Article Journal of Technological Operations
June, 2022 Vol.6 No.17 27-34

Structural analysis, simulation and validation as a strategy for product design

Análisis, simulación y validación estructural como estrategia para diseño de producto

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DOI: 10.35429/JTO.2022.17.6.27.34 Received March 30, 2022, Accepted, June 30, 2022

Abstract

In the process of developing products to meet specific needs or requirements, it is crucial, in terms of functionality, to achieve the interaction of two strategies: on the one hand, end-user feedback and, on the other hand, architectural optimization by applying finite element analysis (FEA). Seeking the consolidation of a new product and identifying opportunities for improvement, this article presents the results of an FEA study applied to a multicultivator (case study) in which the premises were: 1) validation of the design proposal; 2) evaluation of areas detected as "critical"; and 3) optimization of geometry to reduce weight and manufacturing costs. The procedure used to structure the design of the multicultivator under the approaches of architecture validation, production quality improvement and cost reduction is also presented in a simplified manner.

Design, Functionality, Optimization

Resumen

En el proceso del desarrollo de productos destinados a cubrir necesidades o requerimientos específicos es determinante, hablando en términos de funcionalidad, lograr la interacción de dos estrategias: por un lado, la retroalimentación del usuario final y por el otro, la optimización de arquitectura aplicando análisis de elemento finito (FEA). Buscando la consolidación de un nuevo producto e identificando oportunidades de mejora, en el presente artículo se presentan los resultados de un estudio de FEA aplicado a un multicultivador (caso de estudio) en el cual se tenía como premisas: 1) validación de la propuesta de diseño; 2) evaluación de zonas detectadas como “críticas”; y 3) optimización de geometría para reducir peso y costos de manufactura. Se presenta también, de manera simplificada, el procedimiento utilizado para estructurar el diseño del multicultivador bajo los enfoques de validación de arquitectura, mejora de calidad en producción y reducción de costos.

Diseño, Funcionalidad, Optimización

Citation: OJEDA-ESCOTO, Pedro Agustín. Structural analysis, simulation and validation as a strategy for product design. Journal of Technological Operations. 2022. 6-17: 27-34

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1. Introduction

To design is to establish and define pertinent solutions and structures for problems that have not been solved before or new solutions proposed in a different way for problems that have been previously solved. Design is part science and part art. The scientific part of design can be learned through the different philosophies, methodologies and tools that exist and that try to systematize this task. However, the art part of the design process, today, cannot be taught systematically. Therefore, many designers argue that the only way to learn the art part of design is by designing (Evbuomwan et al, Kaspar et al, Tomiyama et al, Tran *et al*).

FEA is currently a powerful tool within the industrial sector, with each solution representing a vast panorama of mathematical physics, numerical methods, user interfaces and visualization techniques. So great has been its success that it is used both for traditional didactic experimental methods and model analysis as well as for solving dynamic problems. The aid of FEA has been both inevitable and progressive, as the high costs and time associated with consuming experimentation have often impeded the desire to produce efficient depth of results (Versteeg, Zienkiewicz *et al*).

This paper reports the procedure and results of an FEA study performed on a multicultivator (case study) structured under the premises: validation of the design proposal, evaluation of areas detected as "critical" and optimization of geometry to reduce weight and manufacturing costs. Likewise, the results obtained from the analysis in each of the situations and cases presented are reported and discussed.

2. Methodology

The design and development of a new product consists of extracting the information by following a methodology, the architecture of the product in question and its procedural details in order to understand it. It is important to mention the methodology needed to be able to propose the solution to a need; that is, to formulate or propose a problem requires a previous analysis of the knowledge about its nature and, therefore, to have considered the important or relevant facts and concepts according to which it is possible to define in a synthetic way the problem in question.

It is also worth mentioning that it is often necessary, for the benefit of the progress of an investigation, to follow methodologies that have already been defined or to follow some variant based on those already mentioned. Fig. 1 presents the methodology used to develop the design of the multicultivator under study in this work, which is an integration of the traditional models developed by Pugh, Ullman, Ulrich et al. and Pahl et al.

