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# Design, modeling, simulation of worm gears: analysis of worm gears

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***ABSTRACT: Computer-based design analysis is nowadays a common activity in most development projects. Traditionally, the design field has been identified with particular end products, e.g., mechanical design, electrical design, ship design. In these fields, design work is largely based on specific techniques to foster certain product characteristics and principles. Gears are machine elements that transmit angular motion and power by the successive engagement of teeth on their periphery. They constitute an economical method for such transmission, particularly if power levels or accuracy requirements are high .Worm gears are crossed-axis helical gears in which the helix angle of one of the gears (the worm) has a high helix angle so that it resembles a screw. The worm can drive the mating gear (the worm gear) but not vice versa. The axes of the two gears are normally at right angles. The scope of this work includes, to design, model and simulate worm, the application of worm gears, the analysis of worm gears and also to detailed factor safety in design. When new software and manufacturing processes are introduced, traditional empirical knowledge is unavailable and considerable effort is required to find starting design concepts. Gears are useful when the following kinds of power or motion transmission are required: (1) a change in speed of rotation, (2) a multiplication or division of torque or magnitude of rotation, (3) a change in direction of rotation, (4) conversion from rotational to linear motion or vice versa (rack gears), (5) a change in the angular orientation of the rotational motion (bevel gears), and (6) an offset or change in location of the rotating motion. Worm drives are used in presses, rolling mills, conveying engineering, mining industry machines, on rudders, and worm drive saws. Worm gears are used on many lift/elevator and escalator-drive applications due to their compact size and the non-reversibility of the gear .In the era of sailing ships, the introduction of a worm drive to control the rudder was a significant advance. A gearbox designed using a worm and worm-wheel is considerably smaller than one made from plain spur gears, and has its drive axes at90° to each other. With a single start worm, for each 360° turn of the worm, the worm-gear advances only one tooth of the gear, regardless of the worms size (sensible engineering limits notwithstanding), the gear ratio is the "size of the worm gear - to - 1".Given a single start worm, a 20 tooth worm gear reduces the speed by the ratio of 20:1. With spur gears, a gear of 12 teeth (the smallest size if designed to good engineering practices) must match with a 240 tooth gear to achieve the same 20:1 ratio. Therefore, if the diametrical pitch (DP) of each gear is the same, then, in terms of the physical size of the240 tooth gear to that of the 20 tooth gear, the worm arrangement is considerably smaller in volume.***

## I. INTRODUCTION

The history of gears is probably as old as civilization itself. Still today, the importance of gears in the manufacturing industry is undiminished and even continues to grow**.** Our short history begins with the first Punic Wars, which started in 264 BC and lasted 23 years. During the first year of Punic war 1, Hieron 11 ascended to the throne of Syracuse and then concluded an alliance with Rome. But Heiron, who never really trusted Rome,, initiated a fleet-building programme which included a warship of a size never seen before. In the ships, by H.W.Van loon,,it is mentioned that the then average size of a ship was 20-30 tons, so it is very likely that Hieron;s giant warship could not have exceeded 40-50 tons Contemporary shipyards were not able to launch ships of such weight, so Hieron enlisted the assistance of Archimedes, one of the greatest scientific figures of the time at Hieron’s request, the developed a revolutionary crane that made it possible, with the help of a few slaves, to launch the giant ship. It was at the launching that Archimedes is supposed to have uttered his famous dictum ‘give me a fixed point’ and I will remove the complete world from its corner Archimedes called his crane the barulkon’ and there is little doubt that in the course of its development in the years 232-31 BC he was the first originator of the worm drive. In the following centuries, the use of the worm gear drive became widespread throughout the then known world. Archimedes, as was then customary, lodged a description of his invention in the Alexandrian library. From this, the Alexandrian Heron, the other leading technocrat of the ancient world. Learned about it, and in about AD 120, that is 350 years later wrote a book on the barulkon Later, during the third century AD,Pappus gave a detailed description of the barulkon in his summarizing work; this consisted of four pairs of gear trains with a worm gear drive added. Pappus mentioned Archimedes as the original Inventor, and Reuleaux,A German Engineer. Used Heron's description to reconstruct and make a drawing of the barulkon The next author mentioning the worm gear drive was the Roman architect vitrinius. In his book De Architecture, published between the years 30-16 BC, there was a description of the hodometer. The Romans' rented passenger vehicles were equipped with a hodometer'.In this device small balls were allowed to fall one-by-one into a drawer, each denoting the fulfillment of a mile This invention provided the first recorded taximeter The first technically significant worm gear drawings were made by Leonardo da Vinci (1452-1519) These drawings were found among his sketches and notes. Surprisingly, not only drawings of worms and worm gears but also of globoid type worms are to be found among them So Leonardo had known of an asymmetrical worm that could be mated with a sprocket wheel and he was ware of the crossed helical gears substituting the worm with more than one start He designed control drives too, where the driving element was the worm gear driving the worm but these have not been used in practice .A worm and worm gear system is the most compact gearing system. Worms and worm wheels transmit motion between non-intersecting right angle shafts shown in fig 6. Worm and worm gears are the most quiet and smoothest running gear system. They can develop high reduction ratios in compact space

