A REPORT

ON

DESIGN & ANALYSIS OF CYCLOIDAL GEARBOX FOR 6 AXIS ROBOT

BY

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2019B2AB0921P

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MTAB Engineers PVT ltd, Thiruvallur

A Practice School-I Station of

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Acknowledgments

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All the individuals mentioned above have been instrumental in making our time at MTAB worthwhile. We were constantly motivated to do our project and help benefit the company.

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ABSTRACT

When it comes to robots, one of the most delicate and essential things is their kinematics. It is keeping in this mechanism all the code is written for anything the robot does. One of the key things that controls its speed and torque is its gears. It is in these gears our project is mainly focused on as of now.

Gears are typically described as circular rotating machine parts which are used to control the torque and rpm. In our project, we mainly work on two kinds of gears that are widely popular and used in different applications: the harmonic gear drive and cycloidal gear drive. In this particular project, we are trying to reproduce a complete six-axis robot made with harmonic gears into cycloidal gears keeping the torque the same.

For this, we were expected to learn about both the gear systems thoroughly, with the central part being the mathematical calculations of both the gear systems. The entire project till now revolved around researching about these gear drives.

BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE

PILANI (RAJASTHAN)

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Title of the Project: DESIGN & ANALYSIS OF CYCLOIDAL GEARBOX FOR 6 AXIS ROBOT

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1.Mr Suganesh (Asst Manager – Design)

2.Mr Anish Richwin (Design Engineer)

Name(s) of the PS Faculty: Dr Faizan Mohammad Rashid

INTRODUCTION

MTAB Engineers Pvt Ltd is one company that has pioneered advanced manufacturing and automation technologies in India. One of the main areas in which the company excels is research, mainly with institutions in India like IIT’s and other very prestigious organizations such as DRDO, CAIR, and so on, adding to their reputation. The company was founded by Mrs. Geetha and Mr. Sairaman after a lot of research and has found exponential growth afterwards.

As mentioned earlier, the company has been working in robotics, and this is where my colleagues and I got the chance to work in the company. The company has developed few robots for IIT Madras with payloads of 6 kg and 10 kg, respectively, and was deployed successfully. It was a six-axis articulated robot that could do various tasks, but they developed it using a gear drive called the harmonic gears.

While manufacturing a robot, you have the choice of selecting from a number of gears. All of these options are usable but have to be chosen intelligently, keeping in mind the budget the size and weight, etc., and the use of the robot after making it. The robot MTAB manufactured was based on a harmonic gear drive, which has its advantages, but another gear system was usable as well-known as cycloidal gear. So, our project focuses on calculating or shifting everything they built on harmonic gear to cycloidal gear, but for this purpose, we are supposed to have a strong foundation and in-depth knowledge of all the gearing systems. Below we start by explaining and comparing both the types of gear

HARMONIC DRIVE GEAR

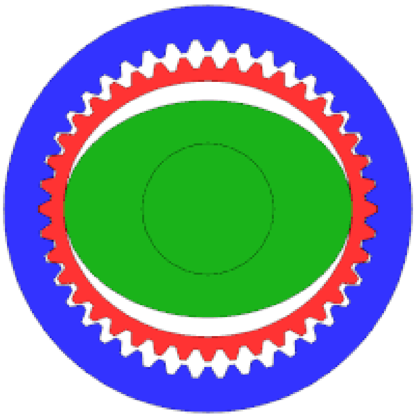


figure 1(source: Wikipedia)

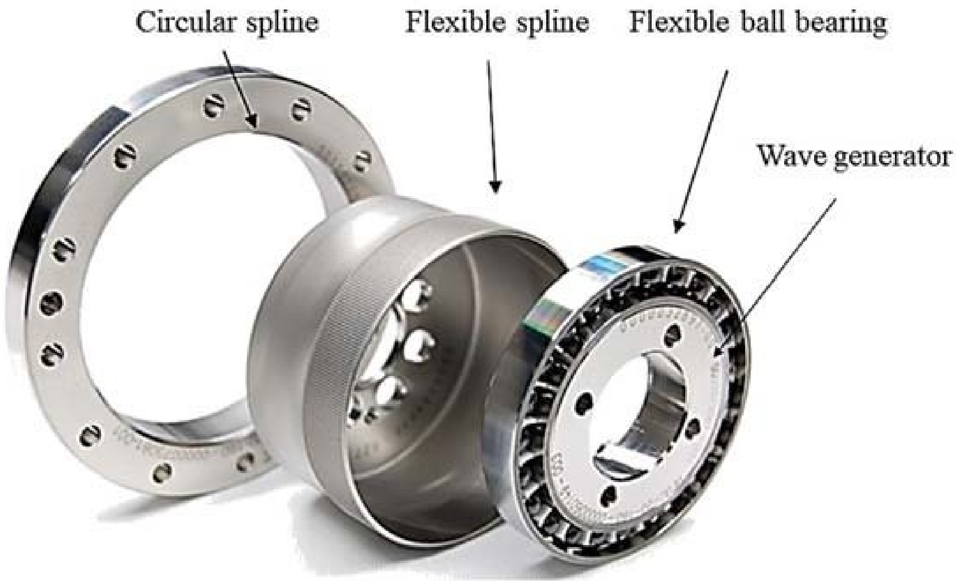
Harmonic gearing, also called strain wave gearing, is a particular type of gearing system which uses a flexible spline with outer teeth, which is also one of the main highlights of this gearing system. The flexible spline is a cup-like structure that is very solid at the bottom, and the upper ring part is flexible, and an elliptical input will make it go around the outer gear, which has more teeth than the inner one as,shown in figure 1.

HISTORY

The basic concept of the harmonic gear system was put forward by C.W Musser, a great inventor who had over 250 patents to his name on various but mostly mechanical-related inventions. But it was first successfully used in 1960 by USM 3 years after the idea was put forward and has gone through some evolution to make it much better.

MECHANISM

The main reason for the design of harmonic gear was it gave us very high reduction ratios in a compact package, compared to planetary and helical gears. The fact that it has zero/negligible backlash is one of the main reasons it is used in robotics. Other advantages such as high torque and accuracy add to the benefits of using it in robotics.



<u>Figure-2 (Source: Wikipedia)</u>

From Figure 2 it is easily understood that it has three parts: wave generator, flexible spline, and circular spline.

Wave generator: It is elliptical in shape and has two parts- the elliptical hub and the thin-walled bearing, which follows the elliptical shape of the hub. This is connected to the motor shaft or our input.

Flex spline: It is thick and rigid in closed-end and very thin walls in the open end, giving its name since it can flex and change its shape from circular to elliptical. It has teeth on the outside of the circular region. The output is connected to it.

Circular spline: It is a rigid ring with teeth in its interior part and is connected to the flex spline, as shown in figure 1.

The circular spline has two more teeth than the flexible spline. This is the principle on which the harmonic gear works. Now the wave generator is inserted in the flex spline, and the flex spline will take the shape of the wave generator. When the input is given, or in other words, the motor is switched on, it causes the wave generator to rotate, and this creates a wave-like motion in the flex spline. For every 180 degrees the wave generator rotates, the tooth mesh with the circular spline will move by one tooth, or in other words, for a full rotation in wave generator, the teeth mesh with the circular spline will move by two teeth.

The reduction ratio of the harmonic gear can be calculated by the following formula:

(Flex spline teeth – circular spline teeth)

flex spline teeth

*The result will be negative because the output is rotating in the opposite direction.

The reduction ratios can be increased by either using same-sized teeth and increasing the diameter of the gear set or using smaller-sized teeth and keeping the diameter of the gear set the same.

ADVANTAGES

1) Very high reduction ratios
2) No backlash
3) Compared to other gears, compact and lightweight
4) High torque

DISADVANTAGES

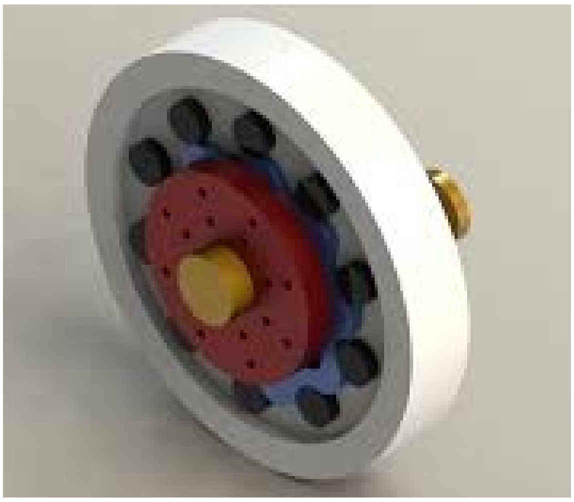
1) Wear and tear are high
2) Not able to back drive

HARMONIC GEAR APPLICATIONS

The most significant use of harmonic gears recently came in space technology. Its significant edge over other gear systems when it came to zero backlash, high torque, and most importantly, its low weight saw it being used in space technology, mainly in mars rovers. Due to its low weight, it was easily a very good option compared to other gear systems. Since it had to be taken up, one of the main things rocket engineers always do is to reduce the weight to the absolute minimum as possible.

