



Design of three speed planetary gear hub system with gear shifting mechanism

Prof. Tanuja Hulavale¹, Ganesh Kondbhar², Rahul Kole³

¹Asst.Professor Mechanical Engineering Vidya Prasarini Sabha's College of Engineering and Technology
,Lonavala

²Student Mechanical Engineering Vidya Prasarini Sabha's College of Engineering and Technology
,Lonavala

³Student Mechanical Engineering Vidya Prasarini Sabha's College of Engineering and Technology
,Lonavala.

ABSTRACT.

Today's 21st century has come a long way in the evolution of transmission systems. This paper aims in keen understanding and conceptual learning of Epi-cyclic gear drive system for transmission of power. The results of planetary gear transmission system yields the key characteristics such as high power density and compact design. To improve the detailed understanding of multi speed planetary gear hub systems, the work in this research will primarily guide through the utilization of these unique systems via the design of 3-speed planetary gear transmission system. Further to better predict the very potential and economical manufacturing process of planetary gears, first, the traditional manufacturing of gears is to be understood and thereby, speculating the creation of 3-D printed metal gears that will more accurately react to changing revolutionary manufacturing technologies and transmission systems, and make more effective use of these basic principles of gear system. The main objective, being, to brief the designers and manufacturers to rapidly conceptualize these basic ideas in to physically possible innovative models for the sake of revolution of the present gear technology

Keywords: Planetary Gears, Three speed system, Transmission system, Gear Technology, Shifting mechanism.

1.Introduction

Although the working principle of planetary gears has been known for years, there is still a great interest towards this types of device. The mechanical Engineers are interested with the aid of this mechanism because they efficiently remedy unique troubles. Planetary gear drives are combination of three main links: a sun toothed wheel, a carrier that hosts gears and a annular gear. In an epicyclic gear train the ring or sun gears maybe

stationary, and the other rotates about own axis. The planet wheel rotate along the carrier and around the carrier. There are mainly three arrangements for a gear train. The gear train may have: One input, one output and one fixed element. The sun or the Carrier may be the input shaft , the output is the other element. In this case the mechanism is a speed retarder (or accelerator). One input, two outputs, and no fixed element. The input shaft may be the carrier, the outputs sun and annular wheels. In this case the mechanism is a differential. The output torque is distributed between the output shafts. Two inputs, one output, and no fixed element. This mechanism is a speed integrator, since the output speed is a linear mixture of the speed of the two input shafts. To obtain a nearly uniform distribution of load among the planet gears and understand the gear calculations. [1] A suitable material was selected for which material selection was done with the help of the versatility and diverse applications of Iron element. Typical properties of Iron were listed down for better evaluation of iron related mechanical models.[2] Light-weight construction of gear system and consideration of in-hand resources resulted in the development with high load ability and power density of gearbox designs. At the instant, high reliability of gears are always expected. To also Optimize the epicyclic equipment train via load evaluation, to prevent load failure from happening in the future with minimum consideration acting load between the two meshing gears.[4] This research paper aims the fulfilment of the design approach in a generalized sense keeping in mind the required necessary parameters for planetary gear system. The generalized approach thus gives the designers to brain storm with the variable design ideas which can be more flexible and advanced than the existing three speed gear hub system. It was found necessary that the paper must conclude the designer with clear and precise basic steps of planetary gear calculations and load assumptions.

2.Problem definition

The bicycle is great suited for a future world due to change in climate, shortage in fuel and a rising population pressure, particularly in cities. Huge problems are spent for the improvement of the bicycle, but the basic design hasn't changed for a prolonged time. The design of bicycle has been significantly improved through the use of stronger and lighter materials, but, the argument ties closely with the new and improvised need for transmission system and therefore an idea for basic three) speed internal gear hub transmission system is introduced in this research.

