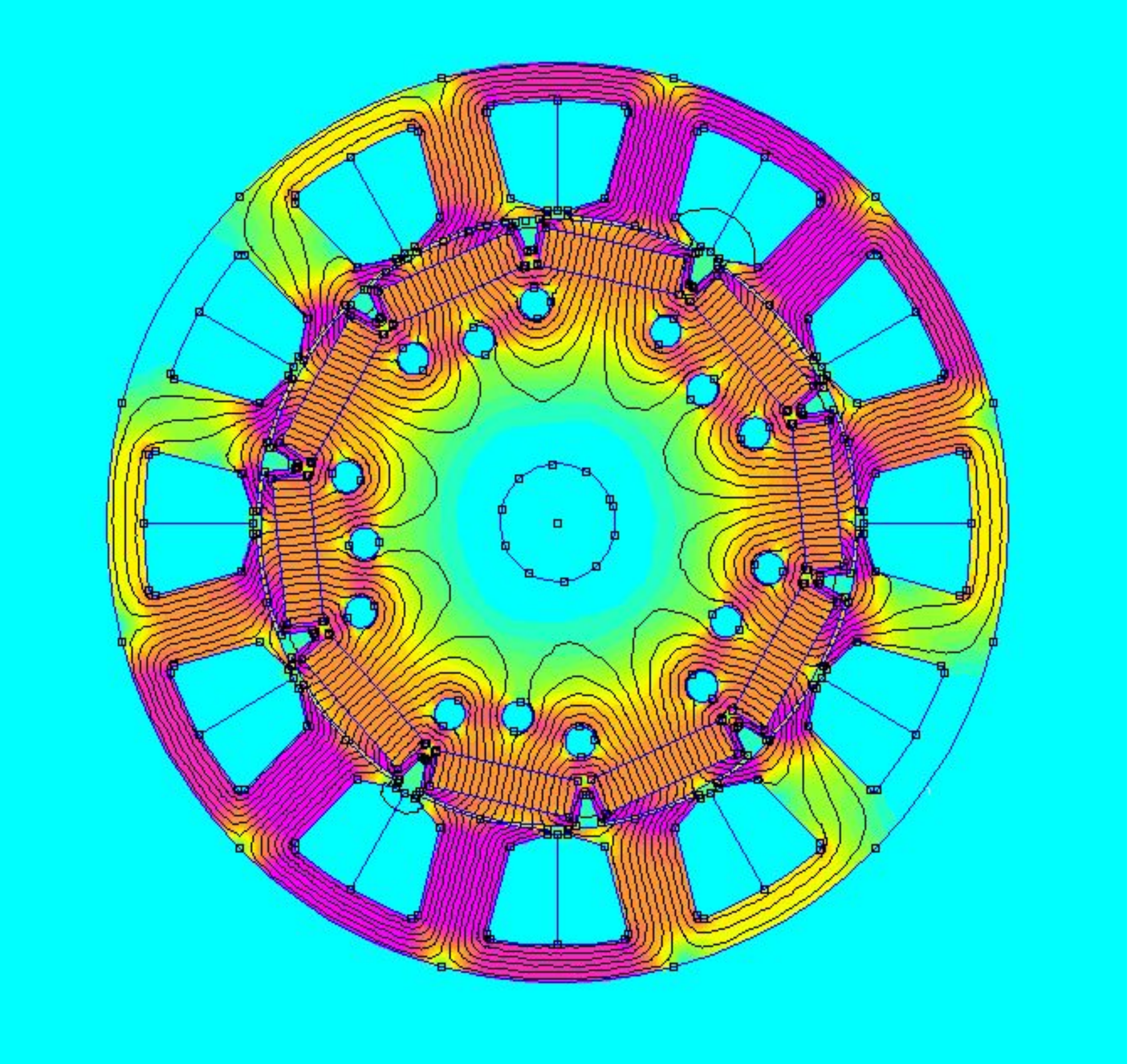


MOTOR DESIGN

By
Arun Ramana

What are we going to learn today?

1. How to design and draw a motor from the geometry specified by Motor Wiz?

2. How to simulate the design we have drawn?

3. Demonstration Of the Motor Design Tool developed at MOTORZ.

Familiarize With Tools

1) **FEMM - Finite Element Method Magnetics:**

   Is a powerful software tool used for simulating and analyzing electromagnetic fields and devices. (It can also be used to simulate Electrostatics and Current Flow)

2) **CAD & DXF:**

   CAD (Computer-Aided Design) is a technology that allows engineers and designers to create detailed digital models of objects and systems.

   DXF (Drawing Exchange Format) is a file format commonly used in CAD software to facilitate the exchange design data between different programs and platforms.

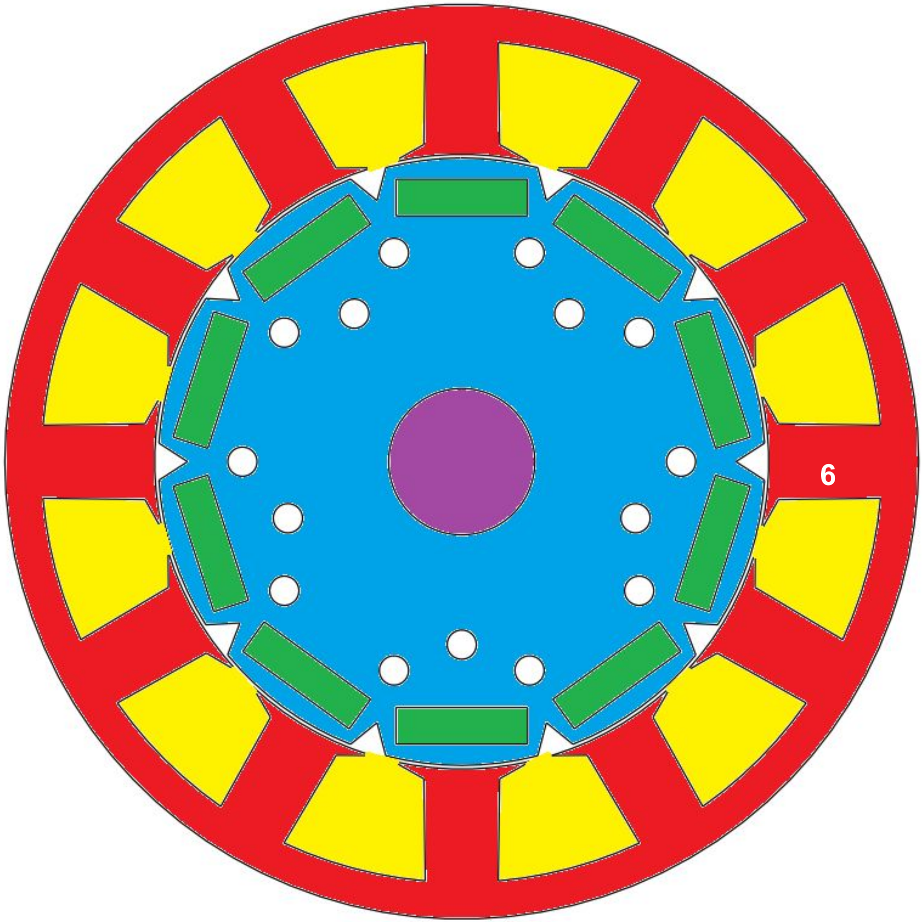
Familiarize With Terminology:

1. **Rotor:** The rotating part of the motor that contains the magnets or windings.
2. **Stator:** The stationary part of the motor that houses the windings to create the magnetic field.
3. **Air gap:** The space between the rotor and stator where the magnetic interaction occurs.
4. **Shaft:** The central axis that connects and supports the rotor and enables rotational movement.
5. **Winding:** The arrangement of coils in the stator or rotor that carries electric current.
6. **Stack Length:** refers to the axial dimension or height of the stator and rotor core laminations, indicating the length of the magnetic path within the motor.

