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Title: **MODELLING AND PERFORMANCE TEST ANALYSIS OF CYCLOID SPEED REDUCER**

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MODELLING AND PERFORMANCE TEST ANALYSIS OF CYCLOID SPEED REDUCER

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ABSTRACT:

The speed reducer is a mechanism where the speed of input to output shaft is reduced by a certain ratio. The work focuses on designing and analysis of cycloid speed reducer. The challenge lies in designing cycloid speed reducer without exceeding the contact stress limit of rollers and disc. The scope of the work is restricted to vibration analysis and dynamic analysis only material selection is beyond the scope of work. Dynamic analysis of cycloid speed reducer is carried out to evaluate contact forces between the disc and rollers. These contact forces obtained through simulation are validated with the analytical values.

1. INTRODUCTION

1.1 Cycloidal Speed Reducers

Cycloidal (planocentric) Gearboxes employ eccentric motion to achieve its speed reduction. It uses noncircular or eccentric motion to convert input rotation into a wobbly cycloidal motion. This motion is then converted back into a circular output rotation. During this process, speed reduction occurs. Unlike Harmonic drives, which employ a flexible cylinder that doesn't move in its entirety but stretches to mesh with the internal circular spline gear to achieve a type of cycloidal motion, the cycloidal (planocentric) drives will actually move the entire internal gear in an eccentric motion. Optional thru-hole.A cycloidal drive or cycloidal speed reducer is a mechanism for reducing the speed of an input shaft by a certain ratio. Cycloidal speed reducers are capable of relatively high ratios in compact sizes. The input shaft drives an eccentric bearing that in turn drives the cycloidal disc in an eccentric, cycloidal motion. The perimeter of this disc is geared to a stationary ring gear and has a series of output shaft pins or rollers placed through the face of the disc. These output shaft pins directly drive the output shaft as the cycloidal disc rotates. The radial motion of the disc is not translated to the output shaft.The input shaft is mounted eccentrically to a Rolling-element bearing (typically a cylindrical roller bearing), causing the cycloidal disc to move in a circle. The cycloidal disc will independently rotate around the bearing as it is pushed against the ring gear. This is similar to planetary gears, and the direction of rotation is opposite to that of the input shaft. The number of pins on the ring gear is larger than the number of pins on the cycloidal disc. This causes the cycloidal disc to rotate around the bearing faster than the input shaft is moving it around, giving an overall rotation in the direction opposing the rotation of the input shaft.

1.2 Cycloid

A cycloid is the curve traced by a point on the rim of a circular wheel as the wheel rolls along a straight line without slippage. A cycloid is a specific form of tro-choid and is an example of roulette, a curve generated by a curve rolling on another curve. The cycloid, with the cusps pointing upward, is the curve of fastest descent under constant gravity, and is also the form of a curve for which the period of an object in descent on the curve does not depend on the object's starting position.

2. LITERATURE REVIEW

[1] Caetano Pacheco, (2011) Analysis of Cycloid Drives Dynamic Behaviour, presented a generalized approach to the minimum volume design of spur gear units based upon a traditional nonlinear programming. The methodology was applied to the design of two-

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stage and three-stage spur gear reduction units, subject to identical loading conditions and design criteria.[2] Gorla C., Davoli P., Rosa F., Longoni C., Chiozz, F., Samarani A., (2008) Theoretical and Experimental Analysis of a Cycloidal Speed Reducer, J. Mech. Des., carried out of the asymmetric spur gear drive using an iterative procedure on the calculated maximum fillet stresses through FEM for different rack cutter shifts. The optimum values of rack cutter shifts were suggested for the given center distance and the speed ratio of an asymmetric gear drive. [3] Li X., He W., LiL., Schmidt L. (2004) A New Cycloid Drive with High-Load Capacity and High Efficiency discussed a two-stage helical gear transmission design problem (complete with the sizing and selection of shafts, bearings, housing, etc.) using a two-phase evolutionary algorithm in a formulation that can be extended to include additional stages or different layouts. [4] Litvin F.L., Feng P.H., (1996) Computerize Design and Generation of Cycloidal Gearing, Mechanism and Machine Theory, algorithms known as particle swarm optimization (PSO) and simulated annealing (SA) to find the optimal combination of design parameters for minimum weight of a spur gear train. [5]. Kudryavtsev, V.N., 1966. Gear geometry and applied theory carried out the complete automated design with genetic algorithms of a two stage helical coaxial speed reducer. The objective function (i.e. the mass of the entire speed reducer) was described by a set of 17 mixed design variables (i.e. integer, discrete and real) and also was subjected to 76 highly non-linear constraints. The results showed that the proposed genetic algorithm can offer better design solutions as compared with the results obtained by using the traditional design method.