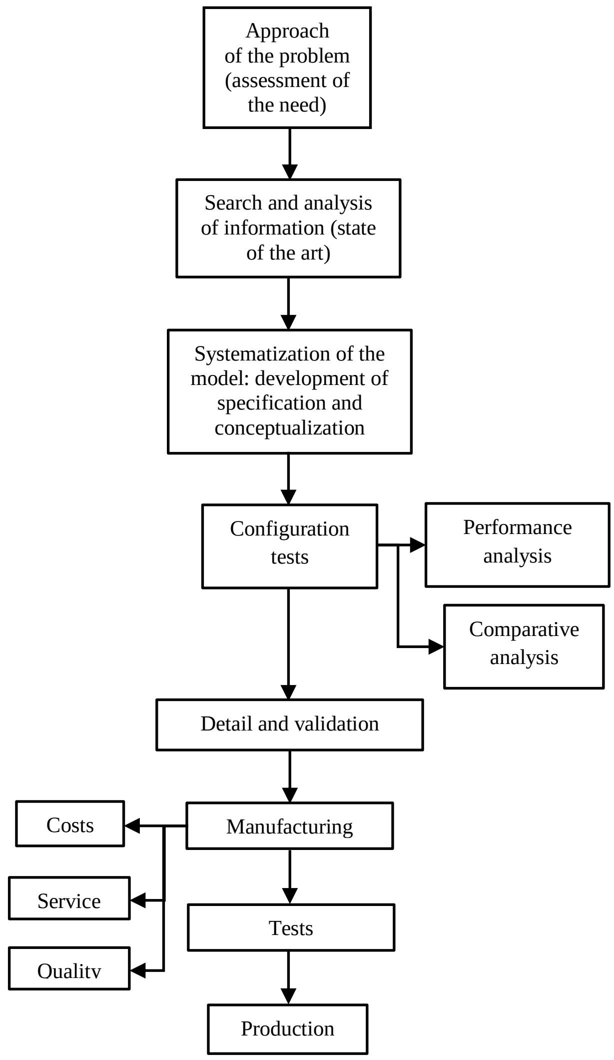


Figure 1 Design Methodology
Source: Own Elaboration

To define the design of the multicultivator, the following approaches were considered: architecture validation, production quality improvement and cost reduction; based on the aforementioned approaches, several configurations were proposed and reviewed to solve the problem under study. Several configurations were conceptualized taking into account the defined approaches and finally the final architecture of the multicultivator was generated. The final proposed geometry is shown in Fig. 2.

ISSN 2523-6806

3. Study approach

3.1 Objective of the analysis

To analyze the main structure of the multicultivator to ensure that it can withstand the normal workloads in an acceptable manner and to locate, in case of occurrence, critical areas of stress concentration and to argue for the possible optimization of these areas.

Figure 2 Case study
Source: Own Elaboration

3.2 Application of boundary conditions

In order to define the most adequate mesh size for the finite element study, several sizes were verified and due to the existing dimensional relationships between the analysis components, a density of 0.375in was finally selected, considering this size the most optimal for such analysis (see Figs. 3 and 4).

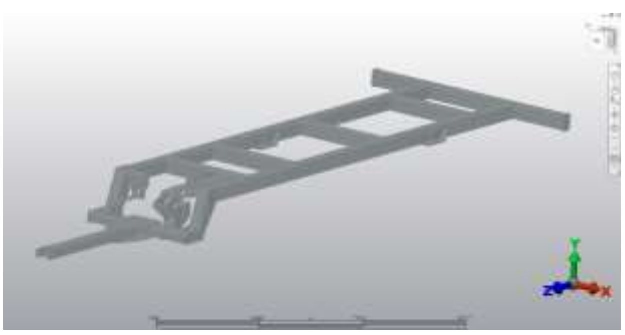


Figure 3 Meshing of the multicultivator chassis.
Source: Own Elaboration

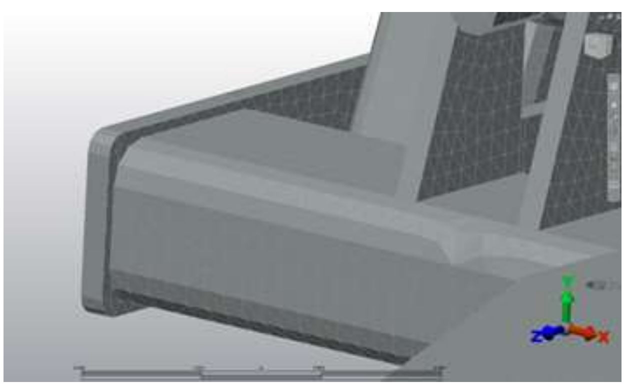


Figure 4 Detail of the multicultivator chassis meshing
Source: Own Elaboration

The loading conditions proposed for the finite element analysis of the multicultivator chassis were defined in several groups to study different situations:

