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A Review Of Computer Application For Selection Of Harmonic Gear Drive

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Abstract: As harmonic-drive transmissions find increased use and acceptance among engineers and designers for robots, manipulators, machine tools, etc. The demand for an accurate and reliable understanding of harmonic-drive operating behavior becomes useful. This review paper is dedicated to the study of the harmonic gear drive, which provides high-speed reduction & power transmission capability. This drive provides preciseness with alot of less area as compared to different power transmission drives further as there's a negligible internal backlash. This paper will discuss the construction, working principle, review on design of harmonic drive, and characteristics of the drive with its advantages. For the selection of proper Drive according to required applications, it is necessary to the study, to develop a computer program that allows the correct choice of the harmonic drive-by developed algorithm. This paper deals with a method of selection of the proper gear drive according to requirements.The three-dimensional models of the gear driveexplain details about selection. This complexity necessitates a more real-life approach based on computer application.
Keywords: Harmonic Gear Drive, Strain Wave, flexispline, wave generator, Computer Application.

I. INTRODUCTION

Most of the conventional gear in the world is circular. This circularity is an inherent choice for avoiding teeth interference in gear. Maintaining a minimum teeth difference between the meshing teeth (pinion and wheel teeth) is also necessary for avoidance of interference. But the harmonic drive is noncircular gear (circular spline is circular, but Flexspline is oval) and teeth difference between the meshing teeth of flexspline and circular spline is only two.

The harmonic drive is widely used in robotic arm, precision full work, in medical equipment as well as used in speed reduction devices for compact spacing for space application and military missions. The cost for the harmonic gear drive is much higher than that of a planetary gearbox. As the manufacturing and design insufficiency, this product is not easily available in India. For the same, the detailed study of harmonic gear drive will lead to compare different materials and different manufacturing process which can reduce the cost, as well as the product, can be indigenous

Harmonic Drives also known as strain wave gearing because of tooth engagement is producing sinusoidal wave patterns.The harmonic drive may be a special style of mechanical gear system which will improve sure characteristics compared to ancient shell systems like spiral gears or planetary gears.

Fig 1: Exploded view of Harmonic Gear Drive

A motorhave harmonic drives which includes elliptically deformable geared cup,the wave generator and the circular spline which changes its contact points with the circular spline when elliptical wave generator rotates. each 3600 rotation of the wave generator moves the flex spline by solely by the distinction within the variety of teeth within the flex spline and therefore the circular spline. Harmonic drives are used during a sort of applications like peddling machines and rotating home-television antennas, low-priced client applications as Camera lenses to classy systems for military and part utilization.Harmonic drives have been utilized in a variety of applications like vending machines and rotating home-television antennas, low-cost consumer applications as Camera lenses to sophisticated systems for military and aerospace utilization.

II. CONSTRUCTION

The harmonic drive consists of three major components:

Flex spline (FS) – It is a non-rigid, thin cylindrical cup with external gear teeth at the open end of the cup (Figure2.a). The closed end of the cup is provided with a flange which is connected to the output shaft. It is the principal element of a harmonic drive, the flexispline should have the flexibility and good vibration characteristics which can sustain a repeated vibration by the wave generator.

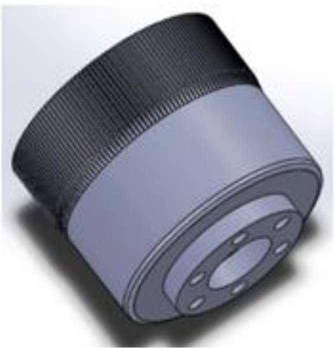
Circular spline (CS) – It is a solid cylindrical ring with internal gear teeth and remains fixed to the ground and heldimmobile i.e. it does not carry ay motion (Figure 2.b). It is stronger than flex spline and having a diameter slightlyhigher than a circular spline. The number of teeth in circular spline is two teeth higher than flex spline.

Wave generator (WG) – It comprises a thin-raced ball bearing fitted onto an oval plug (Figure 2.c). It transferstorque from wave generator to flex spline.

In harmonic drive, 20-30 % of teeth are in contact continuously. For smooth operation and transfer of motion, toothprofiles of circular spline and flex spine plays an important role. Also, many characteristics of the harmonic drive can beimproved by considering a proper tooth profile. In harmonic drive,the tooth profile is basically involute profile (Figures2.d). Some researchers consider the profile of teeth to increase thecontact area and a number of teeth engagement respectively.