CAD (computer-aided design) has its roots in interactive computer graphics. Before the CAD era, engineering drawings were prepared manually on paper using pencils and drafting instruments on a drafting table. The advent of interactive computer graphics replaced the drafting table with a computer monitor and the pencil with an input device such as a light pen or mouse. Instead of using physical drafting instruments, software commands and icons on the computer display are used. The drawing can be created, modified, copied, and transformed using the software tools. At the time, CAD stood for computer-aided drafting. Drafting was confined to 2D because of the paper limitation. With the computer, such limitation is removed. Three-dimensional CAD systems were developed in the 1960s. In 3D CAD, objects are modeled using 3D coordinates (*x*, *y*, and *z*) instead of 2D coordinates (*x* and *y*). The need for modeling parts and products with complex surfaces motivated the development of free-form surface modelers. It is against this background that the study is carried out

## II. SELECTION OF TYPE OF GEAR

Straight-bevel gears are recommended for peripheral speeds up to 1000 feet per minute (ft/min) where maximum smoothness and quietness are not of prime importance. However, ground straight bevels have been successfully used at speeds up to 15 000 ft/min. Plain bearings may be used for radial and axial loads and usually result in a more compact and less expensive design. Since straight-bevel gears are the simplest to calculate, set up, and develop, they are ideal for small lots. Spiral-bevel gears are recommended where peripheral speeds are in excess of 1000 ft/min or 1000 revolutions per minute (r/min). Motion is transmitted more smoothly and quietly than with straight-bevel gears. So spiral-bevel gears are preferred also for some lower-speed applications. Spiral bevels have greater load sharing, resulting from more than one tooth being in contact. Zerol bevel gears have little axial thrust as compared to spiral-bevel gears and can be used in place of straight-bevel gears. The same qualities as defined under straight bevels apply to Zerol bevels. Because Zerol bevel gears are manufactured on the same equipment as spiral-bevel gears, Zerol bevel gears are preferred by some, They are more easily ground because of the availability of bevel grinding equipment. Hypoid gears are recommended where peripheral speeds are in excess of 1000 ft/min and the ultimate in smoothness and quietness is required. They are somewhat stronger than spiral bevels. Hypoids have lengthwise sliding action, which enhances the lapping operation but makes them slightly less efficient than spiral-bevel gears

## III. APPLYING COMPUTERS TO DESIGN

No other idea or device has impacted engineering as computer have. All engineering disciplines routinely use computer for calculation, analysis, design and simulation many of the individual tasks within the overall design process can be performed using a computer. As each of these tasks is made more efficient, the efficiency of the overall process increases as well. The computer is especially well suited to design in four areas, which correspond to the latter four stages of the general design process. Computers function in the design process through geometric modeling capabilities, engineering analysis calculations, automated testing procedures, and automated drafting.

**STATIC ANALYSIS** determines reaction forces at the joint positions of resting when a constant load is applied. As long as zero velocity is assumed, static analysis can be performed on mechanisms at different points of their range of motion. Static analysis allows the designer to determine the reaction forces on whole mechanical systems as well as interconnection forces transmitted to their individual joints. The data extracted from static analysis can be useful in determining compatibility with the various criteria set out in the problem definition. These criteria may include reliability, fatigue, and performance considerations to be analyzed through stress analysis methods fig 3. Detailed the Region with FOS (factor of safety)value less than 1 are shown in red.

**EXPERIMENTAL ANALYSIS** involves fabricating a prototype and subjecting it to various experimental methods. Although this usually takes place in the later stages of design, CAD systems enable the designer to make more effective use of experimental data, especially where analytical methods are thought to be unreliable for the given model. CAD also provides a useful platform for incorporating experimental results into the design process when experimental analysis is performed in earlier iterations of the process. Fig 1 shows the final design of Worm gears , and fig 10 factor of safety indicated that our design is save( material) from that region. Blue region indicate safety which is larger than1.0 while red region indicate unsafe regions which is10 shown in fig7.

## IV. MODELLING OF WORM GEAR

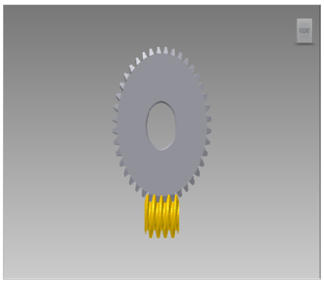


Fig ;1 Worm Gears

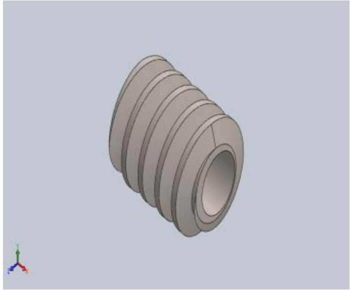


Fig: 2 Worm Gear

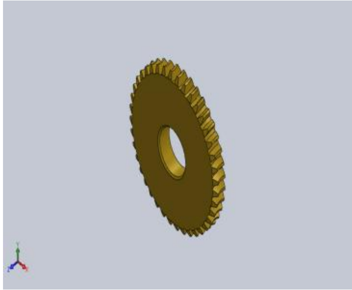
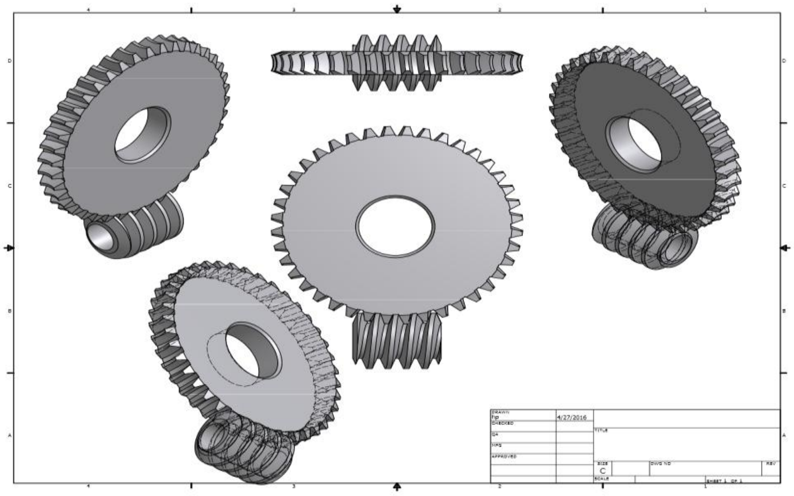


