VIBRATION AND STRENGTH ANALYSIS OF A NEW TYPE OF MECANUM WHEEL BASED ON FEM

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Abstract - There are a lot of challenges when it comes to the development of a new design for a power wheelchair. Those challenges are mainly related to maneuverability and the comfort of the user. One of the challenges is the capability to move in tight areas. This capability mainly depends of the design of the wheel. In this project, the main objectives are giving a better maneuverability for wheelchairs, and consequently improve the life of the users, that is the reason why mecanum wheels were chosen for this project. This paper is investigating the comportment of the mecanum wheel due to vibrations in the structure as well as providing a static analysis of the mecanum wheel using SOLIDWORKS tools. The results showed that the design is reliable and stable and can carry out a person with 80 kilograms.

Index Terms - Mecanum Wheels; Rollers; Omnidirectional; Wheelchair; Vibration;

I. INTRODUCTION

Powered wheelchairs have been developed over the years for locomotion disabilities and for geriatric assistance. Smart electric wheelchairs are special class of powered wheelchair, which are becoming a natural substitute of the conventional wheelchairs as an assistive device [1]. Most of the developed smart wheelchairs are modifications over existing models and one of the topics is the enhancement of the maneuverability. Thinking about that, many researchers are focused on researches related to the use of wheeled omnidirectional running mechanism. Especially, Mecanum omnidirectional vehicles have been widely used in military, storage and transportation, social services, and other fields [2].

Omni directional wheelchairs have special maneuverability due to the mecanum wheels which allows translational as well as lateral mobility [3].Compared to conventional vehicles, omnidirectional robotic vehicles possess multiple advantages in terms of their mobility in narrow spaces and crowded environments. They have the ability to easily perform certain tasks in congested environments foreseen with static obstacles, dynamic obstacles or narrow areas [3]. Usually such environments can be found in factories, workshops, warehouses, hospitals, etc.

Omnidirectional vehicles have 3 degrees of freedom (DOF) on the ground. They can achieve longitudinal motion, lateral motion, center-point steering motion, and any composite motion of above three, so they are suitable for highly maneuverable, narrow or accurate positioning occasions [4].

And even if mecanum wheels have those advantages, however they have some common typical problems such as: unable to perform smooth motion, roller traction is seen in wet or dusty hard surfaces, roller supports under high load applications, the current weight of the wheel is a serious concern, the complex design of the wheel has too many individual components [5].

One of the objectives of this project is the development of a new design more economical in terms of costs and more efficient than other designs. In order to solve a design problem, some procedures should be taken in consideration and they are: Need or Aim, Mechanisms, Analysis of Forces, Material, Design of elements (Size and Stresses), Modification, Detailed drawing, Production [6].

In this paper, the main focus is the analysis of forces, stresses and vibration in this new design of mecanum wheel as wheel as the selection of the best material that should be used.

The importance of machines, equipment or components testing results comes from the fact that different types of testsare an integral part of the research, development, design,manufacture, exploitation and repairing process of the products, contributing significantly totheir continuous improvement, in all phases [7].

Those tests are used with the following goals:

- check if the main constructive parameters, technical and economic indices, qualityof the execution, performance, safety of operation and wear resistance of thecomponents, subassemblies or products correspond to the technical documentationof the manufacturing firms;
- to carry out a permanent control of the manufacture (reparation) quality, ofverification and improvement of prototypes or of the new technological processesand materials etc., at the manufacturing and repair firms;
- in exploitation, to determine which is the type of component, subassembly orproduct most appropriate to certain working conditions as well as to establish thebest working regimes;

Finite element analysis (FEM) [7] of the structures emerged as a necessity tosimplify and reduce the cost of testing in operation or in simulated and accelerated regime;this is important because the maximum stresses and even the lifetime of a structure can be approximated reducing the costs and possible failures

in the project. In this paper we have presented a new design for a 4 wheel driven omnidirectional wheelchair, keeping the focus in the design of the mecanum wheel. One of the analyses described is related to the unavoidable vibration in the mecanum wheel due to its structural shape [8].

