Vibration Characteristic Based Material Optimization of an Automated Wheelchair

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Abstract. The Multifunctional Wheelchair is an automatic vehicle which reduces the user’s efforts and time while moving from one place to another. A wheelchair is a backbone of a disable person and it must be strong enough to sustain the loading of humans. So in present study a motorised wheelchair was designed in Catia and analysed by Ansys on the basis of vibration frequency. Two different materials were analyzed for result comparison to find out the best suited material, which can sustain the failure under vibration and external loading. From the result it was found that aluminium T6 6061 material has higher resonance frequency than Stainless steel- 304. Furthermore aluminium T6 6061 material made base frame was analyzed by static structural analysis with 80 kg of person load. The Simulation result shows that the design wheelchair can sustain the applied loading, because the value of maximum stress in base frame was less than yield strength of used aluminium T6 6061 material.

Keywords: Wheelchair, Resonance frequency, Deformation, Optimization, FEA.

1. Introduction
A wheelchair helps disable people to living their life more comfortably and reduces the effort while moving from one place to another [1]. Now a day’s motorized and automatic wheelchair attracts the researcher’s attention in improving the structural stability and control. Many researchers contributed in designing the high strength and light weight wheelchair. Geonea I. et al [2] designed the wheelchair for disable person, two motors was used separately for the steering and traction control. 3D gear model was prepared using Solidworks and Adams software was used to find out the maximum traction and steering torque with a 70 kg human load. The design was analyzed by Structural analysis to find out the equivalent stress distribution. Thomas M. et al [3] A wheelchair frame was prepared in Solidworks and analyzed by ANSYS. AISI 4130 cold rolled steel alloy material was used for its high strength and less weight. The simulation result was compared with two different values of thickness and stress, deformation, factor of safety were calculated. Putra R. H. et al [4] design a wheelchair with standing mechanism, powered by linear actuators. The designed wheelchair was analyzed by inventor software to find out the stresses in the mild steel frame. Altalmas T. M. et al [5] designed a 3D wheelchair with lifting mechanism. The frame was designed with solidworks designing software and finite element analysis was used for analysis. Two different
materials (steel AISI1020 and Aluminium alloy 1350) were compared for stress and deformation results.

Chelliah R. I. et al [6] used a single geared motor to reduce the cost and weight of Wheelchair. In his Wheelchair the single geared motor moves the rear wheels where as the front wheels were powered by rack & pinion mechanism. The wheelchair was designed in Soildworks and stress, strain and deflection result were obtained by ANSYS software. Rao P. K. V. [7] designed a Tri-Wheel Mechanism for wheelchair, which was mounted in a triangle shape.

In existing literature we found that very less work is being done on vibration and structural strength of wheelchair. So in present study a wheelchair was analyzed on the basis of vibration frequency and static loading. Furthermore the wheelchair frame was analyzed for two different materials, to find out the best suited material. The present study was divided into following section: section 1) provide the introduction with literature, section 2) provide the details of CAD model and used material properties, section 3) describe the Modal analysis and result of modal analysis, section 4) describe the static structural analysis and result of static structural, section 5) conclude the complete study.

2. CAD design and material properties
We already know that the wheelchair is the backbone of a disable person, that’s why there was a tremendous increase in manufacturing of wheelchair now days. But before manufacturing, it was important to analyze the behaviour of wheelchair material under loading condition (person load). To analyze the material behaviour a CAD model of wheelchair was design in CATIA. Figure 1 shows the design model of wheelchair which contains the wheels and body frame. Table 1 shows the material properties which was used to analyzed the wheelchair body frame.

![Figure 1 3D CAD model of wheelchair.](image)

| Name of Material | Density (kg/m³) | Poisson ratio | Modulus of elasticity (MPa) | Ultimate tensile strength (MPa) | Tensile yield strength (MPa) |
|------------------|----------------|---------------|----------------------------|-------------------------------|----------------------------|
| Stainless steel- 304 | 8000          | 0.29          | 193000                     | 505                           | 215                        |
| Aluminum T6- 6061 | 2700          | 0.33          | 68900                      | 310                           | 276                        |
3. Modal analysis and simulation result

Modal analysis is a module of Ansys, in which designed CAD model of wheelchair was analyzed on the basis of vibration frequency. In modal analysis, when we apply the suitable boundary condition to the designed geometry, the loading condition was applied by the programme itself and it is the easiest method to find out the material behaviour [8-10]. The frame was simulated for two different materials, and first six modes of deformation were calculated with respect to vibration frequency. To perform the modal analysis fixed support and material properties were taken as the boundary condition. The body frame was fixed from where the frame was attached to the wheels (see figure 2). In figure 2 blue colour shows the fixed position boundary condition and figure 3 shows the mesh model of body frame. Stainless steel 304 and T6 6061 material based body frame was simulate for same boundary condition and the result were shown in figure 4 and 5 respectively. In all six mode shapes, deformation was shown by colour contour graph. Red colour shows the maximum deformation and minimum was shown by blue colour.

![Figure 2 Fixed boundary condition for lower frame. Figure 3 Mesh model of lower frame.](image-url)
Figure 4 Frequency variation for base frame made of Stainless steel- 304 material. Figure 4 & 5 shows the first six mode shapes in which body frame was subjected to different loading applied by the software itself. In figure 4 & 5 mode shape 1 to 6 shows the deformation in same direction but Aluminium T6 6061 material shows the higher resonance frequency.

