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Development of Customized Software Tool for Design of Cycloidal Drive

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ABSTRACT – This paper proposes a unique software toolfor the design process of cycloidal drive to reduce thedesign time and cost of the whole process.This paperaimstostandardizethedesignprocesswiththehelpofan automatedsoftwaretool.Thispaperincludesthestudyofexistingdesignmethodologiesandtheoreticalanalysis as well as design calculations.These analyticalequationsarethenusedtodevelopthesoftwaretoolwherethecalculationsareperformedwithastandaloneuserinterfacedevelopedwithMATLABandthedesignprocessisthenfurtherautomatedwiththehelpofSOLIDWORKSAPI.Thishelpsinasignificantreductioninthedesigntimeandhelps in studying many iterations in a short time. But thismethod is limited only to the design of cycloidal disc, pins,and housing. The other parts like bearing, nut, bolts havetobeselectedaccordingtoavailabilityinthemarket whichisnearesttodesigndimensions.

Keywords– API,CycloidalDrive,Design,Gearreduction,MATLAB,SOLIDWORKS

I. INTRODUCTION

As robotic applications become more common in today'senvironment, the need for high precision in the movement ofrobots is constantly increasing due to increasing competition.High-torqueandlowbacklashgeardrivesareneededtoachieve these high precision movements.In engineering, aCycloidalDriveisasystemthatreducesthespeedofaninputshaftwhilereversingitsdirection.Itcandothisinatiny spacefor high ratios.They accomplish this by employing a rotorwithadistinctmotion.Therearefivemainpartstoa CycloidalDrive:

1. Thecycloidaldisk
2. TheOutputDisk
3. TheInputShaft
4. TheRollers
5. TheMainHousing

A "Speed Reducer" is similar to a "Gearbox" in constructionandworking.Gearreductionisdonebygearsthataremounted on shafts in a specific arrangement.These shaftshavebearingsonbothendstosupporttheloadandforsmoothoperation. This whole system is tightly sealed inside a casingand properly lubricated. This reduces the chance of corrosiondue to dust and improves the life of the gearbox. Usually, themotors used in machines generate the power at high RPM butat a very low torque value. But in actual applications, a hightorqueisneededtodrivethemachinecomponents.Hencea geardriveisusedtoconvertthemotoroutputfromhighRPM-low torque to low RPM-high torque.

Thetransmission(orspeed)ratioistheratiobetweenoutputandinputspeeds.Geartransmissionsarerequiredfor3 basicreasons:

1. InertiaMatching
2. SpeedReduction
3. TorqueAmplification

Due to mechanical advantage, low-capacity servo motors canonlybeusedincaseswheretheinertiaisupto10times motorinertia.And in cases where high rigidity is needed, we canonly apply a load with inertia four times that of motors. Theefficiencyofmotorsishighestwhentheyareoperatedattheiroptimal speed.For most motors, the optimal speed is farhigher than their actual working speed.The actual workingspeed is decided by the working of the system in which themotorisbeingused.Henceaddingagearboxorspeedreducerat the motor output side is necessary to generate the requiredpoweroutput.

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A. Significance of Study

The design process of the cycloidal drive is very complexas various parameters like backlash, torque ripple has to beconsideredduringthedesignprocess.Thisstudywillhelptoreducethetimetakenforthedesignprocessanditwillalsohelptofindtheerrorsinthedesignwiththehelpofsimulation.Thecycloidaldriveiswidelyusedintheroboticsindustryduetoitscompactsizeandhighreductionratio.

B. Literature Review

Sensingeretal. [1]givesthecomparisonbetweencycloidaldrive and harmonic drive. The gear ratio ripple for cycloidaldrives was much higher than the harmonic drives. When bothof these gearboxes were designed to operate under similartorques, the gear reduction provided by the harmonic drive wassignificantlymorethanthatofcycloidaldrives.
Gorlaetal. [2]developed a theoretical model to improve the performance ofcycloidal drive by predicting the behavior of cycloidal driveduring operation. This helped in improving the overall designprocess. The gearing theory was used to determine the profileof ring gear. In the current market for the cycloidal drive,Sumitomo Heavy Industries and Nabtesco Precision Driveshold the largest share as it is shown in the study presented byKumar [3], Sumitomo provides both general-purpose as wellas precision cycloidal drive. The general purpose cyclo driveis trademarked as "SM-Cyclo" and precision drive as "FineCyclo".