Familiarize With Terminology:

7. **Slot:** An opening in the motor where the winding is placed.
8. **Tooth:** The part of the stator core that helps shape and guide the magnetic flux path.
9. **Poles:** Regions of the stator or rotor where magnetic fields are concentrated (Permanent Magnets In our case).
10. **Pole Arc:** The angular span of the rotor pole, which influences motor performance. In 180° of the rotor, what is the angle covered by the poles?
11. **Topology:** The specific arrangement and configuration of components, such as stator and rotor structures, winding types, and magnetic circuit layouts, in an electric motor design.
12. **Magnetic flux:** is the measure of the total magnetic field passing through a given surface, representing the number of magnetic field lines per unit area perpendicular to the direction of the field. (Radial & Axial)

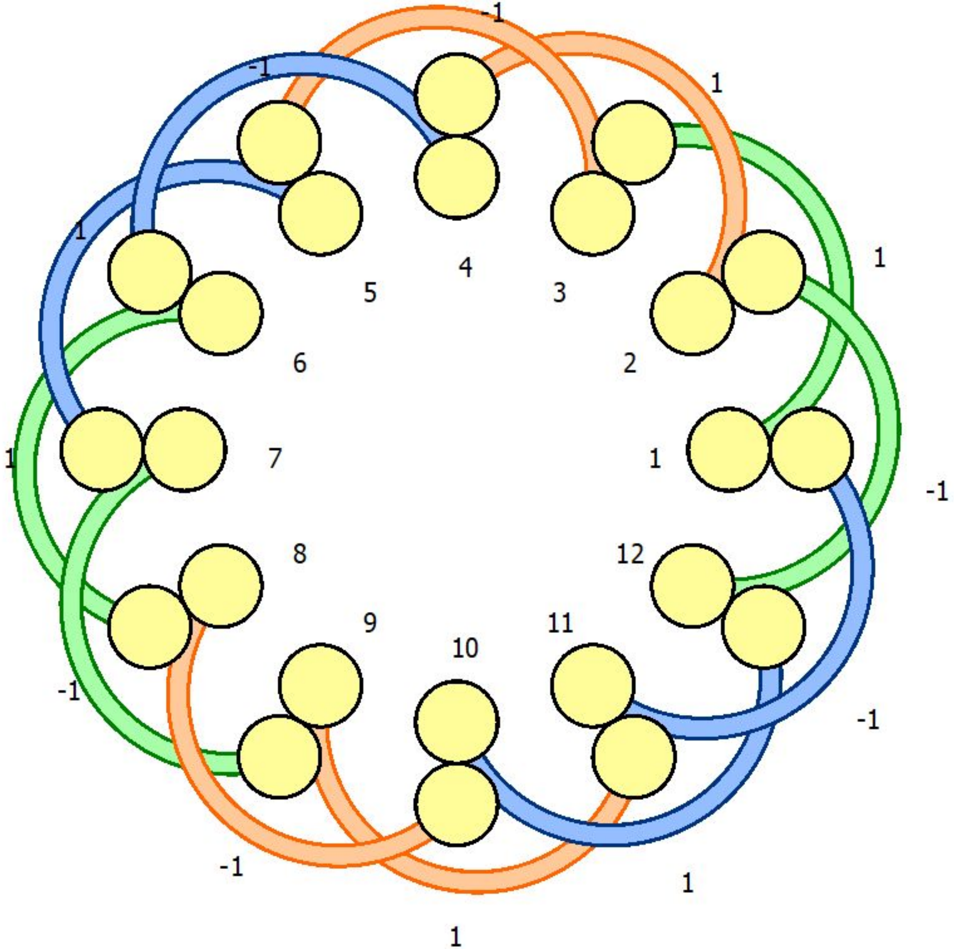
IPMSM - Radial Flux Geometry



LEGEND

1. Shaft
2. Rotor
3. Air Gap
4. Stator
5. Slot
6. Tooth (in Slot)
7. Pole

MOTOR - WINDING DIAGRAM



LEGEND

	U - Phase
	V - Phase
	W - Phase

What are we Designing ?

The motor that we are designing has the following specification:

1. **Topology:**

   IPMSM Radial Flux (Interior Permanent Magnet Synchronous Motor): electric motor with permanent magnets embedded in the rotor and magnetic flux flows perpendicular to the axis.

2. **Slot Pole Combination:**

   12 slots and 10 poles

3. **Winding:**

   Three Phase Double Layer Concentrated Winding.

4. **Materials:**

   1. Magnet: N42 RE (Rare Earth)

   2. Steel: M250-35A

   3. Wire: Copper 20 SWG

What Information Do We Have? (Input)

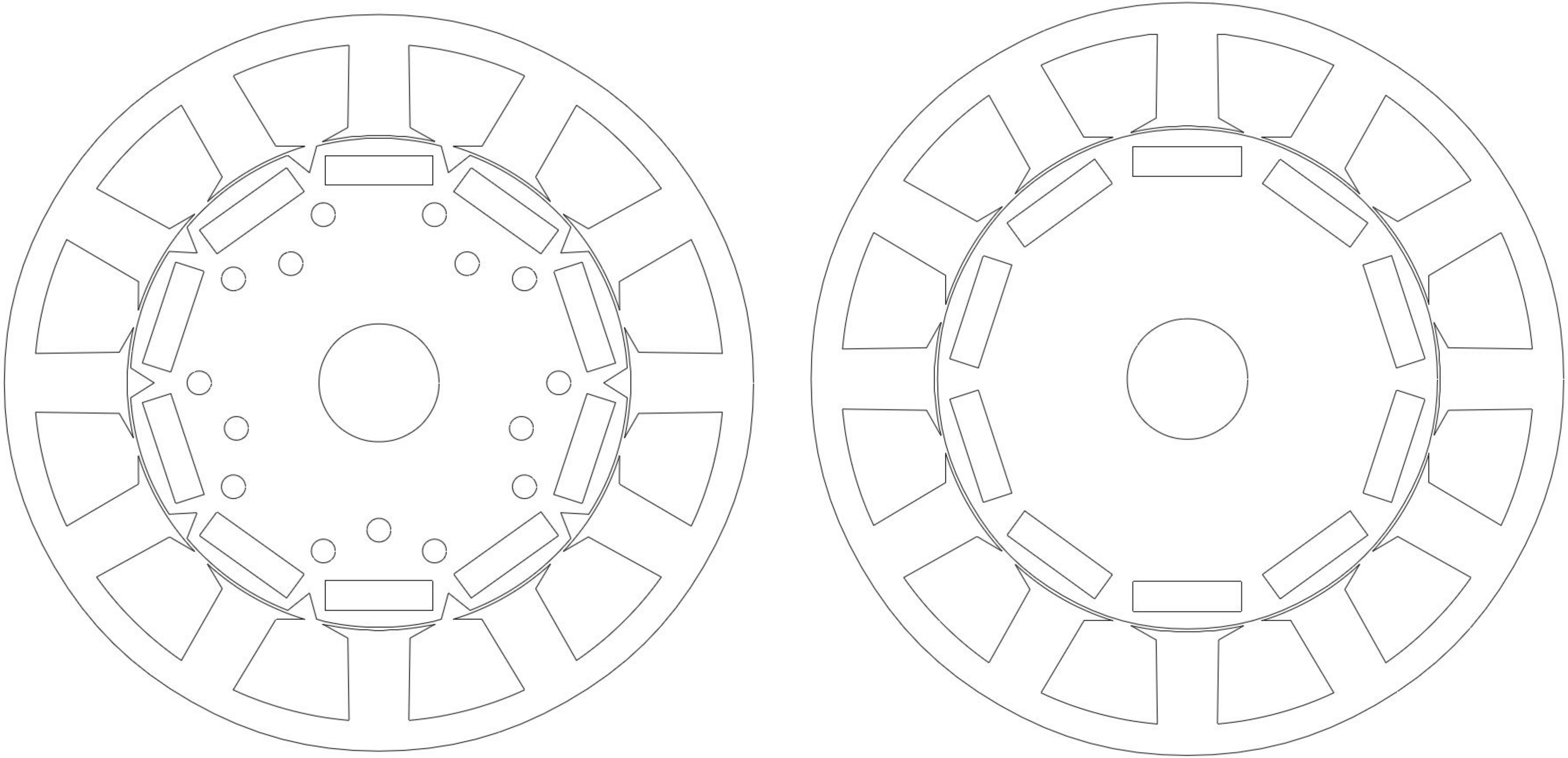
From Motor Wiz:

1. Rotor Outer Diameter (Rotor OD)
2. Tooth thickness (t)
3. Slot OD
4. Slot depth
5. Yoke thickness
6. Stator OD
7. Rotor ID
8. Dm (mean slot dia)
9. Stack Length
10. Number Of Slots (12)
11. Number Of Poles (10)
12. Air Gap (0.5mm)
13. Pole Length
14. Pole Width

Assumptions:

1. Pole Arc: 150°
2. Slot Opening: 3mm
3. Bridge Thickness: 1mm
4. Shaft Diameter: 20mm
5. Tooth Tip Angle: 30°

What Should Be the Output?