A vehicle with mecanum wheels can be excited vertically because the rollers transfer the impact forces to the vehicle body due to the consecutive contacts of rollers with ground. Although the contact between the wheel itself and the ground is continuous, the contact point of the rollers are discontinuous, this causes vertical vibration in the vehicle. And those vibrations will reduce the comfort of the user of our wheelchair, what is essential for the project. That is the reason why the vibration analysis is performed.

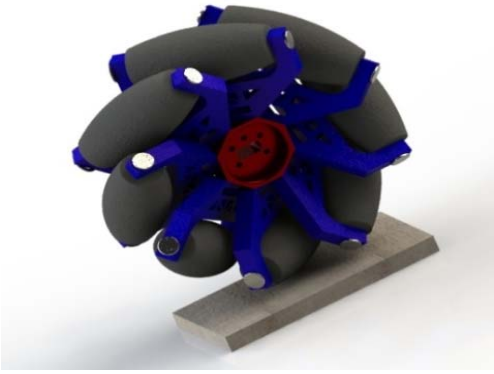


Figure 1 – New Design Proposed

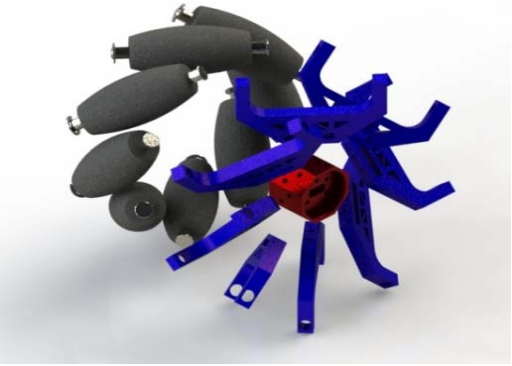


Figure 2 – Exploded view

II. SELECTION OF MATERIAL

The proposed design of the mecanum wheel is composed of a hub and eight forks with its respective roller as can be seen in the figure 1 and figure 2. The diameter and the width of the mecanum were designed to be 229.22 millimeters and 74.5 millimeters. The characteristics of this mecanum wheel were chosen based in the characteristics of the wheelchair. Therefore, the maximum speed of the wheelchair was fixed in 5 Km/h, and the weight capacity, a person of 80 kilograms. The hub and forks were made of aluminum and the rollers were made of nylon. Each fork was inclined at an angle of 45° related to the main axis of the wheel and they were connected to the hub by two bolts for easy installation and replacement in the case of damage or malfunction.

Moreover,eight rollers were installed through the bearings at each forkto rotate freely by the action of frictional forces generatedupon contact with the ground. In the figure 3 is shown the design of the rollers with its dimensions.

III. SIMULATIONS

Structures designed tend to fail by applying larger loads which cannot be withstood by them. They can undergo various node of failure such as, buckling, brittle, fracture, ductile fracture, impact, creep, thermal shock, wear, etc. as well as stress and strain failures [9].

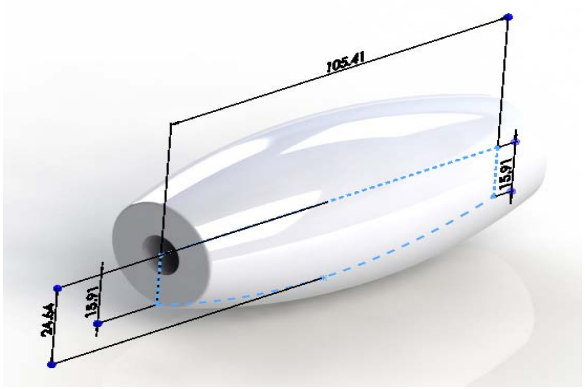


Figure 3 – Roller's 3D model (Dimensions in milimiters)



Figure 4 – Concept design of the wheelchair

FEA analysis was performed in order to check the feasibility of the structure. It was used the software SOLIDWORKS to perform this analysis. Simulations were also carried out to observe the influence of the natural frequency and the vertical vibrations of the proposed mecanum wheel. In this project, the mecanum wheels were designed to be installed on a four-wheel driving wheelchair, with articulated suspension to improve the comfort for the user and also improve the ride quality. The design of the wheelchair is shown in the figure 4.FEA Analysis of

the Mecanum Wheel The basic idea to check the feasibility it was to create a plane for the wheel to roll to check the force impact on both wheel and plane. Static loads are given to the wheel assuming the wheel at the rest and supporting the weight of the wheelchair structure and a person of 80 Kilograms using the wheelchair. The hole at the center of the hub is where the axle of the chassis is inserted. It was considered that all the forces are concentrated at the center of the Mecanum wheel.