II.ANALYTICALSTUDY

For the development of software tool,the design processofcycloidaldriveneedstobestudiedandwellorganized.As comparedtoconventionaldrivesmoreresearchstillneedstobedonefortheanalysisofcycloidalgears.

A.Geometry

Symbol	Description	Unit
r_0	Epicyclic Radius	mm
e_0	Epicycloids Eccentricity	mm
r_c	Radius of Fixed Pins	mm
φ	Rotational Angle of Epicycle	deg
r_1	Radius of Pitch Circle	mm

Table 1
BasicDimensionsofEpicycloid

To generate an epicyclic curve, a small circle is rolled
without slipping on top of another bigger circle. The locus
of any fixed point on the small circle during the duration
of the whole motion generates an epicycloidal curve. The
three main versions of epicycloidal curve are, Normal
epicycloid, shortened epicycloid, and extended epicycloid.
The conventional epicycloid curve can be seen in Figure 1.
The formation of the trail will be detailed here. In Figure 1,
the point is tightly joined on the circle with radii to form the
profile of the normal epicycloid. In this case, it is assumed
that: $r_0 = e_0$.

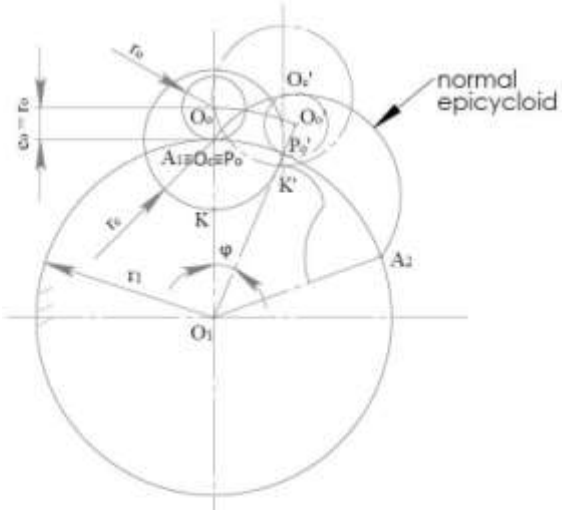

Fig. 1. Normal Epicycloid[5]

B. Gear Terminologies

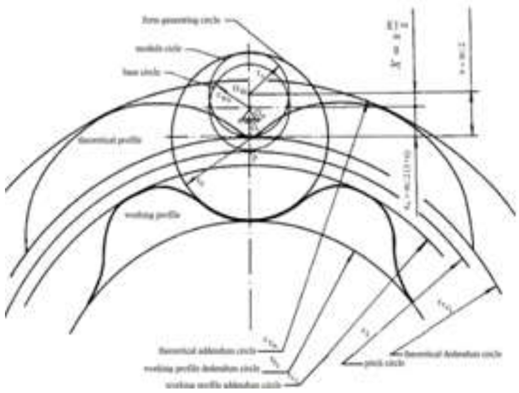

Fig. 2. Gear Terminologies[5]

1) Pitch:
To generate the epicycloidal gear curve, the profile generating circle has to roll without slipping on the perimeter of the bigger circle. This circle is called a pitch circle.

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$p = m\pi$ (1)

2) Theoretical Dedendum Diameter (d_{Tf1}):

The theoretical dedendum circle is the circle at the base of the lobes of thetheoretical profile. The section PO_c of the profile cuttingdevice is equal to X, as can be seen from the above diagram 2:

$d_{Tf1} = m(Z_1 + x)$ (2)

3) Theoretical Addendum Diameter(d_{Ta1}):

$$r_{Ta1} = r_{Tf1} + 2e_0$$
$$where,\ e_0 = \frac{m}{2(1-x)}$$
$$\therefore d_{Ta1} = m(Z_1 + 2 - x) \quad (3)$$

4) Working Dedendum Diameter(d_{f1}):

We know that the main working curve of the cycloidal disk is at an offset curve from the theoretical profile. So, by giving the offsetequal to the fixed pin radius,we can determine the working profile from the theoretical profile.

