Stress Deformation & Stiffness Analysis of Two Materials 
(Steel and Glass / Epoxy) of Flexspline Using ANSYS

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ABSTRACT
The objective of this present work is to estimate stress, deformation & Stiffness Analysis of Flexspline for two materials – steel and composite material (glass/epoxy). A flexspline is a component of harmonic drive which works on elastic theory for the transmission of power. In this work modelling is done by Inventor software and analysis is carried out by Ansys software. Essential difference between harmonic drive and conventional gear drive is that flexspline in harmonic drive is flexible and the centre distances of teeth vary continuously during meshing.

KEYWORDS : Flexspline , stress , deformation , stiffness, ansys & FEM.

1. INTRODUCTION
Flexspline is one part of harmonic drive which works upon elastic theory. In power transmission there are different factors important to consider like size, weight, backlash etc for efficient work. The unique operating principle and flexible design configurations of harmonic drive transmissions make them ideal for a wide range of applications. Harmonic drive are successfully used in industrial robots, machine–tools, printing presses medical equipment, solar applications, aerospace etc.

2. COMPONENTS OF HARMONIC DRIVE
Harmonic drive has three components namely- flexspline, circular spline and wave generator. The wave generator has an oval cam type, which is operated by the input power and contacted with a flexspline. The circular spline has a rigid ring type with an internal gear. The flexspline has a thin circular cup type, it is the main component of a harmonic drive, which can generate a repeated vibration by the wave generator. With such a reason, the flexspline should has good vibration characteristics.

In order to reduce the stress and for improving the tooth profile in flexsplines SHF series uses short axial length, high stiffness, and high accuracy for hollow shaft structures. For the improvement of performance of flexspline there are various factors like selection of material, elliptical shape, surface treatment etc. are considers in SHG series and by implementing all these SHG series has achieved 30 % higher load capacity compared to SHF series. Since stress is gathered at the connecting point of the thin-walled section and diaphragm for silkhat-shape, it was thought that silk hat-shape could not be marketed when the technology was first introduced.

Figure 1: Assembly for harmonic gear drive

Figure 2: Description of harmonic gear drive
Flexspline torsional deformation is one of the main influencing factors on backlash in harmonic gearing. In former theoretic formula, only the flexible torsional deformation of thin-walled cylinder of flexspline was taken into account for the calculation of backlash, so there was much more error. Harmonic drive has several characteristics, for instance, a high precision, compactness, light weight and high reduction ratio characteristics compared with the conventional speed reducer. In modern industrial fields, a speed reducer requires a good driving torque, low backlashes and precise transmission characteristic of power. The harmonic drive has been applied as an actuator of robot, driving parts of measurement system, semiconductor manufacturing system, etc. The conventional speed reducer uses the concept of rigid bodies, but the harmonic drive is operated by the elastic theory. As for this, harmonic drive shows different characteristics in operation principles and analysis compared to the conventional ones.

3. WORKING OF HARMONIC DRIVES

The harmonic gear drives loosely resembles epicyclic gear train except that the flexspline representing planet gear is flexible. The most common method of operation of Harmonic gear drive uses wave generator as an input link, flexspline as an output link & the circular spline as a fixed link. Suppose the wave generator rotates in clockwise direction. The contact between wave generator and flexspline can be assumed as a surface contact. As elliptical wave generator is rotated, major and minor axes also rotates along with it. This causes flexspline to un-mesh from the previous position of major axis of wave generator and get into meshing into new position. The tooth on flexspline follows two motions simultaneously namely Radial and Anticlockwise Rotational motion.

Han Su Jeon et al. (1999) This paper, studies on stress and related vibration characteristics using the numerical analysis tool, has been carried out on the flexspline as part of speed reducer. Analysis has been applied to two kinds of models, which are steel flexspline and steel-composite hybrid flexspline with carbon-fibre epoxy and glass-fibre epoxy composite materials. The stress, stiffness and damping capacity were investigated as a vibration characteristics.

Huimin Dong et al. (2009) In this paper author describe a method to describe the spatial deformation of a cup – type flexspline is used where this deformation is separated into a set of deformed curves on the cross – section normal to the axis. To investigate elastic deformation characteristic of a flexspline under the load conditions a finite element contact analysis ANSYS Parametric design language (APDL) is used.

Chuang Zou et al. (2013) This paper to reveal the stress and deformation states of short flexspline. The boundary condition of the gear teeth meshing is evaluated by experimental formula. The stress and deformation of flexspline are solved and their relationships with varying loads are analyzed. It is found that the deformation and stress at the flexspline gear cross section changes geometrically with heightened load, but the distributions of the deformation and stress increments remain unchanged. The solution results are compatible with the cases of flexspline destruction and axial stress distribution under load. This approach can help to optimize the structure and manufacturing process of harmonic reducer and increase the reliability of related automation equipment.