a. Simulation of the pull by the tractor and restriction of the degrees of freedom on one side of the chassis.
b. Simulation of pulling by the tractor and restriction of the degrees of freedom on both sides of the chassis.
c. Simulation of the tractor pulling and application of a transverse load on one side of the chassis.
d. Simulation of pulling by the tractor and restriction of the degrees of freedom on one of the multicultivator drawbars as a sudden stop due to a foreign object on the ground.
e. Simulation of pulling by the tractor and restriction of the degrees of freedom in the multicultivator tiller as part of the resistance of the ground due to normal work.

4. Study situations

4.1 Case 1: analysis carried out on the multicultivator chassis simulating the pull on the tractor hitch part and restriction of degrees of freedom on one side.

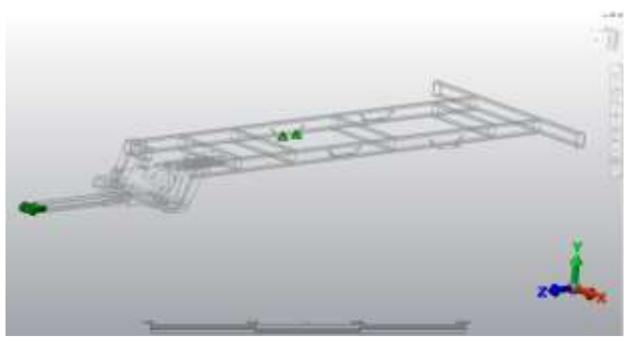


Figure 5 Load groups applied
Source: Own Elaboration

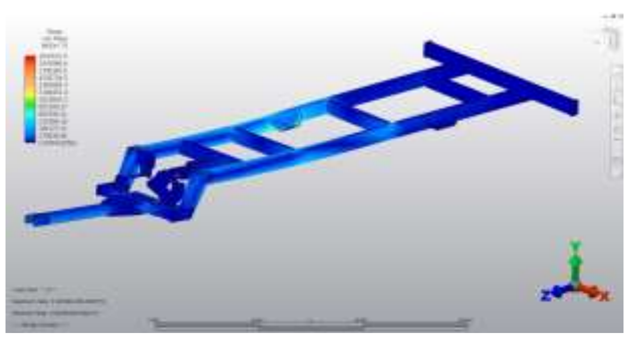


Figure 6 Multicultivator chassis stresses for case 1
Source: Own Elaboration

4.1 Analysis of results: Case 1

In this study, the normal working load (pull) exerted by the tractor on the multi-cropper chassis was applied to the model and the degrees of freedom were restricted in one of the main longitudinal members, as shown in Fig. 6.

The stress analysis shows that the stress magnitudes are below the elastic limit of the material. Therefore, the chassis structure will not present permanent deformations under the loading conditions applied during normal working process.

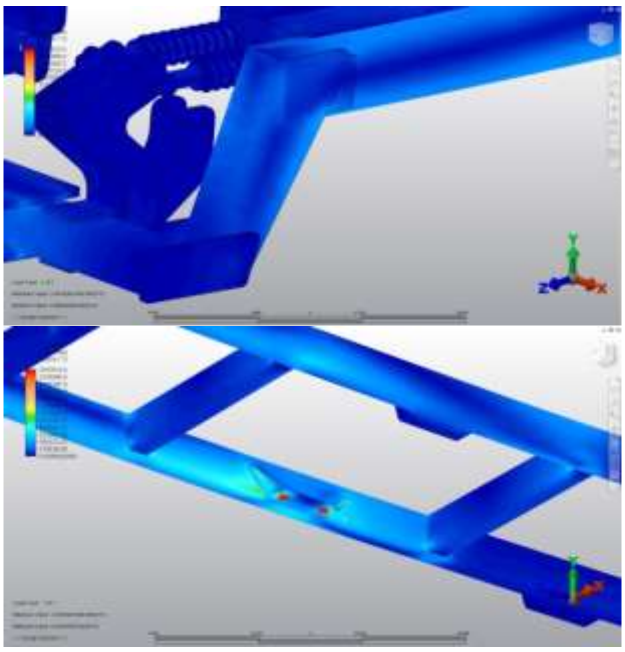


Figure 7 Detail of stresses of the Multicultivator chassis for case 1
Source: Own Elaboration

4.2 Case 2

Analysis performed on the multicultivator chassis simulating the pull on the tractor hitching part and restriction of degrees of freedom on both sides.