Apart from this, it is used in a lot of day-to-day devices such as vending machines and almost all the home devices which need to be rotated in some way.

CYCLOIDAL DRIVE

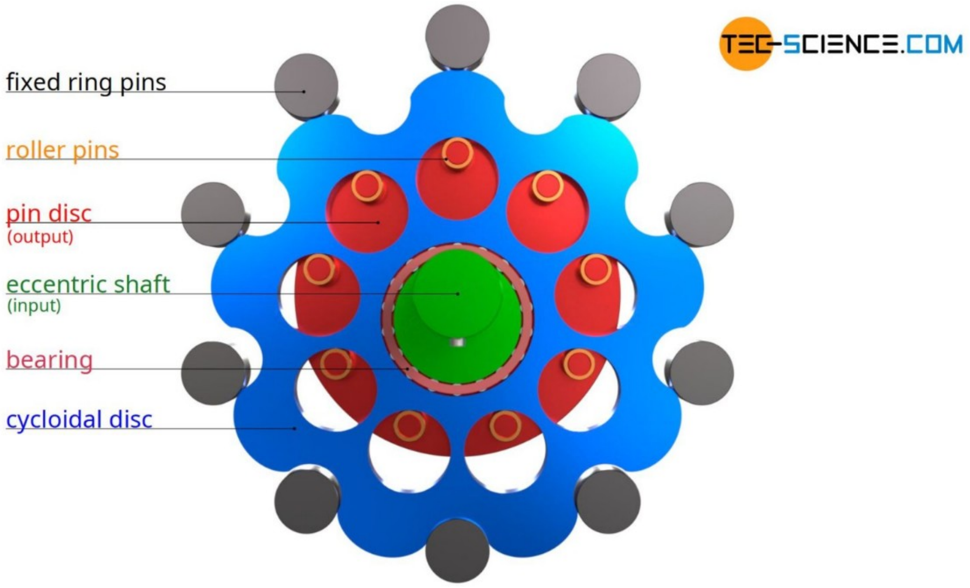


A cycloidal drive is a mechanism to reduce the speed of the input shaft by a certain ratio. They are capable of high gear ratios in a compact size with relatively low backlash. It usually consists of an input shaft, an eccentrically mounted bearing, cycloidal disks, ring pins, and the output shaft.

Working Principle:

The input shaft is placed eccentrically onto the bearing, which causes the cycloidal disk to wobble in a circle. The direction of rotation of the disc and output shaft is opposite to that of the input shaft. The fixed rings are arranged in a circle around the eccentric shaft, so the cycloidal shaft rotates the pins which are connected coaxially to the output shaft
The heart of the drive is the cycloidal disk, whose geometry plays an important role in the kinematics of the gearbox. Sometimes two cycloidal discs are used, which are placed at an offset of 180 to remove unbalanced forces that help in smooth operations at higher speeds.

The core component in the cycloid drive is the cycloid disk, and the cycloid disk tooth (or called lobe hereinafter) profile is drawn by two curves: epicycloid curve and hypocycloid curve. While the ring gear tooth profile is derived either from the location of rollers or the sweeping trajectory formed by the eccentric rotation of the cycloid disk. The cycloid curve is the locus of a fixed point on the rim of a generating circle which rolls align with the baseline without slipping. An epicycloid curve is a kind of cycloid curve whose generating circle rolls outside along the circle below it



The cycloidal gears are difficult to manufacture as they require accurate manufacturing and assembly. The Gears also experience low friction and less wear as the tooth has a rolling contact and lower Hertzian contact stress; they also have good stiffness, which makes them capable of withstanding shock loads

The transmission ratio is the ratio between the number of fixed rings and the number of lobes in the cycloidal disc. The number of lobes will always be less than the number of fixed rings; otherwise, the disc will not fit in between the pins; for example, if there are ten fixed ring pins and nine lobes of the cycloidal disc, then the input shaft must rotate nine times for the output shaft to rotate once

Applications:

The Cycloidal drive is being used at the joints of the robotic arm and is connected to the motor; when the motor runs, the shaft of the motor is connected to the gearbox, which after torque conversion moves the joint of the robotic arm with the torque required. They are used in motion control devices where high accuracy is required. These drives can be seen in centrifugal machines, oil, and solid separation, Pharmaceutical factories, Industrial and biological waste treatment plants, Precious metal recovery, and Food Processing. The cycloidal gear drive is designed to act as an

Internal gear pump, which is also called a generator. In hybrid vehicles, the cycloidal drive is used to start and stop the vehicle

Advantages:

- Cycloidal gears are able to work with zero-backlash and high torque capacity while in a compact size
- Useful when low speed and high torque is required
- It can be designed specifically with high contact areas that can help in very high torque output at the cost of required sliding contact
- Provide more accurate torque conversions and can be used for heavy industrial applications that require extreme accuracy and stiffness
- Cycloidal drives have a small mass and compact design when compared to planetary gears.
- It is low noise

Disadvantage:

- Due to the eccentric nature of the drive, in single disk cycloidal drives, the disk is not balanced; this causes vibrations that propagate over the body.

Comparison between Cycloidal and Harmonic Drives

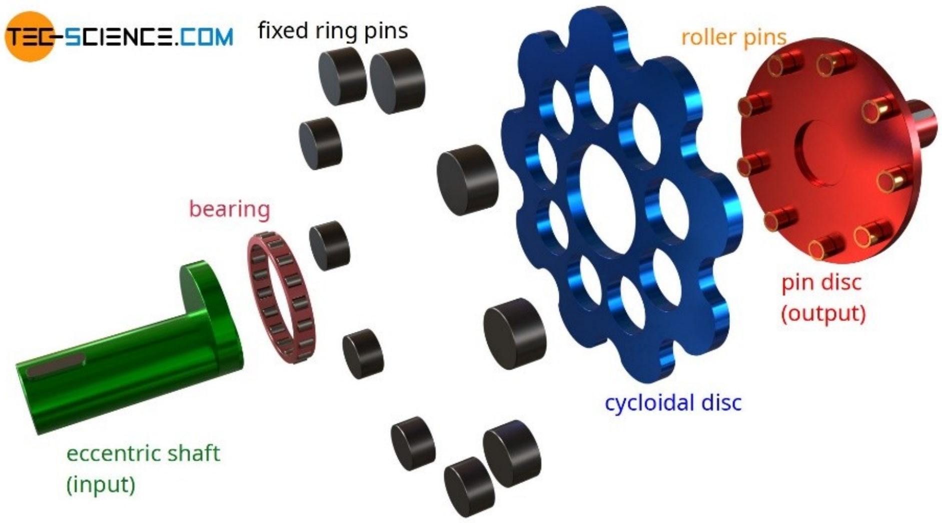
The parameters upon which the “Cycloidal” and “Harmonic” drives are compared are mentioned below-

1. Structure
2. Working
3. Efficiency
4. Precision
5. Back Drivability
6. Reflected Inertia
7. Maximum Gear ratio

Structure

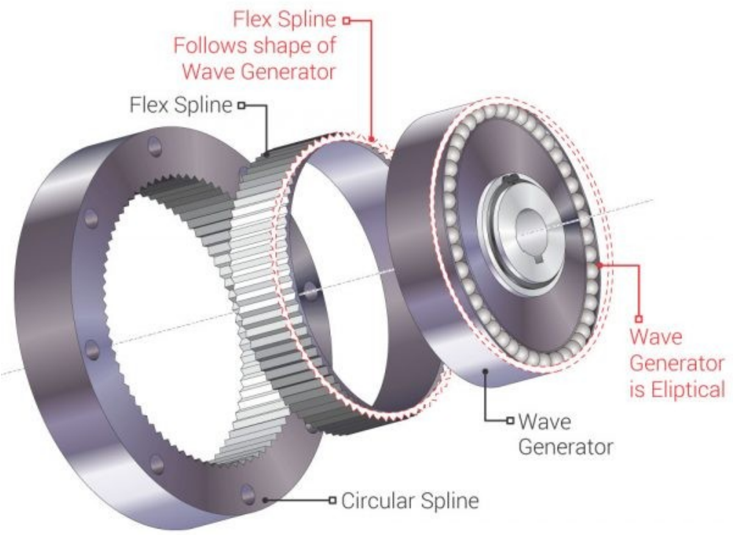
Cycloidal Drive

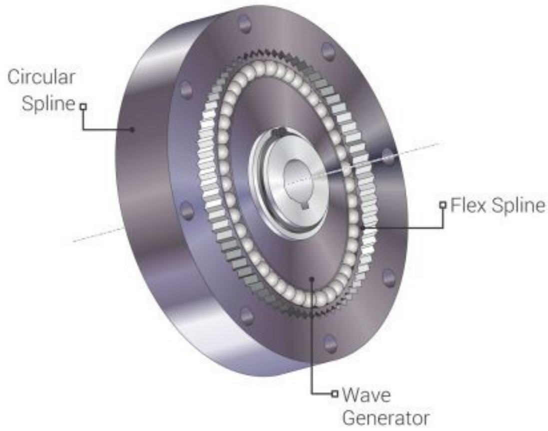
The Cycloidal Drive consists of an **eccentric shaft** that is connected to the **cycloidal disc** via a bearing. **Fixed ring pins** are arranged in a circle around the eccentric shaft, in which the cycloidal disc engages. There are holes in the cycloidal disc, and **Roller pins** of a **pin disc** engage in these holes. The cycloidal disc drives the pin disc, to which the centrally mounted **output shaft** is attached and which is coaxial with the input shaft.



