Introduction to Gears

A gear, also known as a cogwheel, is an important rotating component of machines that is used to transmit power in the form of angular velocity and torque to other rotating gears. Structurally, it comprises of cogs or cut teeth on the edges which fit into the teeth of adjacent gears for power transmission. A gear train is formed by two or more gears working in sync with each other and transmitting power between one part of a machine to another. The main application of using gear trains in machines is for changing the speed and direction of the machine. Gears may also be coupled with other machine components such as racks to influence the movement of the machine in different ways (Chime and Ukwuaba, 2016).

Gears have the advantage of being able to transmit huge loads and working with a very high efficiency. Several complex calculations need to be done to make the maximum use of gears in sophisticated mechanical systems. By optimizing the gear mechanism, the functionality of transmission systems can be improved, thus positively affecting the performance efficiency of the machine (Petrescu and Petrescu, 2014). This type of complex calculations can be time consuming, cumbersome, and error-prone; however, the appropriate use of computational techniques for the design and analysis of gears can enhance the functionality and performance of the component leading to an overall increase in production efficiency of the machine.

This literature review aims to cover different aspects pertaining to the types of analysis, history of computational analysis, computational analysis pertaining to the different types of gears, and factors to be considered when performing computational analysis.

History of Computational Examination of Gears

Before the advent of computers, engineers would prepare drawings manually using a pencil, paper, and drafting instruments. With the advent of computers, interactive computer graphics was born which soon gave way to the use of a computer monitor and mouse for the preparation of engineering drawings. The concept of Computer-Aided Design (CAD) soon became widely adopted and the available software became more specialized with advanced tools and commands for the design, analysis, modification, and transformation of machine components. Where manual analysis of machine components was two-dimensional, CAD offered three-dimensional capabilities where 3D coordinates were used to model machine components (Chime and Ukwuaba, 2016).

Specifically, computer software programs are used for the following functions:

1. Geometric modeling
2. Engineering analysis calculations
3. Automated testing
4. Automated drafting

The advent of CAD has made the process of preparing computational models of gears relatively easy. Mathematically, an equation of cutter and generating mechanism is used to derive an accurate model for a gear (Wang *et al*., 2017). Several computer software have contributed to the ease with which these models are generated and analyzed. The SolidWorks API has effectively simulated the manufacturing processes of gears, especially the shaving process (Chang *et al*., 2013). Inventor has specifically been used to simulate the manufacturing processes of spherical gears (Wang *et al*., 2016).

Modern CAD systems have enhanced capabilities of gear design and analysis. They are widely used for 3D modeling of individual components that form a significant part of large and complex machines. Apart from this, they are also used to perform complex engineering calculations, prototyping, preparation of production setups, preparation of control programs, and a comprehensive management of all engineering analysis data (Antonov, 2018).

Types of Computational Gear Analysis

The two important types of gear analysis that can be performed computationally are described below:

Static Analysis

Static analysis of gears is used to determine reaction forces when a constant load is applied at joint positions of gears in the resting stage. Typically, static analysis is performed at different points of range of motion in mechanisms assuming zero velocity. Using this method of analysis, reaction forces can be determined for entire machine systems and also inter-joining forces transmitted between individual gears can be accurately determined. Data obtained from static analysis can be used to determine compatibility between the gears and other components as per the specified criteria for the machine (Chime and Ukwuaba, 2016).

Experimental Analysis

In experimental analysis, a prototype of a machine or a specific component is fabricated and subjected to different experimental conditions for computational examination (Chime and Ukwuaba, 2016). Machine components, especially gears, are often subjected to harsh operating conditions and a large number of continous load cycles. Continual use of heavy loads, high speeds, and inappropriate operating conditions may lead to severe, sometimes irreversible, damage to the machine components. Hence, it is quite important to perform thorough experimental analysis of a model before taking it to the production stage (Amarnath *et al*., 2011).

There are several approaches by which a thorough experimental analysis can be performed using computational methods. Signal processing techniques are used to obtain frequency and time spectra, which can be analyzed further for component defects. The vibration signature of a model gives an estimate of the severity of the defect and frequency analysis helps narrow down the source of the damage. Other specific wear-and-tear problems that can be analyzed for gears include scoring, pitting, spalling, and breakage of teeth. In the presence of fault growth on the surface of the teeth, the stiffness of the gears can be modified leading to changes in the vibration levels (Amarnath *et al*., 2011).