The parameters given to the force applied as well as the dimensions and other characteristics of the mecanum wheel are shown in the table 1.

Table 1 –Parameters of the wheel

Width (mm)	Diameter (mm)	Self-weight (g)	Force Applied (N)	Materials		
				Hub	Fork	Roller
74.5	229.22	1731.94	196.2	AISI 1020	Aluminum	Nylon

The wheel was analyzed with a load of 196.2 N, what represents a load equivalent to the weight of the wheelchair plus the weight of a person of 80 kilograms divided by four, because the wheelchair has 4 wheels. In the figure 5 is shown the deformation experienced by the wheel structure when the load mentioned in the table 1 is applied.

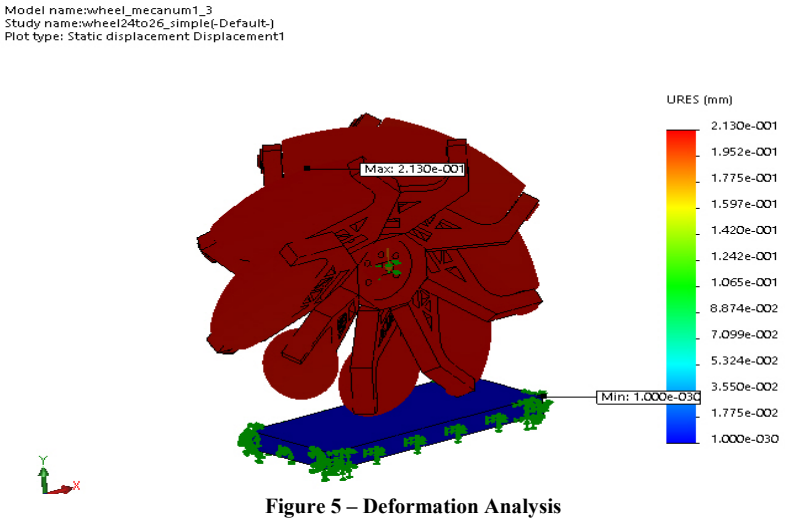


Figure 5 – Deformation Analysis

As can be noticed in the figure 5, the deformation distribution is equivalent in the whole structure, and the values obtained are very small, and the maximum deformation is 2.130e-1 mm, giving us the certain that this structure can support the load applied. And in the figure 6 it is shown the equivalent stress in the mecanum wheel.

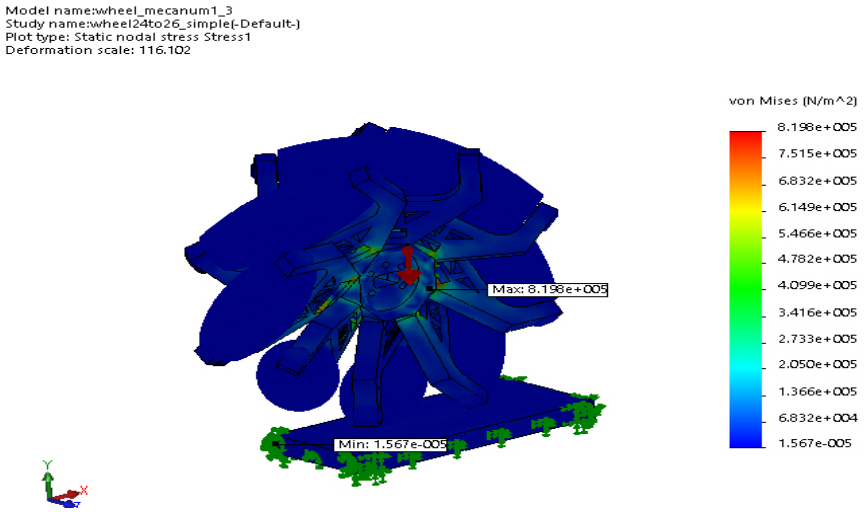


Figure 6 – Equivalent Stress Distribution in the Mecanum Wheel

From the figure 6, it can be concluded that the structure seems to be safe and there is equivalent stress distribution in the whole structure. In the table 2 is shown the maximum and the minimum stress in the structure and compared with the maximum stress allowed for each material that compose the structure.

