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Harmonic Drive Design & Application: A Review

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Abstract

This manuscript investigates research done in the field of harmonic drives. A brief synopsis of papers dealing with material analysis, optimized design parameters for harmonic drive are presented. Another research work investigating the use of harmonic drives for space applications is discussed at length. Lastly, a work discussing optimized flex spline design, interference study and micro harmonic drive design is also put forward in this manuscript.
Keywords- Harmonic Drive, Flexspline, Wave Generator, Micro Harmonic Drive, Planetary Gear

INTRODUCTION

This manuscript investigates research done in the field of harmonic drives. A brief synopsis of papers dealing with material analysis, optimized design parameters for harmonic drive are presented. Another research work investigating the use of harmonic drives for space applications is discussed at length. Lastly, a work discussing optimized flex spline design, interference study and micro harmonic drive design is also put forward in this manuscript. It finds used in various application such as industrial robotics, machine tools, and medical facilities, driving parts of measurement systems, semiconductor manufacturing systems and space exploration equipment [1]. Harmonic Drive uses an elastic deformation principle to transmit power. The difference between harmonic drive and conventional gear drive is that flex spline is flexible element and center distance between teeth is varying continuously [3].

COMPONENTS OF HARMONIC DRIVE

Harmonic drive has three main components – flex spline, wave generator, and circular spline. The wave generator consists of two separate parts: an elliptical disk called a wave generator plug and an outer ball bearing. The gear plug is inserted into the bearing, giving the bearing an elliptical shape. The flex spline is like a shallow cup. The sides of the spline are very thin, but the bottom is thick and rigid. This result in significant flexibility of the walls at the open end due to the thin wall, but in the closed side being quite rigid and able to be tightly secured [6]. Teeth are positioned radially around the outside of the flex spline. The flex spline fits tightly over the wave generator, so that when the wave generator plug is rotated, the flex spline deforms to the shape of a rotating ellipse but does not rotate with the wave generator [6]. The circular spline is a rigid circular ring with teeth on the inside. The flex spline and wave generator are placed inside the circular spline, meshing the teeth of the flex spline and the circular spline. Because the flex spline has an elliptical shape, its teeth only actually mesh with the teeth of the circular spline in two regions on opposite sides of the flex spline, along the major axis of the ellipse [6].