3. DESIGN

CATIA offers a solution to shape design, styling, surfacing workflow and visualization to create, modify, and validate complex innovative shapes from industrial design to Class-A surfacing with the ICEM surfacing technologies. CATIA supports multiple stages of product design whether started from scratch or from 2D sketches. CATIA is able to read and produce STEP format files for reverse engineering and surface reuse

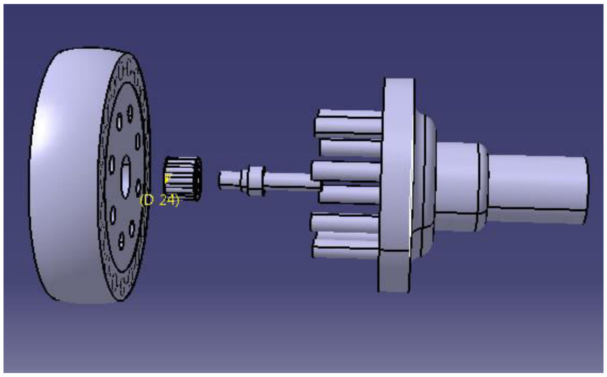

Fig1: 3D Model of Cycloidal Speed Reducer Using CATIA V5.

4. ANALYSIS

ANSYS is general-purpose finite element analysis software, which enables engineers to perform the following tasks:

1. Build computer models or transfer CAD model of structures, products, components or systems
2. Apply operating loads or other design performance conditions.
3. Study the physical responses such as stress levels, temperatures distributions or the impact of electromagnetic fields.
4. Optimize a design early in the development process to reduce production costs.
5. A typical ANSYS analysis work has done in three distinct steps.

4.1 Modal Analysis:

Process for determining the N natural frequencies and mode shapes.Given “suitable” initial conditions, the structure will vibrate

- at one of its natural frequencies.
- the shape of the vibration will be a scalar multiple of a mode shape.

- Given “arbitrary” initial conditions, the resulting vibration will be a Superposition of mode shapes
- Determines the vibration characteristics (natural frequencies and mode shapes) of a structural component.
- Natural frequencies and mode shapes are a starting point for a transient or harmonic.

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4.1.1 Cycloid Disc with High Speed Steel Material

Table 4.1 Physical properties of High speed steel

Density	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
$1.6e^{-009}$ kg / mm^3	$1.9e^{+008}$	0.27	$1.3768e^{+008}$	$7.4803e^{+007}$

Results:

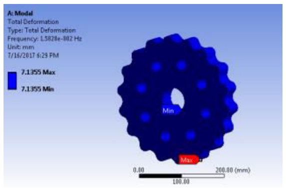


Fig 4.1.1 Total Deformation

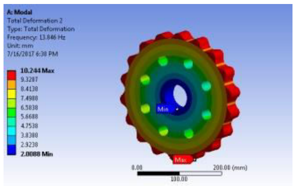


Fig 4.1.2 Total Deformation 2

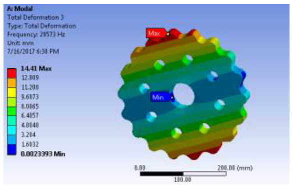


Fig 4.1.3 Total Deformation 3

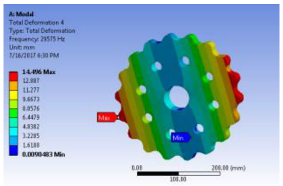


Fig 4.1.4 Total Deformation 4

Table 4.2 Vibration Analysis Results of Cycloid Disc with High Speed Steel Material