Table 2 – Equivalent stress (Maximum and minimum)

Minimum Stress (N/m^2)	Maximum Stress (N/m^2)	Stress AISI 1020 (N/m^2)	Stress Aluminum (N/m^2)	Stress Nylon (N/m^2)
1.567e-5	8.198e+5	35.157e+7	27.5e+7	13.9e+7

As it is observed in the table 2, the maximum stress is much lower than the Yield strength of the materials applied in the confection of the wheel, making us to have sure of the safety of this structure and guarantying that the wheel can carry the load specified.

A transient structural analysis was performed to determine the time-varying displacements, strains, stresses, and forces in a structure as it responds to any transient loads. The structural analysis regarding to the roller, it must be done using an elastic material, with good adherence properties in order to assure traction [10]. In our analysis, the simulation were performed using rubber, nylon and polyurethane, which are the most commonly used materials for this type of rolling components.

The results of the simulation at the imposed loads (gravitational force, and 196.2 N vertical load) give us the following results:

- The value of Equivalent Stress (1.567e-05 N/m^2) is far below the ultimate tensilestrength of nylon (~13.9e+07 N/m^2);
- The contact area between the roller and the running surface represents anellipse, with major radius oriented along the roller's axis of rotation.
- The " Nylon " material chosen from SOLIDWORKS library proves to be resistant for this kind of applications, considering the loads imposed tothe mecanum wheel. Therefore, other materials should be considered forfurther research.

A. Vibration Analysis of the Mecanum Wheel

Vibration analysis can dramatically reduce the possibility of product failures; reduce expensive prototyping, speed-up product development [11]. Vibration simulations provide easy-to-understand results as it follows:

- Determine the natural frequencies and mode shapes to avoid resonance.
- Determine the response of product designs and components to vibration loads that are random such as bumpy roads, rocket launches, earthquakes, etc.
- Calculates the incremental failure accumulating in products over time due to repetitive vibrations imposed by everyday use.

In this work, it was performed vibration simulations in SOLIDWORKS to determine the natural frequencies and the vibration fatigue in order to build a mecanum wheel capable of supporting the random loads caused by the use of the wheelchair in off-road environments. In SOLIDWORKS simulation, the natural damped vibration is one of the first choices for the most analysis of the practical dynamic structures [12]. In this case, the damping vibration is called Rayleigh's damping and its factor gives the contribution of the coefficients α and β in damping rigidity and damping mass respectively. And it is represented for the following equation.

$$[D] = \alpha[K] + \beta[M] \quad (1)$$

Where [M], [D] and [K] are the mass, damping and stiffness matrices respectively.From the simulation, the natural frequencies obtained are show in the table 3.

Table 3–Vibration parameters of the wheel

Modes Number	Natural frequency (Hz)	Participating mass ratio (%) X direction	Participating mass ratio (%) Y direction	Participating mass ratio (%) Z direction
1	248.98	65.874	1.08E-04	0.020569
2	461.83	0.42427	0.079883	8.2156
3	475.53	7.94E-03	0.011908	4.7952
4	484.02	0.017856	10.111	0.20177
5	493.68	5.34E-03	0.093029	0.22442