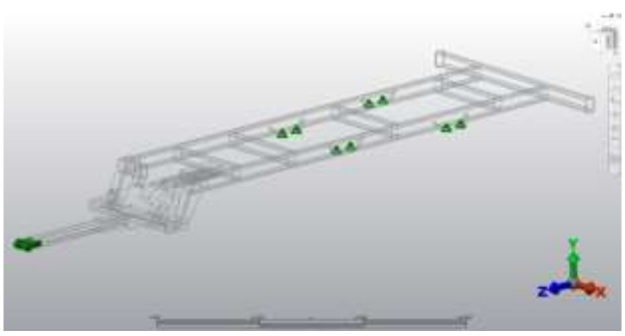


Figure 8 Load groups applied
Source: Own Elaboration

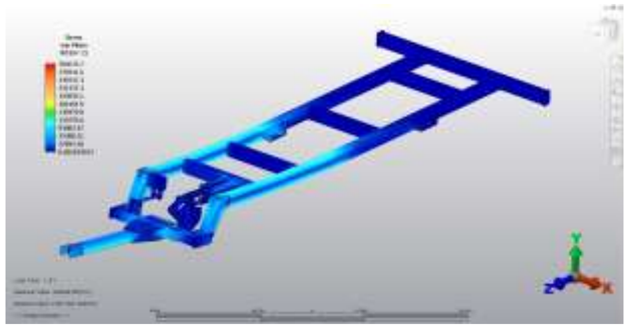


Figure 9 Multicultivator chassis stresses for case 2
Source: Own Elaboration

Analysis of results: Case 2

In this study, the normal working load (pull) exerted by the tractor on the multicultivator chassis was applied to the model and the degrees of freedom in both main longitudinal members were restricted, as shown in Fig. 9. The stress analysis shows that the stress magnitudes are below the elastic limit of the material.

It is worth mentioning that, although the stress magnitudes increased with respect to the results in case 1, they still remain within the normal deformation ranges of the material. Therefore, the chassis structure will not present permanent deformations under the loading conditions applied during the normal working process.

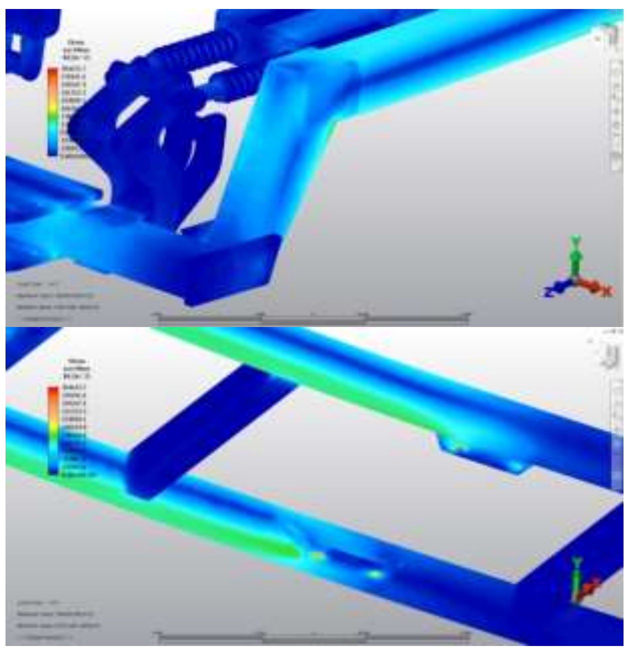


Figure 10 Detail of stresses of the multicultivator chassis for case 2.
Source: Own Elaboration

ISSN 2523-6806

4.3 Case 3

Analysis performed on the multicultivator chassis simulating the pull on the tractor hitching part and restriction of degrees of freedom on one side.

