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Study on Design and Analysis of Single Envelope Worm Gear for Solar Tracking System

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Abstract

The design analysis to be presented in this study would primarily shed light on the development of a single envelope worm gear proposed to be used specifically in solar tracking systems. Solar tracking is an essential aspect of maximizing the efficiency of photovoltaic PV panels by aligning them precisely with the sun as it changes position throughout the day . A single envelope worm gear constitutes a highly compact and efficient mechanism to convert rotational motion to linear movement and ensure accurate and precise alignment of the solar panels. Therefore, the design analysis would include geometrical design of a worm gear, Finite Element Analysis for structural and cooling-system evaluation, and environmental sustainability aspects. Optimization of the geometrical characteristics of the worm gear – pitch diameter, helix angle, and tooth profile – was used to establish the required gear ratio while reducing wear and maximizing the gear's load bearing ability. FEA was also applied to evaluate the worm gear's structural strength and mechanical behavior and confirmed the gear's suitability for various operating outputs and conditions. Therefore, combining the theoretical and numerical simulation with the computational analysis, the research helps to provide meaningful knowledge of the development of effective and environmentally friendly single envelope worm gear for solar tracking.

1.Introduction

Gear reducers have the role of transmitting and modifying torque and velocity from the driving shaft to the driven shaft in a setting with maximum effectiveness and are employed in all industrial sites these days. Such reducers are subdivided by the power transmission type and include belt, chain, gear, friction, etc. The ones that employ belts and the ones using gears are the most prevalent. The shape, relative axes placement, kinds of gears, etc., this equipment is a kind of reducer with two axes and gears, bearings serving as a support, and casing. Depending on the relative positions of the driving shaft and the driven shaft, the synchromesh gears used in gear reducers include three classes: parallel axes, orthogonal axes, and inclined axes. The worm gear strikes: because the helical gear is rotated in a helical way, it has low vibration and noise when running, and it can run quietly; In addition, when running at the same centre distance, it can obtain a larger speed ratio than the gear unit. However, their frictional power loss is very large, and the power transmission efficiency is not high. There are two classes of worm gears, cylindrical worm gears and double enveloping worm gears. Double enveloping worm gear maintains a circular shape along the axis of the worm. Conventional cylindrical worm gears have limited meshing (line contact) between the worm and the worm wheel, resulting in reduced efficiency and power transmission capability. Double enveloping worm gears have a larger contact area (surface contact) compared to cylindrical worm gears, maximizing load transmission capability and efficiency. However, due to the worm maintaining a circular shape along the axis, special machining methods are required, and it is difficult to machine them with dedicated gear-cutting tools primarily using nonferrous alloys for worm wheels. Furthermore, due to the structural characteristics of double enveloping worm gears, greater care must be taken during assembly compared to cylindrical worm gears. Gear reducers using double enveloping worm gears are gradually expanding their usage in related industrial fields due to their high efficiency and performance under high loads compared to gear reducers using conventional cylindrical worm gears. In this paper, we aim to design a compact reducer with high efficiency using single enveloping worm gears for torque capacity of 5000Nm. We performed structural analysis to assess the structural stability of the reducer.

2.Design

Our design process critically examines which gear parameters are essential through a combination of manual calculations and advanced software analysis. These first stages comprise of the manual calculations that help in determining such dimensions as diameter, pitch, and worm and worm wheel's diameters. In this way, we lay the foundation for our gear system by doing it ourselves. Later on, we use advanced MITCalc software to uncover the complexities of gear design. It is only through MITCalc that we can calculate all-inclusive set of gears accurately instead of guessing at random and thus enhancing informed decision-making and given us a performance-reliable structure as required. By merging hands-on calculations with now-a-days tool like MITCalc, we maintain scientific engineering excellence throughout our search to come up with new solutions for gears. The following fig shows the MITCalc data for the worm and worm wheel parameters.