$$r_{f1} = r_{Tf1} - r_c where r_c = mr_c^*$$
$$\therefore r_{f1} = \frac{m}{2}[Z_1 + X - 2r_c^*]$$
$$\therefore d_{f1} = m[Z_1 + X - 2r_c^*] \quad (4)$$

5) Working Addendum Diameter (d_{a1}):

$$r_{a1} = r_{Ta1} - r_c \quad where\ r_c = mr_c^*$$
$$\therefore r_{a1} = \frac{m}{2}[Z_1 + 2 - X - 2r_c^*]$$
$$\therefore d_{a1} = m[Z_1 + 2 - X - 2r_c^*] \quad (5)$$

C. Determination of Theoretical and Working Profile

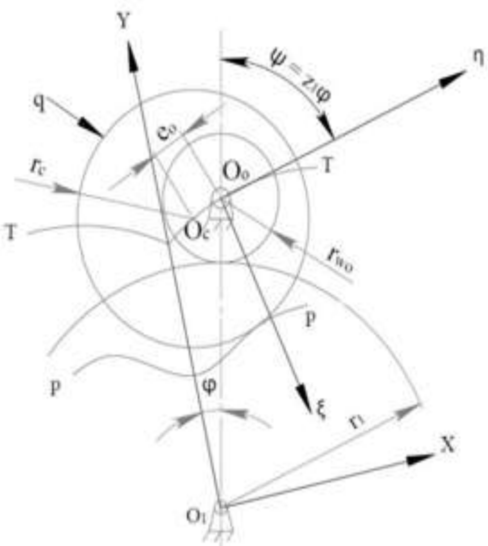

Fig. 3. Theoretical Profile Generation[5]

Steps to Obtain Both Profiles for Cycloidal Gear:

1) The equation for the lobes of the cycloidal disk can be derived by considering a small circle on the circumference of a bigger circle that will rotate in relative motion to each other.

2) Establish two movable Cartesian coordinate systems namelyXO_1Y for the epicycloidal circle and the η$O_0\xi$for the profile generating circle.

3) The equation of the profile generating circle with respect to the central co-ordinate from$XO_1Y$is given by,

$x^2 + (y + e_0) = r_c^2$ (6)

where, x and y are the co-ordinates of the point on profile generating circle.

4) Let the radius of the epicycloidal circle be r_1 and r_{w0} for profile generating circle.

5) Let's assume the relative motion between the two circles. The smaller that is the profile generating circle will move along the perimeter of the larger that is the epicycloidal circle without sliding along with rotation about its own centre.

6) Let's assume the profile generating circle rotate with the angle ψ and the epicycloidal circle will rotate with the angle ϕ. The relation between them can be establish by,

$\frac{\psi}{\varphi} = \frac{r_1}{r_{w0}} = Z_1$ (7)

7) The relationship between the two co-ordinate systems will be given by the following equations,

$$\xi = Xcos(\phi + \psi) - Ysin(\phi + \psi) + \alpha sin(\psi)$$
$$\eta = Xsin(\phi + \psi) + Ycos(\phi + \psi) - \alpha cos(\psi)$$

8) The relation between the $\psi$and $\phi$is given by ψ= $Z_1\phi$.

9) For determining the working profile, it is necessary to first generate the theoretical curve. For generating the theoretical profile, the offset of fixed pin radius is neglected ($i.e.\ r_c = 0$).Hence the initial co-ordinates of point O_c will become $(0, e_0)$.

10) Then by using the above equations and substituting the values in terms of the four basic parameters discussed in the table 3, we will get the equation of the theoretical profile:

$X_t = \frac{m}{2}[(Z_1 + 1)sin\varphi - (1 - x)\,sin(Z_1 + 1)\,\varphi]$(8)

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$Y_t = \frac{m}{2}[(Z_1+1)cos\varphi - (1-x)\, cos(Z_1+1)\,\varphi]$
(9)