Fig ;3 Gear Wheel



Fig; 4 Multiply Views of Worm Gears

Fig; 5 and 6 worm rotation and part name

### *SIMULATION PROCESS OF WORM GEARS*

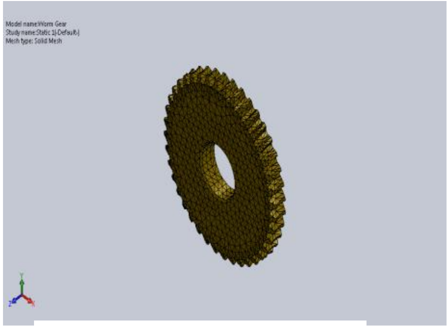


Fig : 7 gear mesh

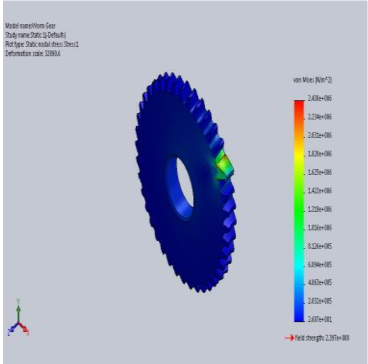


Fig 8 deform

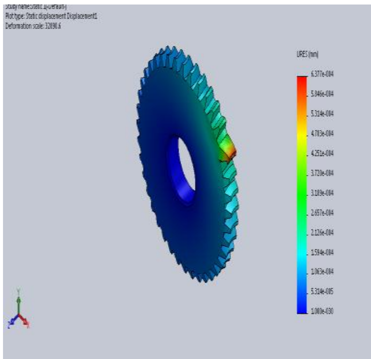


Fig: 9 stress on the gear

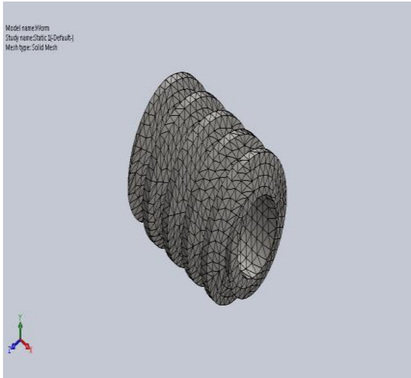


Fig: 10 Worm Mesh

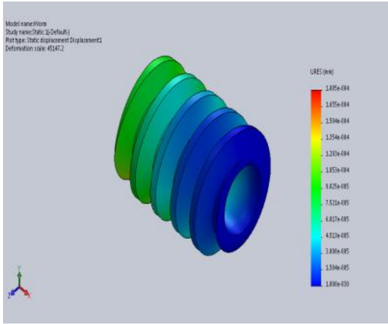


Fig: 11 Worm-Static 1-Displacement-Displacement1

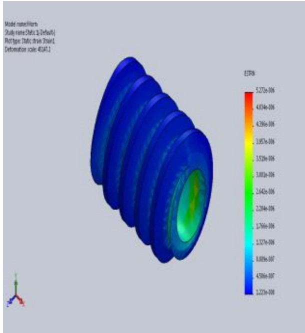
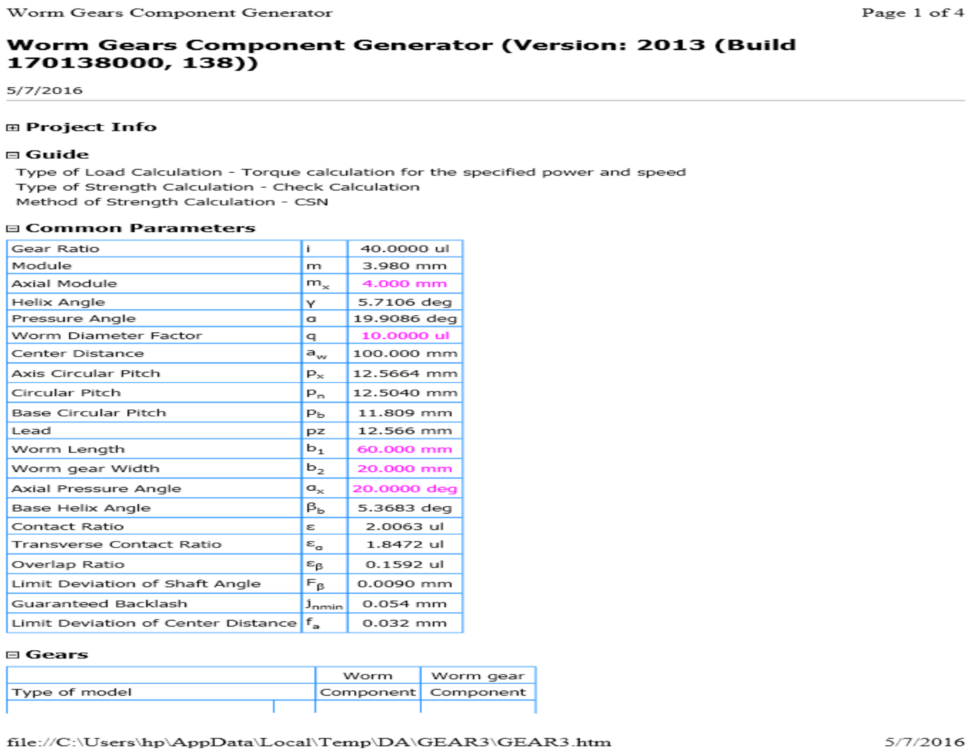


