

# Development of Computer-Based Model for Design and Analyses of Worm Gearing Mechanism

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**Abstract**—Current computer software for designing gear systems have limited flexibility and few offer multiple gearing design options. The objective of this study was to develop an interactive package for the design and analyses of worm gearing mechanisms. The worm gears were designed based on full-depth involute teeth. Mathematical models were developed to compute geometry factors for surface durability of single-enveloping worm gearing cases which were extracted from established American Gear Manufacturers Association (AGMA) standards. Maximum percentage errors from the geometry features, bending loads and wear loads are 0.97%, 3.27% and 1.77% respectively and insignificant. A software capable of computing geometry parameters, bending and wear loads, and selecting appropriate materials for worm mechanisms with good accuracy has been developed.

**Index Terms**—Single Worm; Gear Design; Bending Loads; Wear Loads

## I. INTRODUCTION

When a drive application requires rotary motion to be transferred with speed change or torque change, a number of options available are controlled by system layout, economics and power capacity. The drive transmission selection can be made from the following options: belt drive, chain drive, and gearing mechanism. Toothed gearings convert and transmit rotary motion between shafts with parallel, intersecting, non-parallel, and non-intersecting (crossed) axes; and also convert rotary motion into translational motion, and vice versa. Gear drives are used to transmit power between a prime mover and driven machinery. In addition to the simple transmission of power, gear drives usually change or modify the power being transmitted by: reducing speed and increasing output torque; increasing speed and reducing output torque; changing the direction of shaft rotation; and changing the angle of shaft operation. Worm gearing has won wide acceptance for industrial drives because of its many advantages of conjugate tooth action, arrangement, compactness, and load-carrying capacity. It is quiet, vibration-free and produces

constant-output speed.

Suresh and Purushotham [1] used structural ANSYS to modify the initial design of mechanism to meet the requirement of various drooping intervals of goods such as food items, and cloths bags during cyclone. Sensitive analysis was also carried out to bring out the influence of design parameters on stress and natural frequency of worm gear mechanisms. Ankush and Deride [2] and Oladejo *et al.* [3] developed a self-locking worm gear system with 90% efficiency which was higher than the conventional worm gear system with 40% efficiency [4]. Mokara *et al.* [5] employed Genetic Algorithm (GA) for optimizing the worm-worm wheel to attain high wear capacity by considering module, power, velocity ratio, and speed as design parameters. Center distance and strength of worm gear are the constraints taken into consideration. Based on the generation mechanism and the theory of gearing, Wei-Liang and Chung-Biau [6] developed a mathematical model of a series of worm gears, semi recess action (RA), full RA and standard proportional tooth types, with double-depth teeth as the function of design parameters of the ZN worm-type hob cutter. Tooth surface variations of the generated RA worm gears due to the varying pitch line, pressure angle and tooth height of the hob cutter were investigated.

Litvin *et al.* [7] proposed methods for localization of bearing contact and reduction of transmission errors achieved by double-crowning of the worm of the drive with respect to the hob, the tool that generates the worm gear. A computer program for the simulation of meshing and contact was developed. Wang *et al.* [8] investigated the load capacity of end face engagement worm gear to provide the theoretical basis and industrial applications value for transient analysis of end face engagement of worm gear and manufacturing constant in the future. Argyris *et al.* [9] improved design of worm gear drive based on application of an oversized hob and worm generated by varied plunging of the generating tool. It was discovered that worm generation without tool plunging may cause positive transmission errors, unacceptable for favorable conditions of force transmission. Positive transmission errors are the herald of possible surface interference.

Abu *et al.* [10] and Chim *et al.* [11] developed computer-based models with algorithms implemented using MATLAB. The models generated the geometric parameters of the gear and carried out the stress analysis. The stresses analyzed included static load, dynamic load, wear load and heat dissipation capacity in case of worm gear. Four different gears were analyzed for geometric parameters using the model and they all gave results that showed good agreement with analytical results. Oladejo and Ogunsade [12] developed drafting software for gear using AutoCAD-

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VBA. Falah and Elkholy [13] presented a method for calculating load and stress distributions of the instantaneously engaged teeth of cylindrical worm gears. The method was based on assumption that both worm and gear can be modeled as a series of spur gear slices and gave results in agreement with experimental and analytical results.

