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Mesh sensitivity analysis in the fatigue life simulation based on the experimental load history

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Abstract. Generally, in motorsport, loads are highly dependent on road conditions, with the wheels being sensitive to oscillations on the road surface. In the case of off-road vehicles, these loads can be considerably unpredictable, as they depend on the ground unevenness, dimensions of each ground element, speed, angle of attack, among other several variables. In these cases, to predict the components behavior, experimental forms of analysis can take place through techniques like extensometry in already existing vehicles, allowing the acquisition of real dynamic loads and the creation of a database. The durability of many vehicles componets is affected by cyclical nature's failure, where there are dynamic stresses and variables as a function of time, in most cases with stresses below the yield point and material rupture. For an analysis of fatigue life in vehicle structural components with variable load in computational analysis, the experimental load history can be applied, considering the cumulative damage effect. The analysis of resistance and durability is a crucial task in the dimensioning of automotive components and, in complex geometries, the use of finite element software becomes advantageous. In these analysis, the mesh parameters are directly related to the quality of the analysis, as it refers to a discretization of the model. In this perspective, the present work presents an approach on the influence of the mesh parameters for the model in finite elements, applied to the mechanical component most requested by the suspension of the prototype within the scope of fatigue. Therefore, the load history acquired experimentally was considered for the excitation of the component, while the interference of the main mesh parameters in the final results was verified. The fatigue tool from the Ansys software was used to insert a variable gain in the load parameters. The load history was also incorporated through files obtained experimentally. This history makes the nominal load applied to the component have variable amplitude.

Keywords: Mesh Sensitivity, Fatigue Analysis, Finite Elements, Stub Axle, Baja SAE.

1 Introduction

The Baja SAE design competition is an international engineering event promoted by the Society of Automotive Engineers, created at the University of South Carolina (USA), to allow engineering undergraduate students to participate in the design of an off-road competition vehicle model and prepare them for the job market. In this competition, the students are challenged to design, manufacture and validate all the vehicle's systems. For the design stages of these prototypes, the competitive regulation must be followed, which in addition to imposing conditions of technical and safety specifications also suggests that the vehicle must be designed considering characteristics for large-scale production, such as reliability, maintenance and ergonomics.

The durability of many mechanical components is reduced by cyclical nature's failure, according to Callister [1], about 90% of all metal failures are related to fatigue. In off-road vehicles, the variability and severity of loads contribute to the worsening of this effect. In the case of irregular amplitude loading, according Dowling [2], each event should be counted as a cycle with their own amplitude and average tension (with the Rainflow method for example), so that the Palmgren–Miner rule can be employed. The Palmgren-Miner is a cumulative damage rule in which states that fatigue failure is expected when the sum of the individual damages factor of each cycle corresponds to 1. Figure 1 shows the ”BJ-16” vehicle, the prototype by the UFSM Baja team named Bombaja that competed in the 26th Baja SAE Brasil competition in 2020.

Figure 1. Prototype BJ-16 (Baja SAE media [3])

2 The component analyzed

This work focuses on the most requested mechanical component of the vehicle's suspension, a front stub axle, highlighted in the Fig. 2. This component is responsible for integrating of the vehicle's suspension and steering systems, transmitting steering mechanical forces to the wheels and loads from the wheels to the control arms. This component is made of aluminum 6061 T6, that like most nonferrous alloys do not have a fatigue limit according Callister [1], encouraging a careful durability analysis.

Figure 2. Instrumented front stub axle (Author)

3 Data acquisition

As previously mentioned, the loads in this component are dependent on the conditions of the terrain, which makes the determination and decomposition of the mechanical internal loads in a theoretical way very complex and dependent on many simplifications. In this case, the loads were acquired in the prototype by means of extensometry, where the most stressed region of the stub axle was instrumented with four extensometers connected in a complete Wheatstone bridge as shown in Fig. 3. For the simulation of obstacles, testing track was prepared with similar obstacles to those found in the competition event, and 55 laps on this track were analyzed.

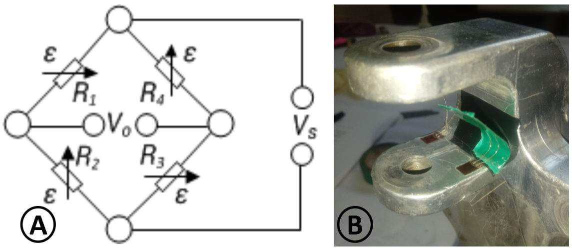

Figure 3. A: Wheatstone bridge (adapted from HBM, [4]); B: sensor positioning (Author)

4 Fatigue life analysis

The fatigue life analysis was based on a structural static analysis, with a static loading corresponding to average value of the load history, and the variation was inserted through a load history file, normalized and inserted through Ansys fatigue tool, as a "non-constant amplitude load". The Goodman's failure criterion was used to correct the effect of mean stress. As the main component due to this load was flexion, unidirectional fatigue analysis was considered. To maintain fidelity to the real case the suspension arms, the shock absorber and the steering link were modeled together with the stub axle, and simplified to reduce computational cost. Figure 4 shows the components.