Material Selection

The noise reduction of gears can be achieved by selecting a correct material. A regularly unnoticed, opportunity is to apply a material that has excessive acoustic damping skills, one such material is grey cast iron. But cast iron is taken into consideration to be susceptible and brittle and it's authentic that the gray irons are pretty brittle, ductile iron isn't always. The graphite is inside the shape of small, spherical nodules in a metallic matrix ductile iron. The common material used for gears is Cast iron's matrix. Both materials which are alloyed with carbon are strong, Carbon mixed with iron to form pearlite, which consists of alternating plates of strong iron carbide and soft Ferrite. In metals the amount of pearlite is controlled by the amount of carbon. The ratio of pearlite-to-ferrite has effect on energy, hardness and machinability in all types of irons. Cast iron is a composite metallic along with of caused graphite in a metal matrix. The mechanical properties in a cast iron part is affected by the size and shape of the graphite particles.

Ductile iron= Spherical Graphite= High tensile strengths. Gray irons= Flake graphite= low tensile strength.

The most suitable cast iron for gear manufacturing are Ductile and gray iron. Ductile iron with a ferritic matrix and 12LI4 steel has similar machining properties. The wear resistance can be improved by the increase the amount of pearlite. An absolutely pearlitic ductile iron has surest solid tensile strength (as much as 100,000 psi) with a 350 BHN hardness. Heat treating will growth power to 850,000 psi whilst quenched and tempered, and up to 970,000 psi whilst austempered.

Instead of steel in all gear applications cast iron is not an alternative material. However, all speed gears can take gain of the growth consistency in austempered Iron. Overall, cast iron may be a profitable answer for hassle created via acoustic and vibration, especially in programs where a mild decrease in power is a manageable change-off. The machining excellence of cast iron provide an environmentally pleasant opportunity to leaded steels, and its huge variety of properties allows the designer to opt the best appropriate grade for an application. Therefore, ductile iron is the most suitable type of forged iron for three-pace planetary transmission system.

3.Design Calculation

Light-weight production and consideration of to be had assets bring about internal hub designs with excessive power. At the same instant, durability of gear are mostly expected. Furthermore, distinctive types of teeth exist: e.g., spur and helical gears, and also double-helical gears are practicable where spur gears are considered. All of these situations require exquisite and robust design criteria, consisting maximum load and dynamic loads under different load situations. The product design process of a gear basically

The calculations for load.

To the point of structure analysis, Gear and component Design.

The quasi-static and dynamic behavior of the gear in actual conditions to be demonstrated. This process does not allow for an efficient gear calculation — especially considering the antsy of the load assumptions. In this case the highly unique and, in component, standardized calculations of system factors can simplest be relevant as a long way because the accuracy of the weight assumptions allow. Design approach for manufacturing of internal gear hub:

- The need for design and fabrication of 3-speed planetary gear transmission system generated.
- Effectively design 3- speed planetary gear system containing four planet gears and a sun gear.
- Creation of design by referencing Stormy Archer 3-speed internal gear hub.
- Assumption of load.
- The gear design calculations using design data book and the factor of safety determined using the same.
- cross verification of the components based on the design
- The CAD models developed considering different axes.
- The dynamic properties to be determined for its structure and meshing of the teeth of gears.
- The analysis performed for its structure and meshing of teeth by using FE analysis software. Let,

S: teeth on sun gear.

P: teeth on planetary gear. R: teeth on ring gear.

m: Module.

Ty: RPM of planetary carrier. Tr: RPM of ring gear.

Ts: RPM of sun gear.

$$(R+S)T_y = R \times T_r$$

$T_r + T_s \times S$ Since, the sun gear is stationary. Therefore, $T_s = 0$. Assumed data: $m = 0.65\text{mm}$. $P = 13$.

$$R = S + 2P = 42$$

Therefore,

$$(R+S)T_y = R \times T_r$$

$$\frac{T_y}{T_r} = \frac{R}{R+S}$$

$$\frac{T_y}{T_r} = \frac{60}{80}$$

For first gear, ring gear will be the driver, therefore,

First gear ratio = 0.75

For third gear, planetary carrier is the driver, therefore,

$$\frac{T_y}{T_r} = \frac{80}{60}$$

Third gear ratio = 1.33

D_s = pitch circle diameter of sun gear.