Seol and Chung [14] developed a computer program which allows the investigation of the influence of misalignment on the shift of the bearing contact and the determination of the transmission errors, the contact ratio and the principle curvatures. The developed approach was applied to ZK type of single-enveloping worm gear drives and the developed theory was illustrated and validated with a numerical example. Oladejo and Bamiro [15] revealed in a survey that only 22.0% of respondents were using existing gear design software and of these 75% used the software for computation of gear features alone, while the rest used multiple software for gear features computation and stress analyses. Bamiro [16] presented a user-friendly software for the design of machine tool gearbox using of C++ to handle specific power transmission and speed ratios (1:2 and 1: 4). Mott [17] presented a computer assisted gear design program for spur and worm gear sets on the platform of QBASIC compiler but employed the diametral pitch system.

Prasad [18] developed a package with analysis capabilities and is appropriate to use when investigating the use of an existing pair of gears in a new application. The input data involves the horsepower or torque at a particular gear, the materials for the pinion and gear, the operating centre distance, number of teeth on the pinion and gear, the pressure angle, face width, pinion RPM, operating temperature, module.

The gear stress analysis, transmission errors, prediction of gear dynamic loads, gear noise, and the optimal design for gear sets are always major concerns in gear design. The specific objectives of this paper are: (i) design algorithms for the design and analysis of the single-enveloping worm considering interference, bending fatigue and pitting fatigue, (ii) development of a computer-based interactive model in place of the algorithms, on the platform of Visual Basic (VB). This includes database for common materials that may be extended by the user with new materials, and (iii) validation of the package by comparing its operational principles and outputs with that of contemporary CAD packages, and existing solutions of standard problems from sets of standard literature.

## II. METHODOLOGY

### A. Analysis of Worm Gear Geometry Features

Successful application of worm gearing begins with an understanding of its unique characteristics and a consideration of the requirements of the application. Worm gearing consists of a threaded input member driving a larger toothed worm gear at right angles. The number of teeth in a worm gear is determined by the required ratio and the minimum number of teeth required for acceptable design. The number of threads in the worm,  $N_w$ , is determined by

the number of teeth in the worm gear,  $N_g$ , and the required ratio,  $m_g$ , as follows:

$$N_w = \frac{N_g}{m_g} \quad (1)$$

The normal range of the number of thread in the worm is one to ten although larger numbers are used, particularly for larger worm gears. For usual application, a worm pitch diameter,  $d_w$ , is selected to fall within the following ranges [19]:

$$\frac{c^{0.875}}{2} < d_w < \frac{c^{0.875}}{1.07} \quad (2)$$

where,  $c$  is centre distance.

The worm gear pitch diameter,  $d_g$ , is calculated as follows:

$$d_g = 2c - d_w \quad (3)$$

A basic requirement of the worm gearing set is that the axial pitch ( $p_{aw}$ ) of the worm must be equal to the circular pitch of the gear ( $p_{cg}$ ) for proper meshing as expressed in (4).

$$p_{aw} = p_{cg} \quad (4)$$

The worm axial pitch is the distance in the axial plane from a point on one thread of the worm to the corresponding point on the next thread. The circular pitch of the worm gear is the distance from a point on a tooth on the pitch circle of the gear to the corresponding point on the adjacent tooth, measured along the pitch circle as shown in Fig. 1.

$$p_{cg} = \frac{\pi d_g}{N_g} \quad (5)$$

The worm lead ( $L_w$ ) is the amount of the axial advance of any point on the worm in one revolution of the worm which can thus be written as

$$L_w = N_w p_{aw} \quad (6)$$

The lead angle,  $\lambda$ , is the angle between the tangent to the worm thread and the line perpendicular to the axis of the worm, and is calculated as follows:

$$\lambda = \tan^{-1} \left[ \frac{L_w}{\pi d_w} \right] \quad (7)$$

Pressures angles, ( $\Phi_n$ ), for worm gearing are  $14\frac{1}{2}^\circ$ ,  $20^\circ$ ,  $25^\circ$ , and  $30^\circ$  although other pressure angles can be used. The  $\Phi_n$  selection is based on the requirements of the application.