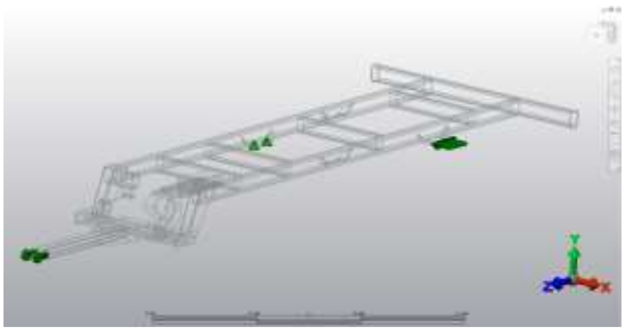


Figure 11 Load groups applied
Source: Own Elaboration

Analysis of results: Case 3

In this study, the normal working load (pull) exerted by the tractor on the chassis of the multicultivator was applied to the model and a transverse load of 50000Lbf was applied to one of the main longitudinal members, as shown in Fig. 12. The stress analysis shows that the stress magnitudes are below the elastic limit of the material.

It is worth mentioning that, although the stress magnitudes increased with respect to the results in case 1, they still remain within the normal deformation ranges of the material. Therefore, the chassis structure will not present permanent deformations under the loading conditions applied during the normal working process.

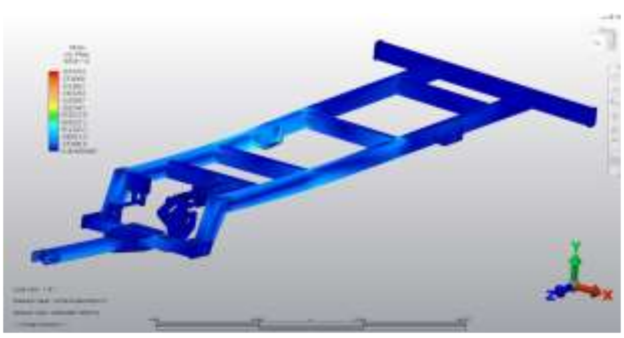


Figure 12 Multicultivator chassis stresses for case 3
Source: Own Elaboration

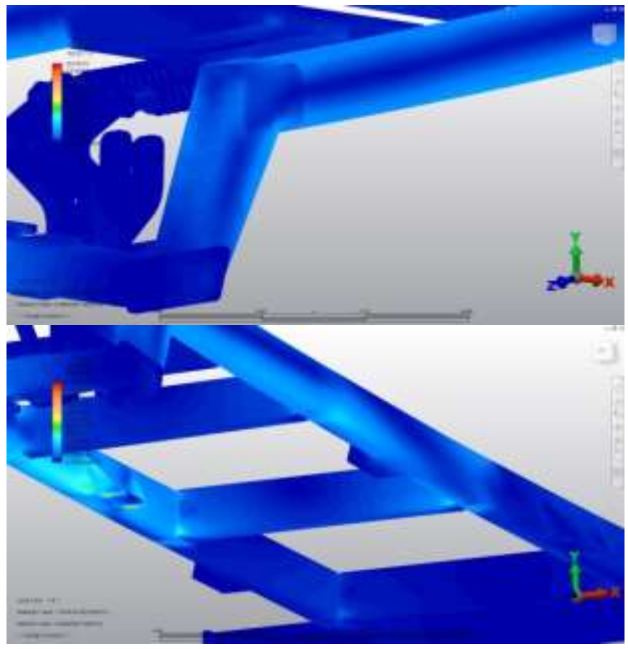


Figure 13 Detail of stresses of the multicultivator chassis for case 3
Source: Own Elaboration

4.4 Case 4

Analysis performed on the multicultivator chassis simulating the pull on the tractor hitching part and restriction of degrees of freedom in one of the multicultivator's rudders as a sudden stop due to a foreign object on the ground.