DXF Entities

1. **Points:** Specified by coordinates (x,y)

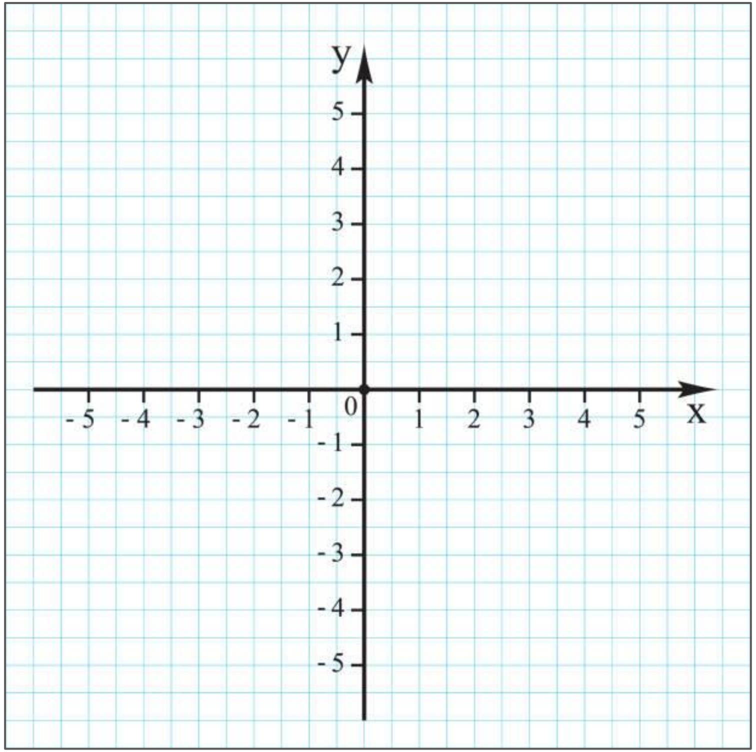
2. **Lines:** Specified by two points ((x1,y1),(x2,y2))

3. **Circles:** Specified by centre point and the radius ((xo,yo), r)

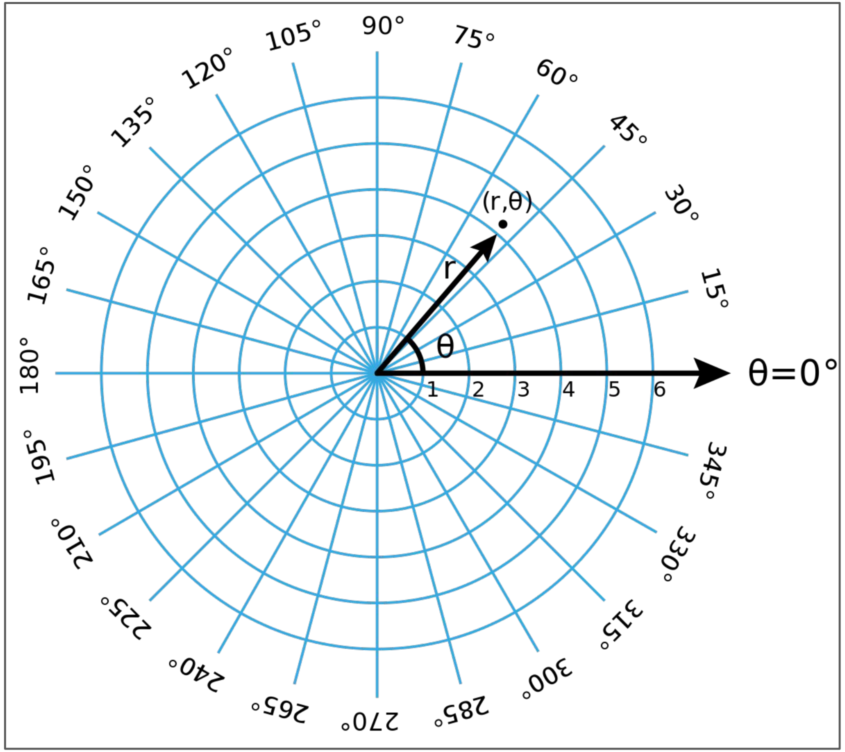
4. **Arcs:** Specified by centre point, radius and an angle ((xo,yo), r, angle)

Coordinate Systems

Cartesian Coordinates (x,y)



Polar Coordinates (r,θ)



Why should we consider Polar Coordinates?

1. To exploit the circular symmetry of the IPMSM Radial Motor’s Topology.

2. The geometrical inputs, we are going to use are already given in terms of radius and angles.

Basic Formulae & Conversions:

$\text{Sin}\theta = \dfrac{\text{opposite}}{\text{hypotenuse}}$

$\text{Cos}\theta = \dfrac{\text{adjacent}}{\text{hypotenuse}}$

$\text{Tan}\theta = \dfrac{\text{opposite}}{\text{adjacent}}$

$S = R\theta$

circumference = $2\pi R$

Polar to Cartesian:

$x = r \times \text{Cos } \theta$
$y = r \times \text{Sin } \theta$

wrt horizontal line

Cartesian to Polar:

$r = \sqrt{(x^2+y^2)}$

θ = Tan inverse(y/x)

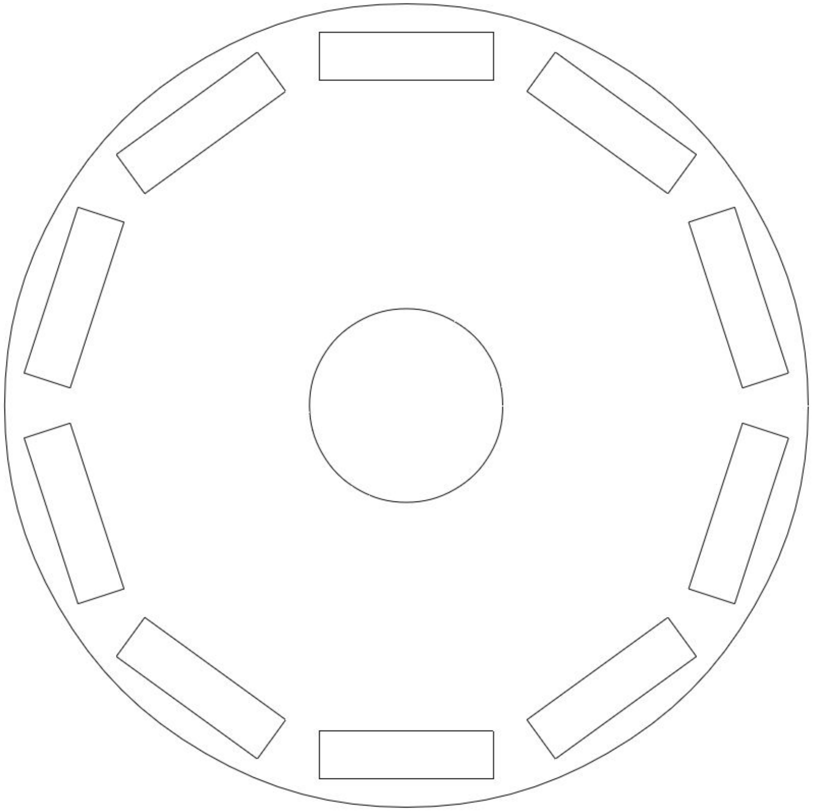
Degrees to Radians:

Deg = (180×radians)/ π

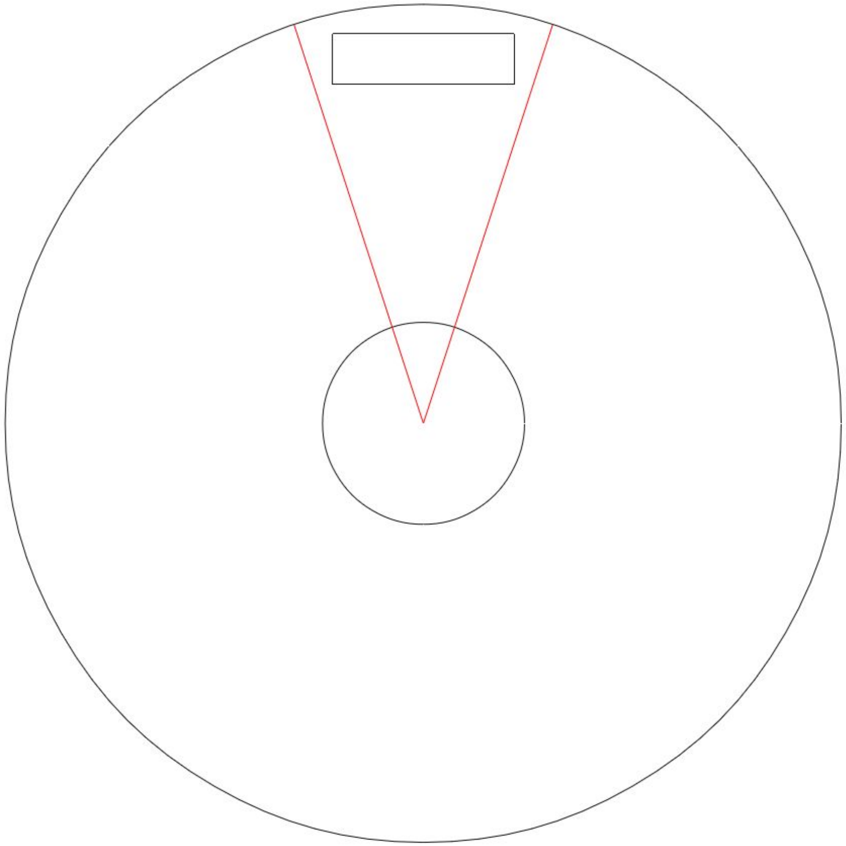
Radians to Degrees:

Radians = (π×degrees)/180

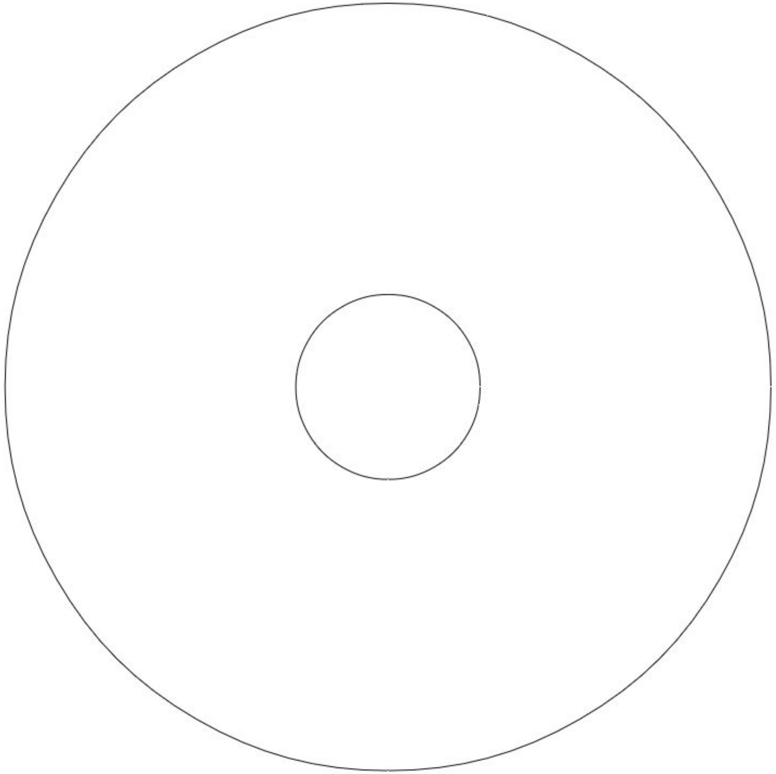
Drawing The Rotor



Rotor Segment



Draw Rotor And Shaft

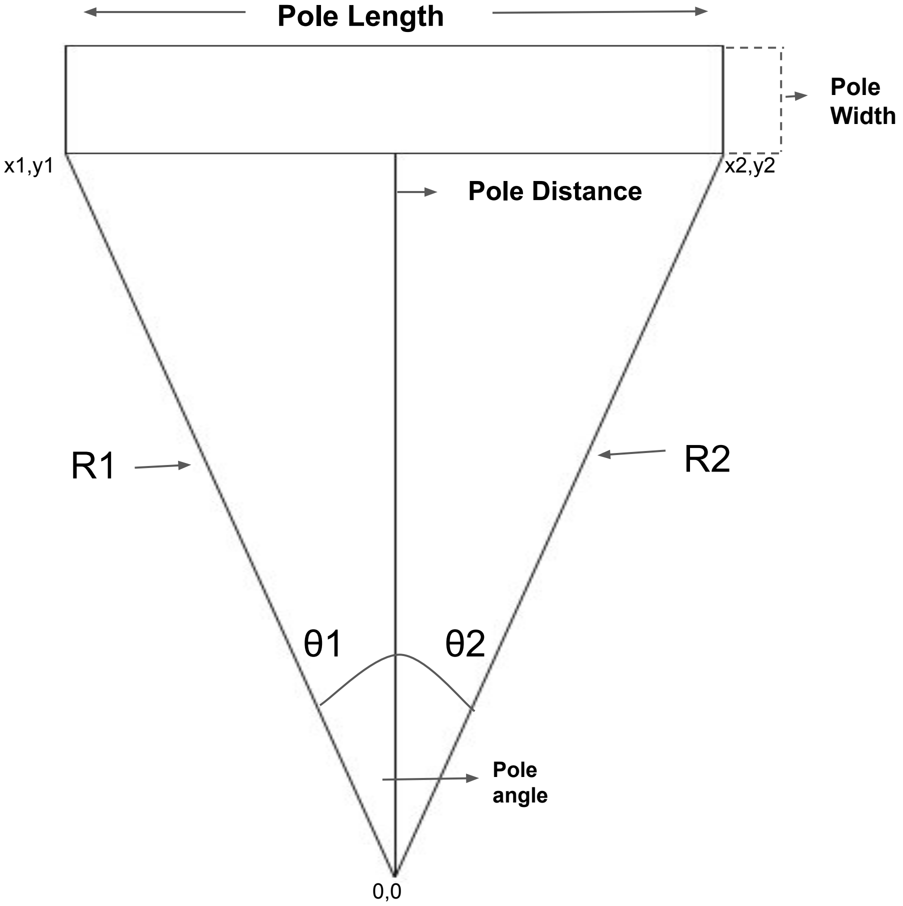


Draw Circle with and origin at (0,0) and radius:

Shaft: Shaft_radius

Rotor: Rotor_outer_radius

Drawing Pole



To Find (x1,y1) and (x2,y2):

reference_angle = 0 (increment by 36 deg)

pole_angle = (pole_arc*2)/no_poles

θ = pole_angle/2
θ1 = reference_angle +θ
θ2 = reference_angle - θ

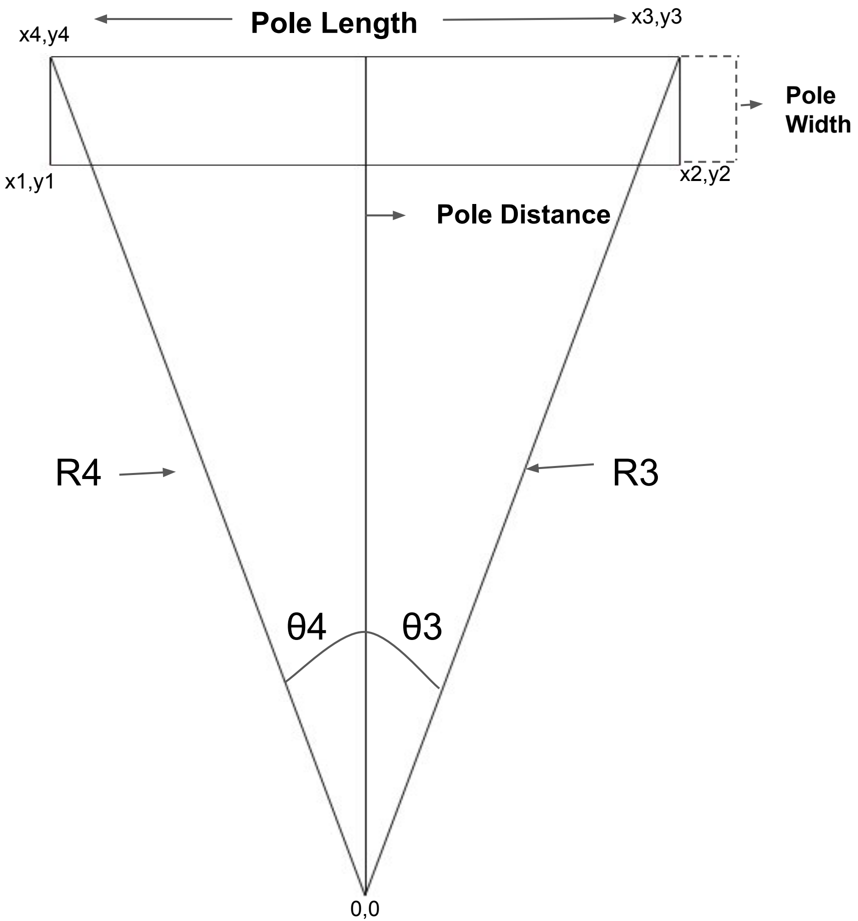
R1 = pole_length/(sin(θ)*2)
R2 = pole_length/(sin(θ)*2)

x1 = R1*sin(θ1)
y1 = R1*cos(θ1)

x2 = R2*sin(θ2)
y2 = R2*cos(θ2)

pole_distance = R1*cos(θ)