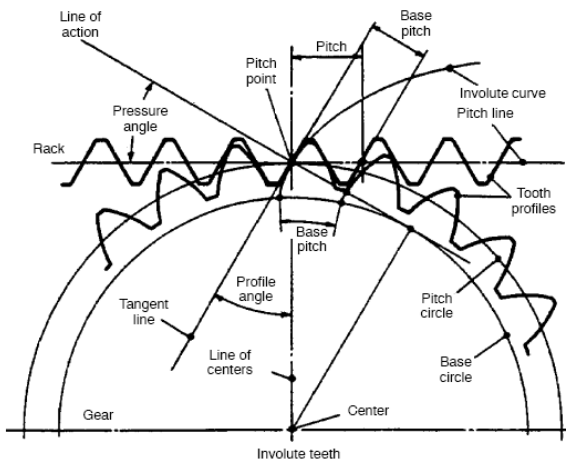
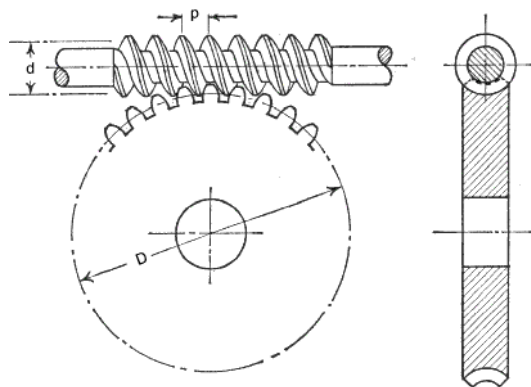


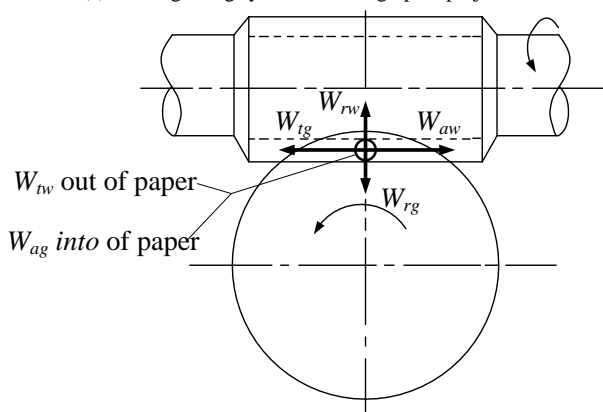
Fig. 1. Geometric features of worm gear mesh [4]

### B. Analysis of Worm Gearing Forces

Gearing forces between the worm and worm gear exist which must be analyzed to assure adequate worm diameter, to calculate housing and bolting stresses, and to calculate bearing loads and life. These forces are assumed to act at the pitch point of the mesh. The force system acting on the worm and worm gear set is usually considered to be made of three perpendicular components. There are a tangential load, a radial load, and an axial load acting on the worm, ( $W_{tw}$ ,  $W_{aw}$  and  $W_{rw}$ ) and the worm gear ( $W_{tg}$ ,  $W_{ag}$  and  $W_{rg}$ ) as shown in Fig. 2.



(a) Worm gearing system in Orthographic projection



(b) Forces acting on worm gearing system  
Fig. 2. Worm and worm gear forces [4]

Meanwhile, because of the  $90^\circ$  orientation of the two shafts, Shigley and Mischke [4] relate forces by the following:

$$W_{tg} = W_{aw} \quad (8)$$

$$W_{ag} = W_{tw} \quad (9)$$

$$W_{rg} = W_{rw} \quad (10)$$

The directions of the paired force are opposite because of the reaction principle. The tangential force on the worm gear is computed first and is based on the required operating conditions of torque, power ( $P$ ) and speed at the output shaft ( $v_{tg}$ ) as follows:

$$W_{tg} = \frac{1000P}{v_{tg}} \quad (11)$$

$$v_{tg} = \frac{\pi d_g s_g}{60000} \quad (12)$$

where  $s_g$  is angular speed of the worm gear.