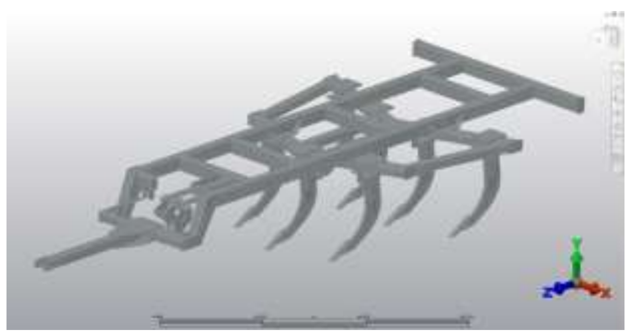


Figure 14 Chassis meshing and multicultivator system
Source: Own Elaboration

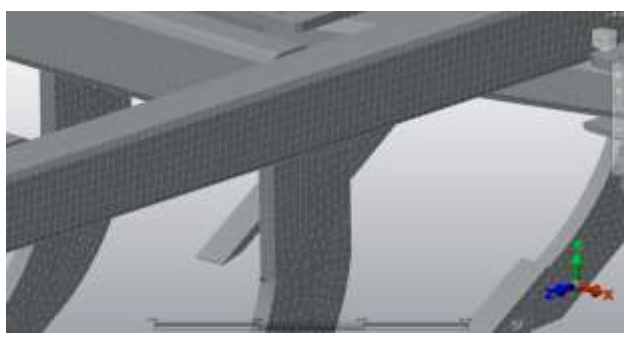


Figure 15 Detail of chassis meshing and multicultivator system
Source: Own Elaboration

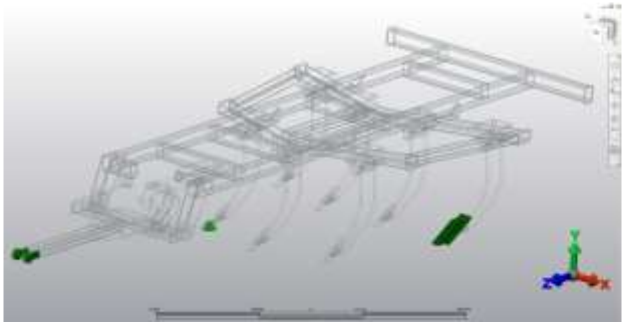


Figure 16 Load groups applied
Source: Own Elaboration

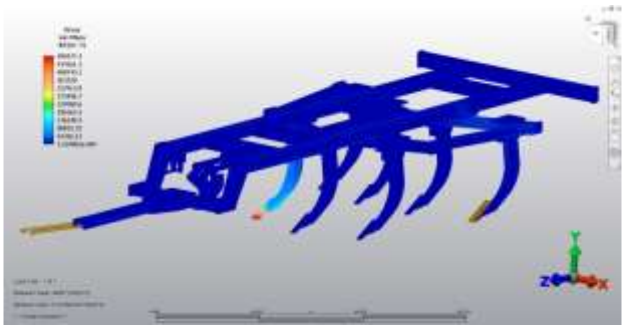
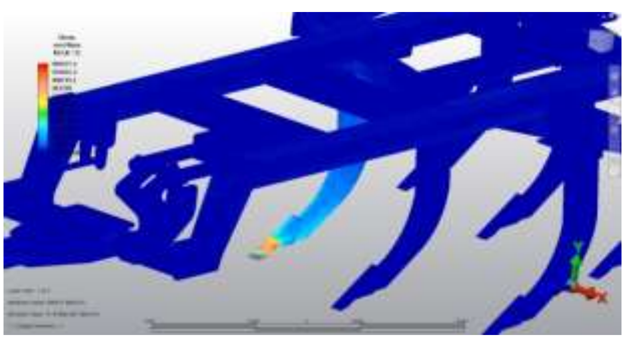


Figure 17 Multicultivator chassis stresses for case 4
Source: Own Elaboration

Analysis of results: Case 4

In this study, the normal working load (pull) exerted by the tractor on the multicultivator chassis was applied to the model and a pivot was placed to restrict the degrees of freedom in this area. A load of 7510.70Lbf was applied to one of the tiller to simulate a sudden stop due to the presence of a foreign object on the working ground, as shown in Fig. 17.

The stress analysis shows that the stress magnitudes are below the yield strength of the material. Therefore, the chassis structure will not present permanent deformations under the loading conditions applied during normal working process.



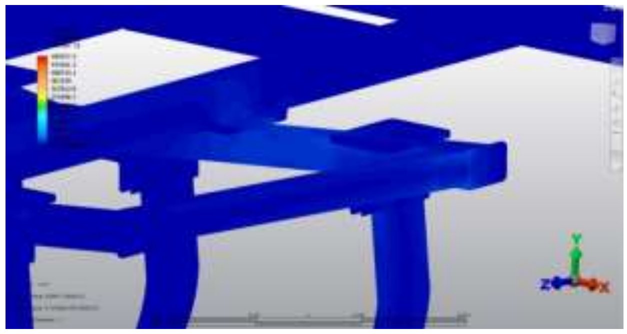


Figure 18 Stress detail of the multicultivator chassis for case 4
Source: Own Elaboration

4.5 Case 5

Analysis performed on the multicultivator chassis simulating the pull on the tractor hitching part and restriction of degrees of freedom on the multicultivator tiller as part of the ground resistance due to normal work.