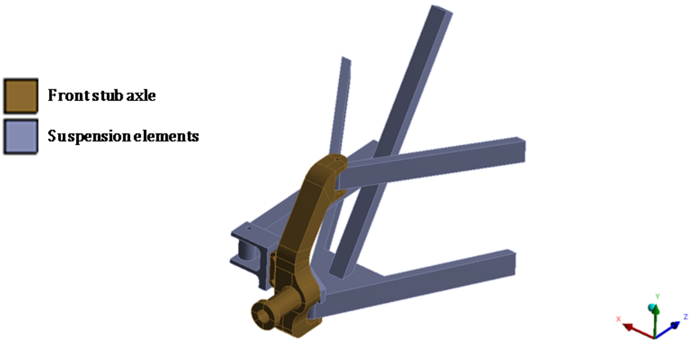

Figure 4. Components considered (Author)

5 Mesh sensitivity

For the mesh sensitivity analysis, most elements of the hexahedral mesh of quadratic order were used due to the need to adapt to some curves. The main parameter considered for this analysis was the global size of the element, through general refinement in five stages. In Fig. 5 we can see three of the meshes used, where A and C are the coarsest mesh (3.5E-03 mm size element) and the most refined mesh(1.75E-03 mm size element), respectively.

6 Results and Discussion

The load history obtained through extensometry and normalized to be applied as a loading standard can be seen in Fig. 6. It is noticed that this graph does not have coordinates on the X-axis, because this set of points is considered as a single cycle, while the Y-axis represents the gain (dimensionless) that will be multiplied by the value of the force.

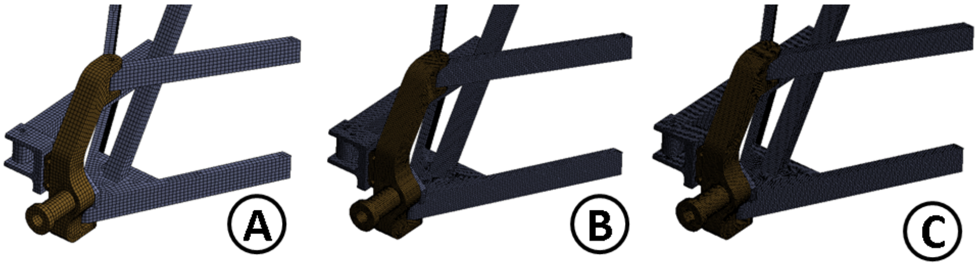

Figure 5. Mesh comparison. (A) Coarsest mesh, (B) Second most refined mesh and (C) most refined mesh.(Author)

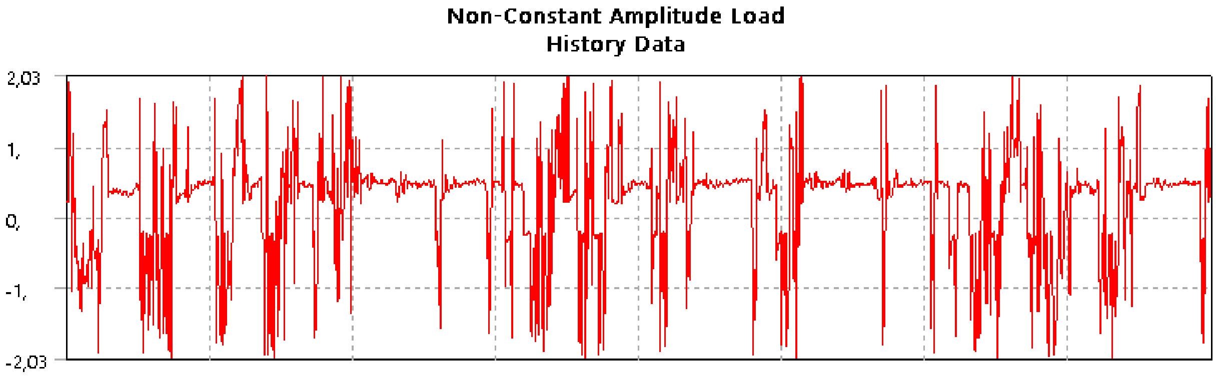

Figure 6. Non-constant amplitude load history data (Author)

The mesh convergence graph is shown in Fig. 7. Both variation in the maximum stress and the variation in the minimum number of cycles that the component supports reduces due to the increase in the number of elements, with a final variation of just over 6% between the two most refined mesh for the maximum stress. The maximum stress in the component in the final mesh was 58.4 MPa, what provides a safety factor for the component close to 2, and 1.7E5 life cycles for fatigue life, where 1 cycle is considered with an application of the history of charge.

