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Analysis of Flexspline in the Harmonic Drive System: A Review

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Abstract

This paper is devoted to various study based on power transmission system called harmonic gear drive, which gives the high-speed reduction & power transmission capacity. This harmonic drive provides accurate as well as precision with much less space as compared to any other power transmission drives. This paper discusses the basic working principle, various problems faces during the analysis of harmonic gear drive, meshing characteristics of the teeth with its advantages. 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, finite element method.

Introduction

Flexspline torsional deformation is one of the main influencing factors on backlash in harmonic gearing. In former theoretic formula , only the f1exible torsional deformation of thin-walled cylinder of f1exspline was taken into account for the calculation of backlash , so there is much more error. The review report on the basis of various previous researchers on calculation formula of backlash resulting from torsional deformation is presented in this paper by considering f1exible deformation of thin-walled cylinder and disk based on the theory of elasticity, and it is compared with ANSYS simulation by example. In this paper, a study on stress, deformation and related vibration characteristics using the finite element method tool has been carried out on the flexspline as a part of speed reducer. The damping ratio of composite flexspline is also more times as high as that of the steel flexspline.

After a strain wave gearing, named Harmonic Drive was invented in the US, this technique was introduced to Japan and bloomed into a robotic industry. Harmonic Drive is a very unique gearing system which can obtain a large reduction ratio in one stage by using an elastic deformation of thin walled gearing, and there is no backlash. After making some improvements, Harmonic Drive systems now commands an 80% share of the strain wave gearing marketing in Japan. New Harmonic Drive, named SHF series was derived from SH series. Its hollow shaft structure achieved a silk hat-shaped strain wave gearing based on US-introduced cup-shaped wave gearing and originally designed by ourselves in Japan (Fig.1).

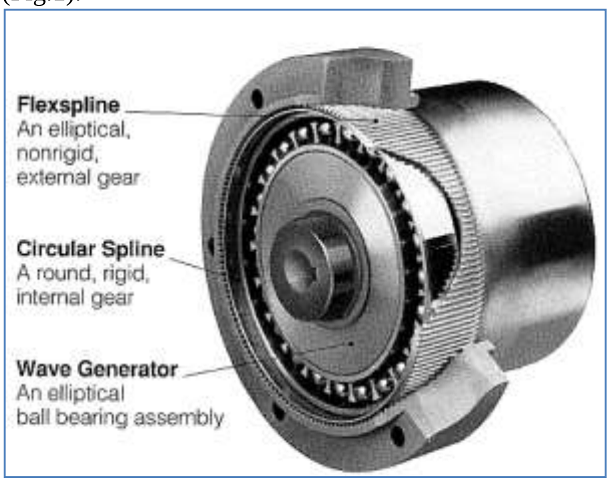

Figure 1. Assembly for harmonic gear drive

In addition to our original tooth profile and stress reduced design, SHF series has achieved short length in axial, high stiffness, robust and high accuracy hollow shaft structure. Thanks to the improvement of tooth profile, material, elliptical shape, surface treatment and so on, 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. In order to overcome this issue, higher strength compared to cup type was obtained by calculation for stress-

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reduced design by FEM and high accurate machining using NC lathe.

Figure 2. Description of harmonic gear drive

Harmonic drive has several characteristics, for instance, a high precision, compactness, light-in-weight property 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.

It is composed of 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 flexspline. and good vibration characteristics.

In this paper, the application of steel and steel-composite hybrid materials uses for analysis. It is important for the design of flexspline. to consider a tooth and dimension in the harmonic drive was analysed. But circular spline has an internal gear type and good strength compared to flexspline.. Many researchers have conducted studies to improve performance since Muser had invented a harmonic drive. The purpose of the study is investigation of a stress and vibration characteristic to apply advanced materials such as carbon-fibre epoxy and glass-fibber epoxy composite materials from analysis of the dynamic characteristic of the harmonic drive. Analysis was performed on a three-dimensional model using an analytic output of the mathematical equation by the tooth elastic deformation.

Working of harmonic drives

The harmonic gear drives loosely resembles epicyclical 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.

Figure3. Principle of operation

Literature review

A few papers were discussed about developing and validating procedures for predicting the analysis of flexspline and harmonic drive system.

Se Hoon Oh et al. (1997) In this paper the author design the hybrid flexspline of harmonic drive with steel and fibre reinforced composite material to improve the dynamic properties of steel flexspline. He concluded that the adhesively bonded hybrid flexspline reinforced with the glass fibre epoxy composite with stacking angle of $(\pm 30^0)_s$ was most appropriate for harmonic drive.

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 characteristic.