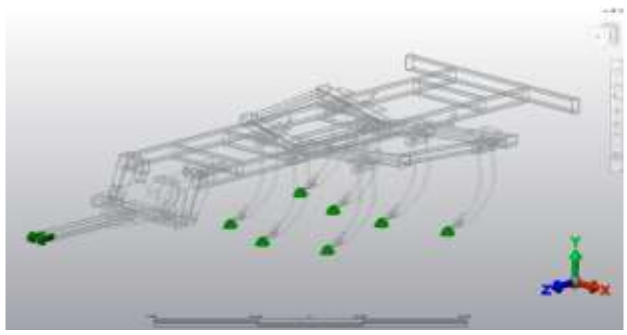


Figure 19 Load groups applied
Source: Own Elaboration

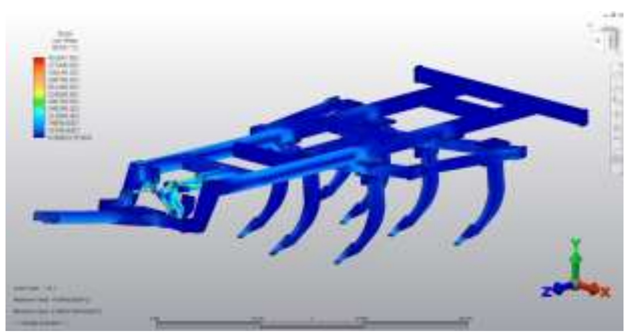
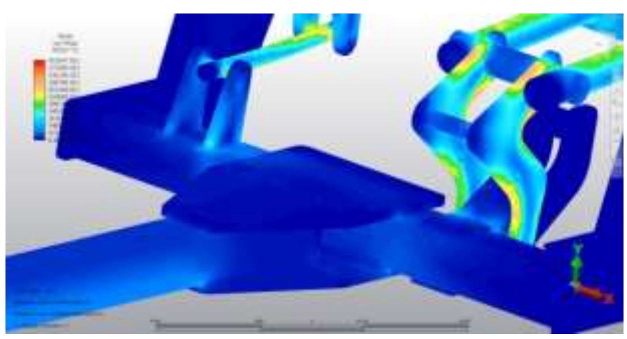


Figure 20 Multicultivator chassis stresses for case 5
Source: Own Elaboration



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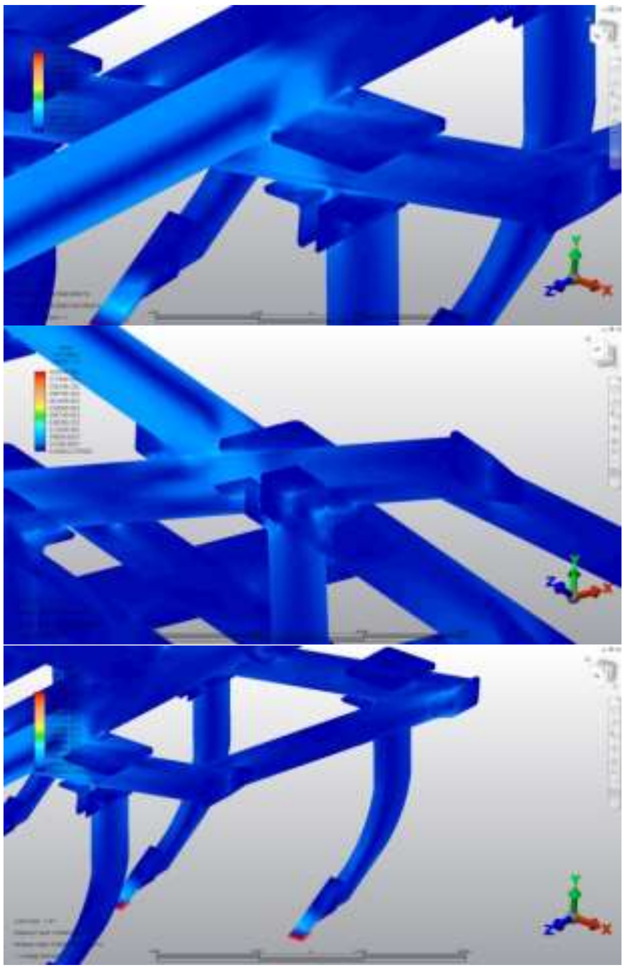