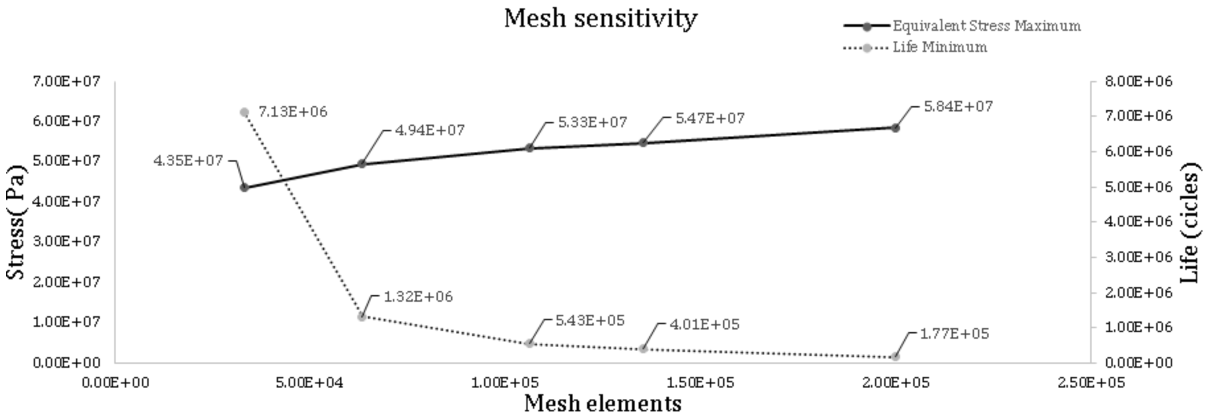

Figure 7. Variation of the results of stress and life as a function of the variation of the mesh (Author)

The quality of the mesh can be analyzed through the percentage of elements that have a metric proportion close to 1, where elements with better quality have a an aspect ratio equal to 1 (closest to the original form, because is the ratio between volume and edge length) and the worst elements have a proportion close to zero. In the final mesh 81.27% (by volume) of the elements created were of hexahedral geometry with a aspect ratio close to 1, and with an average of approximately 0.85, as shown in Fig. 8.

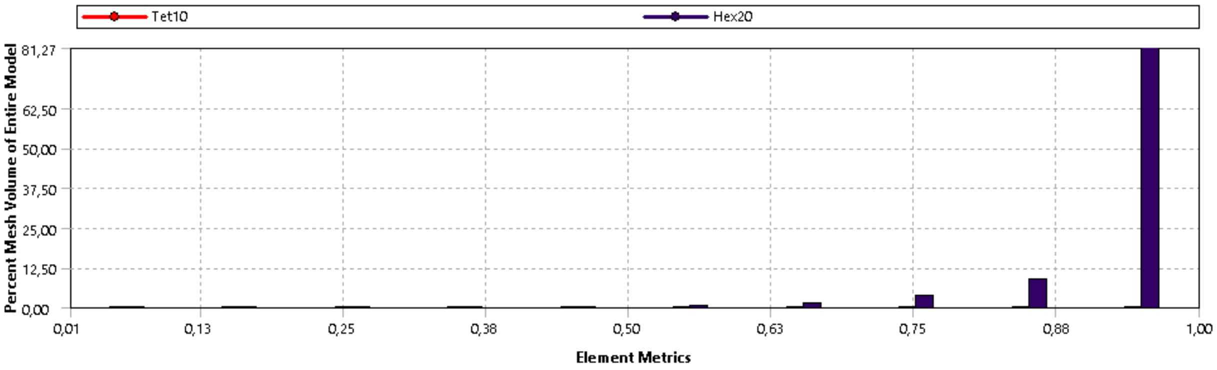

Figure 8. Mesh quality as a function of the aspect ratio of the elements (Author)

7 Conclusions

With the mesh sensitivity analysis performed, we can conclude that it was possible to achieve the convergence of the results, reaching a variation of just over 6% in the final meshes. The variation between the first and the last mesh considered was greater than 34%, which reveals the variation of the results according to the dimensions of the elements used in the mesh. It is noticed that the result of the 3rd and 4th mesh are very close, which suggests that the 4th mesh (represented in C in Fig. 5) can already be considered as satisfactory.

The fatigue analysis showed results lower than the values considered as infinite life, so this component has limited durability. Each cycle considered in the analysis is equivalent to the application of a load history corresponding to one lap on the test track.

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References

[1] Callister, W., 2000. *Ciência E Engenharia de Materiais: Uma Introdução* . Grupo Gen-LTC.

[2] Dowling, N. E., 2012. *Mechanical behavior of materials: engineering methods for deformation, fracture, and fatigue*. Pearson.

[3] *SAE Brasil, 2020. Baja SAE BRASIL.* Disponível em: http://portal.saebrasil.org.br/programas-estudantis/baja-sae-brasil. Acesso em: 11 abr 2020.

[4] *HBM. O circuito de ponte de Wheatstone.* Disponível em: https://www.hbm.com/pt/7163/circuito-de-ponte-de-wheatstone. Acesso em: 05 nov 2019.