Cycloid Disc	Total Deformation	Total Deformation 2	Total Deformation 3	Total Deformation 4
Type	Total Deformation			
Mode	1.	2.	3.	4.
Results				
Minimum	7.1355 mm	2.0088 mm	$2.3393e^{-003}$ mm	$9.0483e^{-003}$ mm
Maximum	7.1355 mm	10.244 mm	14.41 mm	14.496 mm
Information				
Frequency	$1.5828e^{-002}$ Hz	13.846 Hz	29573 Hz	29575 Hz

4.1.2 Cycloid Disc with Carbon Epoxy Material

Table4.3 Physical properties of Carbon Epoxy

Density	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
$1.6e^{-009}$ kg /mm^3	$7.e^{+005}$	0.1	$2.9167e^{+005}$	$3.1818e^{+005}$

Results:

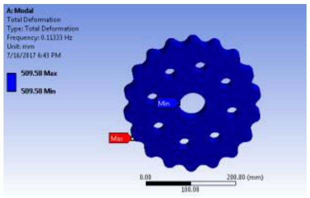


Fig 4.2.1 Total Deformation

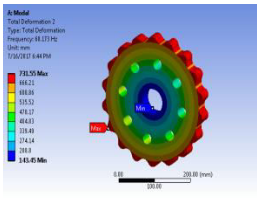


Fig 4.2.2 Total Deformation 2

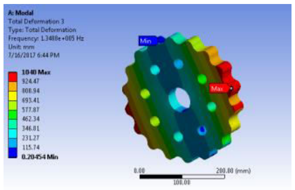


Fig 4.2.3 Total Deformation 3

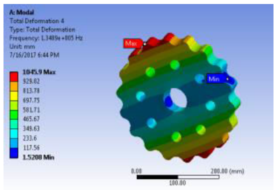


Fig 4.2.4 Total Deformation 4

Table 4.4 Vibration Analysis Results of Cycloid Disc with Carbon Epoxy Material

Cycloid Disc	Total Deformation	Total Deformation 2	Total Deformation 3	Total Deformation 4
Minimum	509.58 mm	143.45 mm	0.20454 mm	1.5208 mm
Maximum	509.58 mm	731.55 mm	1040. mm	1045.9 mm
Frequency	0.11333 Hz	60.173 Hz	$1.3488e^{+005}$ Hz	$1.3489e^{+005}$ Hz

4.1.3 Output shaft and Carrier with Stainless Steel Material

Table 4.5 Physical properties of Stainless Steel

Density	Coefficient of Thermal Expansion	Specific Heat	Thermal Conductivity	Resistivity
$7.75e^{-006}$ kg /mm^3	$1.7e^{-005}$ $^0C^{-1}$	$4.8e^{+005}$ mJ / kg^1 $^0C^1$	$1.51e^{-002}$ W /mm^1 $^0C^1$	$7.7e^{-004}$ ohm mm

Results

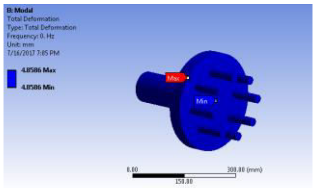


Fig 4.3.1 Total Deformation

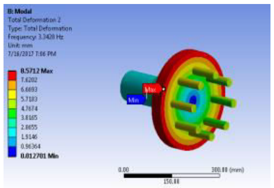
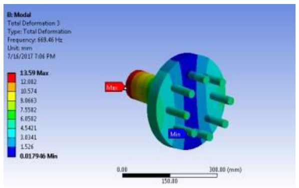