Fig: 12 Worm-Static 1-Strain-Strain1



Worm Gears Component Generator Page 1 of 4

**Worm Gears Component Generator (Version: 2013 (Build 170138000, 138))**

5/7/2016

⊞ **Project Info**

⊟ **Guide**

Type of Load Calculation - Torque calculation for the specified power and speed
Type of Strength Calculation - Check Calculation
Method of Strength Calculation - CSN

⊟ **Common Parameters**

| | | |
|---|---|---|
| Gear Ratio | i | 40.0000 ul |
| Module | m | 3.980 mm |
| Axial Module | $m_x$ | 4.000 mm |
| Helix Angle | γ | 5.7106 deg |
| Pressure Angle | α | 19.9086 deg |
| Worm Diameter Factor | q | 10.0000 ul |
| Center Distance | $a_w$ | 100.000 mm |
| Axis Circular Pitch | $p_x$ | 12.5664 mm |
| Circular Pitch | $p_n$ | 12.5040 mm |
| Base Circular Pitch | $p_b$ | 11.809 mm |
| Lead | pz | 12.566 mm |
| Worm Length | $b_1$ | 60.000 mm |
| Worm gear Width | $b_2$ | 20.000 mm |
| Axial Pressure Angle | $\alpha_x$ | 20.0000 deg |
| Base Helix Angle | $\beta_b$ | 5.3683 deg |
| Contact Ratio | ε | 2.0063 ul |
| Transverse Contact Ratio | $\varepsilon_\alpha$ | 1.8472 ul |
| Overlap Ratio | $\varepsilon_\beta$ | 0.1592 ul |
| Limit Deviation of Shaft Angle | $F_\beta$ | 0.0090 mm |
| Guaranteed Backlash | $j_{nmin}$ | 0.054 mm |
| Limit Deviation of Center Distance | $f_a$ | 0.032 mm |

⊟ **Gears**

| | Worm | Worm gear |
|---|---|---|
| Type of model | Component | Component |

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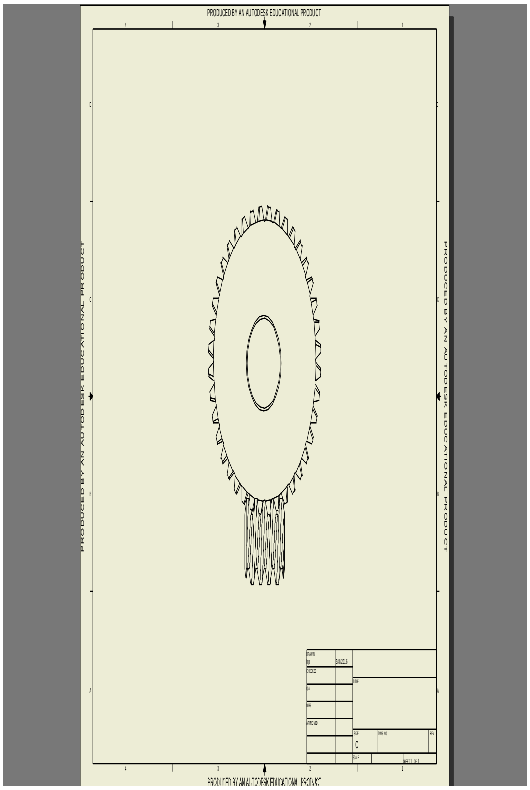
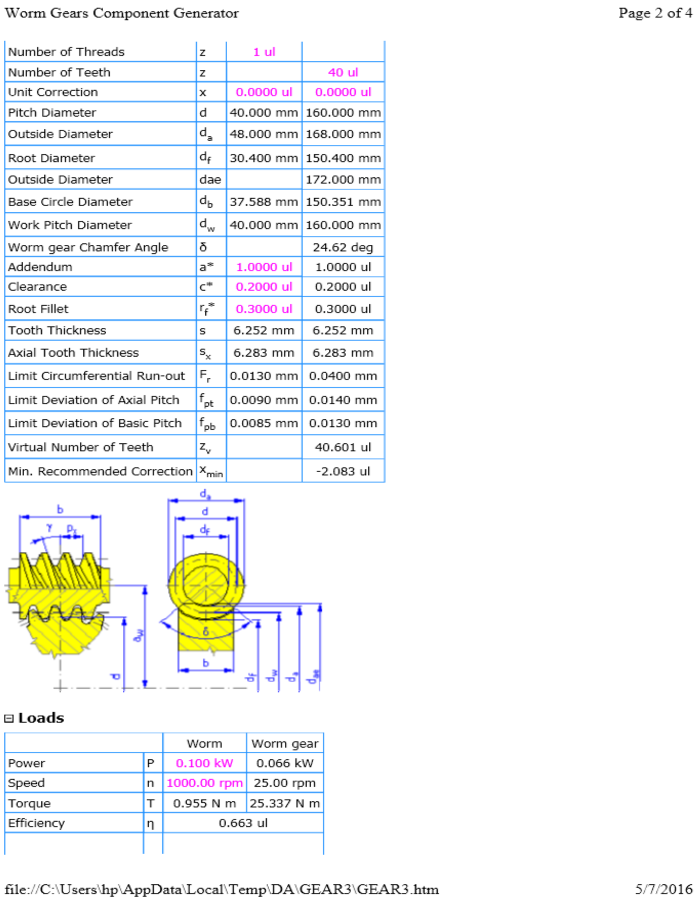