The axial load on the worm gear is computed using

$$W_{ag} = W_{tg} \left[ \frac{\cos \phi_n \sin \lambda + f \cos \lambda}{\cos \phi_n \cos \lambda - f \sin \lambda} \right] \quad (13)$$

$$f = \frac{0.4}{v_s^{0.36}} \quad (14)$$

$$v_s = \frac{v_{tw}}{\cos \lambda} \quad (15)$$

where,  $v_s$  sliding velocity,

$f$  coefficient of friction, and

$v_{tw}$  pitch line velocity of the worm.

The radial load on the worm gear is computed from

$$W_{rg} = \frac{W_{tg} \sin \phi_n}{\cos \phi_n \cos \lambda - f \sin \lambda} \quad (16)$$

Friction plays a major part in the operation of a worm gear set because there is inherently sliding contact between the worm threads and the worm gear teeth. An extension of the force analysis can be used to compute the friction force acting along the face of the gear teeth. The work done by this friction force must be added to the required output work to obtain the input work. The ratio of the output work ( $p_o$ ) to the input work ( $p_i$ ) is the efficiency ( $\eta$ ) of the drive. The resulting equation for efficiency is given by AGMA [20] and Mott [17] as

$$\eta = \frac{P_o}{P_i} = \tan \lambda \left[ \frac{\cos \phi_n - f \tan \lambda}{\cos \phi_n \tan \lambda + f} \right] \quad (17)$$

### C. Bending Strength Analysis on Worm gearing

A modified form of the Lewis equation is used to compute the stress in the teeth of worm gear. The threads of the worm are inherently stronger than the worm gear teeth, so only the latter need be analyzed. The stress in the gear teeth ( $\sigma_{bg}$ ) is computed from:

$$\sigma_{bg} = \frac{W_d}{yFp_{cn}} \quad (18)$$

$$W_d = \frac{W_{tg}}{k_w} \quad (19)$$

$$k_w = \frac{1200}{1200 + v_{tg}} \quad (20)$$

where,  $F$  is face width of the gear,  
 $y$  Lewis form factor,  
 $p_{cn}$  normal circular pitch,  
 $W_d$  dynamic load on the gear teeth, and  
 $K_w$  the wear load factor for worm gears.

The computed value of tooth bending stress can be compared with the fatigue strength of the material of the gear.

### D. Wear Analysis on Worm gearing Systems

The wear analysis is based on a satisfactory wear load limit as compared with the dynamic load on the worm gear teeth. That is,

$$W_w = W_d \quad (21)$$

where,  $W_w$  is limiting load for wear.

$$W_w = d_g F k_w \quad (22)$$

### E. Development of the Computer Package

Computational modeling of dynamic systems is a valuable tool for engineering analysis and design. It allows for active experimentation, design modification, and subsequent analysis without investment in raw materials and supplies. The model reported in this work, OKAS Gear model, was developed on the platform of Visual Basic for geometry design and strength analysis, of gearing mechanisms. The computation employed data and equations from American Gear Manufacturers Association (AGMA) standards and specialized literatures. It supports metric units and performs the following tasks for each gear (i) establishment of effective tooth geometry and meshing parameters, (ii) analysis for bending strength as a criterion for gear capacity, (iii) analysis for pitting resistance as a criterion for wear failure, and (iv) presentation of results in textual and graphical forms. The structure of OKAS Gear Package which is the architecture of the model is illustrated in Fig. 3. It consists of four main sections: introduction, selection, design and output. The algorithm for the package is shown in Fig. 4.

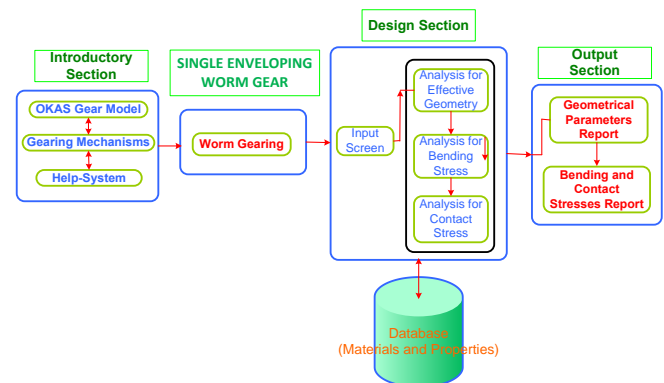


Fig.3. Basic Structure of OKAS Gear Package



(Fig. 8 to 10) were obtained using equations from Shigley and Mischke [4].