Fig 4.3.2 Total Deformation 2



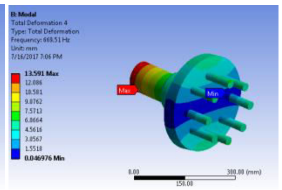


Fig 4.3.3 Total Deformation 3 Fig 4.3.4 Total Deformation 4

Table 4.6 Vibration Analysis Results of Output Shaft and Carrier with High Speed

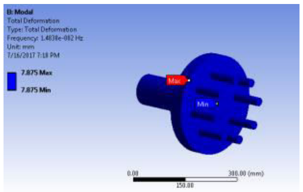
Output Shaft	Total Deformation	Total Deformation 2	Total Deformation 3	Total Deformation 4
Type	Total Deformation			
Mode	1.	2.	3.	4.
Results				
Minimum	4.8586 mm	$1.2701e^{-002}$ mm	$1.7946e^{-002}$ mm	$4.6976e^{-002}$ mm
Maximum	4.8586 mm	8.5712 mm	13.59 mm	13.591 mm
Information				
Frequency	0. Hz	3.3428 Hz	669.46 Hz	669.51 Hz

4.1.4 Output shaft and Carrier with Aluminium silicon carbide Material

Table 4.7 Physical properties of Aluminium silicon carbide

Density	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
$2.95 e^{-006}$ Kg /mm^3	$2.3e^{+008}$	0.154	$1.1079e^{+008}$	$9.9653e^{+007}$

Results



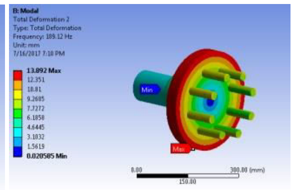
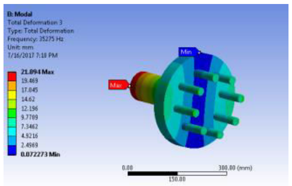


Fig 4.4.1 Total Deformation Fig 4.4.2 Total Deformation 2



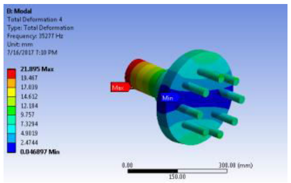


Fig 4.4.3 Total Deformation 3 Fig 4.4.4 Total Deformation 4

Table 4.8 Vibration Analysis Results of Output Shaft and Carrier with High Speed

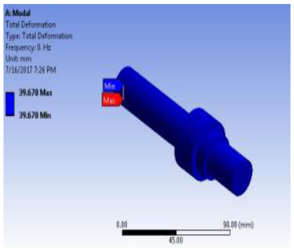
Output Shaft and Carrier	Total Deformation	Total Deformation 2	Total Deformation 3	Total Deformation 4
Type	Total Deformation			
Mode	1.	2.	3.	4.
Results				
Minimum	7.875 mm	$2.0585e^{-002}$ mm	$7.2273e^{-002}$ mm	$4.6897e^{-002}$ mm
Maximum	7.875 mm	13.892 mm	21.894 mm	21.895 mm
Information				
Frequency	$1.4838e^{-002}$ Hz	189.12 Hz	35275 Hz	35277 Hz

4.1.5 Input Shaft with Stainless Steel Material

Table 4.9 Physical properties of Stainless steel

Density	Coefficient of Thermal Expansion	Specific Heat	Thermal Conductivity	Resistivity
$7.7e^{-006}$ Kg/mm^3	1.7e-005 $^0C^{-1}$	$4.8e^{+005}$ mJ/ kg^{1} $^0C^{-1}$	$1.51e^{-002}$ W /mm^{1} $^0C^{1}$	$7.7e^{-004}$ ohm mm

Results



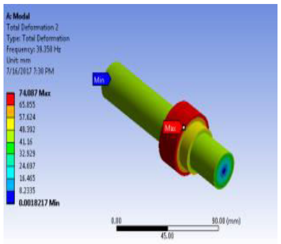
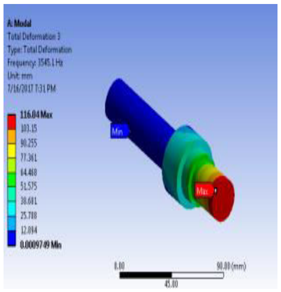