Harmonic Drive

The rotational motion comes from an input shaft that can be a servo motor axis, for example. This is connected to an elliptical shape element called wave generator, which is encircled by an elliptical ball bearing. This part is inserted inside a flex spline that is made from a torsionally stiff yet flexible material. The outer edge of this flex spline features gear teeth. The flex spline is fitted inside the circular spline, which is a round gear featuring internal teeth. This outer ring is rigid, and its internal diameter is marginally larger than the major axis of the ellipse formed by the flex spline.





WORKING

Cycloidal Drive

The eccentric shaft (drive shaft) first drives a cycloidal disk. The cycloidal disc engages in the Fixed ring pins. Due to the eccentric motion, the cycloidal disc is driven around these pins so that the cycloidal disc rotates around its axis of symmetry. The holes in the cycloidal disc rotate clockwise. Roller pins of a pin disc engage in these holes. In this way, the cycloidal disc drives the pin disc, to which the centrally mounted output shaft is attached, and which is coaxial with the input shaft.

Harmonic Drive

The rotational motion comes from an input shaft. The “wave generator” is connected to the shaft. As the shaft rotates, the edges change position, so it looks like it is generating a motion wave. This part is inserted inside the flex spline. The flexible material of the flex spline takes up this wavy motion by flexing according to the rotation of the input shaft and creates an elliptical shape. The gear teeth present on the outer edge of the flex spline transfer high loads without any problem. To transfer these loads, the flex spline is fitted inside the circular spline, which is a round gear featuring internal teeth. This rigid outer ring has an internal diameter that is marginally larger than the major axis of the ellipse formed by the flex spline. This means that the circular spline does not assume the elliptical shape of the other two components, but instead, it simply meshes its inner teeth with those of the outer flex spline side, resulting in the rotation of the flex spline.

Some notable differences on comparing the structure and working of both the drives-

- **Cam vs. Ellipse**: The cycloid drive uses an offset cam input, in contrast to the elliptical harmonic drive input, and requires an additional component (output disk) that retains only the rotational movement.
- **Rollers vs. Teeth**: The intermediate component of a cycloid drive uses rollers, in contrast to the teeth of a harmonic drive.
- **Rolling vs. Flexion Strength**: The output of a cycloid drive uses lobes that travel on rollers, creating only compressive stress at the lobe/roller interface. The absence of shear stress at this interface allows the cycloid disk to withstand higher forces. In contrast, the output of a harmonic drive flexes, allowing multiple teeth to mesh simultaneously, in turn increasing the allowable stress the mechanism can withstand.

Efficiency

Cycloidal Drive is more efficient as compared to **Harmonic Drive**. This is mainly due to the lower coefficient of friction in between the parts of the Cycloidal drive. Cycloid drive efficiency remains constantly high, even at low torques, in contrast to the rated efficiency of harmonic drives, which drop off to 0% for small torques.

Precision

Harmonic Drive offers more precision as compared to **Cycloidal Drive.**

The cycloidal drive has the disadvantage of backlash and gear ratio ripple due to vibrations by eccentric input shaft that affects its precision. On the other hand, the harmonic drive does not feature any backlash or recoil effect, or at least they are negligible in practice due to the elliptical bearing fitted on the outer rim of the input shaft allowing the free rotation of the flex spline.

Back drivability

Back drivability is the ability for interactive transmission of force between the input axis and output axis. The **back drivability of a gearbox** is highly correlated with friction and efficiency.

Both cycloid drives and harmonic drives are non-back drivable for small torques (~1 Nm for cycloid drives and 5 Nm for harmonic drives), which is a function of their input stiction torque amplified by the gear ratio. Harmonic drives have greater stiction torque and accordingly have larger non-back drivable torques and poorer efficiencies at low torques-where stiction dominates than cycloid drives.

Maximum Gear Ratio

Cycloidal drives are not able to obtain a gear ratio as high as the corresponding **harmonic drive**.

The maximum gear ratio of the cycloid drive is limited by the roller intersection constraint, which is a function of roller diameter. Roller diameter, in turn, is limited by shear stress where the roller interfaced with its collars.

Reflected Inertia

Cycloid drives have lower reflected input inertia than their corresponding **harmonic drives**. The reflected cycloid inertia, often two orders of magnitude less than the harmonic drive, is achieved because the large component (cycloid disk) moves at output speed, contrasting with harmonic drives in which the wave generator moves at input speed.

Designing the Cycloidal Drive with a single Cycloidal Disc only

This section is divided into the following topics for better understanding-

1) **Background**
2) **Designing Process**
3) **Designs Achieved**
4) **Failure**
5) **Reason for Failure**
6) **Alternate approach**

Background

The single-stage cycloid disk in a cycloid drive has Z_1 lobes. For the epitrochoid designs considered in this paper, there are Z_2 rollers, where Z_2 is an integer higher than Z_1. The output/input torque gear ratio is:

$$GR = \frac{Z_1}{Z_2 - Z_1} : 1$$

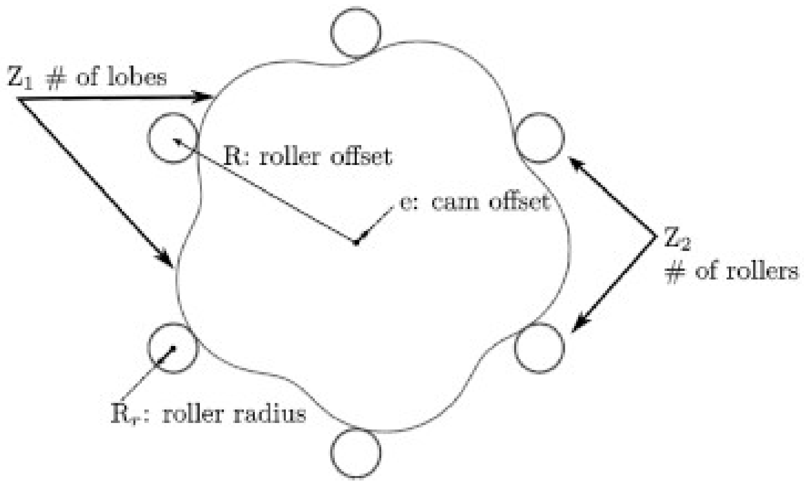
The rollers have radius Rr, are located at position R away from the center, and the cycloid disk spins about this center on an eccentric cam with radius e. The profile of the cycloid disk is defined by the following equations **[Shin and Kwon (2006)]:**

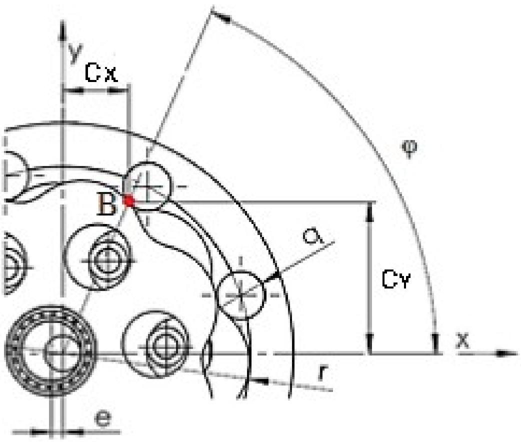
$$C_x = \quad R\cos\phi - R_r\cos(\phi+\psi) - e\cos((Z_1+1)\phi)$$

$$C_y = -R\sin\phi + R_r\sin(\phi+\psi) + e\sin((Z_1+1)\phi)$$

where ϕ is the input angle and ψ is the contact angle between the cycloid lobe and roller, calculated as:

$$\psi = \tan^{-1}\left[\frac{\sin(Z_1\phi)}{\cos(Z_1\phi) - \frac{R}{e(Z_1+1)}}\right]$$





Combining the two equations, we get

CX = **(R*cos(t))-(Rr*cos(t+arctan(sin((1-N)*t)/((R/EN)-cos((1-N)*t)))))-(E*cos(N*t))**

CY = **(-R*sin(t))+(Rr*sin(t+arctan(sin((1-N)*t)/((R/EN)-cos((1-N)*t)))))+(E*sin(N*t))**

Designing Process

The Equation Driven Curve tool was used to sketch the Cycloidal shape disc. Parametric equations for the Cycloidal Disc were used for the same.