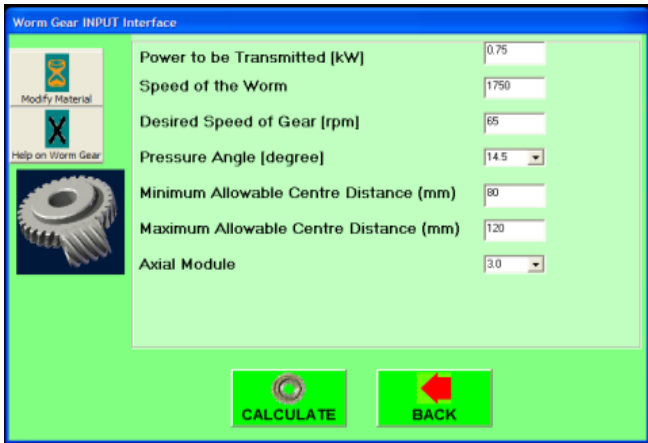


Fig. 5. Input interface

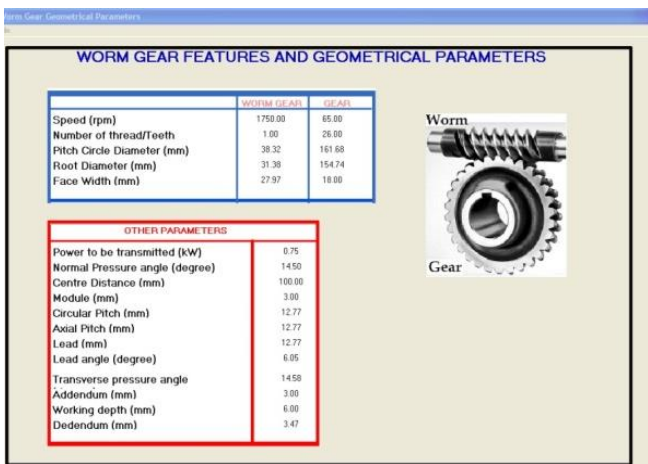


Fig. 6. Output interface I

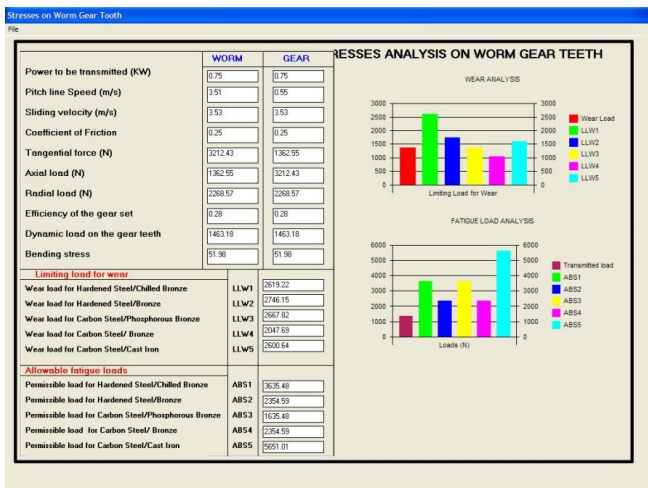


Fig. 7. Output interface II

The results of geometrical data obtained with the model compared reasonably with analytical results in Fig. 8.

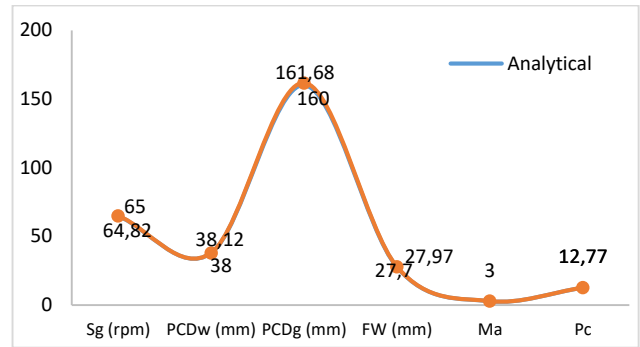


Fig. 8. Comparison Chart for Geometrical Data

The results of bending load obtained with the model is in good agreement with analytical results as shown in Fig. 9.