D_p = pitch circle diameter of planetary gear. D_r = pitch circle diameter of ring gear.

b = Width of the tooth. n = RPM of rear wheel

$$D_s = m \times S = 1 \times 16 = 10.4\text{mm} \quad D_p = m \times P = 1 \times 13 = 8.45\text{mm} \quad D_r = m \times R = 1 \times 42 = 28.6\text{mm} \quad b = 10 \times m = 10\text{mm}$$

$$V = 0.265 \text{ m/sec}$$

Dynamic Load Carrying capacity

$$P_d = 96.368 \text{ N}$$

$S_{ut} = 850$

$S_{yt} = 620$

$$S_b = 1059.4185 \text{ N}$$

Beam strength of gear

Wear Strength of gear Now,

$$S_w = 1184.8519 \text{ N}$$

Power

$$M_{tP} = 8580 \text{ N} \cdot \text{mm}$$

Torque Transmitted

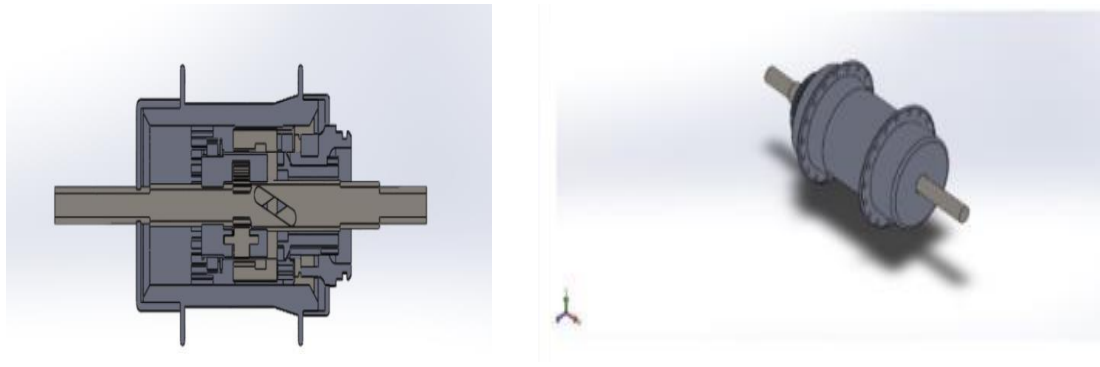


Figure 3.1. Section view and Isometric view of the system

4.Design of shifting mechanism

Despite the system has multi stage speed a mechanism, the engagement is obtained through ideally locking the rotating units via pawls with only working rotary units in action. The working units i.e. driven and driver are engaged through pawls.

1. For the First gear: The pawls on the driver unit will drive the ring gear unit and the pawls on the ring gear unit will drive the planet carrier, the pawls of the planet carrier will drive the hub shell having internal teeth.
2. Second gear: The pawls on the driver unit drives the hub shell having internal teeth. During this stage, the pawls on the ring gear unit are locked.
4. Third gear: In third gear, the complete system rotates. The pawls on the planetary carrier unit drives the ring gear unit and the pawls on the ring gear unit drives the hub having internal teeth.

Snap rings are used to restrict the sliding motion of sprocket. A sprocket is a toothed wheel upon which the chain slides. Ball bearings is used to reduce the rotational friction and guide radial and axial masses. It achieves this by using at the least races to masses. Stop ring will restrict the movement of planetary gear. Dust rings are rings provided to protect the grooves from dust and contaminants.