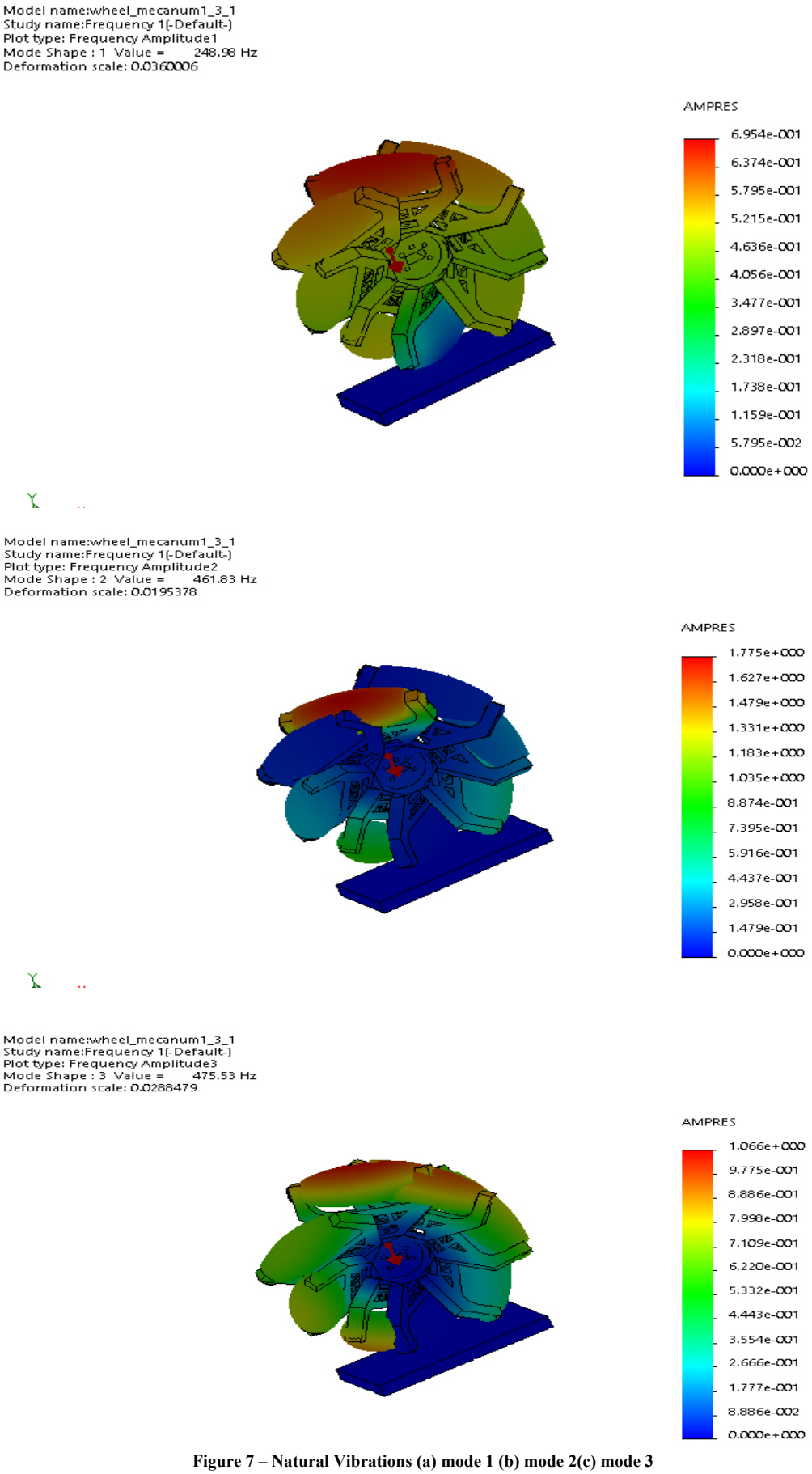


Figure 7 – Natural Vibrations (a) mode 1 (b) mode 2(c) mode 3

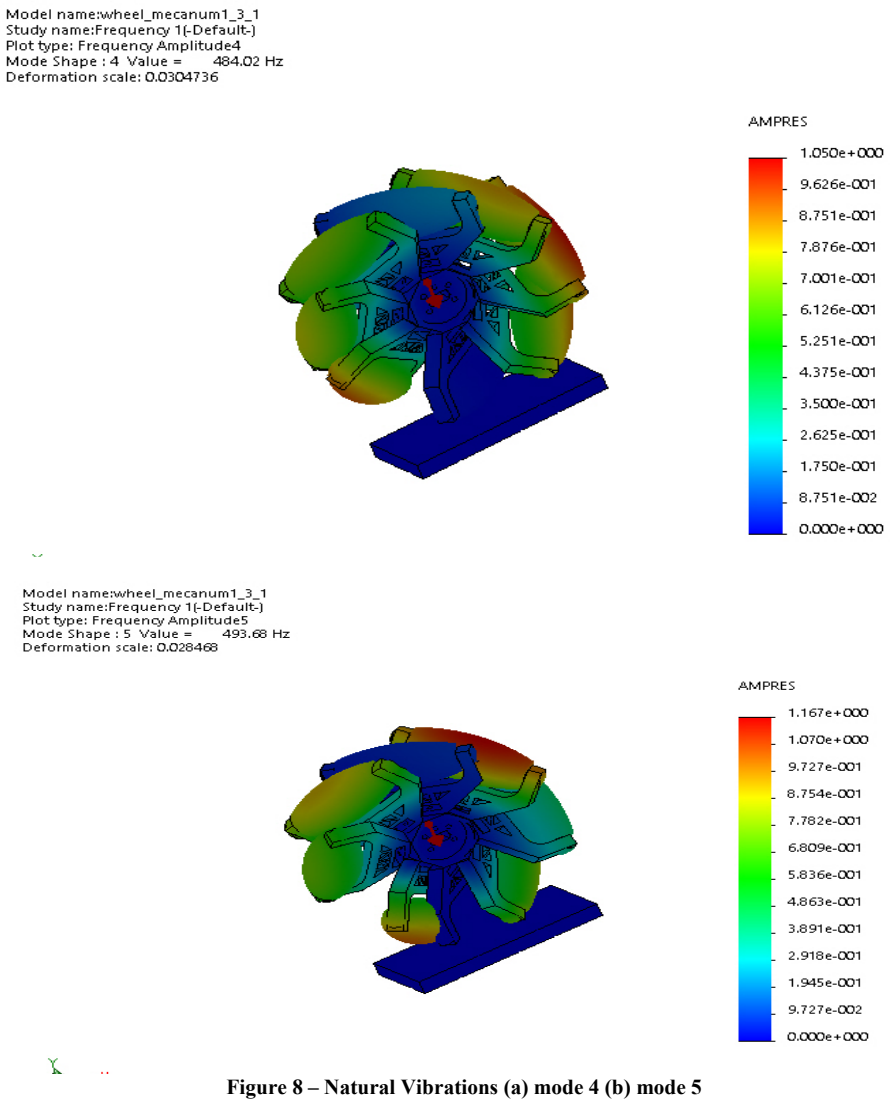


Figure 8 – Natural Vibrations (a) mode 4 (b) mode 5

From the table 3 and the figures 7 and 8, it can be infered that the 1st and 4th mode shapes induce a great strain of the structure. Those two mode shapes are the bending modes of the structure. Those modes are characterized by a great participating mass ratio. The 1st mode has a great participating mass ratio influence in X direction while the 4th mode has a great participating mass ratio in Y direction as can be seen in the table 3. In the figure 9 it is shown a graph that represents the relation between the frequency and the effective mass participation factor (EMPF).