Assembly of components of harmonic drive:

In harmonic gear drive, an oval shape wave generator is inserted into the circular open end of flexispline cup whichdeforms itelliptically. Then elliptically deform Flexispline - wave generator assembly is inserted intocircular spline (Figures 2d) resulting meshing of teeth (20-30% teeth comes in contact) along the major axis ofengagement and separation of teeth along the minor axis of engagement[1]. This is possible because ofthe diameter and numberof teeth difference between flex spline and circular spline. In harmonic drive in one revolution of wave generator,Flex spline rotates two teeth only and that is also in the opposite direction of rotation of wave generator.(Figure 3)



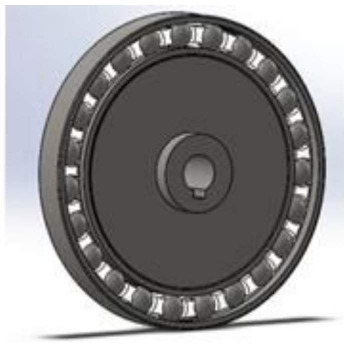


Fig 2a: Flexispline **Fig 2b:** Circular spline **Fig 2c:** Wave Genrator

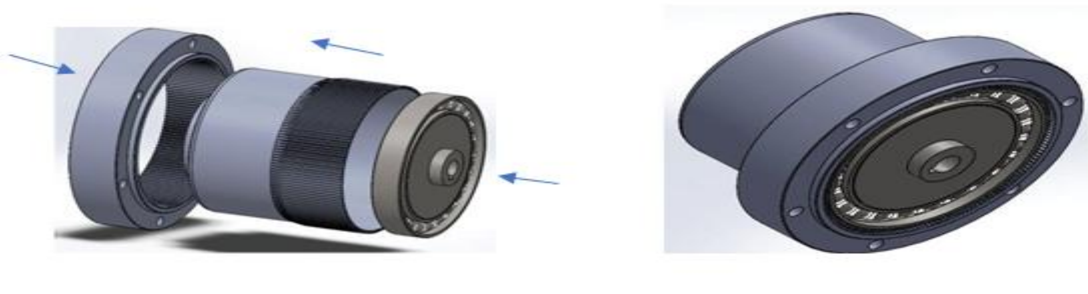


Fig 2d: Assembly of complete drive

III. WORKING

The Flexspline is led into an elliptical formbecause of the wave generator inflicting the Flexspline teeth to have interaction with the tooth profile of the circular spline on the main axis of the Wave Generator conic, with the teeth fully disengaged across the axis of the oval, because the Wave Generator rotates dextral with the Circular Spline mounted, the Flexspline is subjected to elastic deformation and its tooth engagement position moves to show relative to the Circular Spline.As the Wave Generator rotates clockwise with the Circular Spline fixed, the Flexspline is subjected to elastic deformation and its tooth engagement position moves to turn relative to the Circular Spline.

As the wave generator rotates a hundred and eighty degrees dextral, the Flexspline moves counterclockwise by one tooth relative to the Circular Spline. for each full rotation clockwise (360 degrees) of the Wave Generator, the Flexspline moves counterclockwise by 2 teeth relative to the Circular Spline as a result of the Flexspline has 2 fewer teeth than there of the Circular Spline. In general, this movement is treated as output power. The rule may be explained by victimisation Graphical illustration of tooth engagement with the degree of revolution as shownFig3 & 4.

Blue (outer circle): circular spline (fixed)
Red (middle flexible circle): flex spline (attached to the output shaft, which is not shown)
Green (inner oval): wave generator (attached to input shaft; inner ball bearing and shaft are not shown)

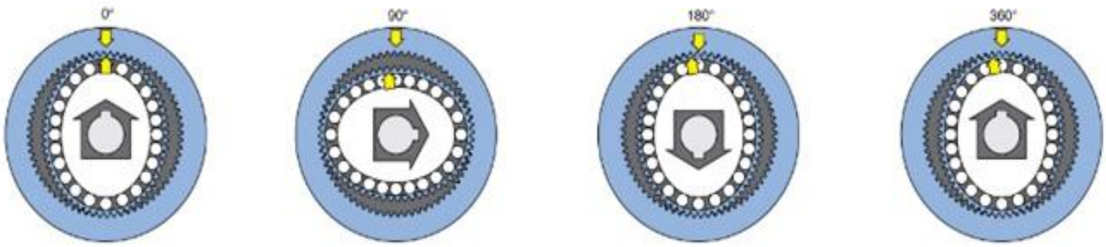


Fig 3: Working Principle of Harmonic Gear Drive and Tooth location after one complete revolution 3600