11) Whereas the working profile is a curve with an offset of r_c from the theoretical curve. It is obtained by adding the offset value to it given by,

$$X_w = X_t + \frac{r_c Y_t}{\sqrt{X_t^2+Y_t^2}} \qquad (10)$$

$$Y_w = Y_t + \frac{r_c X_t}{\sqrt{X_t^2+Y_t^2}} \qquad (11)$$

By this the final equation of working profile can be written in terms of four basic parameters as,

$$X_w = \frac{m}{2}[(Z_1+1)sin\varphi - (1-\mathrm{x})\sin(\mathrm{Z}_1+1)\,\varphi + \mathrm{k}_1] \quad (12)$$

$$\mathrm{Y_w} = \frac{\mathrm{m}}{2}[(\mathrm{Z}_1+1)\cos\varphi - (1-\mathrm{x})\cos(\mathrm{Z}_1+1)\,\varphi + \mathrm{k}_2] \quad (13)$$

$$\mathrm{K}_1 = \frac{2\mathrm{r}_c^*\ [(1-\mathrm{x})\sin(\mathrm{Z}_1+1)\,\varphi - \sin\varphi]}{\sqrt{1-2(1-\mathrm{x})\cos\mathrm{Z}_1\varphi + 1 - \mathrm{x}^2}}$$

$$\mathrm{K}_2 = \frac{2\mathrm{r}_c^*\ [(1-\mathrm{x})\cos(\mathrm{Z}_1+1)\,\varphi - \cos\varphi]}{\sqrt{1-2(1-\mathrm{x})\cos\mathrm{Z}_1\varphi + 1 - \mathrm{x}^2}}$$

III. TOOL DEVELOPMENT

The tool required for the automation is developed with the help of MATLAB where all the analytical equations are solved for the given set of values. These equations provide the required dimensions for the actual CAD modelling and Analysis. To automate the design process further, a specific program is developed using Solidworks API and Visual Basics for Application (VBA). It uses the data generated by MATLAB and generates the CAD models for cycloidal Disk, Gear Housing and Output Disk.

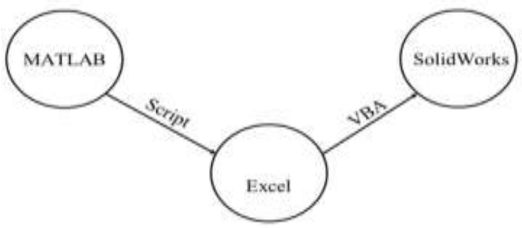

Fig. 4. Data Flow Diagram

IV. CASE STUDY

For this case study, following parameters are given as an input to the system. On the basis of this parameters, the design of major components of cycloidal drive will be done. Cycloidal disk and the housing are the two most important parts of cycloidal gearbox. All the dimensions of these two parts are directly dependant on the basic input parameters. This makes it easier to perform many iterations without affecting the other parts. The remaining parts can be then derived from the dimensions of this two:

1) Input torque: 1.83 Nm
2) Gear Reduction: 19
3) Module: 5
4) Modification factor: 0.3
5) Coefficient of radius: 1

Fig. 5. Cycloidal Disk

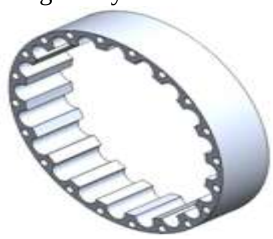

Fig.6.GearHousing

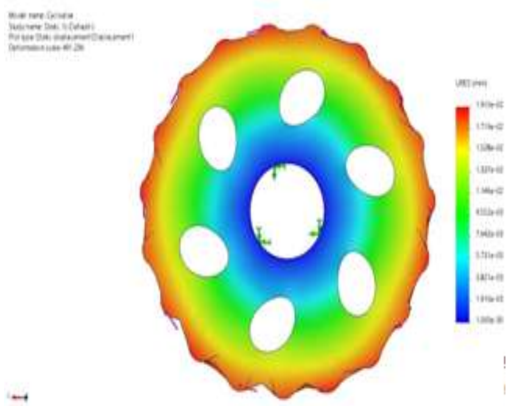

Fig.7.TwistinginCycloidalDisk

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V. CONCLUSIONS

Thisprojecturgesthatthetooldevelopedusing SolidWorksAPI is working properly for all variable data and dimensionsgiventhistoolhelpstoreducedesigntime,reducingcalculationstimerequiredforcalculatingdimensionsofcycloidal drives.The tool developed is cost-effective andreducesthetimeofthedesignprocessbyreducingthe complexity of equations which in return reduces the overallcostoftheproduct.

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