Fig.14 Top Bottom Left of Worm Gears



Worm Gears Component Generator Page 2 of 4

| | | | |
|---|---|---|---|
| Number of Threads | z | 1 ul | |
| Number of Teeth | z | | 40 ul |
| Unit Correction | x | 0.0000 ul | 0.0000 ul |
| Pitch Diameter | d | 40.000 mm | 160.000 mm |
| Outside Diameter | $d_a$ | 48.000 mm | 168.000 mm |
| Root Diameter | $d_f$ | 30.400 mm | 150.400 mm |
| Outside Diameter | dae | | 172.000 mm |
| Base Circle Diameter | $d_b$ | 37.588 mm | 150.351 mm |
| Work Pitch Diameter | $d_w$ | 40.000 mm | 160.000 mm |
| Worm gear Chamfer Angle | δ | | 24.62 deg |
| Addendum | a* | 1.0000 ul | 1.0000 ul |
| Clearance | c* | 0.2000 ul | 0.2000 ul |
| Root Fillet | $r_f^*$ | 0.3000 ul | 0.3000 ul |
| Tooth Thickness | s | 6.252 mm | 6.252 mm |
| Axial Tooth Thickness | $s_x$ | 6.283 mm | 6.283 mm |
| Limit Circumferential Run-out | $F_r$ | 0.0130 mm | 0.0400 mm |
| Limit Deviation of Axial Pitch | $f_{pt}$ | 0.0090 mm | 0.0140 mm |
| Limit Deviation of Basic Pitch | $f_{pb}$ | 0.0085 mm | 0.0130 mm |
| Virtual Number of Teeth | $z_v$ | | 40.601 ul |
| Min. Recommended Correction | $x_{min}$ | | -2.083 ul |

⊟ **Loads**

| | | Worm | Worm gear |
|---|---|---|---|
| Power | P | 0.100 kW | 0.066 kW |
| Speed | n | 1000.00 rpm | 25.00 rpm |
| Torque | T | 0.955 N m | 25.337 N m |
| Efficiency | η | 0.663 ul | |

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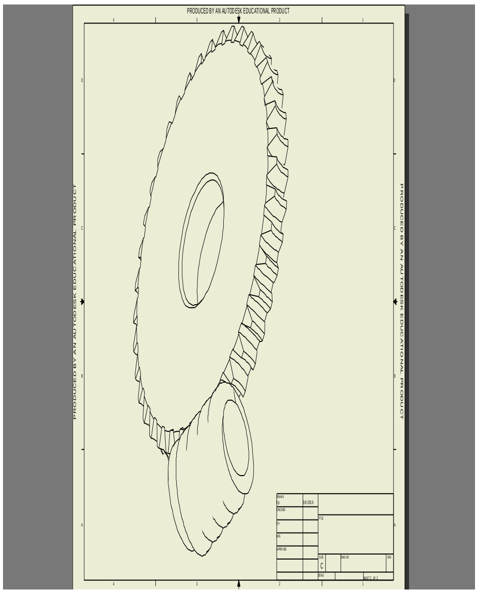
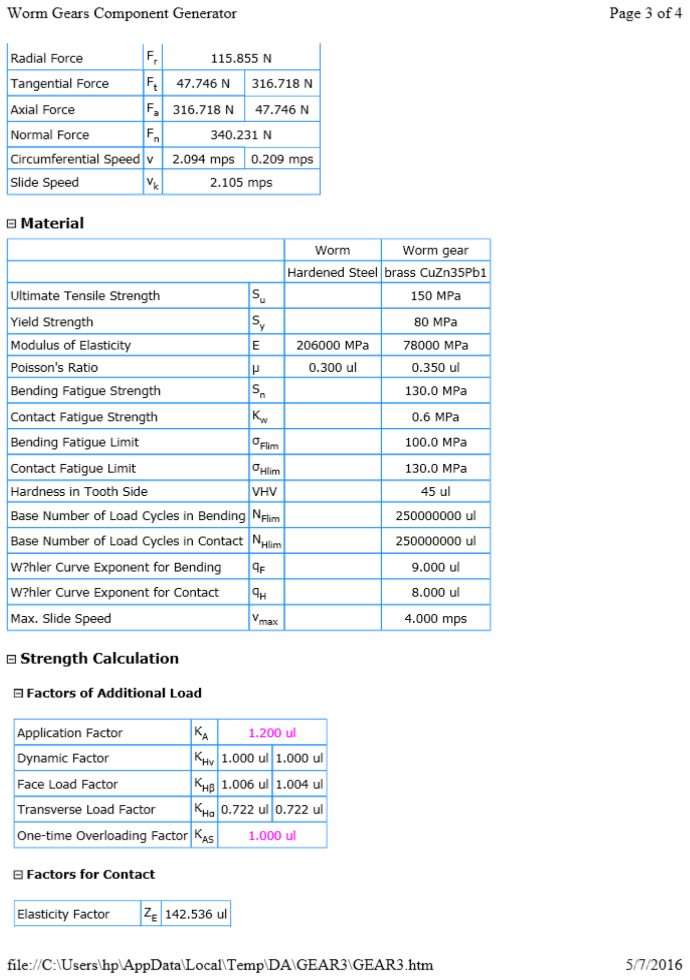