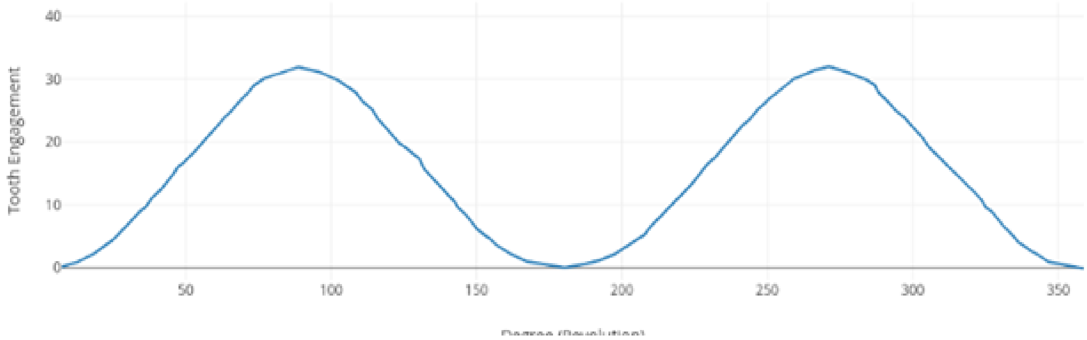


Fig 4: Tooth Engagement in inch while roation per degree of flexispline

IV. SPECIFICATION OF DRIVE FOR SELECTION

Researchers used different shapes and sizes of harmonic drive based on ranges and application requirements of it.

The following are the initials details dimensions of the component of one of harmonic drive which can be used for theanalyzing of it (Figures 1 and 2, Table 1).

For the appropriate gear drive selection; the require parameters are of strength calculations. To determinethe optimal wall thickness of the flexispline and tooth width of the gear ring and the length of the wheel, Preliminary geometrical calculations begin with providing input data such as the torque to betransmitted, gear ratio required, speed reduction, rotational speed and assumed efficiency.For the primary selection following calculation may be carried out

Table 1 Specification of Harmonic drive [Schafer et al., 2005]

Parameters	Values
Reduction Ratio	30:1 – 800:1
Outside Diameter	8 – 300mm
Efficicency	> 80%
Speed	5 – 500 RPM
Peak Torque Capacity	0.5 – 9000 Nm
Life	103 - 105 Rev

Design Parameters of Harmonic Gear Drive
* Referred from Patent C. W. Musser [1]

Parameter	Flexispline	Circular Spline
No of tooth	Zp = 156	Zg = Zp + 2 = 158
Module, m	0.529	0.529
PCD	Rpp = (Zp * m / 2)*2 = 82.55	Rpg = (Zg * m / 2)*2 =83.604
Addendum Factor	a = 7/16 d = 0.7	
Deddundum Factor	ad = 9/16 d = 1.25	
Rim Thickness	0.685 mm	26 mm
Length	64.4 mm	26 mm
Teeth Width	26 mm	26 mm
Semi-Major Axis	a = ri + m = 40.4592	
Semi Minor Axis	cos-1 (b/a) = 39.397	
Speed	200 RPM	

Considering theseCalculations, we can createan algorithm for the proper selection of harmonic gear drive.

V. PAST WORK

Although the concept of gear is not new to scientists andresearchers,they are interested in the constituent parts ofHarmonic Gear; probably started with the aim of reducing the bulkiness of conventional gearbox. Strain Wave Gearingor Harmonic Gear which is known for its compactness took its first rolling with the invention of it by Americanscientist Walt Musser in the year 1959.Research has previously been undertaken on the different aspects of harmonic drive like design, materials, toothprofiles, stress-strain, lubrication, and manufacturing. Some of the works are discussed herewith.

Design & Analysis.

Synthesis of tooth profiles requires the continuous engagement and smooth running of the harmonic gear drive. This, in turn,helps to improve the load sharing and precision of it (Peter 1982). Musser (1959) [1] initially used basic linear teeth(form by mapping a curve between two intersecting lines) which were not good in terms of torque carrying capacityand continuous engagement of Flex spline with Circular spline.