5. MATERIAL PROPERTIES OF FLEXSPLINE

Detailed specifications of flexsplines in harmonic drives are given, for our work we took two materials – steel and composite material( glass/ epoxy). In this section table 1 shows the property of the steel and table no. 2 shows property of glass/ epoxy and dimensions is shown in figure 4.

<table>
<thead>
<tr>
<th>Tensile modulus (GPa)</th>
<th>Shear modulus (GPa)</th>
<th>Poision’s ratio</th>
<th>Tensile strength (MPa)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>210</td>
<td>80</td>
<td>0.3</td>
<td>1000</td>
<td>7850</td>
</tr>
</tbody>
</table>

Table 1 Properties of the steel
### Table 2 Properties of the E-glass/Epoxy

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus</td>
<td>24000 Mpa</td>
</tr>
<tr>
<td>Poission’s Ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>205 Mpa</td>
</tr>
<tr>
<td>Density</td>
<td>1520 Kg/mm³</td>
</tr>
</tbody>
</table>

6. GEOMETRY AND DIMENSIONS OF FLEXSPLINE

The FE modelling of this portion of the flexspline was the most time consuming compared to the two other portions. We had to figure out how to model the phenomenon cause by the meshing process, the actual degrees of freedom to be restrained or allowed as well as the applied load fig 5. To reduce the CPU solving time we use two numerical models. The first model only takes in account the flexibility of the flexspline while the other considers only the circular spline as being flexible. Total rotation for a given torque on the teethed part is obtained by adding the displacement and stress of both models.

![Fig. 4 Specification and dimension of flexspline](image1)

![Fig. 5 Toothed Flexspline](image2)

![Fig. 6 Load Condition On Flexspline](image3)

![Fig. 7(a) Stress analysis of Glass Epoxy at 30° bond angle](image4)

![Fig. 7(b) Stress analysis of steel at 30° bond angle](image5)
Fig. 7(c) Stress analysis of Glass Epoxy at 45° bond angle

Fig. 7(d) Stress analysis of steel at 45° bond angle

Fig. 7(e) Stress analysis of Glass Epoxy at 60° bond angle

Fig. 7(f) Stress analysis of steel at 60° bond angle

Stress Analysis Chart

Fig. 8 Shows Comparison of Stress between glass epoxy and steel

Deformation Analysis Chart

Fig. 9 Shows Comparison of deformation between glass epoxy and steel
7. RESULTS AND DISCUSSIONS

Stress Analysis of The Steel & Composite Hybrid FlexSpline

We have taken two materials steel and glass/epoxy in this research, in this spline the BT is taken as 0.1 mm, the staking angle is 30°, 45° and 60°. The thickness of composite material is 0.5mm and width is 15mm. In the first study by applying 100 N the von mises stress distribution is shown in fig. 8. From the result we can conclude that stress is significantly reduced when we use composite material in place of steel.

Deformation analysis of the steel and epoxy material on composite hybrid flexspline

We have taken two materials steel and glass/epoxy in this research, The steel-composite hybrid flexspline was applied as composite material on some parts of flexspline. Due to the manufacturing process the cost is very low. In this spline the spline BT is taken as 0.1 mm, the staking angle is 30°, 45° and 60°. The thickness of composite material is 0.5mm and width is 15mm. In the first study by applying 100 N step time of 0 0.008 sec. From the result we can conclude that deformation is significantly reduced when we use composite material in place of steel. This analysis is shown in fig. 9.

Stiffness analysis of the steel and epoxy material on composite hybrid flexspline

We have taken two materials steel and glass/epoxy in this research and from the result we can conclude that stiffness is greatly reduced when we use composite material in place of steel. This analysis is shown above in fig. 10.

Table no.3 showing the results of stress, deformation and stiffness for the two materials steel and composite(glass/epoxy) used in flexspline in harmonic drive for this we have taken three values of bond angle 30°,45° and 60°.

<table>
<thead>
<tr>
<th>Bond Angle</th>
<th>Stress (In MPa)</th>
<th>Deformation (In mm)</th>
<th>Stiffness (N/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steel</td>
<td>Glass</td>
<td>Steel</td>
</tr>
<tr>
<td>30°</td>
<td>723</td>
<td>613</td>
<td>3.5</td>
</tr>
<tr>
<td>45°</td>
<td>617</td>
<td>573</td>
<td>3.4</td>
</tr>
<tr>
<td>60°</td>
<td>538</td>
<td>511</td>
<td>3.0</td>
</tr>
</tbody>
</table>

8. CONCLUSION

In this paper a study on stress, deformation and stiffness characteristic using FEM tool has been carried out. The analysis was carried on two types of materials steel and composite material (glass/epoxy). Stress, deformation and stiffness were analysed. As per the above result by applying 100 N load there are variation seen in both the material. Stress is reduced by 8% on composite material as compared with steel. Stiffness and deformation is lower as half as compared with steel material. This complete analysis is carried by keeping BT 0.1

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REFERENCES