Vibration Analysis of Gears Obtained by 3D Printing and Lattice Structure Topology Optimization Method

D. A. Magallanes-Quintanar[1a], J. Cruz-Castro[1b], J. Mares-Carreño[1c], Y. López-Grijalba[1d], G. S. Abarca-Jiménez[1e], D. Palma-Ramírez[1f], J. L. Calderón-Osorno[1g]

Abstract

Topological optimization has generated a wide interest in the development of various mechanical elements to obtain functional designs without compromising their structural integrity by reducing the mass of the element. However, the elements obtained have complex geometries, which are difficult to manufacture using traditional methods. Additive manufacturing, in both metals and polymers, has contributed to obtaining such models. By using the reticular structure method in topological optimization, an appreciable decrease in mass is achieved in mechanical elements. Dynamic behaviour is affected by reduction mass and modify the natural frequencies. This paper presents the study of the dynamic behaviour of gears manufactured from various polymers from 3D printing by fused deposition modeling (FDM) by using numerical and experimental methods. A structural evaluation by finite element method was performed to identify the ratio of variation on the response to the vibration of the tested gears in terms of the stresses and deformations.

Introduction

Mechanical components used in power transmission systems are exposed to high speed, variations in torque during operational conditions, environmental changes, etc. These conditions can affect their performance and require maintenance constantly. To avoid these problems, several approaches have been carried out including redesign techniques, updating maintenance programs, improving manufacturing processes, and introducing new materials. Topological optimization has contributed greatly to the reduction of mass in the manufacturing of various elements for different areas or industries [1, 2].

Statement of the problem and method

Structural optimization reduces material consumption in component manufacturing. However, this alters their mass and stiffness, thereby modifying their natural frequencies and mode shapes (eigenmodes). Furthermore, tridimensional models obtained from various forms of optimization have an organic geometry. This leads to complex manufacturing processes that can only be performed by using additive manufacturing (AM) instead of the traditional process. When an optimization method is applied it is crucial to establish objectives, whether it is mass reduction, reduction of stress, reduction of concentrations, etc. This work reports the dynamic evaluation of a spur gear made from various polymeric materials, including PLA, PETG, ABS, and PLA-CF. This was accomplished by determining the component's natural frequencies and mode shapes and then reviewing its response to external excitation forces using a response spectrum. Fig. 1 shows the development of the study of vibration spur gears manufactured using different types of polymers and the evaluation of the optimized model.