Ishikawa [2] replaced mapped teeth with involute teeth having zero or negative deviation. Teeth deviation helped to reduce the flexural stress and the involute shape of teeth improves torque carrying capacity but teeth engagement was not continuous and interference was very prominent in involute teeth. Ishikawa further replaced tooth faces of both splines with convex profile and tooth flank of both teeth with a concave profile to improve the continuous engagement or contact of both the spline.

Bikash Routh et al [3] studied regarding secondary force contacts of tooth pairs in typical harmonic drives with involute toothed gear set when insertion of wave generator flexispline tooth shape distorted, pitch curve becomes longer than the outer boundary of the initial pitch circle. Considering 2 cases, one with elliptical cam and oval pitch (case I) and the another with elliptical pitch curve with oval pitch cam (case II). The pitch between consecutive teeth of the flex spline varies endlessly whereas the cam rotates.

W. Ostapski [4] Ostapski and Mukha investigated the effect of variable curvature of Flex spline and bearings of wave generator on stress-strain by ANSYS software.the problem of failure of the elastic bearing supporting the generator in a harmonic drive is presented. To investigate the explanation for the failure, material investigations, equally as simulations of stress strainstate inside the bearing versus compound deviations and fits between the bearing and also the generator cam, are meted out.

XiangGuoQi[5] studied the problem of fatigue strength of a flexible wheel which mainly influences the life of the harmonic drive. He uses the concept of elastic theory, 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 a flexible wheel are discussed. He concluded that axial wave producer improves the stress distribution of flexible wheels, holds the merit of harmonic gear drive and increases the life of it.

BaoShuXin [6] worked on the Analysis of flexspline stress and tooth wear in harmonic gear drive. In this paper,the author mainly studies the fatigue – strength and the wear of gear teeth. Based on the 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.

R. Maiti et al, [7,8,9,10,11] introduced a new wave generator with uncorrected involute profiles, in which the wave generator is regardedas a cam containing circular and elliptical arcs, also produced similar results using a different method. Furthermore, they have taken into account the effect of the variation in rim-thickness in load sharing patterns. In the analysis, the back-up ratios (ratio of rim-thickness to tooth height) are varied below one, which generally happens in harmonic drives.Maiti proposed a newer strain wave generating cam to work with involute gears, presented design and manufacturing methods of the novel cam with which harmonic drives with involute teethed gears showed better performances with respect to the output torque capacities. Latter, the cam was further improved, and the split cam design has been proposed for easy manufacturing, easy assembly with the center distance adjustment facility. As already established fortunately two teeth difference avoiding tooth tip interferences is possible even with involute gears in internal-external gears in harmonic drives due to flexion of externally toothed gear in flexispline. Results of such investigations strengthen further the design possibilities of improved harmonic drives with involute teeth.

Materials:

Se Hoon Oh et al. [12]suggested concerning Improvement of the dynamic properties of a steel-composite hybrid flexspline of a harmonic drive, Composite Structure during this paper the author designs the hybrid flexspline of the harmonic drive with steel and fiber-reinforced stuff to enhance the dynamic properties of steel flexspline. He ended that the adhesively secure hybrid flexspline strengthened with the glass fibre epoxy of the composite with stacking angle of (± 300) was most applicable for a harmonic drive.

Han Su Jeon et al. [13 study on stress and vibration analysis of a steel and hybrid flexspline for a harmonic drive, Composite Structure This paper, studies on stress and concerned vibration characteristics taking advantage of the numerical analysis tool, has been meted out on the flexspline as a part of the speed reducer. Analysis has been applieddifferentvarieties ofmodels, that are steel flexspline and steel-composite hybrid flexspline with carbon-fiber epoxy and glass-fiber epoxy composite materials. The stress, stiffness and dampingwere investigated as a vibration characteristic.

Kwang SeopJeong et al [14] worked in area of Development of the composite flexspline for a cycloid-type harmonic drive using net shape manufacturing method; the carbon-fiber epoxy composite material was used for the flexspline material thus on extend the torsional stiffness by trade the stacking sequence and to boost the manufacturing productivity by molding rather than machining. Jeong showed that using different weight may be reduced for a drive system that is helpful for space application.

Lubrication:

Lubrication in harmonic drive gear plays an important role in the improvement of performance and life of it. Though tremendous works have been registered on lubrication and lubricants very few works are done on lubrication analysis of harmonic drive.