Figure 21 Stress detail of the multicultivator chassis for case 5
Source: Own Elaboration

Analysis of results: Case 5

In this study, the normal work load (pull) exerted by the tractor on the multicultivator chassis was applied to the model and the degrees of freedom in the multicultivator rudders were restricted to simulate the resistance of the soil due to normal and sudden work of the multicultivator, as shown in Fig. 19. As can be seen in Fig. 20, the damping zone of the chassis presents the highest stress magnitudes.

The stress analysis shows that the stress magnitudes are below the yield strength of the material. Therefore, the chassis structure will not present permanent deformations under the loading conditions applied during normal working process.

5. Results (global analysis)

The stress study carried out on the chassis of the multicultivator shows that each and every one of the elements that make up the chassis present stress magnitudes below the permissible elastic limit of the material. In the damping zone of the chassis is where the highest stress magnitudes are found, showing stress concentration at some points, this is due to the geometry itself and the work under which the elements of this part work. Even so, these magnitudes are within the normal deformation ranges, so they can be disregarded for the moment to continue with the analysis.

The chassis longitudinal members were considered as critical elements to apply the loads because they have the largest dimensions and are the main parts of the chassis. Likewise, it was decided to analyze the chassis by integrating the multicultivator to ensure even more the resistance that the implement will have in normal work. The analysis also shows that the chassis structure of the multicultivator is sufficiently rigid to support and absorb the work loads to which it will be subjected.

6. Acknowledgements

The author of this article wishes to acknowledge the technical, economic and logistical support of the Academic Secretariat of the Universidad Tecnológica de Aguascalientes.

7. Conclusions

The use, development and implementation of methodologies for the design or redesign of products based on new technologies increases the probabilities of market alignment and the increase of knowledge and technology transfer to the industrial sector.

Advances in computational and technology analysis allow engineers, designers and researchers to have effective diagnostic and simulation tools that facilitate, at a given moment, the design, redesign or optimization of a mechanical system.

In this article, the results obtained from the FEA study performed on a multicultivator were presented in order to verify the design and to support, if necessary, the optimization of geometry to avoid stress system concentration.

ISSN 2523-6806

On the other hand, with these results it was possible to make changes to the main structure of the multicultivator and, under the approach of weight and manufacturing cost reduction, it was also feasible to generate application strategies for the assembly of such implement and, in this way, facilitate the alignment to mass production.

8. References

Evbuomwan, N. F. O., Sivaloganathan, S., Jebb, A. (1996). A Survey of Design Philosophies, Models, Methods and Systems, Proceedings of the Institution of Mechanical Engineers, Part B. *Journal of Engineering Manufacture*, 210, 301-320.

Kaspar, J., Baehre, D., Vielhaber, M. (2016). Material selection based on a product engineering integration framework, 26th CIRP Design Conference. *Elsevier Ltd. Journals*, 50, 2-7.

Pahl, G., Beitz, W. (1996). Engineering Design – A Systematic Approach. Springer-Verlag. Great Britain.

Pugh, S. (1990). Total Design. Addison Wesley. Great Britain. ISBN 0-201-41639-5.

Tomiyama, T., Gu, P. Jin., Y., Lutters, D. Kind, Ch., Kimura, F. (2009). Design methodologies: Industrial and educational applications, CIRP Annals – Manufacturing Technology. *Elsevier Ltd. Journals*, 58, 543-565.

Tran, T., Park, J. (2014). Development of integrated design methodology for various types of product – service systems. *Journal of Computational Design and Engineering*, 1(1),37-47.

Ulrich, K. T., Eppinger, S. D. (1995). Product design and development, Mc. Graw-Hill, International Editions. ISBN 0-07-113742-4.

Ullman, D. G. (1992). The Mechanical Design Process. Mc. Graw-Hill. New York, ISBN 0-07-112871-9.

Versteeg, W. (1995). An introduction to computational fluid dynamics: the finite element method. *Longman Scientific & Technical*.

Zienkiewicz O. C. and Taylor R. L. (1989). The Finite Element Method Vol. 1: Basic Formation and Linear Problems. McGraw-Hill. USA.