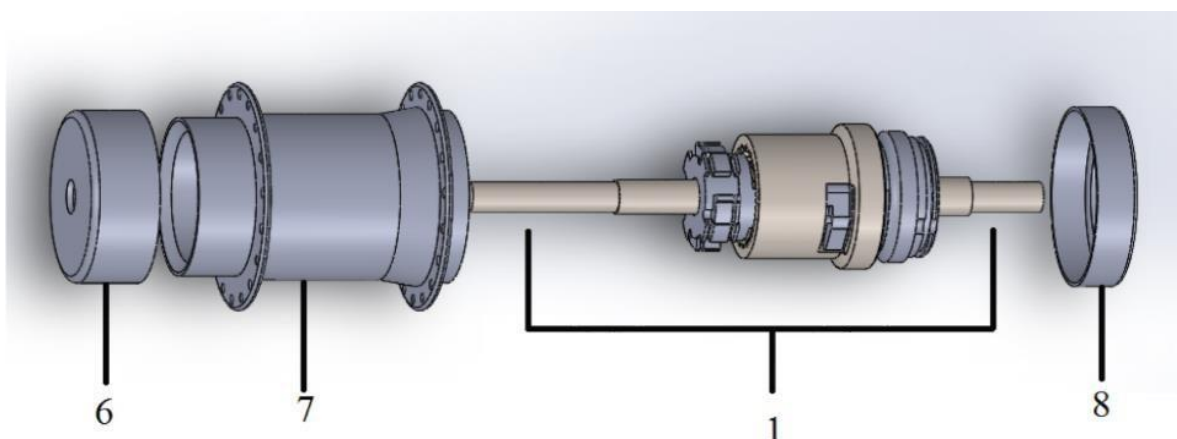


Figure 4.1. Exploded view of the system, 1 Internal Assembly, 6 Left hand hub cap, 7 Hub Shell, 8 Right hand hub cap

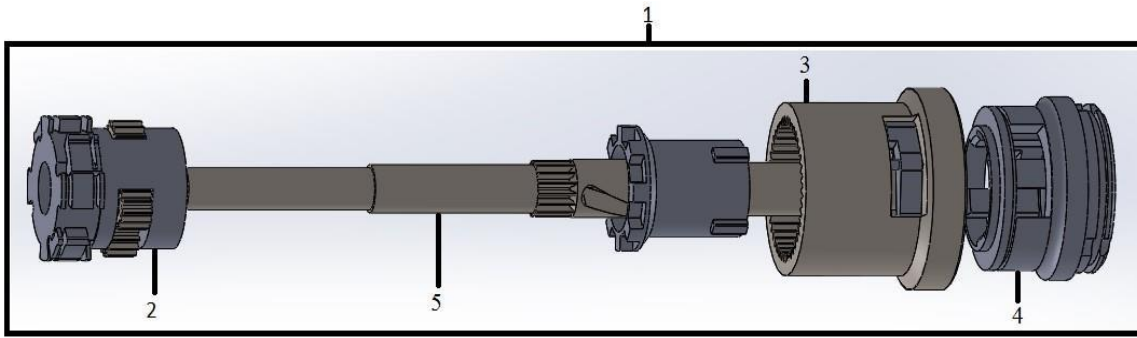


Figure 4.2 Exploded view of internal assembly, 2. Carrier unit, 3. Ring gear unit, 4. Driver unit, 5. Sun gear shaft unit