Figure 5 Frequency variation for base frame made of Aluminum T6- 6061 material.
After simulating the base frame the upper frame was simulate with same material properties. Figure 6 and 7 shows the fixed boundary condition and mesh model of upper frame of wheelchair respectively. The upper frame was fixed from five positions; these five positions were the attachment position to the actuator and the base frame. The mode shape results of upper frame are described in figure 8 and 9, for stainless and aluminium material respectively.

**Figure 6** Fixed boundary condition  
**Figure 7** Mesh model of upper frame

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**Figure 8** Frequency variation for upper frame made of Stainless steel- 304 materials.
Figure 9 Frequency variation for upper frame made of Aluminum T6-6061 material.

Figure 10 Frequency response comparison of wheelchair base frame.
In figure 8 and 9 mode shapes 2, 3 & 6 shows the result in twisting loading condition. Figure 10 and 11 shows the frequency comparison of base frame and upper frame of wheelchair respectively. It can be seen that, aluminum T6 6061 material based wheelchair body frame gives higher resonance frequency and can be used for higher dynamic loading condition.

4. Static structural analysis and simulation result
In this section the base frame was analyzed by the static loading of 80 Kg (person load) using T6 6061 as frame material. We assume that, all the load of person was carry by the upper frame clamp road. Figure 12 shows the applied loading force (Newton) on the upper frame clamp road. The frame was fixed from the bottom wheels position as shown in figure 2. Figure 13 and 14 shows the total deformation and stress result respectively. From the figure 14, we can see that, the T6 6061 made base frame has maximum stress of 59.687 Mpa but T6 6061 has Ultimate tensile strength of 310 Mpa, which make the material safe under 80 Kg of person load. Furthermore, the frame can sustain more than 80 Kg of loading.
5. Conclusion
CATIA has been used for 3D designing of wheelchair. The design wheelchair frame was successfully analyzed by FEA software Ansys. The upper and base frame of wheelchair was analyzed for vibration using two different materials. The analysis helps in finding out the mode shapes and resonance frequency of design geometry. Figure 10 and 11 concludes that aluminium T6 6061 has higher resonance frequency. Furthermore, in static structural analysis the base frame was simulated by 80 Kg of static loading. The base frame sustained the deformation and can be used in heavy person loading application, because at 80 Kg of load it has very less stresses in the body frame (59.687 Mpa). For future work, it is interesting to analyse the actuator reaction/force applied on the frame joint position.

Reference

[1] Glaser, R. M., Sawka, M. N., Young, R. E., & Suryaprasad, A. G. (1980). Applied physiology for wheelchair design. Journal of Applied Physiology, 48(1), 41-44.

[2] Geonea, I. D., Dumitru, N., & Margine, A. (2015). Design And Structural Analysis Of A Powered Wheelchair Transmission. ACTA Universitatis Cibiniensis, 67(1), 37-43.

[3] Thomas, M., Bhaktar, A., Nair, A., Biju, B., & Shetty, A. (2019, January). Design and Analysis of the Frame of Smart Wheelchair. In 2019 International Conference on Nascent Technologies in Engineering (ICNTE) (pp. 1-6). IEEE.

[4] Putra, R. H., Rahman, A. G. W., Ningrum, E. S., & Purnomo, D. S. (2017, September). Design and stress analysis on electric standing wheelchair. In 2017 International Electronics Symposium on Engineering Technology and Applications (IES-ETA) (pp. 112-117). IEEE.

[5] Altalmas, T. M., Ahmad, S., Aula, A., Akmeliawati, R., & Sidek, S. N. (2013). Mechanical design and simulation of two-wheeled wheelchair using solidworks. In IOP Conference Series: Materials Science and Engineering (Vol. 53, No. 1, p. 012042). IOP Publishing.

[6] Chelliah, R. I., Paul, B. P., Gnanaraj, S. D., Paul, P. S., & Thomas, T. K. (2016, December). Design and Development of Cost Effective Motorised Wheelchair. In Proceedings of 6th International & 27th All India Manufacturing Technology, Design and Research Conference (AIMTDR-2016) College of Engineering, Pune, Maharashtra, INDIA.

[7] RAO, P. K. V. (2018). Design of stair-climbing wheelchair using tri-wheel mechanism. International Journal of Mechanical and Production Engineering Research and Development, 8(4), 685-694.

[8] Kumar, A., Jaiswal, H., Ahmad, F., & Patil, P. P. (2014). Dynamic vibration characteristics analysis of truck transmission gearbox casing with fixed constraint of vehicle frame based on FEA. Procedia Engineering, 97, 1107-1115.

[9] Ahmad, F., Bhandari, A., Kumar, P., & Patil, P. P. (2019, November). Modeling and Mechanical Vibration characteristics analysis of a Quadcopter Propeller using FEA. In IOP Conference Series: Materials Science and Engineering (Vol. 577, No. 1, p. 012022). IOP Publishing.

[10] Ahmad, F., Kumar, P., & Patil, P. P. (2020, August). Structural Analysis of a Quadcopter Propeller using Finite Element Method. In 2020 International Conference on Advances in Computing, Communication & Materials (ICACCM) (pp. 59-64). IEEE.