Drawing Pole



To Find (x3,y3) and (x4,y4):

reference_angle = 0 (increment by 36 deg)

h = pole_distance+pole_width

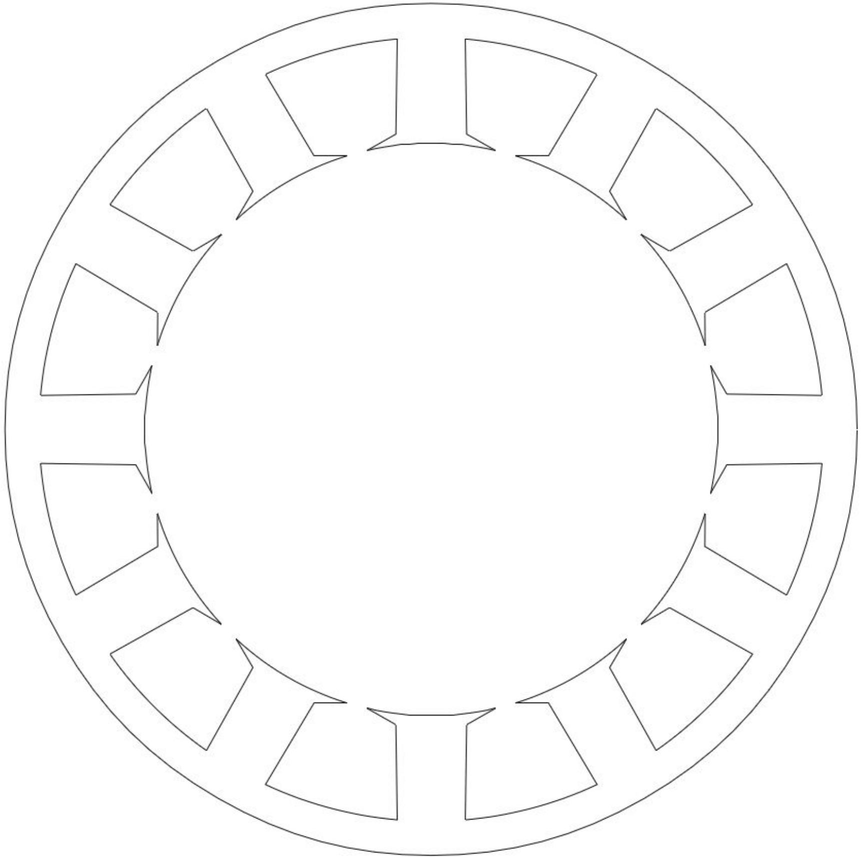
θ = taninv(pole_length/(2*h))
$\theta 3$ = reference_angle -θ
$\theta 4$ = reference_angle + θ

R3 = pole_length/(sin(θ)*2)
R4 = pole_length/(sin(θ)*2)

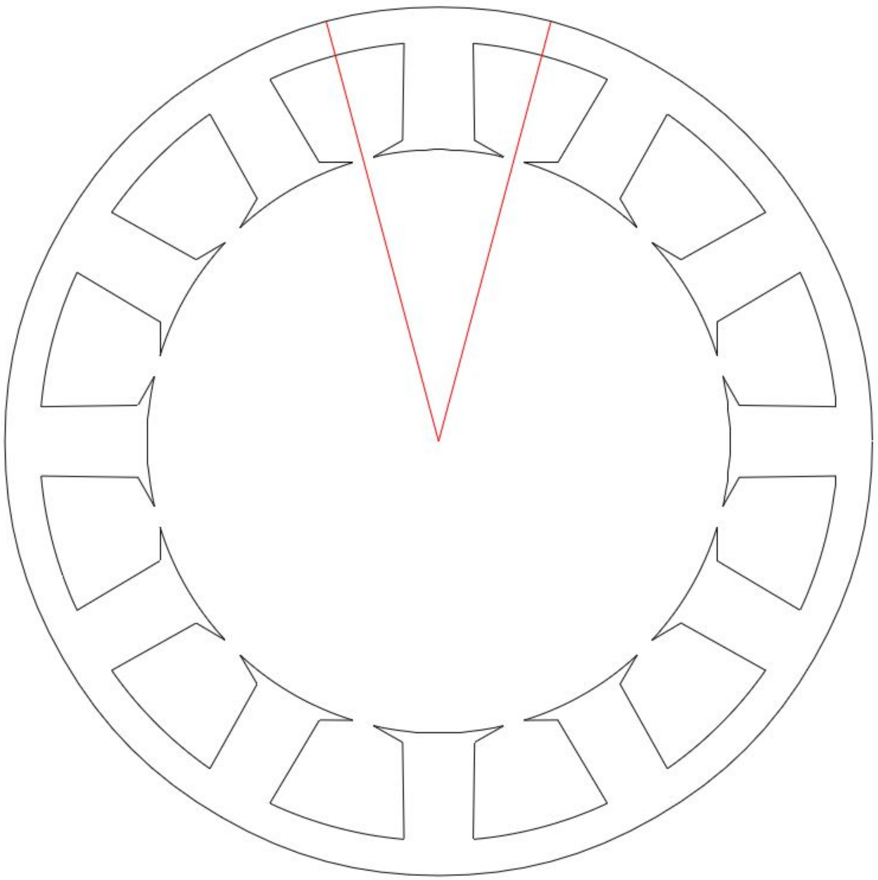
x3 = R3*sin($\theta 3$)
y3 = R3*cos($\theta 3$)

x4 = R4*sin($\theta 4$)
y4 = R4*cos($\theta 4$)

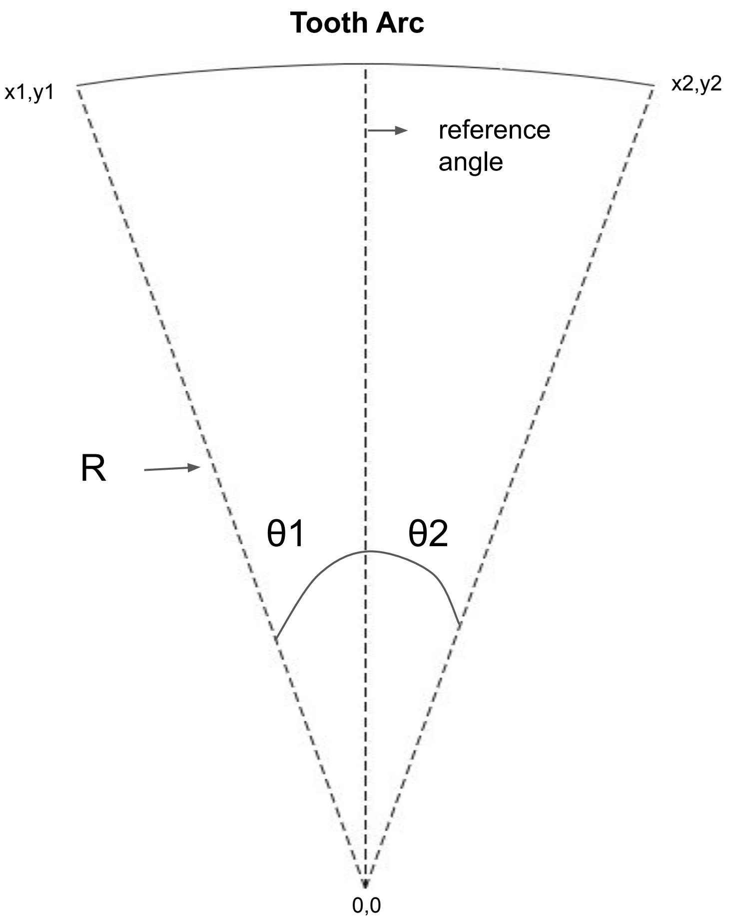
Drawing The Stator



Stator Segment



Tooth Arc



To Find (x1,y1) and (x2,y2):

reference_angle =0
R = Stator Inner Radius

stator_opening_total = 2πR- slot_opening*no_slots

tooth_arc_s = stator_opening_total/no_slots
tooth_arc_theta = (tooth_arc_s*2)/stator_id