The Parametric equations are-

X = **(R*cos(t))-(Rr*cos(t+arctan(sin((1-N)*t)/((R/EN)-cos((1-N)*t)))))-(E*cos(N*t))**

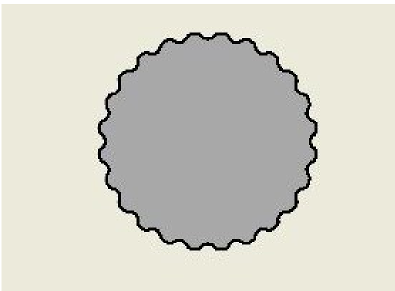
Y = **(-R*sin(t))+(Rr*sin(t+arctan(sin((1-N)*t)/((R/EN)-cos((1-N)*t)))))+(E*sin(N*t))**

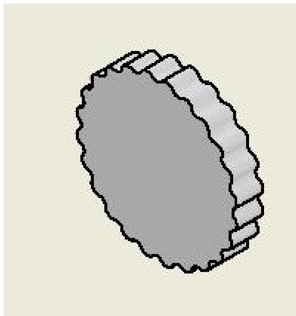
“R” is the radius of the Rotor, “E” is the eccentricity (or offset) from the Input Shaft to the center of the Rotor, “Rr” is the radius of the Rollers and finally “N” which is the number of Rollers

The initial Parameter values used to sketch the Disc (in 2-D) were-

N_	25	ul	Reduction Ratio
E_	1	mm	Eccentric Radius
Rr_	2	mm	Radius of Outer Rollers
R_	32	mm	Distance to Outer Rollers

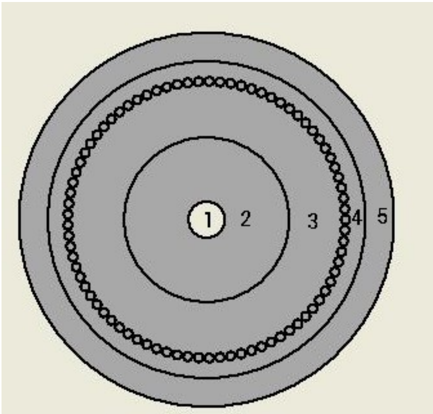
Then the disc was then **Extruded** to the desired thickness.

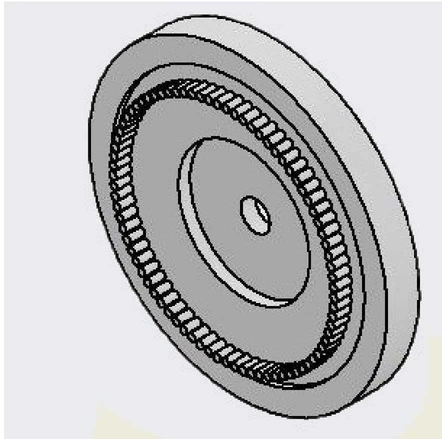




For the designing of the Fixed Ring Pins, the following parts were sketched on a 2-D plane and then were Extruded to the required dimensions-

1) Hole for the output shaft
2) Cylindrical space for the pin disc
3) Cylindrical space for Cycloidal Disc
4) Fixed Ring Pins/ Rollers
5) Outer Covering/ Casing