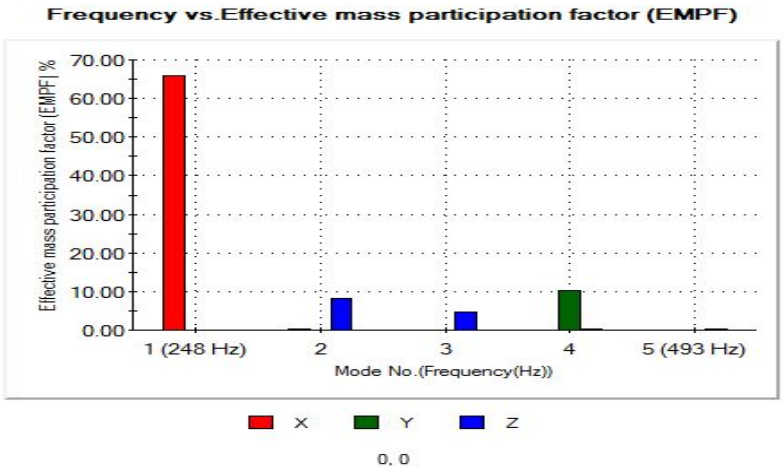


Figure 9 - Graph representing Frequency vs. EMPF

CONCLUSION

In the present paper, a new mecanum wheel design was proposed and the structure analysis were performed using the software SOLIDWORKS. The structure analysis simulation was based on 3D finite elements analysis. Strength, displacement and vibration simulation were presented in this paper. The ultimate purpose of this project is to make a power wheelchair with a better maneuverability and also give more comfort for the user. That is why the focus of this paper is the design of a new mecanum wheel in order to improve the mobility and give more freedom for the wheelchair users.