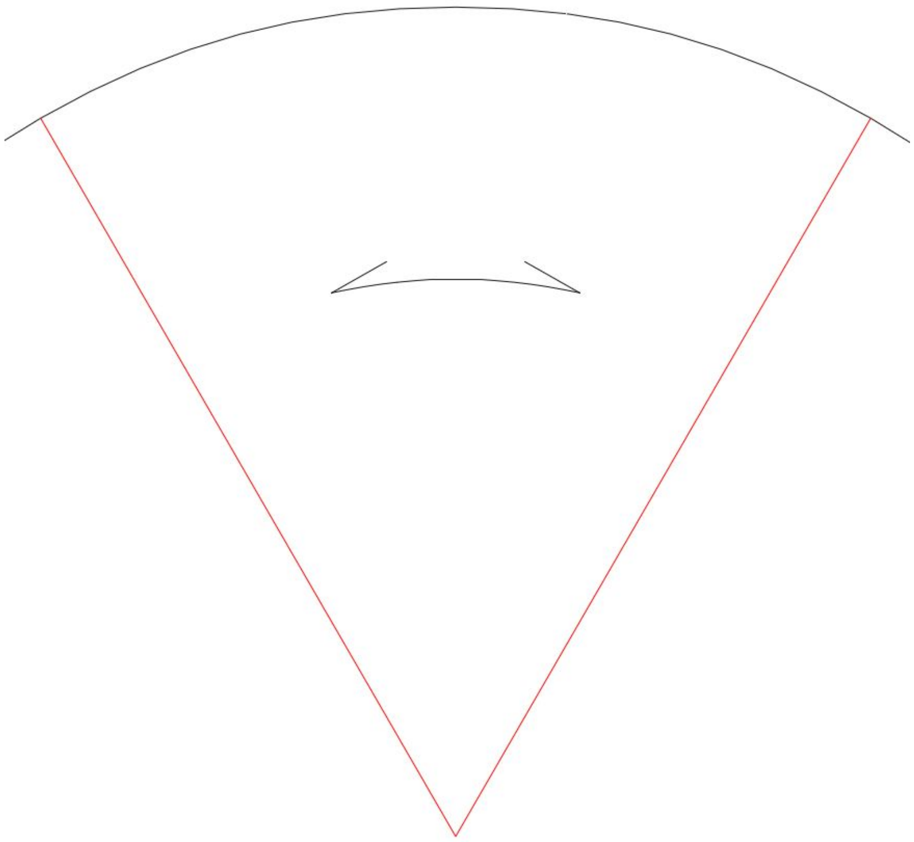
θ = tooth_arc_theta*180/π/2
θ1 = reference_angle + θ
θ2 = reference_angle - θ

Draw arc using (R,θ1,θ2 and (0,0))

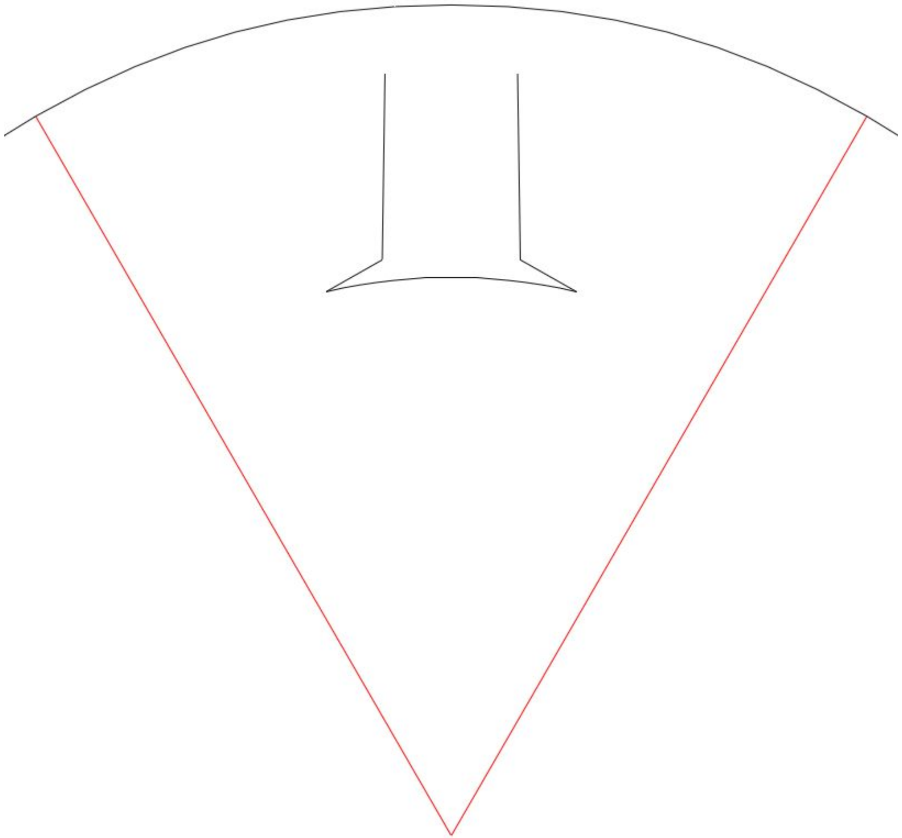
x1 = R*sin(θ1)
y1 = R*cos(θ1)

x2 = R*sin(θ2)
y2 = R*cos(θ2)