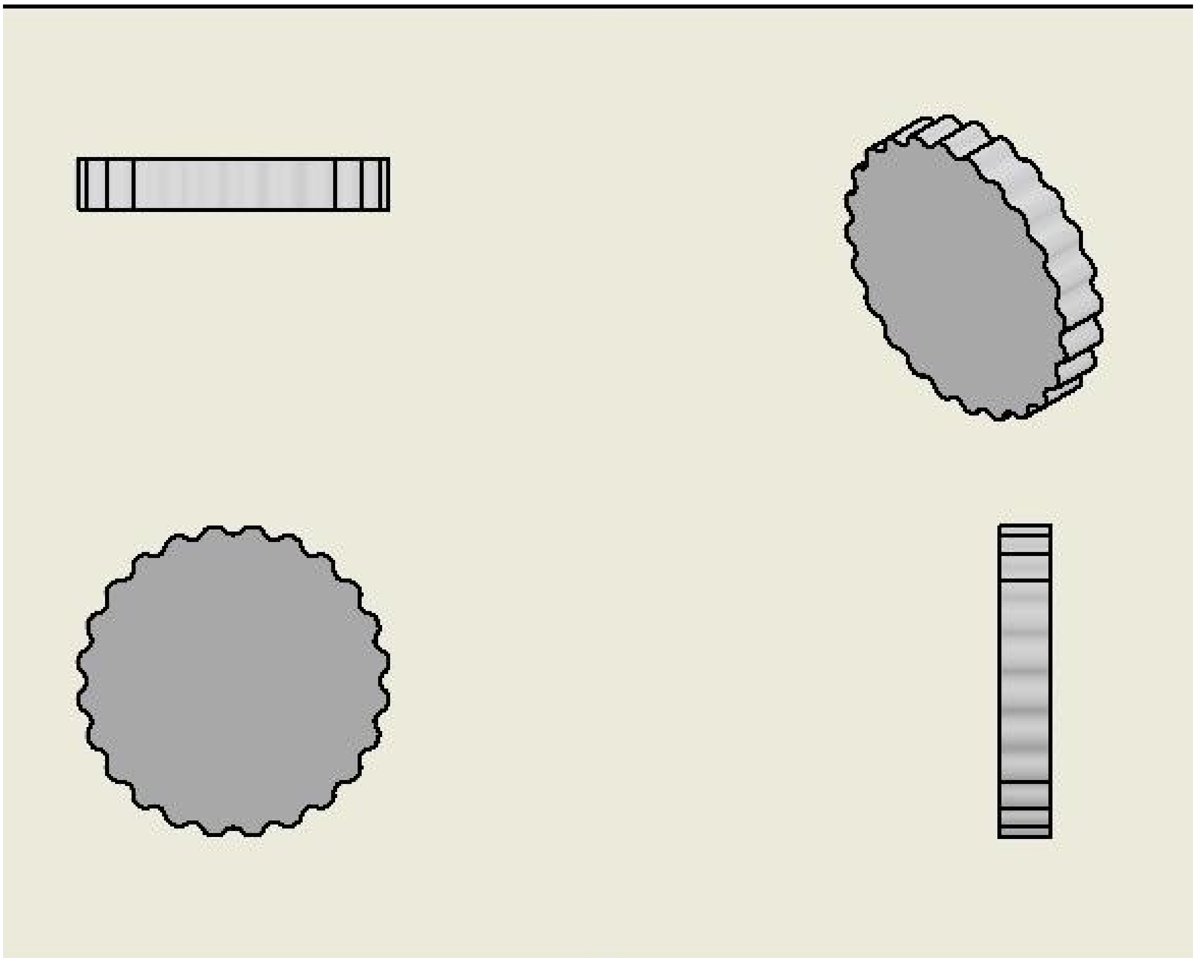




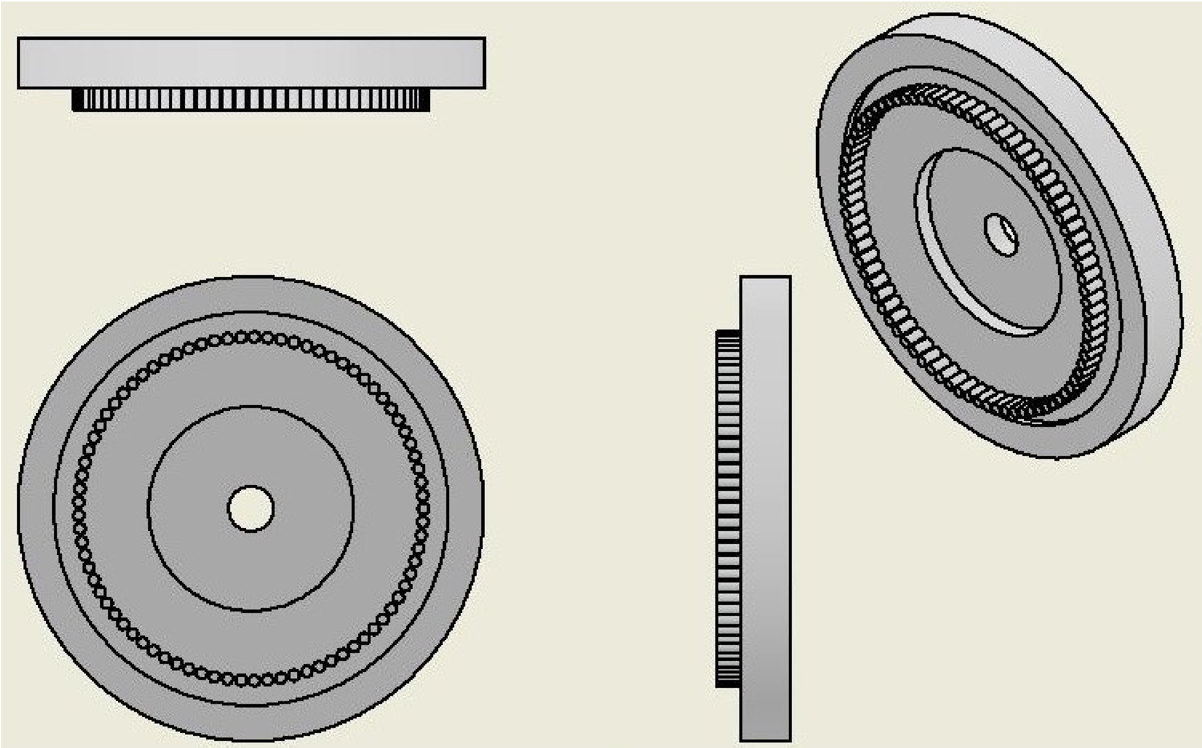
Designs Achieved

The following designs were achieved during the process of trying to design the Cycloidal Drive-

1)A Cycloidal disc (with the parameters mentions before)



1) **An array of 81 fixed pins/Rollers mounted on the Disc casing**



Failure

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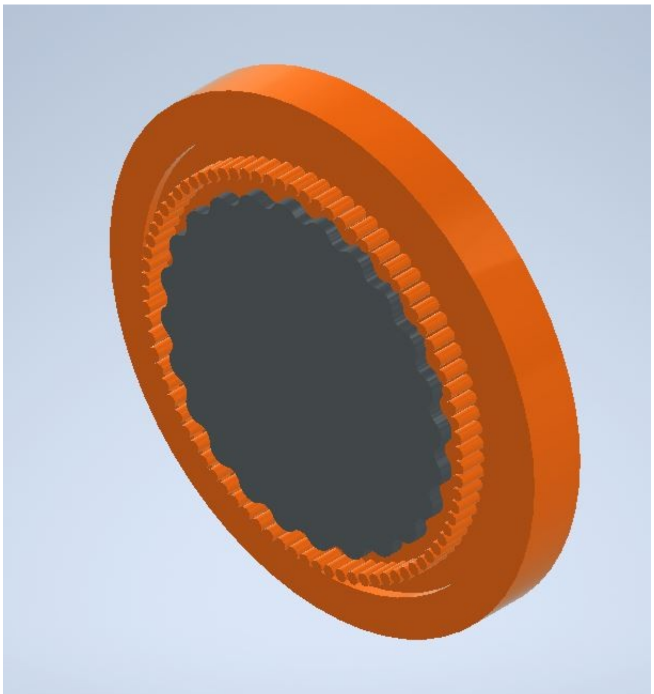


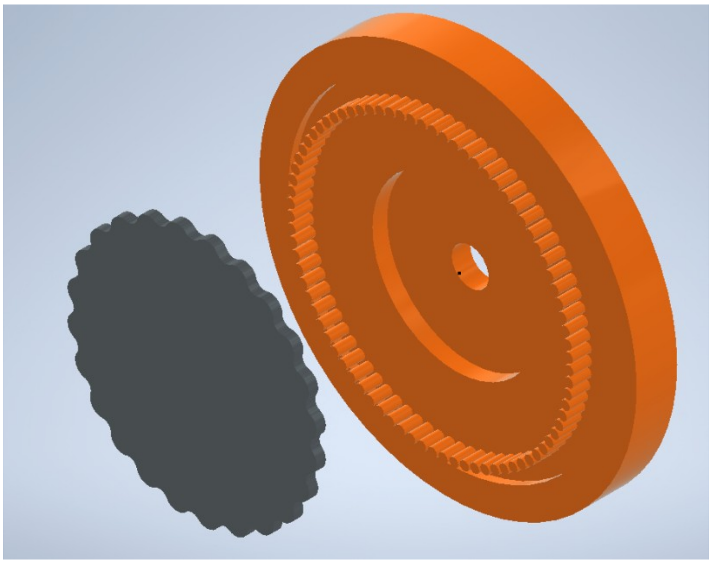
The Cycloidal Disc with the reduction ratio of 25 got designed perfectly (with the given parameters).

But, when the reduction was increased to 80, the software reported an error. It was deduced that the reason for this error was not altering the other parameters in accordance with the new Reduction Ratio.

An effort was made to find the correct set of values for the parameters (in accordance with the new reduction ratio) through Trial and Error but, it was not successful.

So, an alternate approach was considered.

Reason for failure



Two factors constrain the design of cycloids: the radial forces caused by the eccentric cam and the feasibility of the geometric profile. These two factors affect the maximum possible gear ratio.

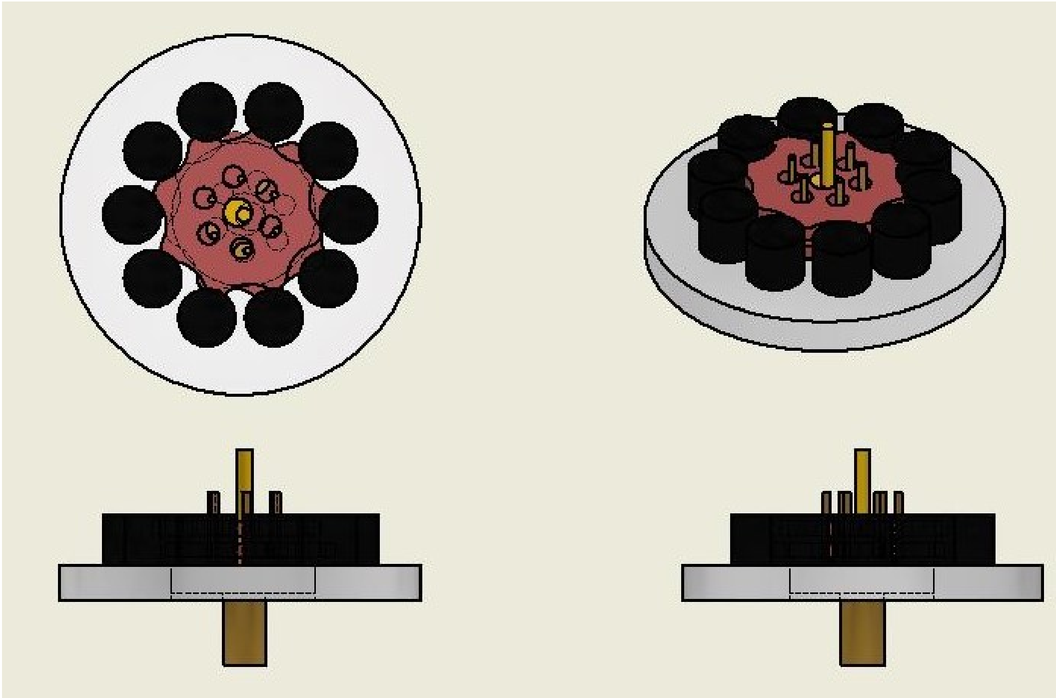
The maximum gear ratio is indirectly constrained by the radial force, which determines the smallest roller diameter that will not shear under load. The diameter of the rollers and the radius of their offset determine how many rollers may be arrayed before they start to intersect each other, which in turn defines the gear ratio.

Hence, in this case, designing a single disk Cycloidal Drive with 81 fixed ring pins and a Cycloidal Disc with 80 lobes with dimensional constraints would not be geometrically feasible.