1)Power = 3kW 2)Speed ratio = 31.5

	Worm gearing				
i	Calculation without errors.		Worm	Gear	
ii	Project information				
?	+ Input section				
1.0	Options of basic input parameters				
1.1	Calculation units		SI Units (N, mm, kW...)		
1.2	Driven worm / worm gear		Worm		
1.3	Transferred power	Pw [kW]	3.530	3.000	<= Max. Pw
1.4	Speed (Worm / Worm gear)	n [/min]	160.00	5.05	i <= n1,n2
1.5	Torsional moment (Worm / Gear)	Mk [Nm]	210.69	5669.89	Pw2 <= Mk2,n2
1.6	Transmission ratio / from table	i	31.67	31.50	
1.7	Actual transmission ratio / deviation	i	31.67	0.00%	
2.0	Options of material, loading conditions, operational and production parameters				
2.0	Material identification according standard :		ISO		
2.1	Material of the worm:		Carbon structural steel C60ER(683/1-87) (Rm=740 MPa) nitro-carburized		
2.2	Material of the gear :		Bronze (continuous casting) CuSn12Ni2-C-GC (DIN EN 1982) (Rm=300 MPa)		
2.3	Type of worm (profile type)		ZN (N) Wormgear		
2.4	Loading of the gearbox, driving machine - examples		A...Continuous		
2.5	Loading of gearbox, driven machine - examples		A...Continuous		
2.6	Type of lubrication		Worm oil bath lubrication		
2.7	Type of oil		Oil based on Polyglycols (PEG)		
2.8	Oil designation - selection		ISO VG - 220 (AGMA no 5)		
2.9	Kinematic viscosity for 40°C and 100°C	ν40,ν100	220.00	40.00	[mm^2/s]
2.10	Lubrication density at 15°C	ρoil15	1.060	[kg/dm^3]	
2.11	Roughness average value of the worm	Ra1	0.50	[microm]	
2.12	Application factor	KA	1.00	1.00	
2.13	Desired service life	Lh	50000	[h]	
2.14	Requested coefficients of safety				
2.15	Wear safety	SW	1.10	≥1.10	
2.16	Pitting safety	SH	1.00	≥1.00	

Fig.1

Material selected for worm and worm wheel are:

Worm: Carbon structural steel C60ER(683/1-87)(Rm=740MPa)nitro-carburized

Worm wheel: Bronze CuSn12Ni2-C-Gc(DIN EN 1982)(Rm=300MPa)

5.1	Module: Normal / transverse / axiale	mn,mt,mx	4.5909	38.2575	4.6243	[mm]
5.2	Pitch: Normal / transverse / axiale	pn,pt,px	14.4227	120.1895	14.5277	[mm]
5.3	Pressure angle: Normal / transverse / axiale	alfan,alfat,al	25.0000	75.5686	25.1595	[°]
5.4	Number of teeth Worm / Worm Gear	z1,z2		3	95	
5.5	Tip diameter	da1,da2		123.9543	448.3269	[mm]
5.6	Reference diameter	d1,d2		114.7725	439.3099	[mm]
5.7	Root diameter	df1,df2		103.2952	427.6678	[mm]
5.8	Pitch cylinder diameter	dw1,dw2		114.9374	439.3099	[mm]
5.9	Mean diameter	dm1,dm2		115.6079	439.1439	[mm]
5.10	Outside diameter of wormgear	de2		468.6000	468.6-482.4	[mm]
5.11	Addendum	ha1,ha2		4.5909	4.5085	[mm]
5.12	Dedendum	hf1,hf2		5.7386	5.8211	[mm]
5.13	Center distance	a		276.9588		[mm]
5.14	Worm face width / Wormgear face width	L/b2H		76.6680	92.9700	[mm]
5.15	Pitch angle on: Mean diameter / Pitch diameter	γ, γw		6.8921	6.8823	[°]
5.16	Tooth thickness in normal plane	sn1,sn2		7.2114	7.1345	[mm]
5.17	Tooth thickness in centr-line plane	sx1,sx2		7.2639	7.1864	[mm]
5.18	Tooth space thickness in normal plane	en1,en2		7.2114	7.2882	[mm]
5.19	Tooth space thickness in centr-line plane	ex1,ex2		7.2639	7.3413	[mm]