From the simulation results, the following conclusions were drawn:

- The proposed design is capable of carrying out a person with 80 kilograms.
- Just the first bending mode have influence on the structure modal behavior, the influence of the other nodes is feeble.
- Computer-Aided-Design save design resources, shortens product development cycle, verifies and assesses the design quality of the mecanum wheel before prototyping.

REFERENCES

[1] AnandaSankarKundu, OisheeMazumder, Prasanna K. Lenka, SubhasisBhaumik. “Design and Performance Evaluation of 4 Wheeled Omni Wheelchairwith Reduced Slip and Vibration”.2016 IEEE International Symposium on Robotics and Intelligent Sensors, IRIS 2016, 17-20December 2016, Tokyo, Japan.

[2] A. Ramirez-Serrano, R. Kuzik, G.Solana. “Elliptical double Mecanum wheels for autonomously traversing rough terrain”.

[3] Kundu, A.S., Mazumder, O., Chattaraj, R., Bhaumik, S. “Close loop control of non-holonomic wmr with augmented reality and potential field.”In: Engineering and Computational Sciences (RAECS), 2014 Recent Advances in. 2014, p. 15.

[4] FlorentinaAdascalitei, IoanDoroftei. “Practical Applications for Mobile Robots based on Mecanum Wheels – a Systematic Survey”. Proceedings of International Conference On Innovations, Recent Trends And Challenges In Mechatronics, Mechanical Engineering And New High-Tech Products Development – MECAHITECH’11, vol. 3, year: 2011.

[5] Kamdar, Shruti Deepak, "Design and Manufacturing of a Mecanum Wheel for the Magnetic Climbing Robot" (2015). Dissertations and Theses. 269.

[6] Khurmi, R. S, and J. K Gupta. A Textbook of Machine Design. New Delhi: Eurasia Publishing House, 2005. Print.

[7] V. Vlăduţ, S. Biriş, S. Bungescu, N. Faur. A. Cernescu, P. Cârdei, M. Matache, O. Kabaş, G. Paraschiv, At. Atanasov, Gh. Ivan. “The Verification of Stress by FEM Analysis/Mechanical Testing of a Traction Bar”.43. Symposium "Actual Tasks on Agricultural Engineering", Opatija, Croatia, 2015.

[8] R. Holmberg and O. Khatib, “Development and control ofa holonomic mobile robot for mobile manipulation tasks,”International Journal of Robotics Research,vol.19,no.11,pp.1066–1074, 2000.

[9] Matsumoto, K., T. Matsumoto, and Y. Goto. 'Reliability Analysis of Catalytic Converter as an Automotive Emission Control System'.(1975): n. page. Web. 12 Mar. 2015.

[10] Tiberiu GIURGIU, Constantin PUICĂ, Cristina PUPĂZĂ, Florin-AdrianNICOLESCU, Miron ZAPCIU. “Mecanum Wheel Modeling for Studying Roller-ground Contact Issues”. U.P.B. Sci. Bull., Series D, Vol. 79, Iss. 2, 2017.ISSN: 1454-2358

[11] https://blogs.solidworks.com/solidworksblog/2017/07/shock-vibration-simulation-tools-demystified-use.html

[12] CherifKhelifi, Mohammed Ouali, FatehFerroudji, LahouariAdjlout. “Modal Analysis of a Small SavoniusAerogenerator by Using SolidWorksSimulation”.Applied Mechanics and Materials Submitted: 2015-07-21, ISSN: 1662-7482, Vol. 806,pp 214-221, 2015 Trans Tech Publications, Switzerland.

[13] SOLIDWORKS Inc., 2016. SolidWorks help Guide. s.l.: s.n.

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