The maximum stress obtained of 50.3, 52.2 and 56.3 MPa for von Mises stress, Tresca and Maximum principal stress method respectively. The maximum principal stress method occurred highest through the global length range. Thus TET10 and maximum principal stress method are selected for linear static and dynamic analyses of the suspension arm. Thus TET10 at mesh size 0.1 and maximum principal stress method are selected for linear static and stochastic design improvement of the suspension arm.

Stochastic simulation

A stochastic simulation generates multiple scenarios of a model by repeatedly sampling values from the probability distributions for the uncertain variables. The stochastic simulation takes the uncertainty of variables into account to determine the level of uncertainty in the outputs. From Figure 8, the relative influence of tolerances in input variables on the scatter in a particular functionality (output) can be obtained. The pressure gives the largest

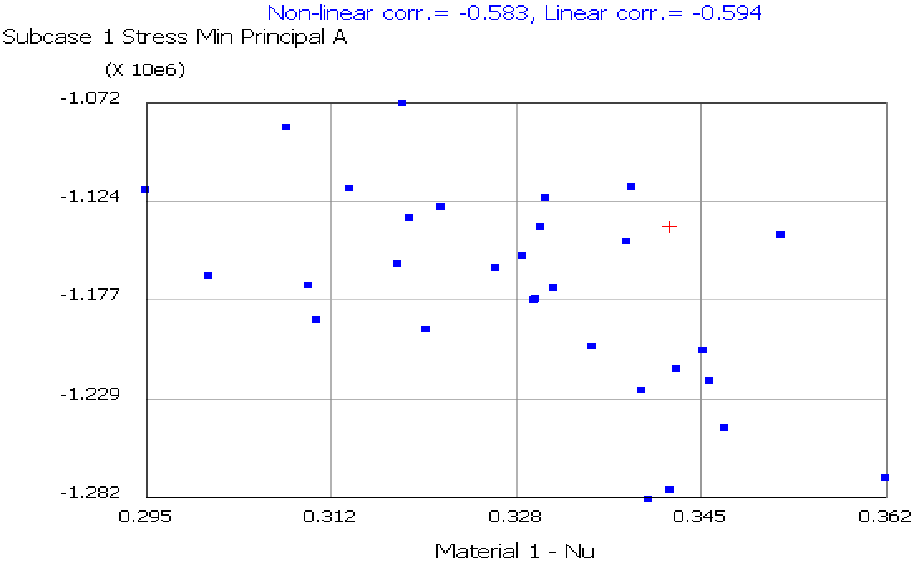


Figure 9. Ant hill scatter plot for stress VS Poisson ratio.

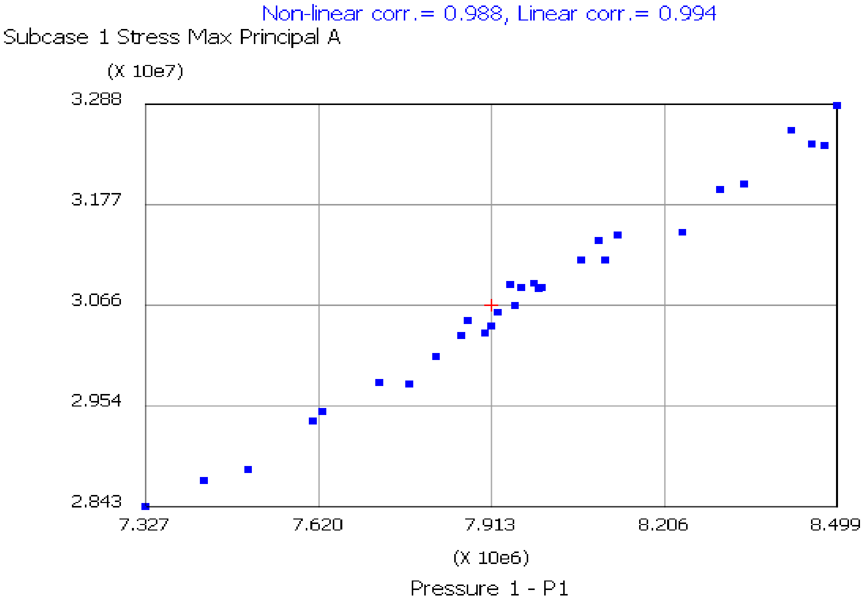


Figure 10. Ant hill scatter plot for stress VS pressure.

influence on the stress value followed by the Poisson ratio, modulus of elasticity, and density respectively. This result is very logical and showed that the design is functioning correctly. Figure 9 shows ant hill scatter for stress against materials. It can be seen that there is less interaction (correlation) between them. Linear and non-linear correlation between them are obtained as negative (linear cor.= -0.594 and non-linear cor. = -0.583). Figures 10 to 11 shows the ant hill correlation between the maximum principal stress and von Mises stress versus pressure respectively. It can be seen that the correlation between the stress and load scale factor are strongly correlated between them (linear cor. = 0.994 and non-linear = 0.988 for maximum principal stress and linear cor. = 1.0 and non-linear = 1.0 for von Mises stress. It is to be more dominant, that is, confirming the result in the pie chart in Figure 8.