Alternate Approach

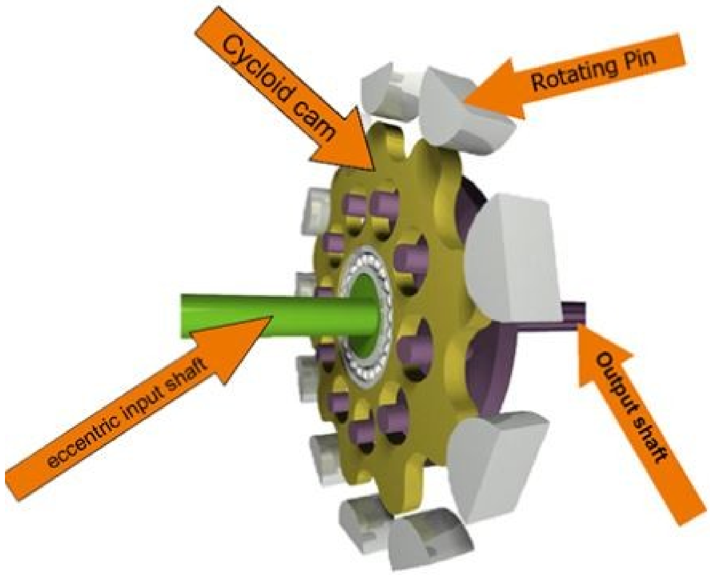
To overcome the shortcomings in our previous approach, we decided to take an alternate approach.

We designed the Cycloidal Drive with 2 Cycloidal Disks (offset by 180 degrees)- each with 9 lobes and 6 roller pins constrained by 10 ring pins



DESIGN OF 2-STAGE CYCLOIDAL GEAR

From the previous method, it was very clear that we won't be able to design the cycloidal gear in the traditional way because of the reasons of dimensions and other conditions which fail to satisfy. Then 81 ring pins weren't possible in the ring gear with that dimension; the pin had to go to a diameter of 1 mm, which is not possible to manufacture, and making a cycloidal disc with a reduction ratio of 80 was also out of the picture for reasons above, so it was necessary that we come up with something new to design the cycloidal gear. The dimension of the cycloidal gear shouldn't exceed the limit of 80 mm it was a necessary condition since we wanted to replace the harmonic gear. So, we came up with a new design.



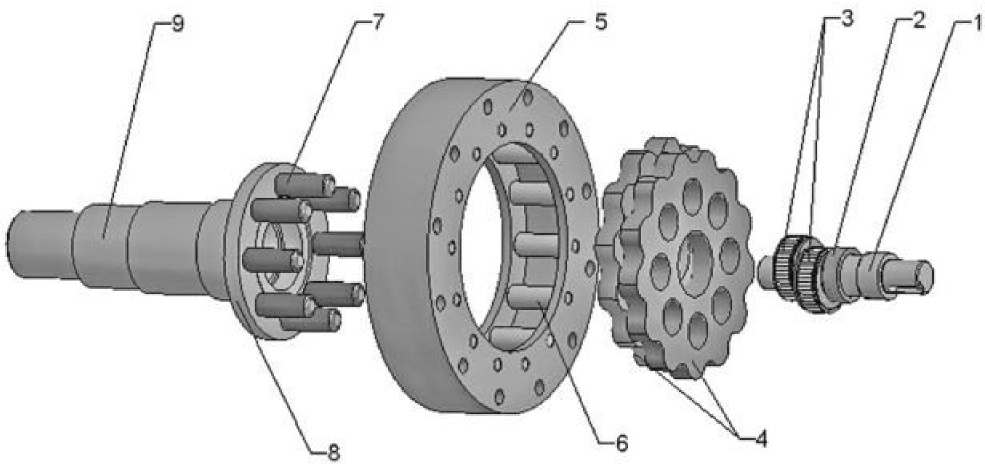
This is the typical cycloidal gear with a single disk and then input shaft and rotating pins. The normal reduction ratio can be calculated using the formula number of lobes divided by the difference in lobes and pins. Since the difference generally always is one, it will suffice to say that the reduction ratio is almost likely to be the number of the lobes in the cycloidal disc. So, the reduction ratio being 80 means we need 80 lobes to get our gear to work the way the harmonic gear behaved. But getting to fit 81 ring pins in that small diameter was a task that was not at all practical, which led us to two ways to solve the problem,

1) Make the reduction ratio less but increase the torque of the motor and decrease the reduction ratio so as to get the same output torque.
2) Come up with a new design to get the required output torque by using the same motor.

The idea of bringing in a new motor completely defies the laws of the project as we had the motor torque as one of the parameters, and changing one of the parameters was not the way to go, although there is no harm in doing that and it would've worked.

So, we took the second path and looked to work out how we can improve the design so as to get the same output keeping in mind the constraints which were the dimensions that were quite of a challenge.

The solution lies in introducing a new cycloidal disc to the assembly, but we had to first calculate the reduction ratios and then other things such as torque and other factors, the contact pressure, and the materials to use. One thing we found out was we could actually multiply the reduction ratios of 2 discs if we keep the discs in such a way that one of the discs fed the other.



This was the design which we first took; we found that if we keep the discs in such a way that one of them is 180 degrees out of phase of the other, we can manage to make it multiply the reduction ratios as in if one disc offers a ratio of 9:1 and the other one offers the ratio of 8:1 then the total ratio will be the multiplication of the two since we are feeding one on to the other and the ratio becomes 72:1. This model will be discussed very well in the latter part of this report; the one part which will be discussed extensively in this part will be the new design which was made by a few scientists.

DESIGN OF 2 STAGE CYCLOIDAL GEAR

This designed was made by four scientists Mirko Blagojevic, Nenad Marjanovic, Blaza Stojanovic, and Aleksandar Disc; all of them hail from Serbia and are professors in different universities. The paper will be referenced on the reference page. These four scientists came up with the design, which is one way to model the cycloidal disc and is actually one of the solutions on how to design the cycloidal gearbox. They also tested the model out, and it was found to be successful. The model looks like the one discussed above with a few modifications

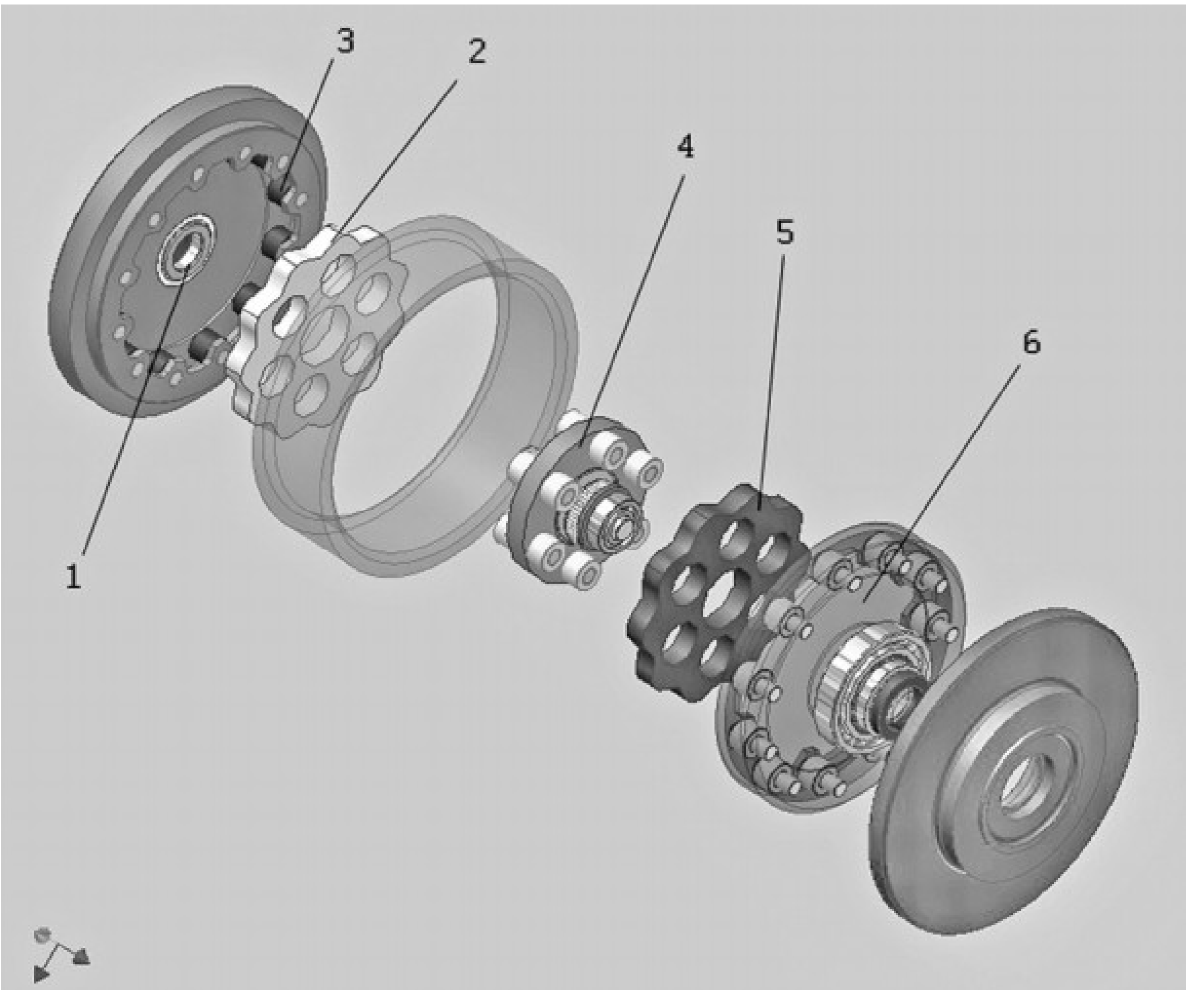


Figure A

The above image shows the disassembled two-stage cycloidal speed reducer of the new design. It is pretty clear from the image that there are a few differences from the one before that two pretty clear being this has an extra ring gear which is actually rotatable apart from having only the fixed one and have another component connecting both the discs.