XiangGuoQi (2005) The problem of study on fatigue strength of flexible wheel which mainly influences life of harmonic drive. He uses concept of elastic theory,

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non- linear F.E.M. & CAD/CAE. A 3-D Model of flexible wheel established. He compares stress versus displacement of flexible wheels & deformation and loading distributions of flexible wheel are discussed. He concluded that axial wave producer improves stress distribution of flexible wheels, holds the merit of harmonic gear drive and increases the life of it.

W.Ostapski et al. (2007) In this paper a solution to the problem of elastic deformation of thin – wall shell structures with complex shape within the theory of geometrically non- linear shells has been presented . In this work lagrange's method is used. For the analysis of stress state in flexspline and validated the results by ANSYS Software.

BaoShuXin (2008) In this paper author mainly study the fatigue – strength and the wear of gear teeth. Based on experimental result he analyzed the stress and displacement. He established a 3 –D model of flexspline by using elastic theory & non – linear Finite Element Method. He calculated the load & stress in flexspline.

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.

Grzegorz Budzik et al. (2009) In this paper author presents an analysis of the feasibility of using the model similarity method in engineering design. In this task the stress has been found out on virtual model of flexspline by F.E.M. and verified by Extensometer for defining the aim of model similarity. The numerical calculations were made by means of ADINA application which uses FEM with the use of the contact elements. The subject of this analysis was the impact of different values of the torque moment on the stresses in the flexspline.

Qianjin xiao et al. (2011) In this paper author established a mathematical model for the cam wave generator by integrally taking it's static & dynamic performances into consideration. He executed the size optimization of cam wave generator by zero method in ANSYS. Results showed that the final volume of cam wave generator is declined by 42.18 % from original volume. Also he implemented static & dynamic modal analysis and proved that the result of dynamic design is considerably reasonable.

Huimin dong (2012) In this paper a dynamic simulation model of harmonic gear drive is established to study the intensity of stress in flexspline by FEM. & also tooth profile of circular spline's and parameters of flexspline are optimized. The parameterized finite element grid of harmonic gear drive model is realized by MATLAB & the assembly of wave generator is simulated by ABAQUS Software. He concluded that stress on flexspline cup decreases gradually from the open end to close end of the cup in axis direction.

Gao Hai-bo et al. (2012) In this paper author develops parameterized equivalent contact model between a flexspline & wave generator by APDL language of ANSYS software & compared the results by theoretical formula. In this paper 32 types of flexspline , circular spline, and wave generator are designed and manufactured and uses these models in the wheel of rover prototype and it is found that the mass of the wheel hub is decreased by 0.42 kg.

P. Folęga (2013) In this paper author presents strength calculations for the teeth in toothed ring of a flexspline of a double harmonic drive by means of boundary elements method (BEM). In the numerical analysis conducted, the influence was investigated of the design features of a flexspline and of the basic rack tooth profile on the value of stresses in the bottom lands of the toothed ring.

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.

Compared to classical toothed gears, harmonic drives have numerous advantages, but there are some disadvantages as well. Their main advantages include: high torque capacity, excellent positioning accuracy and repeatability, compact design, zero backlash, high single-stage reduction ratios and high torsion stiffness. On the other hand,

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their drawbacks are: high elasticity and nonlinear stiffness and damping. The application of toothed harmonic drives in various fields of life is more and more wide. They are currently used in the automotive and space industries, in aviation, medicine, automatics and robotics.

Advantages

1. Since power is transmitted through multiple teeth engagement harmonic gear drive offers high output torque capacity than conventional planetary gear drive having nearly twice its size and thrice its weight.
2. High speed - reduction ratios from 50: 1 to 320: 1 can be achieved by harmonic gear drive.
3. Harmonic gear drive operates with zero backlash in mating gear due to natural gear preload and radial tooth movement.
4. The input and output shafts are coaxial hence drive becomes compact compared to other high ratio, high torque drives.
5. The harmonic drives can be used as reversible drives.

Due to these advantages the harmonic drives find applications in Industrial Robots and Assembly Automation, Machine Tools, Printing and Paper Converting Machines, Measuring and Testing Machines, Aerospace, etc.

Summery

Harmonic Drive gears have a long success story in demanding machine tools applications. The range of applications is increasing quickly due to continuous product development, which is leading to greatly improved product performance. One area of particular interest is the development of Light weight gears. The latest research results can reduce weight by more than 50 % without any reduction in torque capacity or accuracy. This research is continuing with gears manufactured from titanium using special surface treatments currently being tested. It is anticipated that this development can lead to even better performance that already achieved using composite or aluminium components.

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