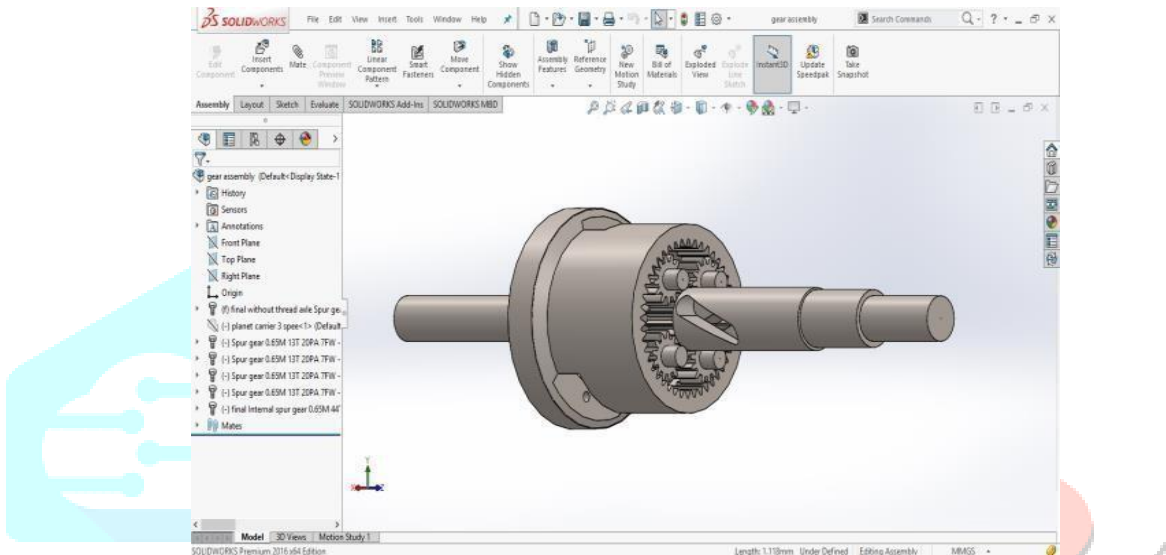


Figure 4.3 CAD model of final parts of assembly

Finite element analysis

The finite element analysis is capable of proving the longevity of the planetary gear. In order to reduce the modeling time, a 3-D model is created in solid modeling software. The model is transferred to ANSYS in IGES format after its construction. In ANSYS, one can click File > Import External Geometry > IGES > and check. The main focus of this analysis is:- 1) To develop and determine the bending stress using ANSYS and compare the results with conventional methods. 2) To compare the accuracy of results obtained in ANSYS by varying mesh densities.

The reaction of the gears is expressed in terms of strain, stress, displacement. The Static Structural is used as tool in the static analysis. The procedure of finite element analysis of spur gear is given below:-

- Creation of a 3D model of spur gear.
- Define the gear's material properties.
- Using finite element software meshing of the model.
- Boundary conditions for ANSYS Workbench as mentioned below
 - i) Fixed displacement constraint carried out on gear.
 - ii) Moment carried out on gear. iii) In order to arrest the displacement on x, y, z directions and rotation on

x, y directions remote displacement constraint on pinion surface.

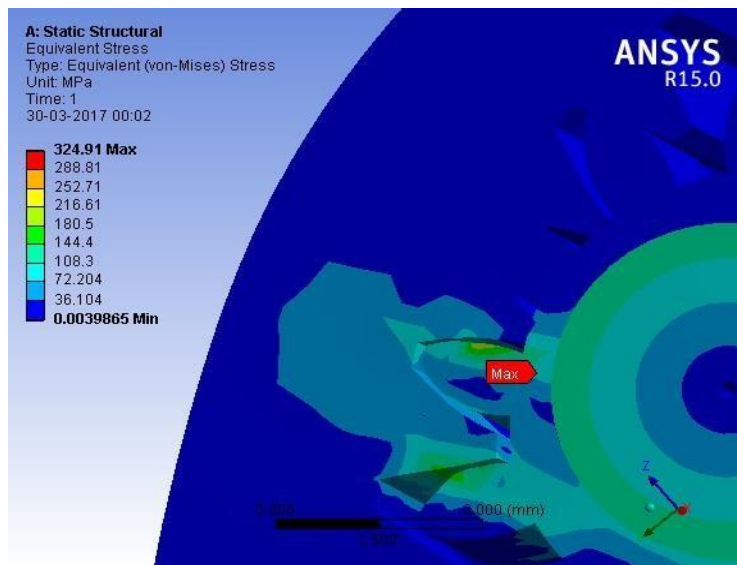


Figure 4.4. The CAD model of the gears used for FEA (Maximum stress – 325 MP)