The figure above shows the manufactured version of the new design of cycloidal gear. All the discussion in the coming paragraph will be on figure A which shows the disassembled view of the cycloidal gear.

The disc which contains the part 1 and 3 is the fixed ring pin it is from there the input shaft is taken, and part 3 is the bearings in which the cycloidal disc can move through. Parts 1-4 all belong to the first stage of the cycloidal disc, and then 2 and 5 are the cycloidal disc itself, with 2 being of the first stage then 5 being the second stage for the second stage, we have parts 5 and 6 where part 6 is the interesting part the part which is new to this design which is the rotatable ring pin gear which actually also provides the output or where the output shaft is connected. The ring gear of the second stage (6) actually receives the resulting motion and the torque. The ring gear (6) is tightly connected to the output shaft of the reducer and rotates in the same direction as the input shaft.

MATHEMATICAL EQUATIONS AND RELATIONS

Firstly, the basic characteristics which differentiate this gear from the typical ones are as follows,

1)Both the stages have a common input shaft.

2)For each stage, there is only the usage of a single disk.

3)There is a central disc roller that connects both the second and the first stage Cycloidal disc.

4)The part which is completely different is that it has a rotatable ring gear; all the designs before had only the fixed ring pin.

Since this is a new concept and has a considerable difference in the workings, the torque distributions and other factors cannot be simply defined as per the definitions or in the normal way, so we try to determine it by deriving it.

Also, please note that all the losses due to friction and wearing are neglected during the derivation of these equations.

TORQUE:

The drive torque (TEM) is in two parts:

1)The drive torque in the first stage. (T1)

2)The drive torque in the second stage. (т2)

TEM = T1 +T2

But if we define the transmission ratio of the first stage as u1, then we can say that:

T2 = T1*u1

Now, if we say that T4 is the torque on the ring gear of the second stage, then we can say that,

T4 = TEM*u1*u2

Where u2 is the second transmission ratio.

T3 is the torque on the stationary ring gear on the first stage, T5 is the torque on the first-stage cycloid disc.

T6 is the torque on the second-stage cycloid disc.

Balancing the torque gives as 2 more equations, and that is,

$T5 - T6 = 0$

$T2+T4-T6=0$

By rearranging all these equations, we get the following results,

$T1 = (TEM)/(u1+1)$

$T3=(TEM)(1+u1*u2)$

$T2=(TEM)(u1)/(1+u1)$

$T6=(TEM)(u1)\ (1/(1+u1) + u2)$

These are all the equations that relate to the torque of each disc and the transmission ratio. These results are crucial while designing and while figuring out how many lobes and then how many pins are respectively required to get the required output torque.

The transmission ratio and the overall transmission ratio will be discussed in the next section so that it will be easier to calculate all the torques from those equations.

TRANSMISSION RATIO

Let u1 and u2 be transmission ratios of stages 1 and 2, respectively; also, let z1 be the number of teeth of the first cycloidal disc and then z2 be the number of rollers of the stationary ring gear. Also, let z3 and z4 be the number of teeth and the pins of the cycloidal disc and the rotatable ring gear, respectively then,

Transmission ratio $u1 = -(z1)/(z2-z1)$ and $u2=-(z2)/(z3-z4)$

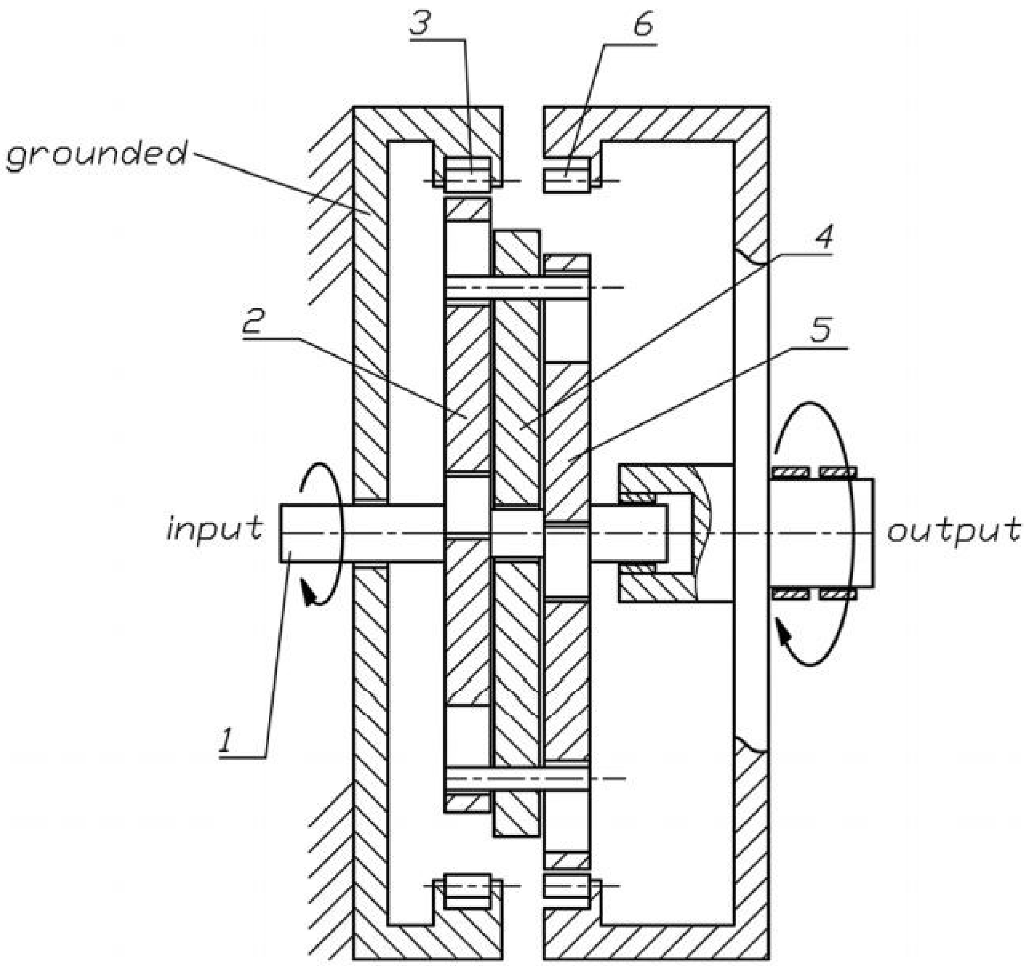
In almost all the cases, the difference between the number of teeth in the cycloidal gear is 1, which makes the result just the numerators of the following and also ultimately the total transmission ratio of the entire gearbox becomes,

Let overall transmission ratio be ucr then $ucr= z1*z4$

This means if we keep the number of the gears in any way, we can easily achieve a very high value of reduction ratios without many pins or a large number of pins; this makes the manufacturing of these gears very easy.

ADVANTAGES OF THE NEW DESIGN

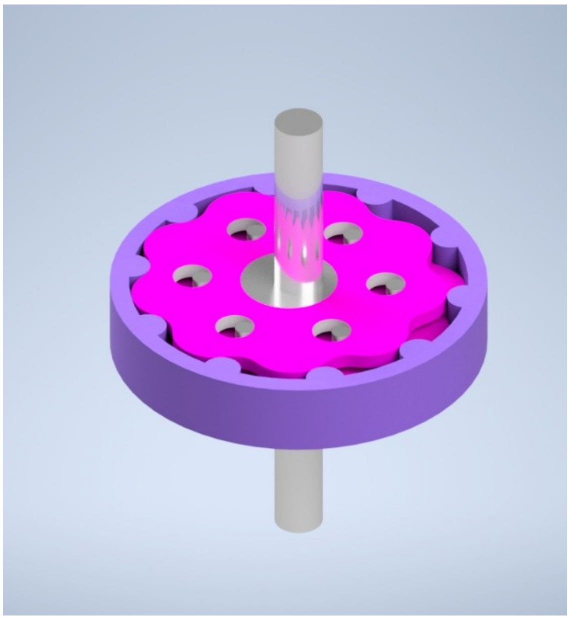
1) The first advantage being it is more compact than any other design currently available, making it very useful in robotics, where it is used very extensively; the compactness can be seen in the image below.