Types of Gears and their Computational Analysis

Several types of gears exist and are chosen for various end applications of machines. Given below are the different types of gears and the methods to perform computational analysis for each of these.

i. Spur Gears

Spur gears are the most basic gears comprising of a radial disk with projecting teeth. Design and analysis of a spur gear transmission system requires careful selection of parameters for the gear including the strength of gear teeth. Apart from this, the strength and rigidity of the rotating shaft is also calculated for the design of the shaft, and the calculated lifetime of bearings gives an estimate of the durability of the transmission system. Other parameters that are considered for the computational analysis of spur gears are force analysis, bending stress of gear teeth, durability, and gear geometry (Geramitcioski and Trajcevski, 2003).

ii. Helical Gears

This type of gears are used in power transmission systems that need to carry heavy loads at high speeds and need to function with minimal generation of vibration and noise. Their computational design and analysis is very critical due to their high functional requirements. The helical gears in the power transmission system need to have identical width, long teeth, enhanced load carrying capability, high touch ratio, and smoother operational capacity (Naresh and Chandrudhu, 2016).

iii. Bevel Gears

Bevel gears are positioned in power transmission systems where two shaft axes intersect and are placed at a specific angle to each other. The teeth of the bevel gears are conically shaped and their computational analysis needs to account for all parameters that contribute to their structural and functional specificity. Modifying the parameters can give rise to either straight or cylindrical bevel gears ensuring that the involutes are curved appropriately to give the specific shape and flank form. The bevel gear teeth need to be aligned on a spherical plane and the number of teeth needs to be estimated based on the other parameters (Sharma and Chauhan, 2016).

iv. Worm Gears

This is another type of specialized gear that is widely used in cross-axes transmission systems. It is preferred for most applications because of its self-locking capabilities and high gear ratio. The contact dynamics between two adjacent worm gears is very important in minimizing manufacturing errors and this can be solved accurately by computational methods (Chen and Tsay, 2011).

Unlike other gears, the virtual manufacture of worm gears depends on the generation motion between the generated gears and the cutter. The inversed mechanism concept is applied here where the cutting edge of the gear is rotated along the axis of the worm. A worm-type hob cutter is used to generate the model and the worm gear's rotation angle is obtained by dividing the cutter's rotation angle by the gear ratio. Parameters such as pressure angle, axial module, number of teeth, and pitch diameter may be altered to obtain different types of worm gears (Wang *et al*., 2017).

Factors to be Considered for Computational Examination of Gears

The different aspects of gears that are important for their accurate design, analysis, and simulation are described below:

i. Gear Geometry

Gear geometry is a very important factor in the computational examination of gears. Any change in gear geometry can increase localized stress, decrease errors in transmission, and promote smoother interactions. Every gear has certain specific areas whose size and shape determines the amount of stress that can be concentrated on the gear. One example is the radius of curvature of the gear that determines several functional aspects of the machine (Paul and Bhole, 2010).

A basic geometry theory has been developed to design and analyze gears with asymmetric teeth. This enables engineers to increase the load carrying capacity of the gear system, reduce its weight and dimensions, and minimize its noise and vibrations. The two important parameters that need to be considered in this method are contact ratio and pressure angle (Kapelevich, 2000).

ii. Transmission Error

Error in power transmission between the master gears and the slave gears is an important cause for vibration and noise in the machine. Several techniques are used to reduce this error, and an important one is 'Tooth Profile Modification'. This involves modifying the geometry profile of the gear by means of root relief or tip relief to positively regulate transmission error of gears (Paul and Bhole, 2010).

iii. Gear Tooth Stress

An important aspect of computational examination of gears is stress analysis which determines the parameters that affect interlocking of gears in complex mechanisms. The Finite Element Method (FEM) is one of the first and most popular methods for analyzing gear tooth stress. Wilcox *et al* (1973) simulated gear tooth in two dimensions along with finite elements and determined the stress values of the model. Both symmetric and asymmetric profiles were analyzed using this method and a simplified stress formula was determined where stress was given as a function of tooth shape of the gear and loading conditions (Wilcox *et al*., 1973). A cyclic symmetry concept has also been described where teeth displacement was used to calculate the gear teeth stress. This greatly reduces computational effort for stress analysis and the process is much more efficient (Ramamurti *et al*., 1998).

iv. Contact Ratio

Increasing the contact ratio of a gear system should be carefully considered as it has both advantages and disadvantages. It leads to the introduction of compressive stress and lower bending in the system which are positive consequences; however, it can also lead to increase in flash temperature and heat generation due to friction (Staph, 1976).

v. Strength Calculation

In most modern software such as SolidWorks, AutoCAD, CATIA, and TopSolid, strength and kinematic calculations are performed automatically. The structural aspects of the gear system can be modified countless number of times until the desired strength value is achieved.