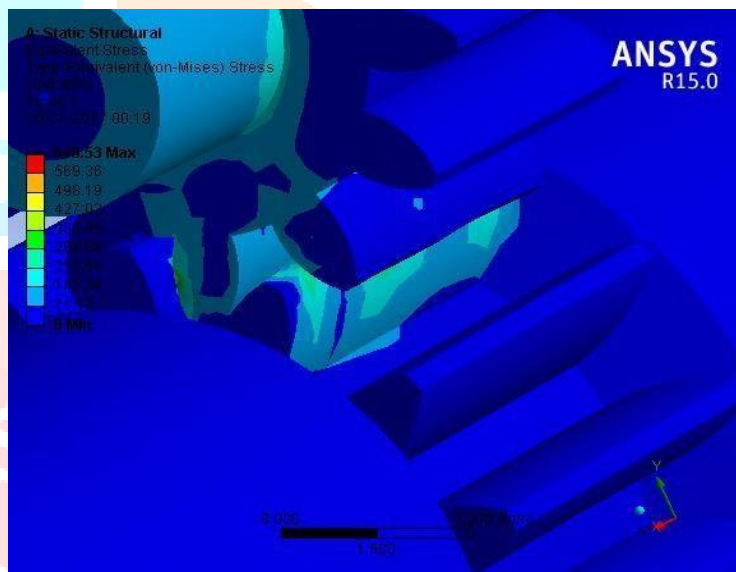


Figure 4.5. The CAD model of the gears used for FEA (Maximum stress – 640 MPa)

From the FEA Analysis we conclude that the Maximum stress generated is 325 MPa and 640 MPa as shown in Figure-05 and Figure-06. While the maximum ultimate stress of selected material is 340 MPa and yield strength is 840 MPa. So design is safe.

Manufacturing process

Gear production has been one of the maximum complex of the machining techniques. Objective is to cut the wide variety of operations or machines thru which a work gear desires to pass to acquire the final specifications of dimensions and teeth shape quality. The process for producing planetary gears and sun gear for internal hub, starting from raw material, are these production steps.

1. Soft- turning
2. Soft hobbing of gear teeth
3. Heat treatment
4. Hard-turning

- | | |
|--------------|------------------|
| 3. Deburring | 7. Grinding |
| 4. Shaving | 8. Finished gear |

Three-operation clean finishing ensures easy outside diameter (Shaving, grinding and honing). However the operation can be used is two operation blank cutting and finishing. The first operation involves the soft- turning and soft-hobbing of gear teeth. The second operation involves the deburring of gears with the deburring tool. The third operation involves the shaving of gear which removes small pieces of material scrap from the hobbled gear. Further the gear is heat treated for its better strength .At last the gear undergoes, hard-turning and grinding operations.

Future scope

Future research can be carried out on light-weight design for planetary gear transmissions. Also, we can find the benefits of the usage of a carrier in first place apart from planets float in system. A logical procedure to determine gear size can be observed and worked upon in future.

Conclusion

Based on the studies conducted in this look at the following outcomes and conclusions may be derived. 3-Speed i.e. multi stage planetary gear system was designed and approach is suitable. The system was successful under different loading conditions. The system is compact and free from contaminants due to dust caps. Three gear ratios are successfully obtained with this system. Use of standard components in the system can be well suited and can work effectively. The grade obtained for manufactured gears in near to its set value of AGMA 13 grade quality. The gearing processes to manufacture planet and sun gears can be manufactured using automated CNC gear shapers with clean processes. Precision amongst the manufacturing of tooth profile can be improved with the improved quality standards. The complete research is economically feasible. The research and design parameters has led to efficient working of the planetary gear system.

References

- [1] Joshi, R., & Darpe, A. K. (2018, September). Detection of Gear Tooth Crack in a Wind Turbine Planetary Gearbox. In International Conference on Rotor Dynamics (pp. 520-533). Springer, Cham.
- [2] Chen, T. H., & Long-Chang, H. (2019). The Design and Prototype Manufacture of a Planetary Gear Reducer. Proceedings of Engineering and Technology Innovation, 11, 46.
- [3] Chen, T. H., & Hsieh, L. C. (2018). The Design and Prototype Manufacture of Helical Gear Reducers with Two Gear Pairs. In Applied Mechanics and Materials (Vol. 883, pp. 37-42). Trans Tech Publications.
- [4] Hsieh, L. C., & Chen, T. H. (2016). THE ENGINEERING DESIGN AND TRANSMISSION EFFICIENCY VERIFICATION OF HELICAL SPUR GEAR TRANSMISSION WITH A SINGLE GEAR PAIR. Transactions of the Canadian Society for Mechanical Engineering, 40(5), 981-993.
- [6] Hsieh, W. H. (2013). Kinetostatic and mechanical efficiency studies on cam-controlled planetary gear trains (Part II)–Design and experiment.
- [7] Wu, Y. C., & Chan, C. T. (2018). A novel bicycle rear hub transmission with a magnetic gear mechanism. Advances in Mechanical Engineering, 10(7), 1687814018784825.
- [8] Wu, Y. C., & Chen, L. A. (2015). Design of an 8-speed internal gear hub with a rotary control