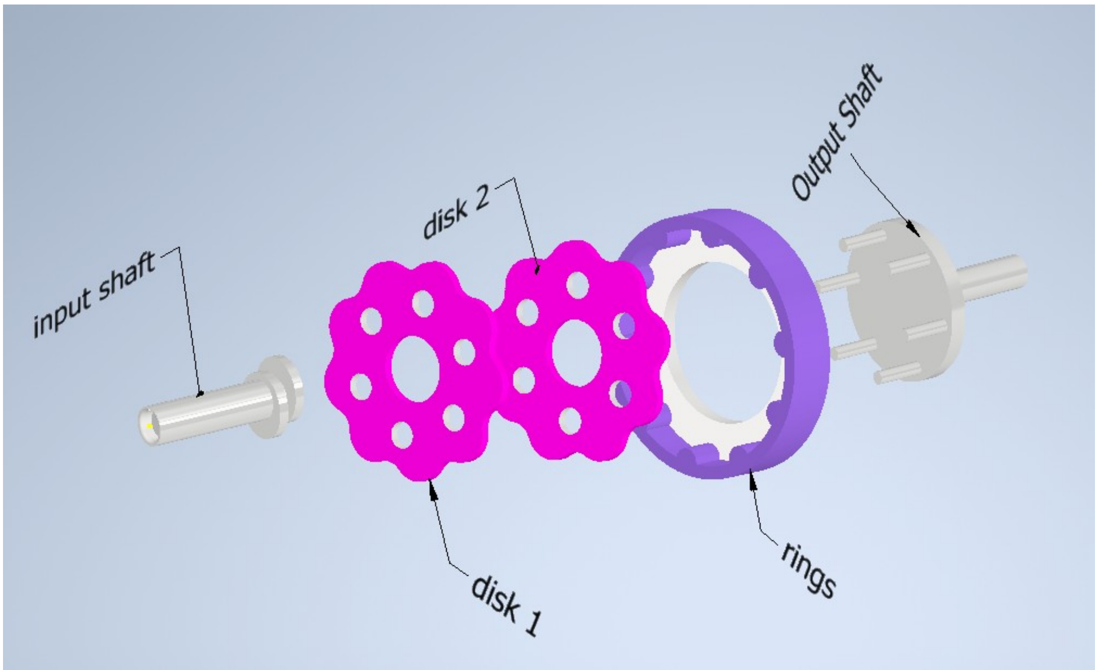
2) It has very few rollers compared to the typical one, which makes it very useful as it decreases the contact forces.
3) There are very few moving parts in this, so that makes it very less noisy.

4) The second disc also vibrates eccentrically, so it cancels out the vibrations of the first cycloidal disc.

Conclusion



Our final design consists of 2 discs, one ring, input shaft, and output shaft. The reduction ratio was decided depending on the reduction ratio of the harmonic drive that we are trying to replace. The dimensions have also been chosen so that we can replace the harmonic drive and place our cycloidal drive in its place. For further improvements, we can place a mounted bearing to reduce vibrations. The disc joints and the rings can be lined with steel faces which can be easily lubricated to reduce friction while using the drive. More clarity on each part is provided below.



Cycloidal disk:

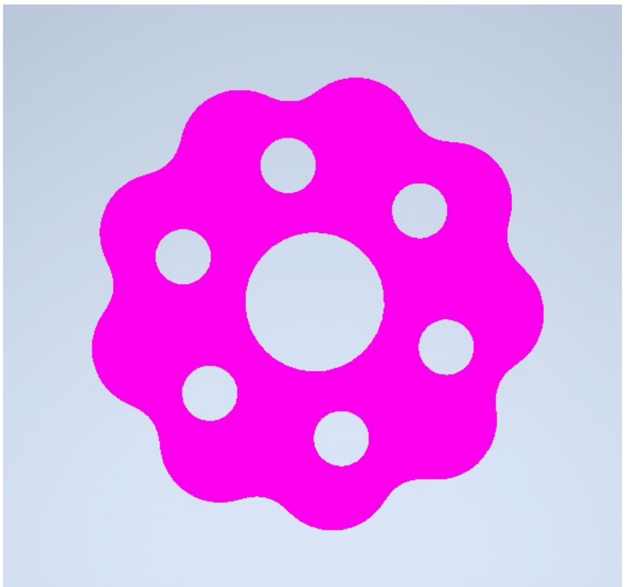
The disk was designed following the equations mentioned above, and the required parameters were provided. Which were:

N: 10

E: 2mm

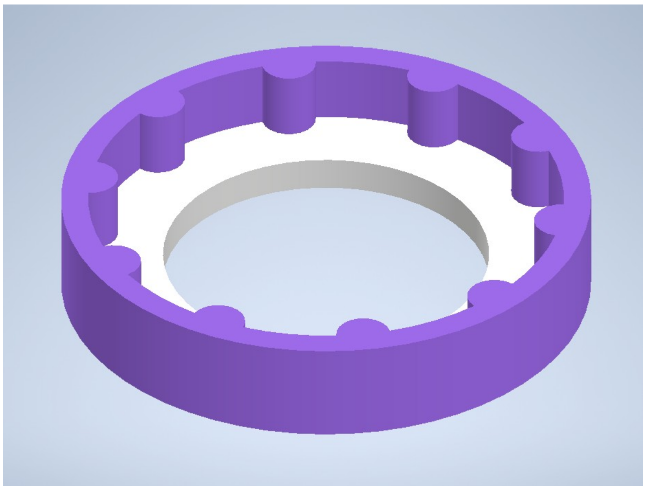
R: 35mm

Rr: 4mm



The circular holes are required by the input and output shaft. Their dimensions would be mentioned later and were matched into the disc for proper functioning

Rings:

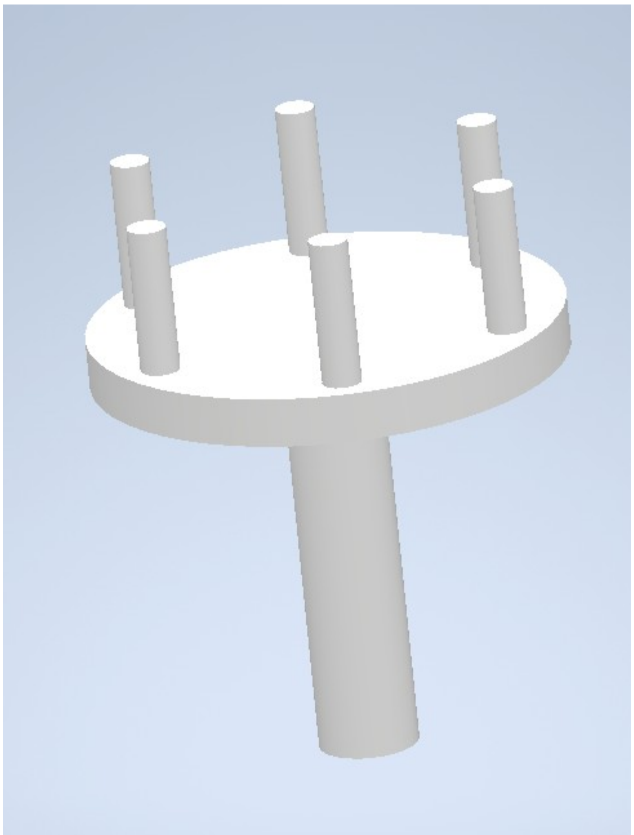


The rings were designed following the parameters used for the disc so that the disc can function properly; the 10 rings were made each of 4mm radius and were placed evenly over a circle of 35mm. The rings were given a height of 10mm for allowing the place for 2 discs and a gap in between them for maximum efficiency. The circular hole is of 48mm diameter for the output shaft

Input Shaft:

The input shaft is the connection between the motor and the cycloidal disk; The upper portion will have a cavity to fit the pin of the motor driver, whereas the 2 circles each of 20mm diameter are made with an eccentricity of 2mm for each disc. The circles can have steel coverings to reduce friction.

Output Shaft:



The output shaft is moved when the cycloidal disk rotates around the rings. Hence they need to be in contact with the disc; the 6 poles see to it that they are properly connected, and they don’t break due to stress, as the total stress is divided between the 6 poles each of 2mm radius as the circles in the disc are of 4mm radius and the radius of the circles in the disc has to be equal to the radius of poles in the output shaft plus 2 times the eccentricities for maximum efficiency.

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Building a Cycloidal Drive with SOLIDWORKS By Omar Younis

MODELLING THE MESHING OF CYCLOIDAL GEARS Jerzy NACHIMOWICZ* , Stanisław RAFAŁOWSKI