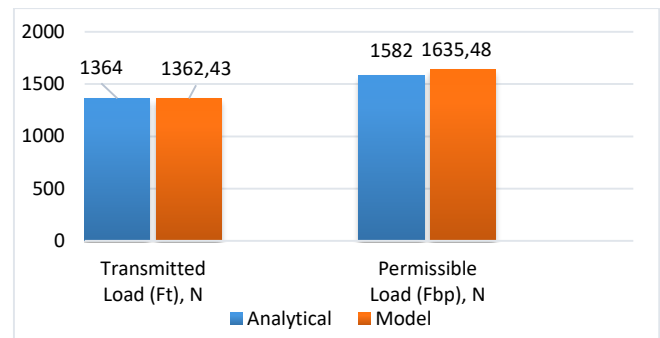


Fig. 9. Comparison Chart for Bending Load

The results of wear load obtained with the model almost equaled the analytical results as shown in Fig. 10.

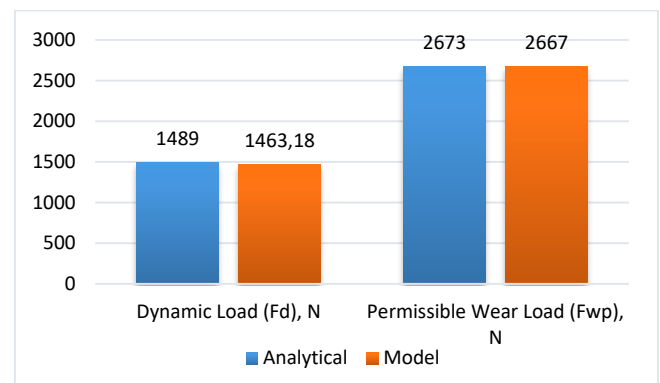


Fig. 10. Comparison Chart for Wearing Load

Maximum percentage errors from the geometrical data, bending loads and wear loads are 0.97%, 3.27% and 1.77% respectively as shown in Table I. These errors are insignificant and therefore validated the accuracy of the model.

TABLE I: PERCENTAGE ERRORS OBTAINED FROM THE RESULTS

		Percent Error (%)
Geometrical Features	Sw (rpm)	0.00
	Sg (rpm)	0.28
	PCDw (mm)	0.32
	PCDg (mm)	0.42
	FW (mm)	0.97
	Ma	0.00
	Pc	0.00
Bending Load	Transmitted Load (Ft), N	0.12
	Permissible Load (F <sub>bp</sub> ), N	3.27
Wear Load	Dynamic Load (F <sub>d</sub> ), N	1.77
	Permissible Wear Load (F <sub>wp</sub> ), N	0.23

### III. CONCLUSIONS

This study has presented a robust OKAS gear model for design and analysis of gearing mechanisms involving worm types. Putting into consideration factors causing stresses on gear teeth, the model was developed as a design aid, allowing the analyst to quickly visualize the response of the system to a broad range of speed and torque inputs. The need for readily available computer software locally to take care of the design gearing mechanisms prompted this model development. The model was tested and validated based on geometry feature, bending load and wear load using numerical example. The maximum percent errors obtained for salient parameters in the design of the worm gears are insignificant (error<5%). These were adjudged acceptable in accordance with a general rule of thumb for measurement system acceptability. Based on the technical evaluation of the package, the model has simplified the design of relatively complex gearing systems through its intelligent application.