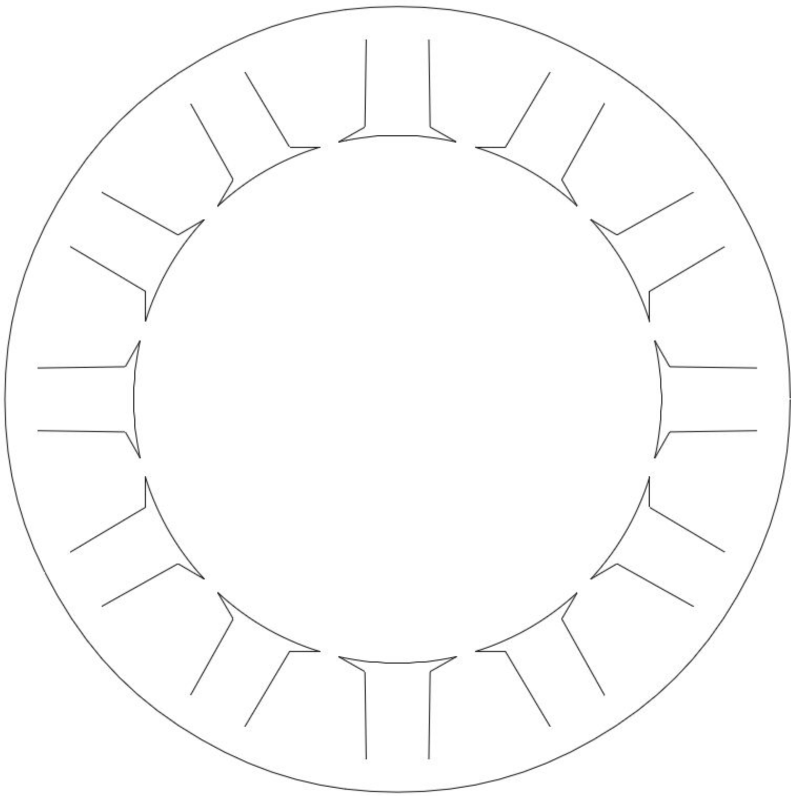
Draw Tooth Tip

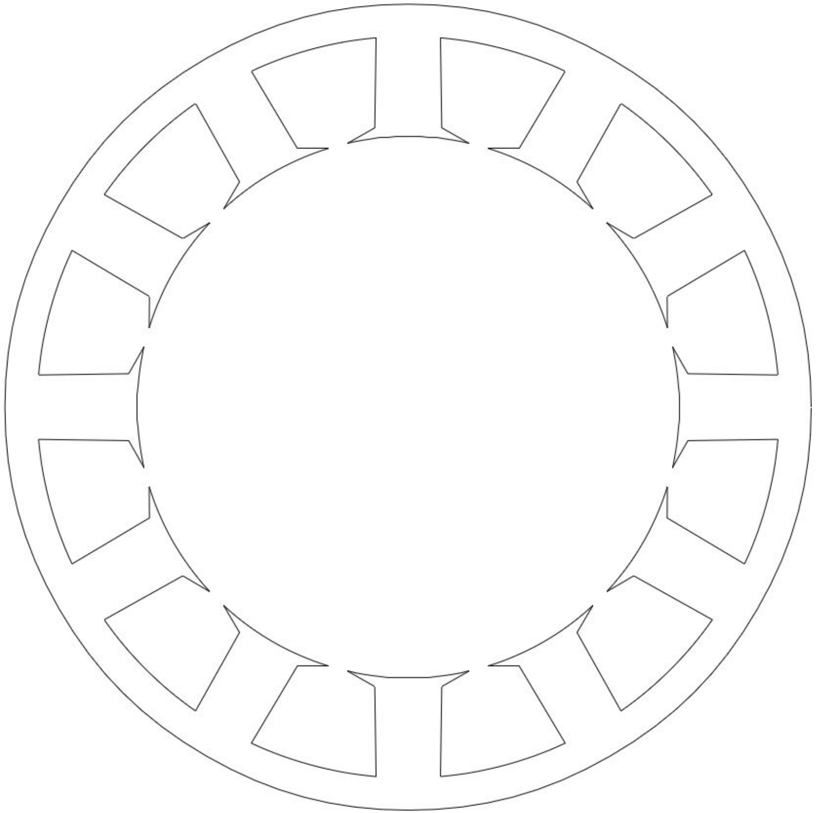


Draw Toothbase

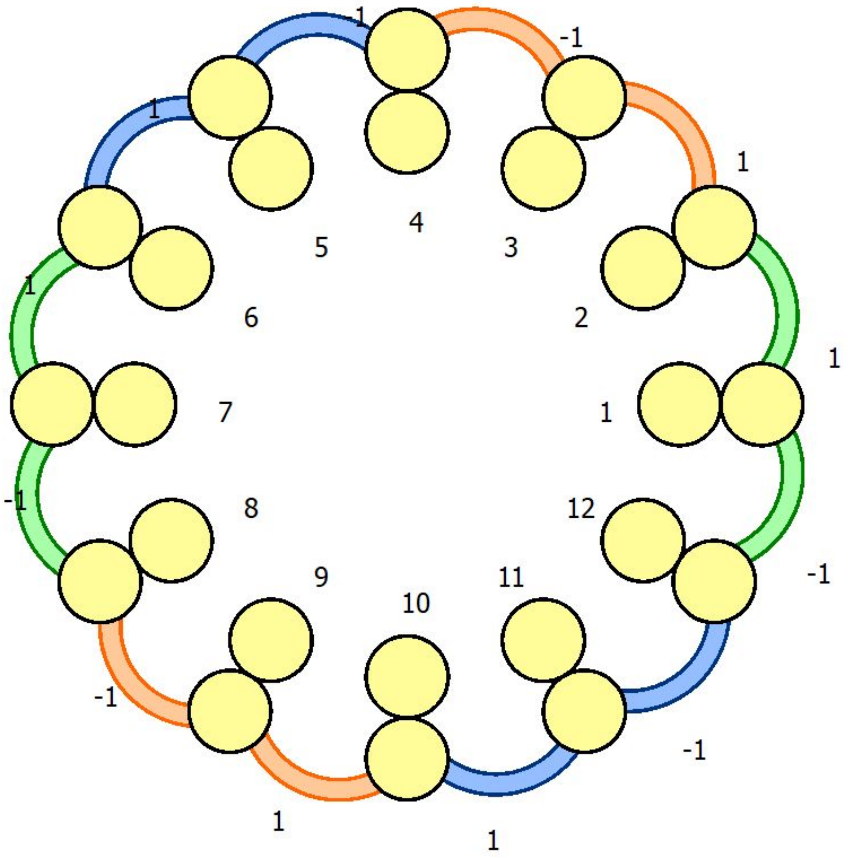


Connect All the Teeth





Winding Diagram



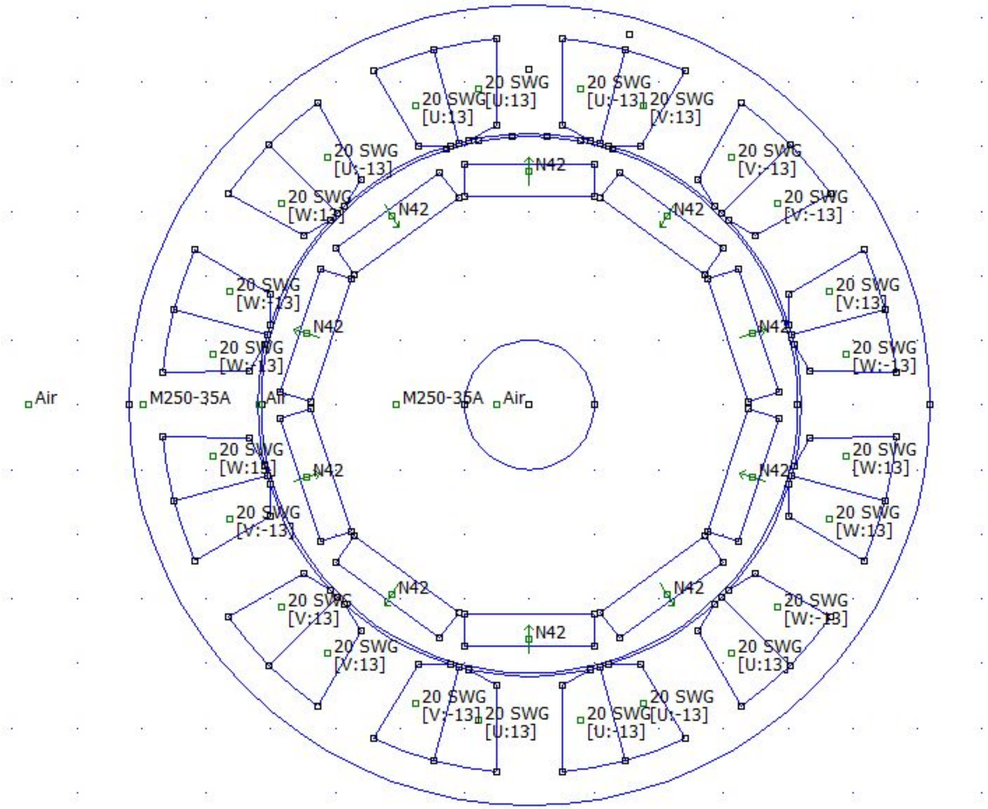
<u>Legend</u>

U - Phase

V - Phase

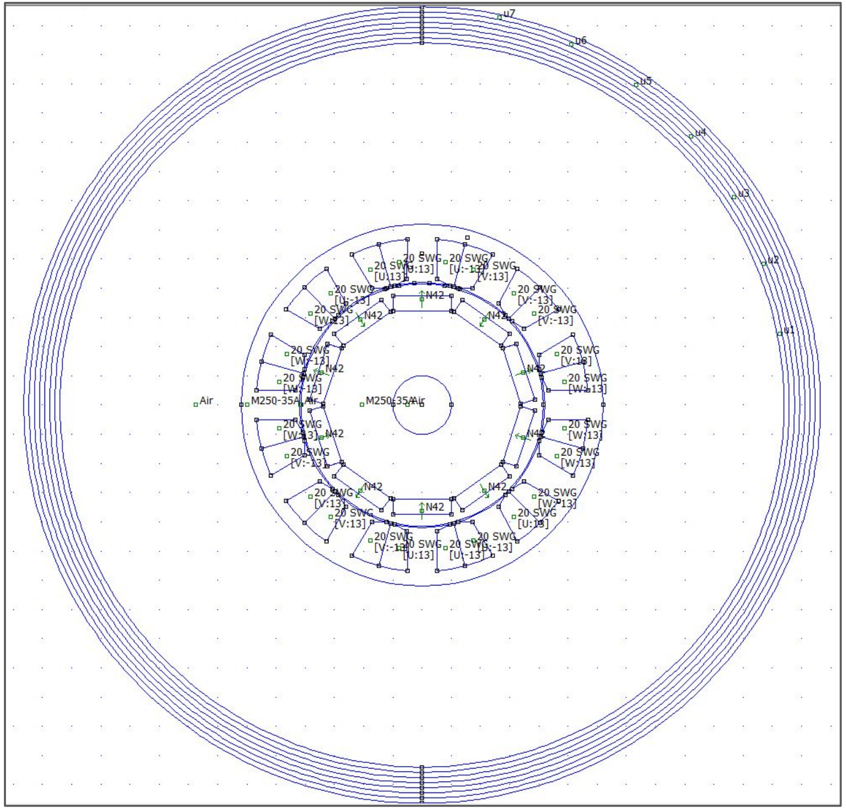
W - Phase