Fig.2

Notations:

α_n = Normal pressure angle

γ = Worm lead angle

b_1 = Length of worm wheel.

d_1 = Ref dia of worm (Pitch dia of worm)

$d_{a.1}$ = Tip diameter of worm

d_2 = Ref dia of worm wheel (Pitch dia of worm wheel)

$d_{a.2}$ = Tip dia worm wheel

$h_{a.1}$ = Worm Thread addendum

$h_{f.1}$ = Worm Thread dedendum

m = Axial module

m_n = Normal module

n_1 = Rotational speed of worm

n_2 = Rotational speed of worm wheel

p_x = Axial pitch of worm threads

p_n = Normal pitch of worm threads and gear teeth

z_1 = Number of threads (starts) on worm

z_2 = Number of teeth on worm wheel

3.Modelling:

SolidWorks design software helps in the challenging techniques of 3D modelling, and it is through this that our project succeeds. This software provides us with a suitable platform for making sure that each part we make is described in detail and precision. After considering specific geometry or technical requirements, worm wheels are modelled differently from worms using MITCalc software which offers extensive data. We therefore capture all the details of every part which may be very fine or subtle allowing their seamless incorporation and operation as planned in final product. Moreover, these components can be assembled by SolidWorks smoothly enhancing their visualization and possible modifications to enhance their performance. The comprehensive approach of 3D modelling in this case assures that our designs are of high fidelity thereby ensuring that they will work when implemented in real cases.