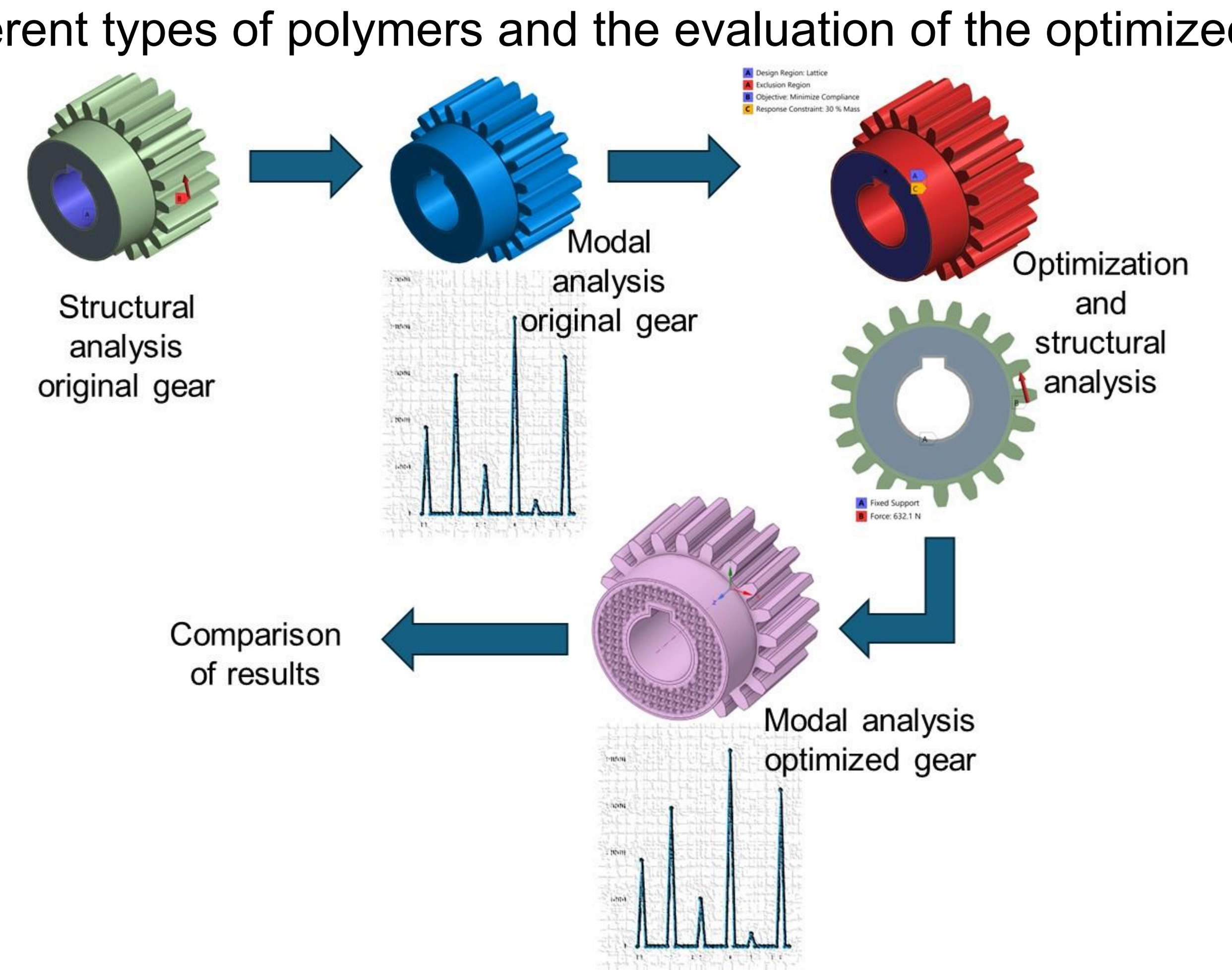

Fig. 1. Methodology proposed for the evaluation

This methodology was replicated using different polymers. Table 1 shows the mechanical properties of each polymer. After a lattice method was applied to the structural optimization a multibody piece was obtained, where the inner part is made up of facets (STL format). Due to this it was necessary to edit the model into a 3D solid model and perform a modal analysis to determine the frequencies and vibration modes for the optimized model.

Table 1. Mechanical properties of polymers

Material	ρ (kg/m³)	E (GPa)	ν	Su (MPa)
PLA	1240	2.58	0.331	35
PETG	1280	1.81	0.35	34
ABS	1050	2.20	0.41	33
PLA-CF	2790	2.79	0.4	38

Numerical analysis

At first, a structural analysis was applied in the spur gear considering as boundary conditions a transmission force of 632.1 N and a fixed support in the shaft zone. Then a modal analysis was performed in order to establish a reference point before the optimization process (as a solid 3D model). The optimization of the spur gear is performed, the objective region for the reduction of mass is the hub zone where the lattice method is applied. In this case a 30% reduction mass was assigned. A modal analysis was performed in the optimized 3D model.

Results

Since the models used for the last analysis, natural frequencies and mode shapes were obtained for the spur gear of 20 teeth. The 3D model was used to manufacture using AM with the listed materials of Table 1. Fig. 2 shows the comparison of the natural frequencies of the solid and optimized spur gears, and in Fig. 3 shows the second mode of vibration for the solid and optimized spur gear.