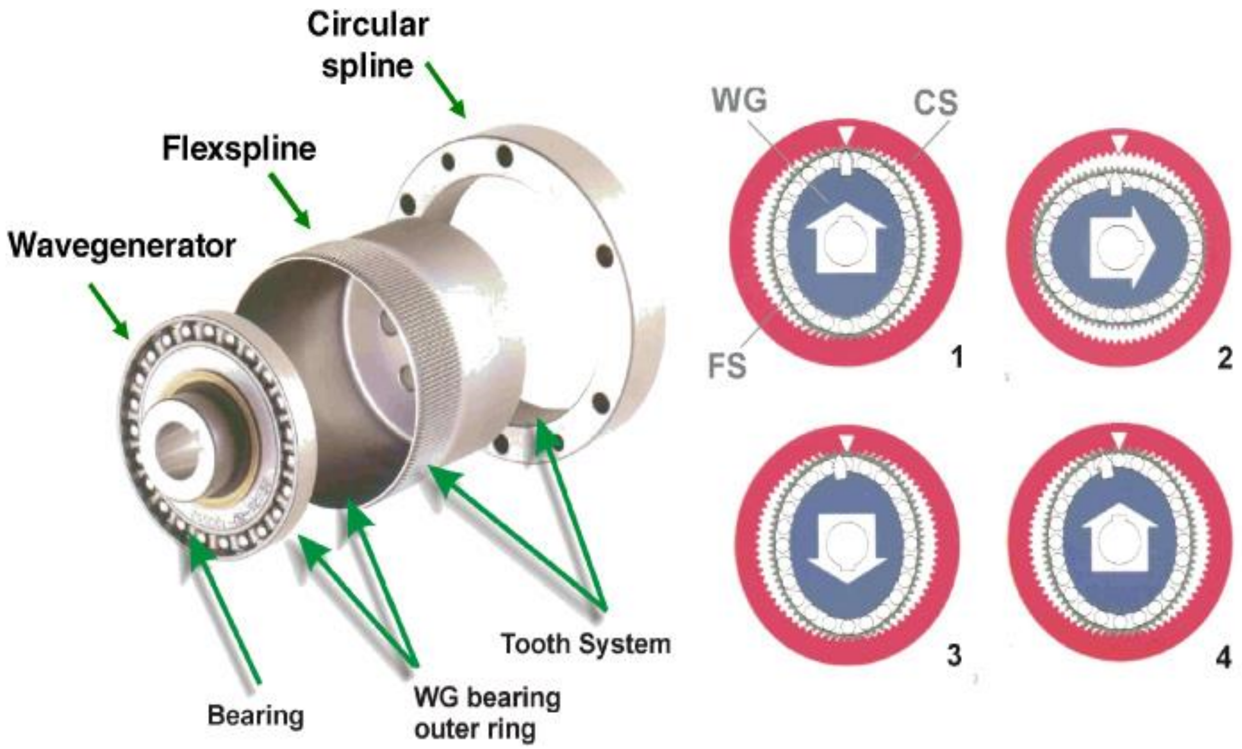

Fig. 1: Components and Working of harmonic drive [2]

WORKING OF HARMONIC DRIVE

The harmonic drive closely resembles epicycles gear train except that flex spline representing planet gear is flexible. It has three methods of operation.

1) Wave generator as input link, flex spline as an output link and circular spline as a fixed link (most common method)
2) Wave generator as input link, circular spline as an output link, and flex spline as a fixed link.
3) Wave generators as output link; flex spline as an input link, circular spline as a fixed link (not used mostly).

The contact between wave generator and flex spline can be assumed as a surface contact [2]. As elliptical wave generator is rotated, major and minor axes also rotates along with it. This cause flexes spline to un-mesh from the previous position of major axis of wave generator and get into meshing into new position. The tooth on flex spline follows two motions simultaneously namely radial and anticlockwise rotational motion. [2].

LITERATURE REVIEW

Research on harmonic drive design and analysis procedure of flex spline has been carried out for the past few years. Some of this work are of interest to this paper and have been discussed below.

GAO Haibo et al. (2012) in this paper, authors have optimized 32-type harmonic reducer. Based on ANSYS software, parameterized equivalent contact models of a flex spline have been researched. They have collected data using finite element method and analyze the effect of variables of flex spline on maximum equivalent stress of flex spline. The variables of flex spline are length of the cylinder, the wall thickness of the tooth ring, the wall thickness of the smooth cylinder and the tooth width. Authors have reduced axial length of flex spline and design new cup-shaped harmonic reducer. Body of harmonic reducer has been optimized as a functions volume of flex spline and transmission efficiency. Through the optimization and analysis, it is found that volume of the flex spline of the new 32-type short cylindrical cup-shaped harmonic reducer is reduced by approximately 30% through comparing with the conventional 32-type harmonic reducer. A performance test bench is designed to carry out testing on both harmonic reducers. The experimental results are approximately equal in terms of efficiency between the new 32-type short cylindrical cup-shaped harmonic reducer and the conventional 32-type reducer. The new 32-type short cylindrical cup-shaped harmonic reducer is used on the wheel of a rover prototype. It is found that the mass of the wheel hub is decreased by 0.42 kg.

Sandeep Awasthi et al. (2014) Authors give primary information of harmonic drive and explain its working. He made stiffness and stress deformation of two materials (Steel and Glass/Epoxy) of flexes spline using ANSYS. To reduce the CPU solving time they use two numerical models. The first model only takes in account the flexibility of flex spline while other considers only the circular spline as being flexible. Stress is less for composite material as compared to steel material (based on result). Stiffness and deformation is lower as half as compared with steel material.