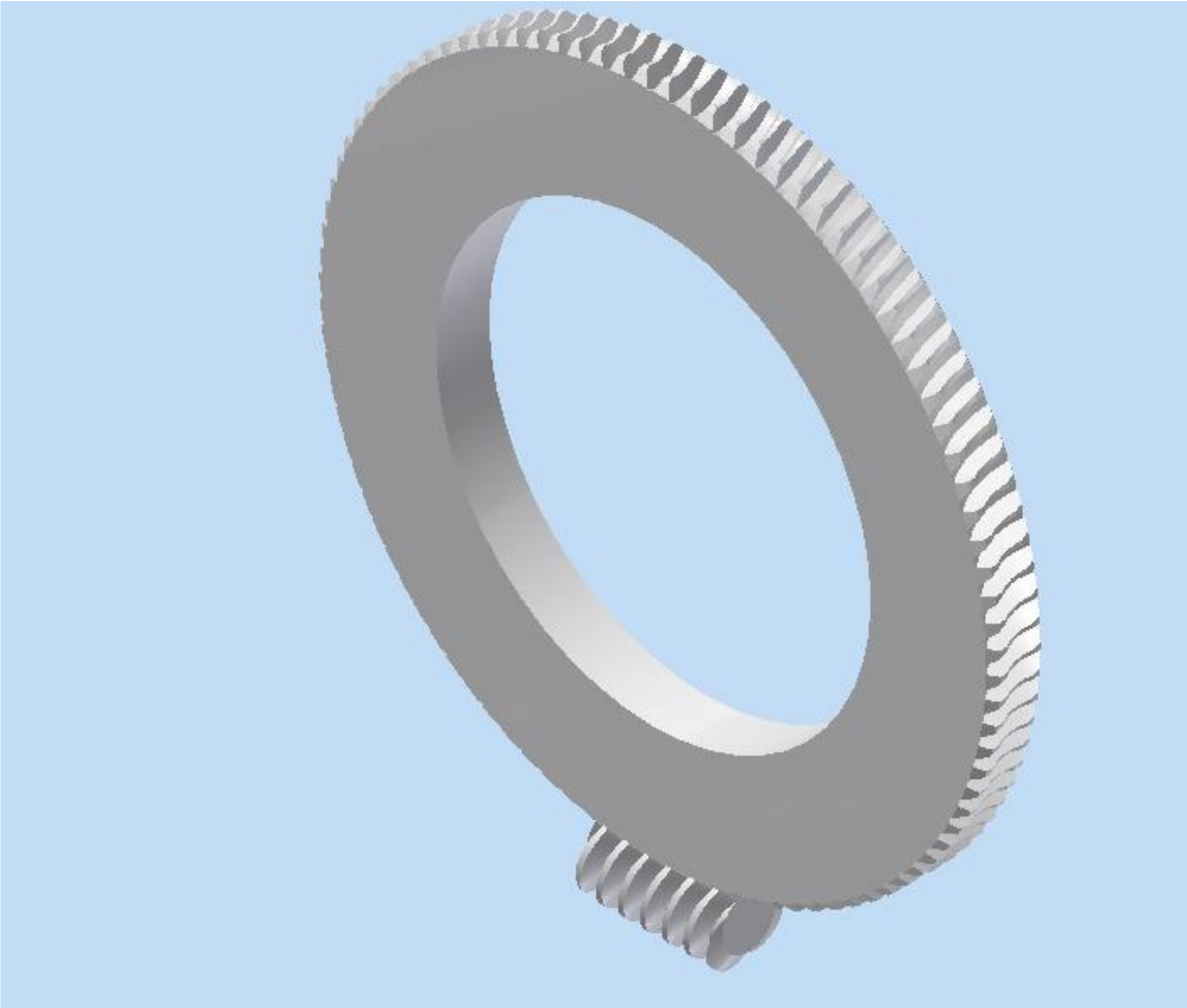

Fig.3 3D Model

4.Analysis:

When we finished with meticulous modelling of worm and gear components without any design and assembly mistakes, the next important stage involves testing these components using ANSYS Workbench software. We use this powerful software suite to simulate real conditions and assess important factors such as stress distribution and deformation in our designs. Different load scenarios and boundary conditions allow us to understand whether the structure is durable enough under different working environments. This kind of comprehensive analysis helps to identify problematic areas, improve efficiency through modification of design and ensure that safety standards are adhered to as well as performance requirements met. By taking advantage of sophisticated capabilities offered by ANSYS Workbench, we can confirm that our designs are accurate while also refining them so as to enhance reliability and durability for our products thus making them have better results when used in practical applications.