Fig 4.5.1 Total Deformation Fig 4.5.2 Total Deformation 2



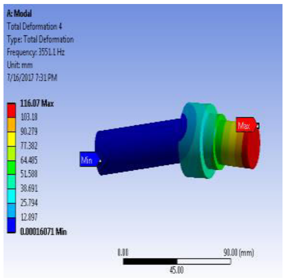


Fig 4.5.3 Total Deformation 3 Fig 4.5.4 Total Deformation 4

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Table 4.10 Vibration Analysis Results of Input Shaft with Stainless Steel

Input Shaft	Total Deformation	Total Deformation 2	Total Deformation 3	Total Deformation 4
Mode	1.	2.	3.	4.
Results				
Minimum	39.678 mm	1.8217 e^{-003} mm	9.749 e^{-004} mm	1.6071 e^{-004} mm
Maximum	39.678 mm	74.087 mm	116.04 mm	116.07 mm
Information				
Frequency	0. Hz	39.358 Hz	3545.1 Hz	3551.1 Hz

4.1.6 Input Shaft with Aluminium silicon carbide Material

Table 4.11 Physical properties of Silicon Carbide

Density	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
$2.95e^{-006}$ kg/mm^3	$2.3e^{+008}$	0.154	$1.1079e^{+008}$	$9.9653e^{+007}$

Results

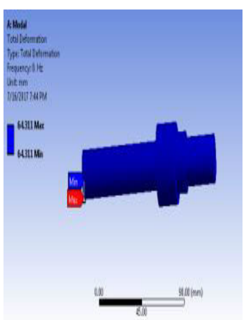
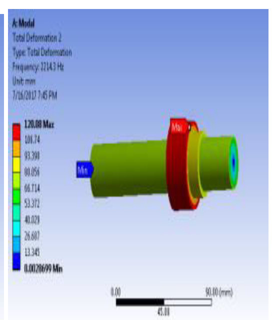



Fig 4.6.1Total Deformation Fig 4.6.2 Total Deformation 2

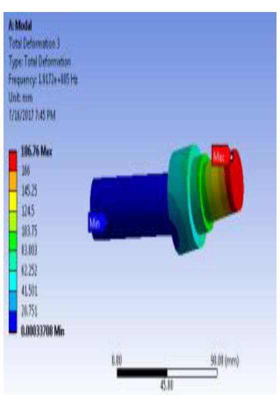
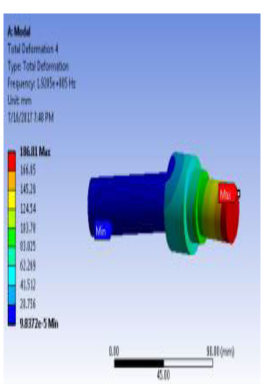



Fig 4.6.3 Total Deformation 3 Fig 4.6.4 Total Deformation 4

Table 4.12 Vibration Analysis Results of Input Shaft with Silicon Carbide

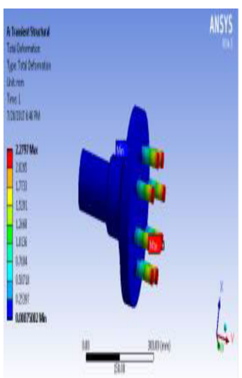
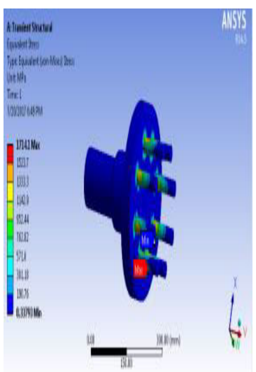
Input Shaft	Total Deformation	Total Deformation 2	Total Deformation 3	Total Deformation 4
Definition				
Type	Total Deformation			
Mode	1.	2.	3.	4.
Results				
Minimum	64.311 mm	$2.8699e^{-003}$ mm	$3.3708e^{-004}$ mm	$9.8372e^{-005}$ mm
Maximum	64.311 mm	120.08 mm	186.76 mm	186.81 mm
Information				
Frequency	0. Hz	2214.3 Hz	$1.9172e^{+005}$ Hz	$1.9205e^{+005}$ Hz

4.2 DYNAMIC ANALYSIS

Transient dynamic analysis (sometimes called time-history analysis) is a technique used to determine the dynamic response of a structure under the action of any general time-dependent loads. You can use this type of analysis to determine the time-varying displacements, strains, stresses, and forces in a structure as it responds to any combination of static, transient, and harmonic loads. The time scale of the loading is such that the inertia or damping effects are considered to be important. If the inertia and damping effects are not important, you might be able to use a static analysis instead.