In the optimization process for the design, all the

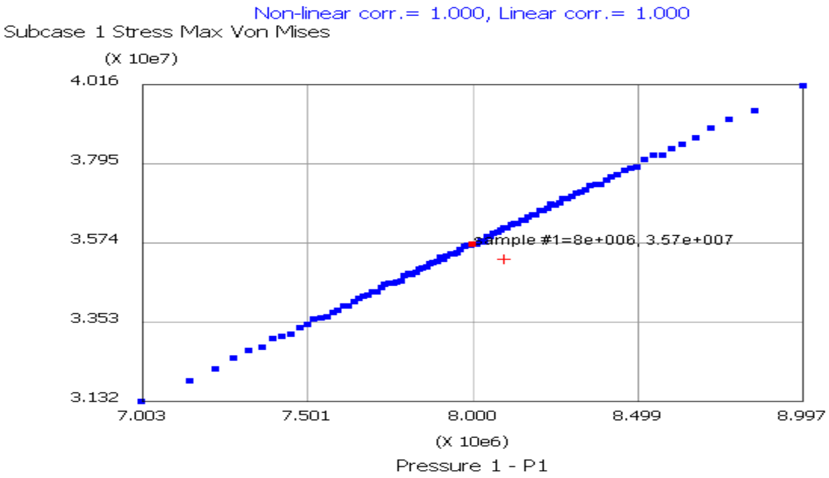


Figure 11. Ant hill scatter plot for stress VS pressure.

Table 3. Comparison of the design parameter before and after optimization.

Design parameter	FEM	SDI
Modulus of elasticity (Gpa)	71.7	69.1
Density (g/cc)	2.7	2.489
Poisson Ratio	0.33	0.3428
Pressure acted on the design (Mpa)	8	9.18
Maximum von Mises stress (Mpa)	50.3	41.0

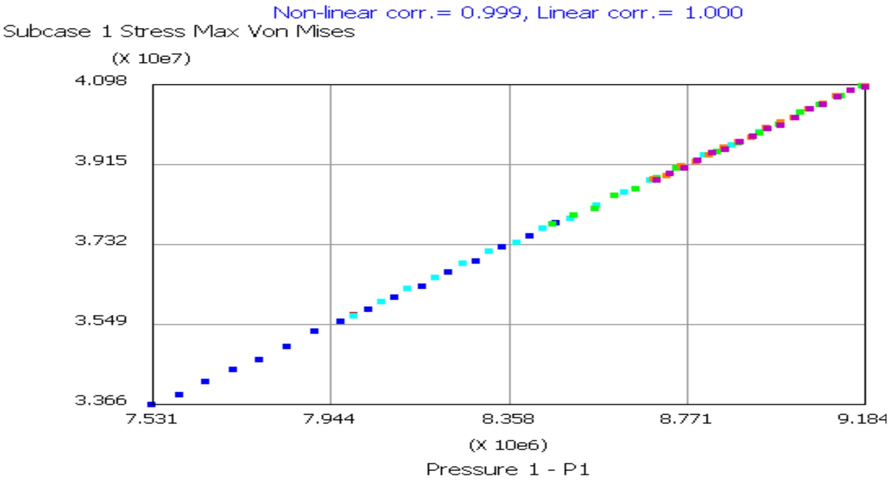


Figure 12. Ant hill scatter plot for stress VS pressure (After SDI).

bounds of function study have been set as follows.

1. Max SDI step is 5.
2. Design variable: Modulus of Elasticity, Poisson Ratio, Density, Pressure.
3. Hard target: Von Mises Stress (50.3 MPa).

The results of SDI show that there are multiple samples from the ant hill scatter plot that give the value of the parameter to use in the optimization process. So the outcome from the SDI had been selected, and it can be shown in Table 3. Figure 12 shows that lower arm design has a higher capability to stand a higher pressure as 9.18

MPa with the stress acted on the lower arm as 41 MPa.

Conclusion

The above study is an example on how robust design technique could be applied in the design stage of the product optimum process to maximize product reliability. The following results were obtained from the results of the simulation of the robust design of the lower arm as improved by SDI.

1. After SDI the model capable of enduringmore loads with lower predicted stress.
2. A new parameter of material can be chosen as an optimum result for the lower suspension arm.

REFERENCES

Al-Asady NA, Abdullah S, Arrifin AK, Rahmman MM, Beden SM (2008). Improving the automotive lower suspension arm durability using finite element analysis.Seminar on Engineering Mathematics. Department of Mechanical and Materials Engineering, Universiti Malaysia Pahang.

Bharatendra R, Nanua S, Mustafa A (2004). Robust design of an interior hard trim to improve occupant safety in a vehicle crash. Reliab. Eng. Syst. Saf., 89(3): 296-304.

Conle FA, Mousseau CW (1991). Using vehicle dynamic simulation and finite element result to generate fatigue life contours for chassis component. Int. J. Fatigue, 13(3): 195–205.

Kim HS, Yim HJ, Kim CM (2002). Computational durability prediction of body structure in prototype vehicles. Int. J. Automotive Technol., 3(4): 129-136.

Rahman MM, Kadirgama K, Noor MM, Rejab MRM, Kesulai SA (2009). Fatigue life of lower suspension arm using strain-life approach. Eur. J. Sci. Res., 30(3): 437-450.

Rakesh M, Tong LH, Zhijie L, Ibrahim Y (2002). Robust design of a spindle motor: A case study, 75(3): 313-319.

Seo PK, Kim HC, Kang EG (2007). Numerical integration design process to development of suspension parts by semi-solid die casting process. J. Mater. Process. Technol., 183: 18-32.

Sreeram P (1994). Robust Design of an Automotive Suspension System. M.S. Thesis. Michigan Technological University, USA.