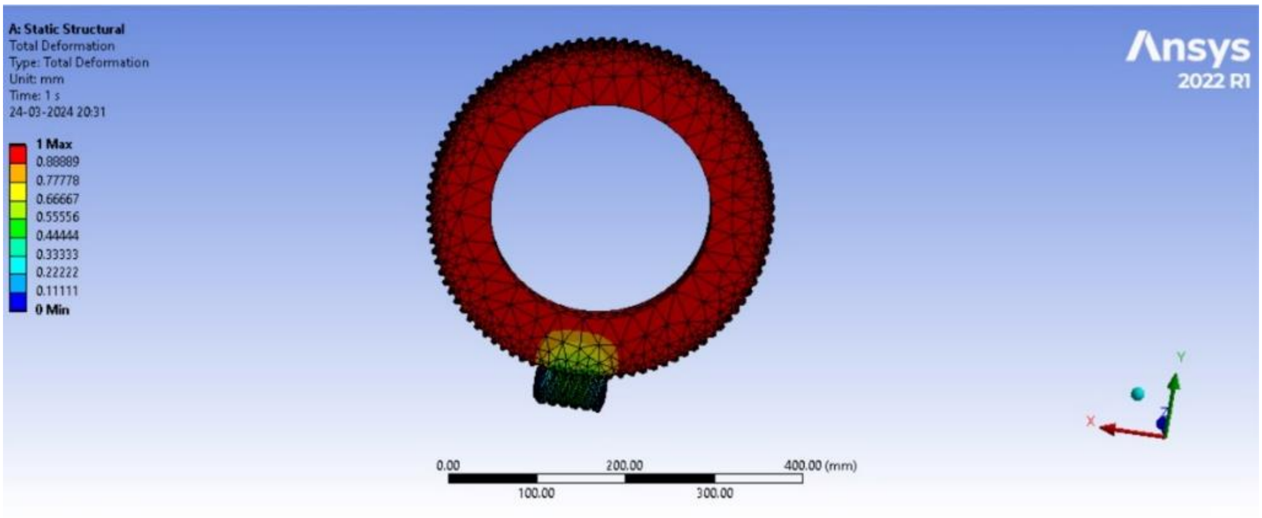

Fig.4 Total Deformation

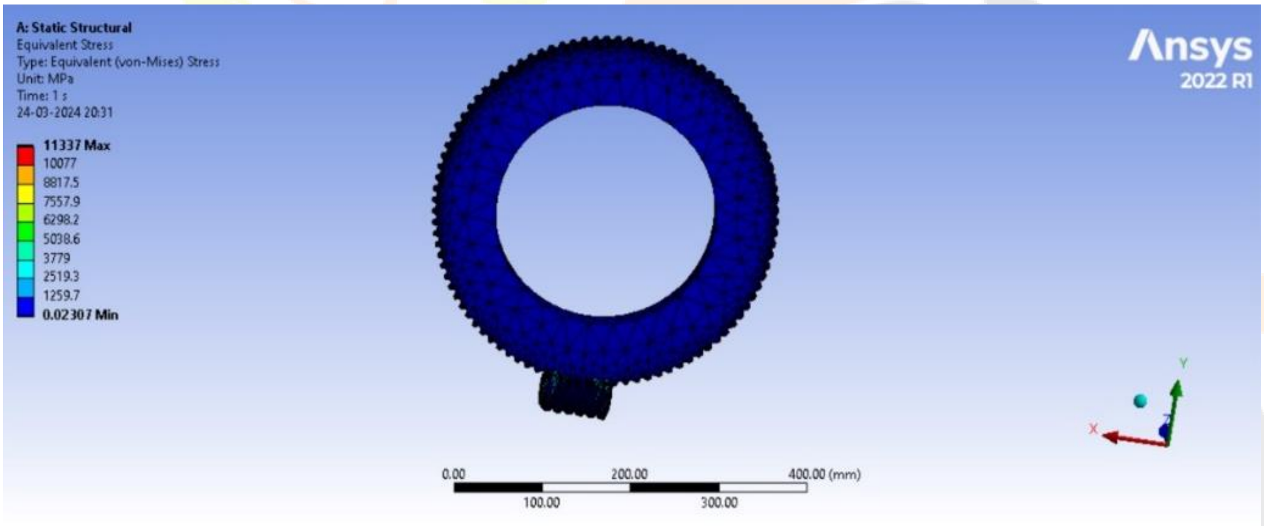

Fig.5 Equivalent Stress

5.Conclusion:

Our success in the project work saw us accomplish a comprehensive design, modelling and analysis of a single envelope worm and worm wheel system. The ANSYS Workbench software which was used for the analysis gave an insight on the stress distribution and deformation characteristics of these components well designed. This deep scrutiny confirms not just our design's structural integrity but also provides guidance on how to optimize performance as well as reliability. We were able to obtain great knowledge in different areas throughout this project, including gear mechanics, application of designing software and advanced analysis methods. Our skills in SolidWorks and ANSYS Workbench having being polished through learning process have taught us tricky gears system, while teaching us on scientific projects importance. The growth of our careers as engineers and researchers can be traced back to this project. These discoveries we made are bound to influence our future endeavours by helping us become more innovative in engineering design and analysis.

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