However, if specific processes for determing the strength of gear systems need to be followed, a program can be developed using MATLAB or MathCad wherein loads are placed on the model of a gear system and the strength of the assembly is calculated (Antonov, 2018).

Conclusion

The age of computational examination of gears has brought a revolution in the way machine components are designed, analyzed, and simulated, and has led to the realization of several engineering objectives very rapidly. Hundreds and thousands of studies have been conducted to try and devise different approaches to accurately design individual machine components and test them in assembly. It gives the advantage of saving time and production cost when most of the understanding and comprehension can be achieved at the design and simulation stages. However, a deep comprehension is needed to modify parameters correctly and to assign values to strength, kinematics, and structural parameters to obtain the desired result. Engineers now have a myriad of approaches and computational models to choose from when prototyping a particular machine component and the flexibility to do so paves the way for the birth of engineering miracles.

References

Amarnath, M., Chandramohan, S., & Seetharaman, S. (2011). Experimental investigations of surface wear assessment of spur gear teeth. Journal of Vibration and Control, 18(7), 1009–1024. doi: 10.1177/1077546311399947

Antonov, S.I. (2018). Trends in Computer Design of Reduction Gear. International Scientific Journal “Machines, Technologies, Materials”, 12(11), 440-444.

Chang, S. L., Huang, C. K., Doan, K. H., & Liu, J. H. (2013). Serration Design and Simulation of Gear Plunge Shaving Cutter. Applied Mechanics and Materials, 376, 377–382. doi: 10.4028/www.scientific.net/amm.376.377

Chen, W.L., and Tsay, C.B. (2011). Mathematical Model and Tooth Surfaces of Recess Action Worm Gears with Double-Depth Teeth. Journal of Mechanism and Machine Theory, 46, 1840-53.

Chime, R.O., & Ukwuaba, S.I. (2016). Design, Modeling, Simulation of Spur Gear; Analysis of Spur Gears. International Journal of Engineering Research and Development, 12(1), 56-67.

Deshmukh, S. (2014). Computer Aided Modeling, Design and Analysis of Spur Gear. International Journal of Mechanical, Civil, Automobile and Production Engineering, 14(12), 209-214.

Geramitcioski, T., & Trajcevski, L.J. (2003). Design Analysis of Spur Gear with the Usage of the Advanced Computer. International Conference Power Transmissions 3.

Kapelevich, A. (2000). Geometry and design of involute spur gears with asymmetric teeth. Mechanism and Machine Theory, 35(1), 117–130. doi: 10.1016/s0094-114x(99)00002-6

Naresh, K., & Chandrudhu, C. (2016). Design and Analysis of Helical Gear. International Journal of Professional Engineering Studies, 6(4), 194-203.

Paul, I.D., & Bhole, G.P. (2010). Modification of Spur Gear Using Computational Method-Involutes Profile Being Modify. Proceedings of the 2010 International Conference on Industrial Engineering and Operations Management, 197-203.

Petrescu, F.I., & Petrescu, R.V. (2014). Gear Design. Engevista, 16(4), 313-328.

Ramamurti, V., Vijayendra, N. H., & Sujatha, C. (1998). Static and dynamic analysis of spur and bevel gears using FEM. Mechanism and Machine Theory, 33(8), 1177–1193. doi: 10.1016/s0094-114x(97)00112-2

Sharma, N., & Chauhan, D.V.S. (2016). Design & analysis Of Bevel Gear for Dynamic and Wear Loading using geometrical programming. International Journal of Innovative Science, Engineering & Technology, 3(7), 202-212.

Staph, H. E. (1976). A Parametric Analysis of High-Contact-Ratio Spur Gears. A S L E Transactions, 19(3), 201–215. doi: 10.1080/05698197608982795

Takashi, Y. (1990). The Novel Conical Gear and Spherical Gear with Variable Cross-Section Shapes Mechanical Design, 34(13), 53-60.

Wang, P.Y., Chang, S.L., & Cao, C.W. (2016). CAD/CAE of Spherical Gears. Proceedings of the International Conference on Automation, Control and Robotics Engineering, doi: 10.1145/2952744.2958871

Wang, P. Y., Chang, S. L., Lee, B. Y., Nguyen, D. H., & Cao, C. W. (2017). Characteristics study of the gears by the CAD/CAE. IOP Conference Series: Materials Science and Engineering, 235, 012009. doi: 10.1088/1757-899x/235/1/012009

Wilcox, L., & Coleman, W. (1973). Application of Finite Elements to the Analysis of Gear Tooth Stresses. Journal of Engineering for Industry, 95(4), 1139–1148. doi: 10.1115/1.3438262