Simulating in FEMM: Adding Material And Winding

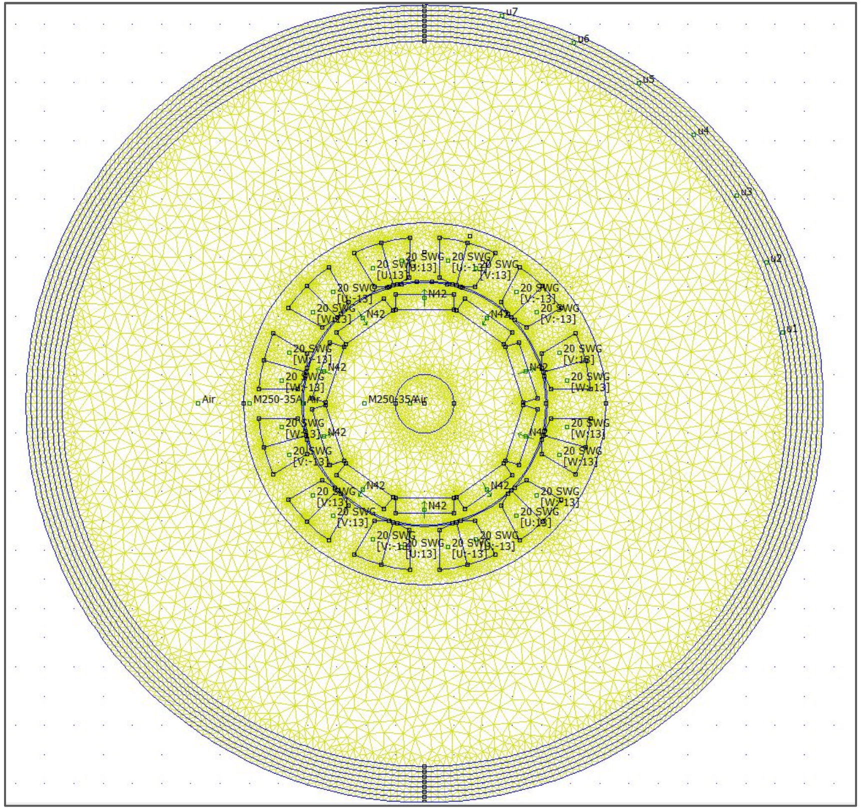


Simulation Results: Boundary & Meshing

Dirichlet Boundary

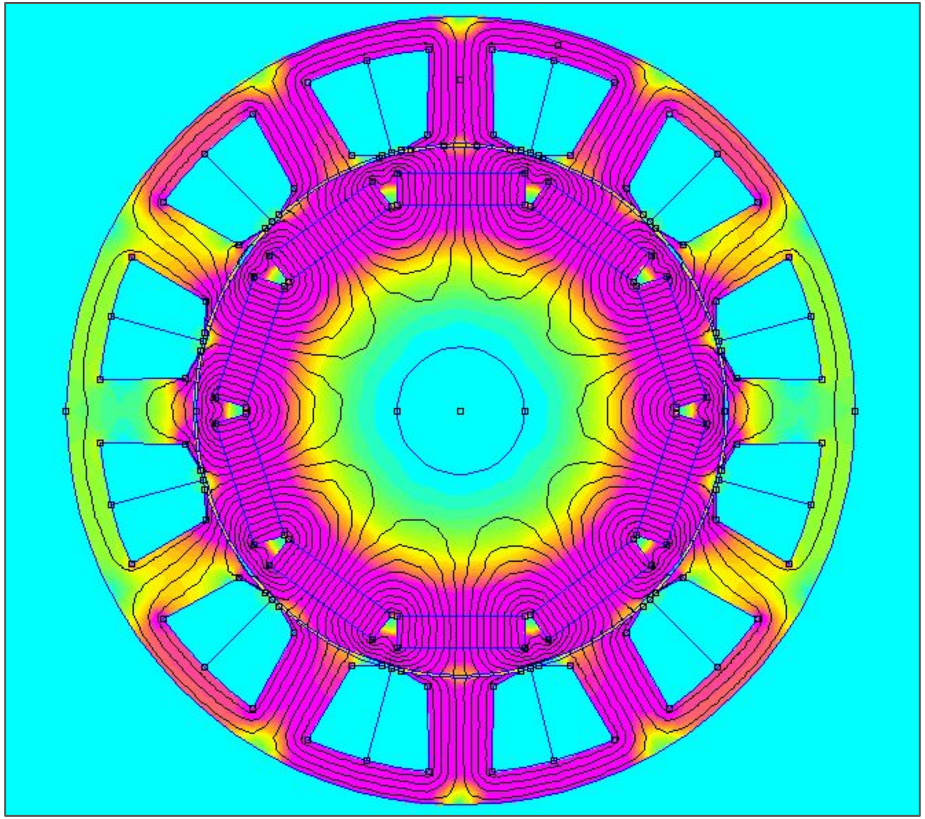


Meshing

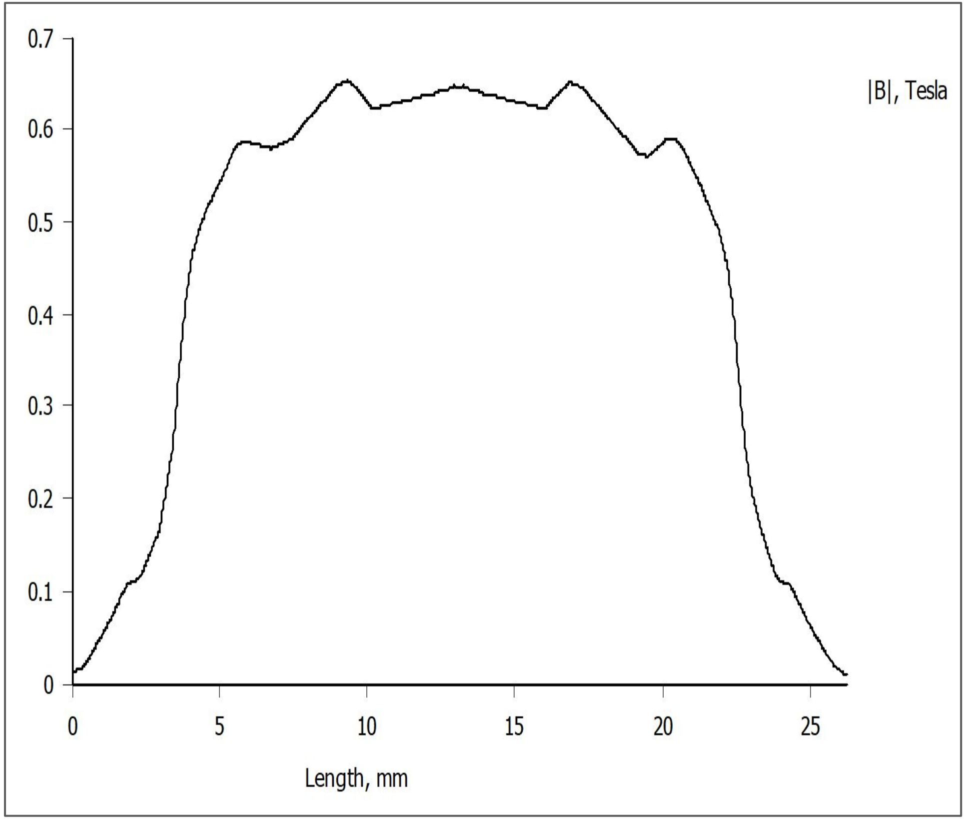


Simulation Results

Magnetic Flux Density Plot



Air Gap Flux Plot



THANK YOU