Fig 15 Top Bottom Right of Worm Gears



| | | | |
|---|---|---|---|
| Radial Force | $F_r$ | 115.855 N | |
| Tangential Force | $F_t$ | 47.746 N | 316.718 N |
| Axial Force | $F_a$ | 316.718 N | 47.746 N |
| Normal Force | $F_n$ | 340.231 N | |
| Circumferential Speed | v | 2.094 mps | 0.209 mps |
| Slide Speed | $v_k$ | 2.105 mps | |

**⊟ Material**

| | | Worm | Worm gear |
|---|---|---|---|
| | | Hardened Steel | brass CuZn35Pb1 |
| Ultimate Tensile Strength | $S_u$ | | 150 MPa |
| Yield Strength | $S_y$ | | 80 MPa |
| Modulus of Elasticity | E | 206000 MPa | 78000 MPa |
| Poisson's Ratio | $\mu$ | 0.300 ul | 0.350 ul |
| Bending Fatigue Strength | $S_n$ | | 130.0 MPa |
| Contact Fatigue Strength | $K_w$ | | 0.6 MPa |
| Bending Fatigue Limit | $\sigma_{Flim}$ | | 100.0 MPa |
| Contact Fatigue Limit | $\sigma_{Hlim}$ | | 130.0 MPa |
| Hardness in Tooth Side | VHV | | 45 ul |
| Base Number of Load Cycles in Bending | $N_{Flim}$ | | 250000000 ul |
| Base Number of Load Cycles in Contact | $N_{Hlim}$ | | 250000000 ul |
| W?hler Curve Exponent for Bending | $q_F$ | | 9.000 ul |
| W?hler Curve Exponent for Contact | $q_H$ | | 8.000 ul |
| Max. Slide Speed | $v_{max}$ | | 4.000 mps |

**⊟ Strength Calculation**

**⊟ Factors of Additional Load**

| | | | |
|---|---|---|---|
| Application Factor | $K_A$ | 1.200 ul | |
| Dynamic Factor | $K_{Hv}$ | 1.000 ul | 1.000 ul |
| Face Load Factor | $K_{H\beta}$ | 1.006 ul | 1.004 ul |
| Transverse Load Factor | $K_{H\alpha}$ | 0.722 ul | 0.722 ul |
| One-time Overloading Factor | $K_{AS}$ | 1.000 ul | |

**⊟ Factors for Contact**

| | | |
|---|---|---|
| Elasticity Factor | $Z_E$ | 142.536 ul |

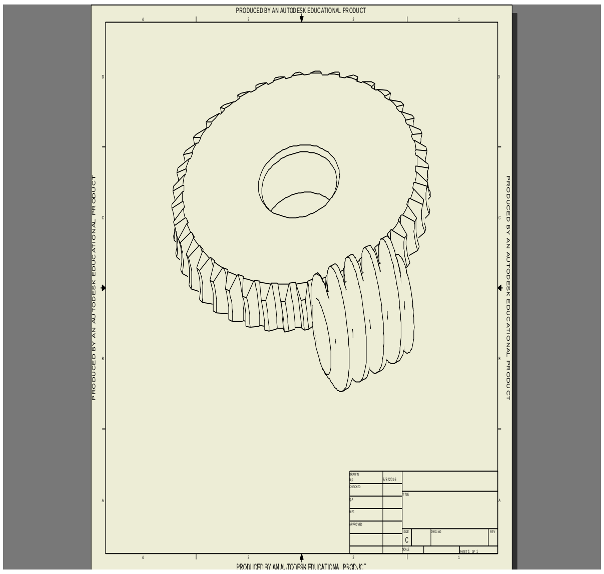


Fig 16 Worm Gears

Worm Gears Component Generator Page 4 of 4

| | | |
|---|---|---|
| Zone Factor | $Z_H$ | 2.493 ul |
| Contact Ratio Factor | $Z_\varepsilon$ | 0.734 ul |
| Life Factor | $Z_N$ | 1.421 ul |
| Lubricant Factor | $Z_L$ | 1.000 ul |
| Speed Factor | $Z_v$ | 1.000 ul |

⊟ **Factors for Bending**

| | | |
|---|---|---|
| Form Factor | $Y_{Fa}$ | 1.542 ul |
| Helix Angle Factor | $Y_\beta$ | 0.992 ul |
| Contact Ratio Factor | $Y_\varepsilon$ | 0.633 ul |
| Alternating Load Factor | $Y_A$ | 1.000 ul |
| Life Factor | $Y_N$ | 1.367 ul |
| Size Factor | $Y_X$ | 1.000 ul |

⊟ **Results**

| | | |
|---|---|---|
| Factor of Safety from Pitting | $S_H$ | 2.412 ul |
| Factor of Safety from Tooth Breakage | $S_F$ | 40.996 ul |
| Worm Deflection Factor | y | 0.0003 mm |
| Lost Power | Pz | 0.037 kW |
| Max. Dissipated Heat | Q | 0.768 kW |
| Check Calculation | | **Positive** |

⊟ **Summary of Messages**

10:00:22 PM Calculation: Calculation indicates design compliance!