Table 1: Properties of the steel

Tensile Modulus(GPa)	Shear Modulus(GPa)	Poisson's ratio	Tensile strength(MPa)	Density(kg/m3)
210	80	0.3	1000	7850

Table 2: Properties of the E-glass/Epoxy

Parameter	Young's Modulus(MPa)	Poisson's Ratio	Tensile Strength(MPa)	Density(kg/m3)
Value	24000	0.3	205	1520

Table 3: Stress, Deformation and Stiffness

Bend Angle	Stress (MPa)		Deformation(mm)		Stiffness(N/mm)	
	Steel	Glass Epoxy	Steel	Glass Epoxy	Steel	Glass Epoxy
30^0	723	603	3.5	2.1	8.0	6.1
45^0	617	573	3.4	1.7	8.0	5.2
60^0	538	511	3.0	1.2	5.8	4.0

A. J. Bamnote et al. In this paper, they have done meshing analysis of teeth of harmonic drive for module as variable of teeth based on computer. The dimensions of elliptical wave generator are to be designed that there should be no fouling and interference of teeth near the minor axis between the corresponding teeth on the flex spline and the circular spline. Optimization of clearances between the minor axis of flex spline and the circular spline is necessary since the reduction in the minor axis is restricted by the bending stresses induced in the flex spline based on the major axis due to sharp radius of curvature. For modeling, flex spline is made elliptical by deforming a circular shape external gear. The concentric ellipse has the same center as that of pitch circle of flex spline and having same perimeter and called as pitch ellipse. Hence the major axis of pitch ellipse is equal to the pitch circle diameter of the circular spline. From result, interface value increases as module is increased. Also, as module reduces, torque carrying capacity of the drive is reduces.

Dr. Rolf Slatter et al. This paper is all about micro harmonic gear. In micro harmonic gear, there is one more part included named Dynamic Spline. Micro harmonic gear mainly used in camera and space mission. The parts are manufactured by Direct-LIG process. Its size is small with lower parts count. The Principle of operation is similar to conventional harmonic drive. It has many advantages like common manufacturing process for all parts of it, assembly effort minimized; total reduction ratio of gear increases, rotational speed of micro motors in only one stage, and wave generator possesses a low moment of inertia. Outer dimension for micro drive are 1 mm axial length and 8 mm in diameter. It can provide reduction ratios between 160:1 and 1000:1. It has many advantages similar to conventional harmonic drive and other than that are hollow shaft capabilities, applicable under extreme environmental conditions etc. Micro drive has main application in a vacuum environment. Special attention must be paid to the selection of materials, selection of lubricants and methods of energy transfer.

Keiji Ueura et al. In this paper, harmonic drive is discussed from space application point of view. First space application of harmonic drive was in Apollo 15 mission. This paper gives information of harmonic drive parts and its working. Also, there is improvement of the tooth profile. For conventional involute tooth profile, 15% of teeth are in simultaneous contact, while for the IH profile this proportion increases to 30%. The torsional stiffness of gear is increased due to increased number of teeth in contact. More even loading occurs on bearing. Larger tooth radius of IH profile reduces critical stress in the flex spline. Weight of circular spline and wave generator is reduced by using aluminum alloy. Main parameters for design consideration from space application point of view are material selection, mechanical design, lubrication. Mainly dry lubricant bearing are used in drive.