- mechanism for bicycles. *Tehnički vjesnik*, 22(4), 865-871.
- [9] Wu, Y. C., Chen, L. A., & Chang, C. W. (2014). Prediction of efficiency of an existing 14-speed bicycle internal drive hub. *Universal Journal of Mechanical Engineering*, 2(8), 266-273.
- [10] Wu, Y. C., & Sun, Z. H. (2013). Design and analysis of a novel speed-changing wheel hub with an integrated electric motor for electric bicycles. *Mathematical Problems in Engineering*, 2013.
- [11] Wu, Y. C., & Lin, S. L. (2011). Conceptual design of a 16-speed bicycle drive hub. In *Applied Mechanics and Materials* (Vol. 52, pp. 279-284). Trans Tech Publications.
- [12] Kim, J. (2016). Design of a compact 18-speed epicyclic transmission for a personal mobility vehicle. *International Journal of Automotive Technology*, 17(6), 977-982.
- [13] Xue, S., Entwistle, R., Mazhar, I., & Howard, I. (2016). The spur planetary gear torsional stiffness and its crack sensitivity under quasi-static conditions. *Engineering Failure Analysis*, 63, 106-120.
- [14] Gu, C., & Chen, X. (2016). A novel universal reducer integrating a planetary gear mechanism with an RCRCR spatial mechanism/Integracija planetnega gonila in prostorskega mehanizma RCRCR v novem univerzalnem reduktorju. *Strojniski Vestnik-Journal of Mechanical Engineering*, 62(12), 730-741.
- [15] Tesar, D. (2018). *U.S. Patent No. 9,862,263*. Washington, DC: U.S. Patent and Trademark Office.
- [16] Xue, S. (2016). *An investigation of gear meshing behaviour of planetary gear systems for improved fault diagnosis* (Doctoral dissertation, Curtin University).
- [17] Hsieh, L. C., Chen, T. H., & Tang, H. C. (2015). The design and meshing efficiency analysis of helical spur gear reducer with single gear pair for electric scooters. *Transactions of the Canadian Society for Mechanical Engineering*, 39(3), 455-465.
- [18] Cooley, C. G., & Parker, R. G. (2014). A review of planetary and epicyclic gear dynamics and vibrations research. *Applied Mechanics Reviews*, 66(4), 040804.
- [19] Lin, J., & Parker, R. G. (1999). Analytical characterization of the unique properties of planetary gear free vibration.
- [20] Chen, L. A., Ren, P. W., & Wu, Y. C. (2013). Design of a Gear-Shifting Control Mechanism for 8-Speed Bicycle Drive Hub. *Smart Science*, 1(2), 94-98.
- [21] Hsieh, W. H. (2013). Kinetostatic and mechanical efficiency studies on cam-controlled planetary gear trains (Part I)– Theoretical analysis.
- [22] Tsai, M. C., Huang, C. C., & Lin, B. J. (2010). Kinematic analysis of planetary gear systems using block diagrams. *Journal of Mechanical Design*, 132(6), 065001.
- [23] Tsai, M. C., Huang, C. C., & Lin, B. J. (2010). Kinematic analysis of planetary gear systems using block diagrams. *Journal of Mechanical Design*, 132(6), 065001.
- [24] Hsu, C. H. (2002). An analytic methodology for the kinematic synthesis of epicyclic gear mechanisms. *J. Mech. Des.*, 124(3), 574-576.
- [25] Nyunt, S. Z., Thanlyin, M., & Latt, A. H. 3D Modeling of Five Speed Manual Transmission System for Teaching Aid Vehicles.
- [26] Uematsu, S. (1997). An application of graph theory to the kinematic analysis of planetary gear trains. *International Journal of the Japan Society for Precision Engineering*, 31(2), 141-