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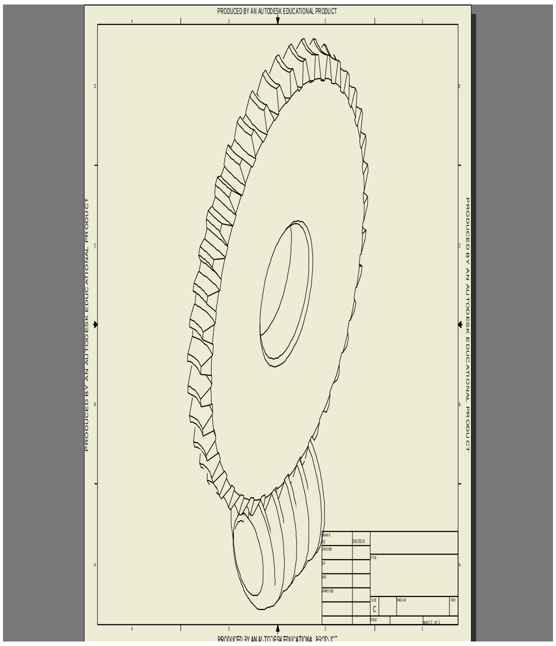

Fig 17 side view of worm gear

## V. DESIGN PROCESS

The ability to create something out of nothing makes design one of the most exciting aspects of engineering. To be successful, design engineer require abroad set of talents include knowledge creativity, human skill and planning ability .Engineers use CAD to create two− and three−dimensional drawings, such as those for automobile and airplane parts, floor plans, and maps and machine assembly. While it may be faster for an engineer to create an initial drawing by hand, it is much more efficient to change and adjust drawings by computer. In the design stage, drafting and computer graphics techniques are combined to produce models of different machines. Using a computer to perform the six−step'art−to−part' process: The first two steps in this process are the use of sketching software to capture the initial design ideas and to produce accurate engineering drawings. The third step is rendering an accurate image of what the part will look like. Next, engineers use analysis software to ensure that the part is strong enough as shown in fig;2 .Step five is the production of a prototype, or model. CAD began as an electronic drafting board, a replacement of the traditional paper and pencil drafting method. Over the years it has evolved into a sophisticated surface and solid modeling tool. Not only can products be represented precisely as solid models, factory shop floors can also be modeled and simulated in 3D. It is an indispensable tool to modern engineers

**WIRE FRAME** The most basic functions of CAD are the 2D drafting functions. 2D geometry such as line, circles, and curves can be defined. A 2D profile can also be extruded into a 21⁄2 D object. The extruded object is a wireframe of the object CAD also allows a 3D wire-frame to be defined.To cover the wire-frame model, faces can be added to the model. This creates a shell of the object. Hidden line/surface algorithms can be applied to create realistic pictures. Many menu functions are used to help simplify the design process. Annotation and dimensioning are also supported. Text and dimension symbols can be placed anywhere on the drawing, at any angle, and at any size.

## VI. MODELLING

Modeling is the process of producing a model; a model is a representation of the construction and working of some system of interest as shown in fig 1-4and13-16 different views of worm gear .A model is similar to but simpler than the system it represents. One purpose of a model is to enable the analyst to predict the effect of changes to the system. On the one hand, a model should be a close approximation to the real system and incorporate most of its salient features. On the other hand, it should not be so complex that it is impossible to understand and experiment with it. A good model is a judicious tradeoff between realism and simplicity. Simulation practitioners recommend increasing the complexity of a model iteratively. An important issue in modeling is model validity. Model validation techniques include simulating the model under known input conditions and comparing model output with system output. Generally, a model intended for a simulation study is a mathematical model developed with the help of simulation software. Mathematical model classifications include deterministic (input and output variables are fixed values) or stochastic (at least one of the input or output variables is probabilistic); static (time is not taken into account) or dynamic (time-varying interactions among variables are taken into account). Typically, simulation models are stochastic and dynamic

## VII.SIMULATION

A simulation of a system is the operation of a model of the system. The model can be reconfigured and experimented with; usually, this is impossible, too expensive or impractical to do in the system it represents. The operation of the model can be studied, and hence, properties concerning the behavior of the actual system or its subsystem can be inferred. In its broadest sense, simulation is a tool to evaluate the performance of a system, existing or proposed, under different configurations of interest and over long periods of real time. Simulation is used before an existing system is altered or a new system built, to reduce the chances of failure to meet specifications, to eliminate unforeseen bottlenecks, to prevent under or over-utilization of resources, and to optimize system performance. For instance, simulation can be used to answer questions like:What is the best design for a new network? What are the associated resource requirements? How will a telecommunication network perform when the traffic load increases by 50%? How will new routing algorithm affect its performance? Which network protocol optimizes network performance? What will be the impact of a link failure? The subject of this tutorial is *discrete event* simulation in which the central assumption is that the system changes instantaneously in response to certain discrete events. For instance, in an M/M/1 queue - a single server queuing process in which time between arrivals and service time are exponential - an arrival causes the system to change instantaneously. On the other hand, continuous simulators, like flight simulators and weather simulators, attempt to quantify the changes in a system continuously over time in response to controls. Discrete event simulation is less detailed (coarser in its smallest time unit) than continuous simulation but it is much simpler to implement, and hence, is used in a wide variety of situations. Figure , 7-12and 17 is a schematic of a simulation study. The iterative nature of the process is indicated by the system under study becoming the altered system which then becomes the system under study and the cycle repeats. In a simulation study, human decision making is required at all stages, namely, model development, experiment design, output analysis, conclusion formulation, and making decisions to alter the system under study. The only stage where human intervention is not required is the running of the simulations, which most simulation software packages perform efficiently. The important point is that powerful simulation software is merely a hygiene factor - its absence can hurt a simulation study but its presence will not ensure success. Experienced problem formulators and simulation modelers and analysts are indispensable for a successful simulation study. The steps involved in developing a simulation model, designing a simulation experiment, and performing simulation analysis are:

[1.] Step 1. Identify the problem.
[2.] Step 2. Formulate the problem.
[3.] Step 3. Collect and process real system data.
[4.] Step 4. Formulate and develop a model.
[5.] Step 5. Validate the model.
[6.] Step 6. Document model for future use.
[7]. Step 7. Select appropriate experimental design. Step [8.] Establish experimental conditions for.
[8.] Step 9. Perform simulation runs.
[9.] Step 10. Interpret and present results.
[10.] Step 11. Recommend further course of action. Although this is a logical ordering of steps in a simulation study, much iteration at various sub-stages may be required before the objectives of a simulation study are achieved. Not all the steps may be possible and/or required. On the other hand, additional steps may have to be performed. The next three sections describe these steps in detail

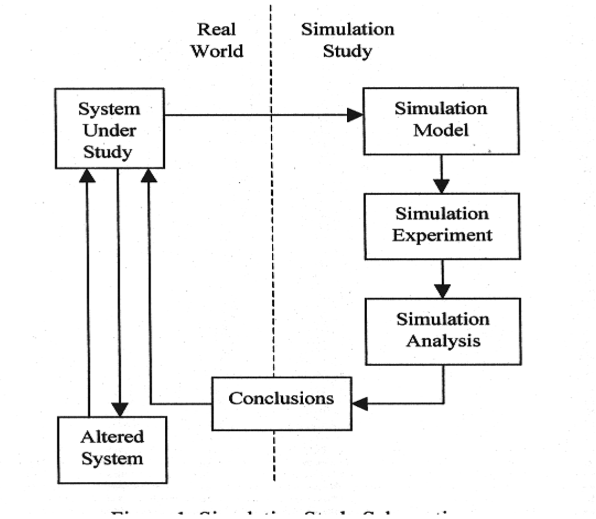

**Fig 18: Simulation Study**

## VIII. RESULT AND DISCUSSION

Engineering analysis can be performed using one of two approaches: analytical or experimental. Using the analytical method, the design is subjected to simulated conditions, using any number of analytical formulae. By contrast, the experimental approach to analysis requires that a prototype be constructed and subsequently subjected to various experiments to yield data that might not be available through purely analytical methods. There are various analytical methods available to the designer using a CAD system. Finite element analysis and static and dynamic analysis are all commonly performed analytical methods available in CAD.

**SAFETY** An engineer must always design products that are safe for the end user and the artisans who construct the product. it is impossible to design completely safe products because they would be too costly. Therefore, the engineer often must design to industry standards for similar product

**FACTOR OF SAFETY** is the ratio of ultimate strength of the material to allowable stress. The term was originated for determining allowable stress. The ultimate strength of a given material divided by an arbitrary factor of safety, dependent on material and the use to which it is to be put, gives the allowable stress. In present design practice, it is customary to use allowable stress as specified by recognized authorities or building codes rather than an arbitrary factor of safety. One reason for this is that the factor of safety is misleading, in that it implies a greater degree of safety than actually exists. For example, a factor of safety of 4 does not mean that a member can carry a load four times as great as that for which it was designed. It also should be clearly understood that, though each part of a machine is designed with the same factor of safety, the machine as a whole does not have that factor of safety. When one part is stressed beyond the proportional limit, or particularly the yield point, the load or stress distribution may be completely changed throughout the entire machine or structure, and its ability to function thus may be changed, even though no part has ruptured. Although no definite rules can be given, if a factor of safety is to be used, the following circumstances should be taken into account in its selection:

1. When the ultimate strength of the material is known within narrow limits, as for structural steel for which tests of samples have been made, when the load is entirely a steady one of a known amount and there is no reason to fear the deterioration of the metal by corrosion, the lowest factor that should be adopted is 3.
2. When the circumstances of (1) are modified by a portion of the load being variable, as in floors of warehouses, the factor should not be less than 4.
3. When the whole load, or nearly the whole, is likely to be alternately put on and taken off, as in suspension rods of floors of bridges, the factor should be 5 or 6.
4. When the stresses are reversed in direction from tension to compression, as in some bridge diagonals and parts of machines, the factor should be not less than 6.
5. When the piece is subjected to repeated shocks, the factor should be not less than 10.
6. When the piece is subjected to deterioration from corrosion, the section should be sufficiently increased to allow for a definite amount of corrosion before the piece is so far weakened by it as to require removal.
7. When the strength of the material or the amount of the load or both are uncertain, the factor should be increased by an allowance sufficient to cover the amount of the uncertainty.
8. When the strains are complex and of uncertain amount, such as those in the crankshaft of a reversing engine, a very high factor is necessary, possibly even as high as 40.
9. If the property loss caused by failure of the part may be large or if loss of life may result, as in a derrick hoisting materials over a crowded street, the factor should be large.

## VI. CONCLUSION

CAD combines the characteristic of designer and computer that are best applicable made CAD such as popular design tool. CAD Has allowed the designer to bypass much of the Manuel drafting and analysis . Simulation tools enable us to be creative and to quickly test new ideas that would be much more difficult, time-consuming, and expensive to test in the lab. (Jeffrey D. Wilson, Nasa Glenn Research Center) It also help us reduce cost and time-to-market by testing our designs on the computer rather than in the field. Many of the individual tasks within the overall design process can be performed using a computer. As each of these tasks is made more efficient, the efficiency of the overall process increases as well. The computer is well suited to design in four areas, which correspond to the latter four stages of the general design process; Computers function in the design process through geometric modeling capabilities, engineering analysis calculations, testing procedures, and automated drafting, From the result of the testing and the affordability in terms of cost, it can be concluded that the project is successful. Therefore software design should be encouraged in our institution of higher learning base on the following facts, long product development, countless trial and error, and accountability and limited profitability

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