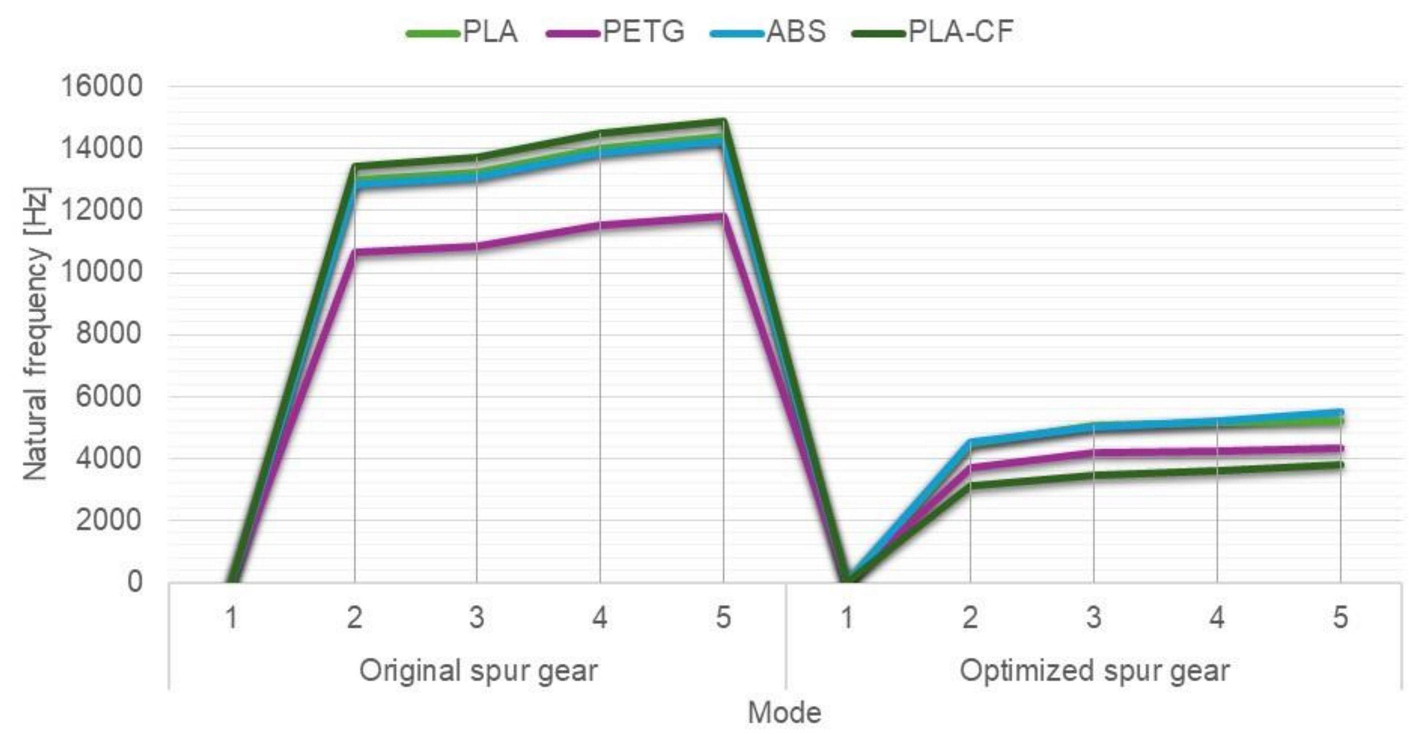

Fig. 2 Comparison of the natural frequencies obtained by FEM

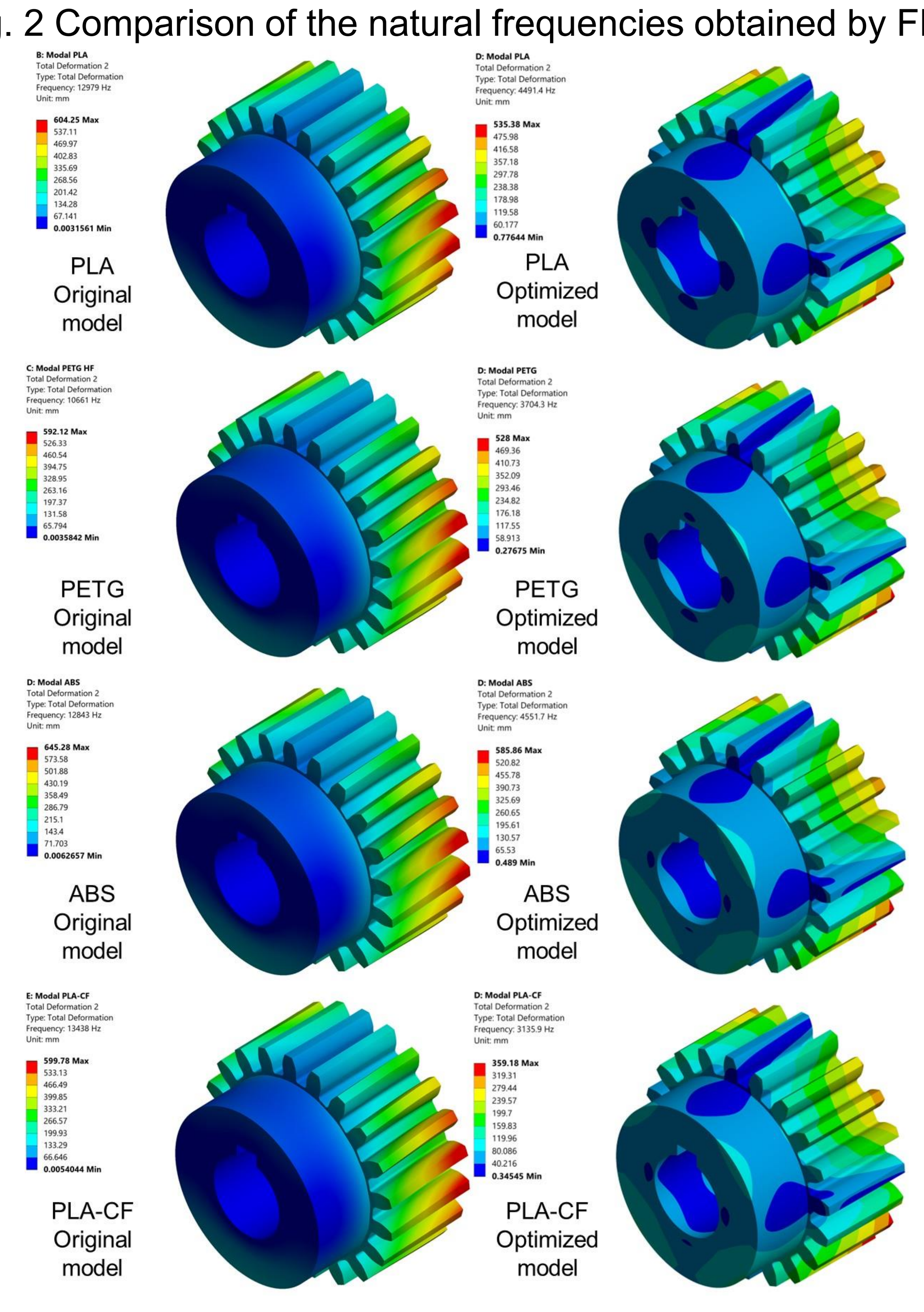

Fig. 3 Comparison of the mode shapes obtained by FEM

Conclusions

Topologic optimization has proved to be an important tool in the redesign of mechanical. However, it was observed that there was a significant reduction in the natural frequencies when a reduction of mass is applied in optimization. PLA with carbon fiber presented a notice difference in the variation of the natural frequencies. The models generated by the optimization process only can be manufactured by AM techniques due its complex geometries.

References

[1] Ramadani, R. , Pal, S., Kegl, M., et al. "Topology optimization and additive manufacturing in producing lightweight and low vibration gear body," The International Journal of Advanced Manufacturing Technology, vol. 113, pp. 3389-3399, 2021.

[2] Marafona, J. D., Carneiro, G, N., Marques, P.M.,et al. "Gear design optimization: Stiffness versus dynamics," Mechanism and Machine Theory, vol. 191, p. 105503, 2024.

Acknowledgement

The grant for the development of the Project SIP20253567 y SIP20254472 was awarded by the National Polytechnic Institute (IPN). It is kindly acknowledged.

NAPLES, ITALY 30 JUNE - 4 JULY
ACEX2025 NAPLES
18th International Conference on Advanced Computational Engineering and Experimenting

[1]Instituto Politécnico Nacional, Unidad Profesional Interdisciplinaria de Ingeniería campus Hidalgo, carretera Pachuca-Actopan km 1+500, Distrito de Educación, Salud, Ciencia, Tecnología e Innovación, C.P.42162, San Agustín Tlaxiaca, Hidalgo. México.
E-mail: dmagallanesq2000@alumno.ipn.mx[a], jucruzc@ipn.mx[b], jmaresc@gmail.com[c*], ylopezg@ipn.mx[d], gabarcaj@ipn.mx[e], edpalmar@ipn.mx[f], jcalderono@ipn.mx[g]

ACEX 188