4.2.1 Output shaft and Carrier with Stainless Steel Material

Results:

Total Deformation Equivalent Stress

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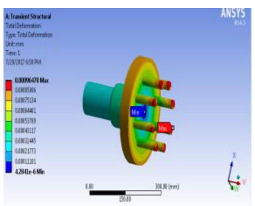
Table 4.13 Dynamic Analysis Results of Output shaft and Carrier with Stainless Steel

Output shaft and Carrier	Total Deformation	Equivalent Elastic Strain	Maximum Shear Elastic Strain	Equivalent Plastic Strain	Equivalent Stress
Results					
Minimum	$7.5002e^{-004}$ mm	$1.943e^{-006}$ mm/mm	$2.51e^{-006}$ mm/mm	0. mm/mm	0.33793 MPa
Maximum	2.2797 mm	$8.916e^{-003}$ mm/mm	$1.18e^{-002}$ mm/mm	0. mm/mm	1714.1 MPa

4.2.2 Output shaft and Carrier with Aluminium silicon carbide


Total Deformation

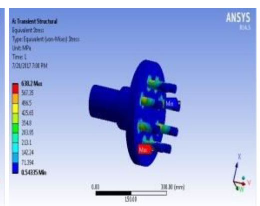
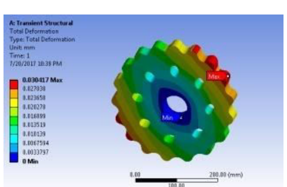

Equivalent Stress

Table 4.14 Dynamic Analysis Results of Output shaft and Carrier with Aluminium silicon carbide

Output shaft and Carrier	Total Deformation	Equivalent Elastic Strain	Maximum Shear Elastic Strain	Equivalent Plastic Strain	Equivalent Stress
Results					
Minimum	$4.2841e^{-006}$ mm	$2.3897e^{-009}$ mm/mm	$3.0462e^{-009}$ mm/mm	0. mm/mm	0.54335 MPa
Maximum	$9.6478e^{-004}$ mm	$2.782e^{-006}$ mm/mm	$3.2426e^{-006}$ mm/mm	0. mm/mm	638.2 MPa

4.2.3 Cycloid Disc with High Speed Steel Material


Total Deformation

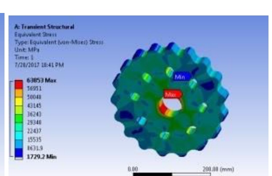
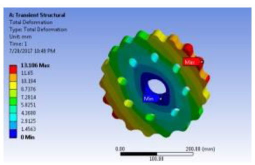

Equivalent Stress

Table 4.15 Dynamic Analysis Results Cycloid Disc with High Speed Steel

Cycloid Disc	Total Deformation	Directional Deformation	Equivalent Elastic Strain	Shear Elastic Strain	Equivalent Stress
Minimum	0. mm	$-8.2617e^{-004}$ mm	$1.2719e^{-005}$ mm/mm	$-1.4753e^{-004}$ mm/mm	1729.2 MPa
Maximum	$3.0417e^{-002}$ mm	$8.2617e^{-004}$ mm	$3.3607e^{-004}$ mm/mm	$1.4753e^{-004}$ mm/mm	63853 MPa

4.2.4 Cycloid Disc with Carbon epoxy


Total Deformation

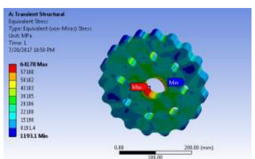
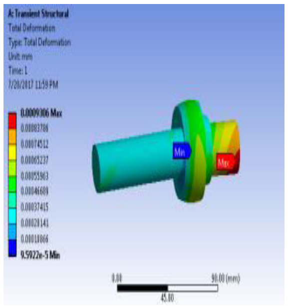