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### CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

### REFERENCES

- [1] D. Suresh and A. Purushotham, "Design and analysis of a mechanical system for deployment of goods," *International Journal of Mechanical Engineering (IJME)*, vol. 3, no. 8, pp. 9-14, 2015.
- [2] R. D. Ankush and P. D. Darade, "Design and analysis of worm pair used in self-locking system with development of manual clutch," *IJRET: International Journal of Research in Engineering and Technology*, vol. 3, no. 8, pp. 427-433, August 2014.
- [3] K. A. Oladejo, D. A. Adetan, S. A. Ajayi and O. O. Aderinola, "Finite element simulation of bending stress on involute spur gear tooth profile," *International Journal of Engineering Research in Africa*, vol. 30, pp. 1-10, May 2017.
- [4] J. E. Shigley and C. R. Mischke, *Mechanical engineering design*, Boston: McGraw-Hill Book Company, 2001, pp. 831-950.
- [5] B. V. Mokara, P. Deepika, and S. Jyothirmal, "A performance prediction of worm-worm wheel and its multi objective design parameter optimization based on genetic algorithm," *International Journal of Scientific and Research Publications*, vol. 5, no. 2, pp. 1-6, February 2015.
- [6] C. Wei-Liang and T. Chung-Biau, "Mathematical model and tooth surfaces of recess action worm gears with double-depth teeth," *Mechanism and Machine Theory*, vol. 46, no. 12, pp. 1840-1853, December 2011.
- [7] F. L. Litvin, M. De Donno, A. Peng, A. Vorontsov and R. F. Handsch, "Integrated computer program for simulation of meshing and contact of gear drives," *Computer Methods Applied Mechanics and Engineering*, vol. 181, pp. 71-85, January 2000.
- [8] K. Wang, J. Yao, J. Wang and X. Deng, "Theoretical research on load capacity of double-roller enveloping end face engagement worm gear," *The Open Mechanical Engineering Journal*, vol. 8, pp. 967-973, December 2014.
- [9] J. Argyris, M. De Donno, and F.L. Litvin, "Computer program in Visual Basic language for simulation of meshing and contact of gear drives and its application for design of worm gear drive," *Computer Methods Applied Mechanics and Engineering*, vol. 189, pp. 595-612, September 2000.
- [10] R. Abu, O. J. Ajao and K. A. Oladejo, "Development of computer-based model for gear design and analysis," *International Conference of Mechanical Engineering, Energy Technology and Management (IMEETMCon)*, 2016, pp. 92-113.
- [11] R. O. Chime, T. O. Chime, and R. C. Chime, "Design, modeling, simulation of worm gears: analysis of worm gears," *International Journal of Engineering Science and Innovative Technology, (IJESIT)*, vol. 5, no. 5, pp. 21-32, September 2016.
- [12] K. A. Oladejo and A. A. Ogunsade, "Drafting of involute spur-gears in AutoCAD-VBA customized environment," *Advancement in Science and Technology Research, (ASTR)*, vol. 1, no. 2, pp. 18-26, October 2014.
- [13] A. H. Falah, and A. H. Elkholy, "Load and stress analysis of cylindrical worm gearing using tooth slicing method," *Trans. Can. Soc. Mech. Eng.*, vol. 30, no. 1, pp. 97-111, 2006.
- [14] I. Seol and S. Chung, "Design and simulation of meshing of new type of worm-gear drive with localized contacts," *KSME International Journal*, vol. 14, no. 4, pp. 408 - 417, April 2000.
- [15] K. A. Oladejo, K. A. and O. A. Bamiro, "Technical survey of gear-drives design and manufacturing practices in some selected states in Nigeria," *1st Faculty of Technology Conference, OAU, Nigeria, Vision 20: 2020, (RETAV)*, 2009, pp. 69-73.
- [16] T. T. Bamiro, "Design of machine tool gearbox user-friendly computer software," B.Sc. Project, Dept. of Mech Eng., Univ. of Ibadan, Nigeria, 1998.
- [17] R. L. Mott, *Machine elements in mechanical design*, Columbus, Ohio: Charles E. Merrill Publishing Company, pp. 260-582, 1995.
- [18] D. Y. Prasad, (2001). Spur gear design calculator. [Online]. Available: <http://www.eng.uwo.edu/commend/Sgdc>. (Last Accessed: February 2014).
- [19] American Gear Manufacturers Association, "AGMA 933-B03: Basic gear geometry," Virginia 22314: AGMA Publication, 2003.
- [20] American Gear Manufacturers Association, "ANSI/AGMA 6022-C93-Design manual for cylindrical worm gearing," Virginia 22314: AGMA Publication, 1993.