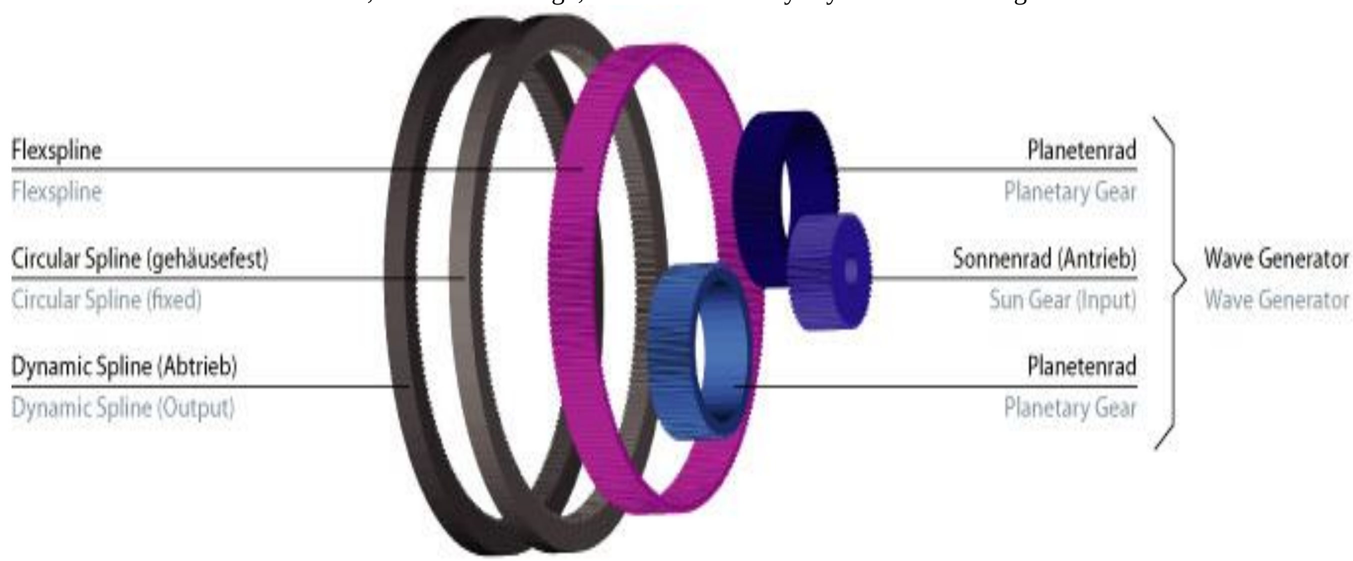

Fig. 2: Micro Harmonic Drive [8]

SUMMARY

It can be concluded that harmonic drives are really important for applications involving high torque requirements. It has clear advantages over planetary gear head and is generally used in conjunction with the same in joint designs. It can also be concluded that it can find application in space missions where torque applications are high. Finally, optimized design parameters of harmonic drives have been researched and its usage can lead to better performance of the drive according to application.

Future scope for harmonic drive is to reduce cost, reduce weight, increase torque capability and reduce size.

REFERENCES

Basic

[1] GAO Hai¬bo, ZHUANG Hong¬chao, LI Zhi¬gang, DENG Zong¬quan, DING Liang, LIU Zhen "Optimization and experimental research on a new-type short cylindrical cup-shaped harmonic reducer" Central South University Press and Springer¬ Verlag Berlin Heidelberg 2012, 10.1007/s11771¬012¬1221¬0, pp.1-14

[2] Sandeep Awasthi 1, Rajesh Kumar Satankar2,Stress "Deformation and Stiffness analysis of two materials(steel and glass/epoxy) of flexspline using ANSYS" International Journal of Scientific Research Engineering & Technology (IJSRET), ISSN 2278 – 0882, Volume 3, Issue 3, June 2014, pp 1-6

[3] A.J.Bamnote, Prasad Mahale and Rahul Gulhane "Meshing analysis of teeth of harmonic drives: A computer based approach", Dept. of Mechanical Engg., Y.C. College of Engg., Nagpur, pp1-8

[4] Dr. Rolf Slatter, Dr.-Ing. Reinhard Degen, "Miniature zero-backlash gears and actuators for precision positioning applications" Managing Director, Micromotion GmbH, An der Fahrt 13, 55124 Mainz, Germany,

[5] Keiji Ueura, Dr. Rolf Slatter, "DEVELOPMENT OF THE HARMONIC DRIVE GEAR FOR SPACE APPLICATIONS", Harmonic Drive Systems Inc., Minamiohi 6-25-3, Shinagawa-ku, Tokyo 140,Japan

Website References

[6] https://en.wikipedia.org

[7] http://carpenterswoodworking.com/

[8] http://www.micromotion-gmbh.de/