Equivalent Stress

Table 4.16 Dynamic Analysis Results of Cycloid Disc with Carbon Epoxy

Cycloid Disc	Total Deformation	Directional Deformation	Equivalent Elastic Strain	Shear Elastic Strain	Equivalent Stress
Results					
Minimum	0. mm	-0.3991 mm	$5.3874e^{-003}$ mm/mm	$-7.6152e^{-002}$ mm/mm	1193.1 MPa
Maximum	13.106 mm	0.3991 mm	0.14262 mm/mm	$7.6152e^{-002}$ mm/mm	64178 MPa

4.2.5 Input Shaft with Stainless Steel


Total Deformation

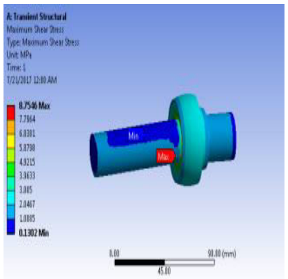

Equivalent Stress

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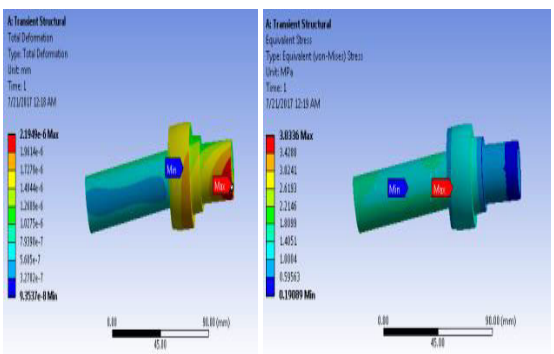
Table 4.17 Dynamic Analysis Results of Input Shaft with Stainless Steel

Input Shaft	Total Deformation	Directional Deformation	Equivalent Elastic Strain	Maximum Shear Elastic Strain	Equivalent Stress
Results					
Minimum	$9.5922e^{-005}$ mm	$-8.5734 e^{-004}$ mm	$1.8173 e^{-006}$ mm/mm	$1.7675 e^{-006}$ mm/mm	0.22788 MPa
Maximum	$9.306e^{-004}$ mm	$4.1208 e^{-004}$ mm	$1.2276 e^{-004}$ mm/mm	$1.1885 e^{-004}$ mm/mm	15.197 MPa

4.2.6 Input Shaft with Aluminium silicon carbide Material



Total Deformation Equivalent Stress

Table 4.18 Dynamic Analysis Results of Input Shaft with Silicon Carbide

Input Shaft	Total Deformation	Directional Deformation	Equivalent Elastic Strain	Maximum Shear Elastic Strain	Equivalent Stress
Results					
Minimum	$9.3537e^{-008}$ mm	$-1.0023e^{-006}$ mm	$6.422e^{-009}$ mm/mm	$5.945 e^{-009}$ mm/mm	0.19089 MPa
Maximum	$2.1949e^{-006}$ mm	$5.4101e^{-007}$ mm	$1.2805 e^{-007}$ mm/mm	$1.2222 e^{-007}$ mm/mm	3.8336 MPa

Conclusion:

As with all machines and devices, there exist machining tolerances at cycloidal speed reducer. Three the most critical cases for cycloid disc have been analyzed in the paper, from aspects of stress and strain values. Problem is observed as being planar using software ansys.There are numerical analysis for stationary central gear and for eccentric, too. Analysis for this elements was done in software CATIA. 3D finite elements were used. Based on realized stress-strain analysis using FEM, the following conclusions can be made: - The most unfavourable case for cycloid disc, from aspect of stress and strain values, is the case of the single meshing and the most favourable case is the triple meshing;-Even in the case of the most unfavourable single meshing, maximum stress and strain values are within the limits that provide reliable work of cycloid disks during the foreseen working life; -Values of contact stress and strains for stationary central gear and for eccentric are very close to values of Von- Misses stress and strains of cycloid disc. It means that all vital elements are very uniformly loaded and this is very important advantage of the single stage cycloidal speed reducer.

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