Schafer et al. [15] worked on Dry lubricant it was preferred initially but to improve the life and saving the cost, grease lubricant is applied. Space lubrication and performance of harmonic drives. Emyr W Roberts [15] work on the performance and life of fluid-lubricated harmonic drive gears, auther present and compare data on the study, based on in-vacuo life testing of Harmonic Drive with PFPE and MAC fluid lubricants at +90°C.This information embrace unaltered measurements of potency, torsional stiffness and, uniquely, axial force at the Flexspline/Wave-Generator interface

Ueura et al. [16] investigated the behavior of grease-lubricated HD gear in environment and vacuum condition and found that it passed the test in environment condition but failed in space or vacuum condition. conducted numerical analysis in the wave generator-flex spline interface under the mist lubrication model and showed the distribution of oil flow and oil flow thickness in the clearance. In the wave generator-Flex spline interface of Harmonic drive due to metal to metal contact, some worn-out particles or dirt particles mixed with lubricant and asa consequence lubricant behalves like a non-Newtonian fluid.

Maniwaya and Obara [17] found by contact electric resistance technique that lubrication regime in the three interfaces of HD gear namely inner-outer races of wave generator bearing, wave generator-Flex spline interface and flex spline-circular spline teeth is either boundary lubrication or mist lubrication based on environmental pressure or input speed. Also, the wave generator-flex spline interface is one of the typical interfaces for lubrication and it is the interface that failed the drive under vacuum environment or space application.

Application:

Chen et al. [18, 19]showed the algorithmic rule for generating the double-circular arc tooth profiles and its influence on the purposeful backlash of the harmonic drive. And additionally tested that the center line of the flexible gear doesn't extend and analyzed the tangential deformation of the flexible gear below each no-load and load conditions by the theory of finite element.

NedžadRepčić et al [20] In this paper it is described some cases of using Harmonic drive gear in machine tools such as Gantry Milling Machine (Milling Head C-Axis) with very high cutting forces of up to 30 kN; Machining Centre NC Rotary TableTo keep the height of the table to a minimum the motor is mounted with Harmonic gear drive. Waterjet Cutting Machine Fast Linear Axes research results can reduce weight by more than 50 % without any reduction in torque capacity or accuracy.

KeijiUeura et al, [21] developed the harmonic gear drive for space applications like lander applications, satellite applications, rover applications by considering different materials, optimization in flexispline as well as components, reduction in length, etc.

Javier gamboa [22] worked for the design and implementation of a pilot test for an Industrial prototype of a harmonic drive using anFPGA Real-time system to implements control and Instrumentation. He prepares experimental setup and studied the expected position-error frequency distribution over characteristical frequencies.

Various attempts are made to improve performances of strain wave gearing in terms of design, materials, tooth profiles, stress-strain, lubrication and manufacturing of it. In this paper at first details specification and working principle of each component of the harmonic drive is discussed and then a review of available analyses and experiments of a harmonic drive for its performance improvements is presented. But for a further selection of appropriate gear drive computer application is required very few researchers studied about a need-based selection of harmonic gear drive.

VI. FUTURE WORK

The variety of types and sizes currently in the production of harmonic gear drive isa problem in their rational choice as per requirement. The properly selected harmonic drive must meet certainrequirements such asTorque, Speed, Reduction ratio, tooth deviation during operation under loading condition, etc,to achieve the anticipated service life. The proposed work will discussthe problems associated with the selection of the harmonic gear drive. It will also present thecorrect choice of harmonic drive-by computing for the required application. The main objective will be to study by developinga computer program that allows the correct choice of the harmonic drive-by developed algorithm. To ensure a trouble-free operation of the machine or device and to obtain the assumeddurability, the basic factor influencing the proper operation of the transmission system (motor-transmission-machine) is the selection of the wave transmission. The right choice of the transmission enables rational use of technical parameters and design features of the entire drive system.

As part of the work, a computer program will be created with which it is possible to correct the selection of toothed wave gear. The application also allows you to carry out geometrical and strength calculations of flexible wheels. The algorithm for strength calculations leads to the determination of the optimal wall thickness of the wheelsusceptible and helps in the selection of a rational tooth width of the toothed ringand wheel length. The computer application will provide a selection of harmonic gear drive and different characteristics of gear drive

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