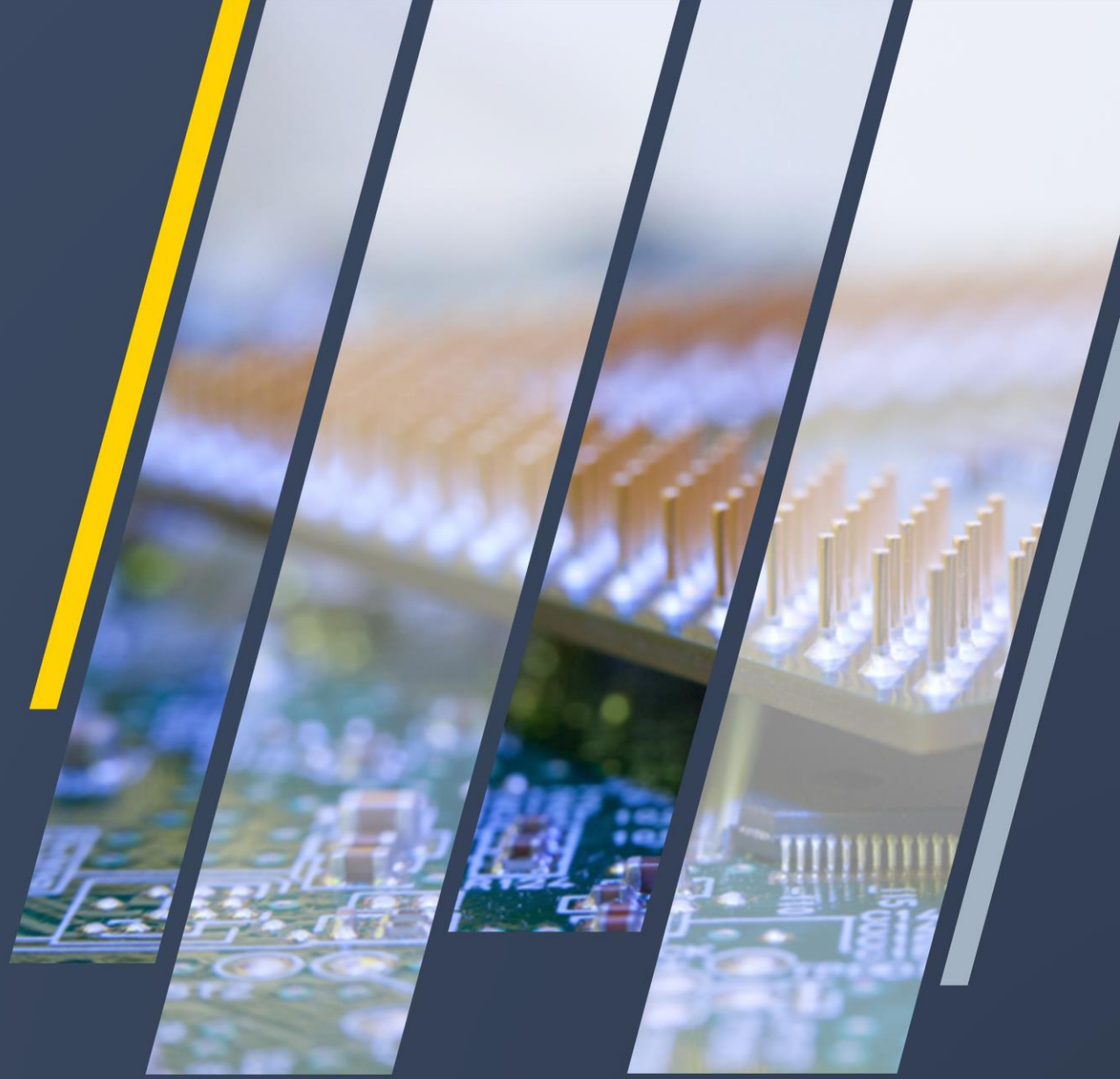
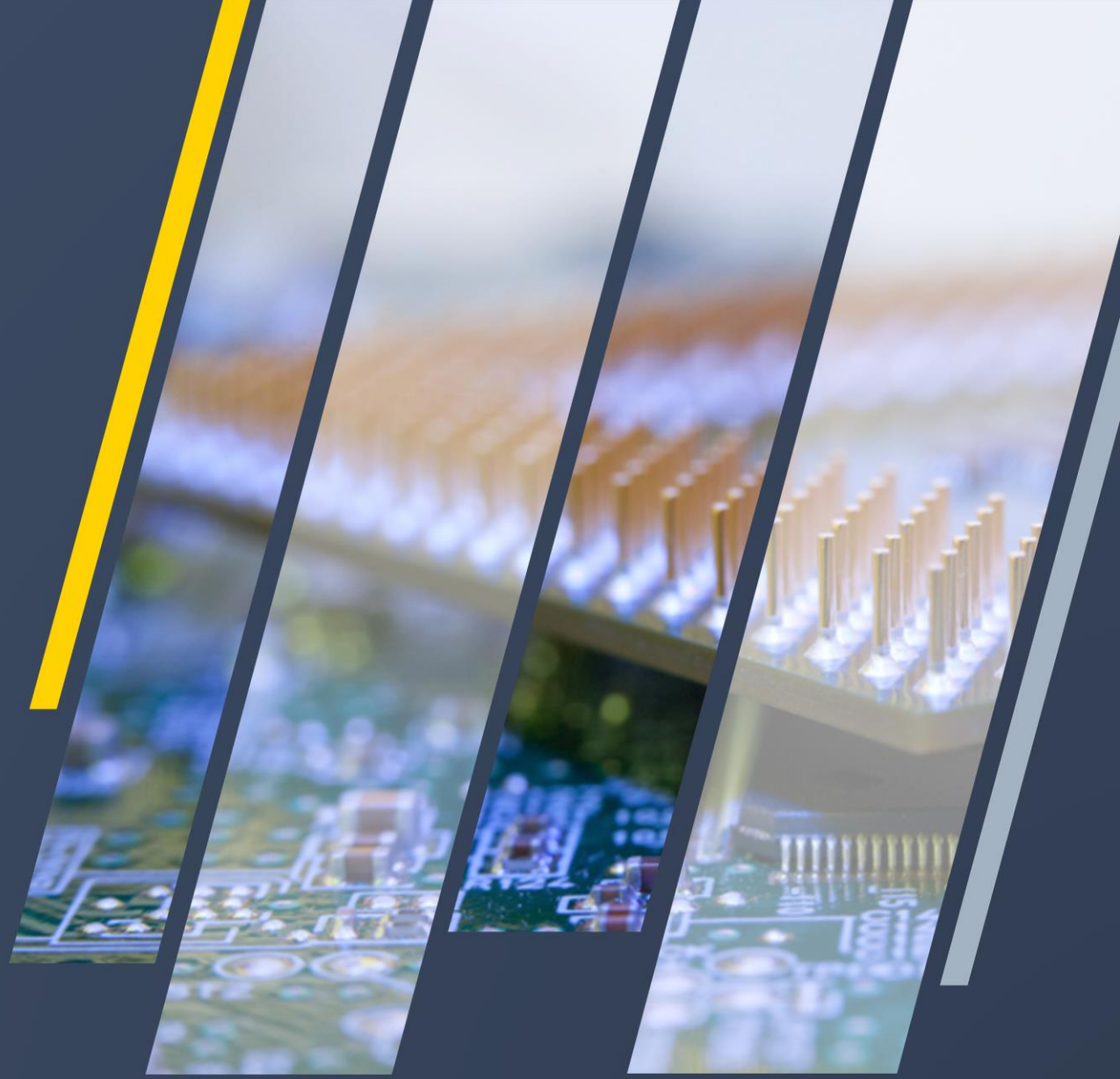


# Module 03: Mesh Operations for Rotating Machines

ANSYS Maxwell Advanced Motor Training

# Overview

- **Mesh for Rotating Machines**
  - This module deals with the meshing techniques available within ANSYS Maxwell. The goal is to describe how to apply suitable mesh operations (if and when required) to the simulation model, in order to improve results accuracy without excessively increasing the overall simulation time
  - In particular we will discuss:
    - The basics of mesh operations
    - How to set manually the initial mesh settings surface approximation, to avoid over-meshing regions of no/poor interest
    - How the Clone Mesh advanced technique works both in 2D and 3D
    - How the additional Clone Mesh density can help improving the mesh quality
- **Workshop 3.1: Mesh Operations for Rotating Machines**



# Basics of Meshing

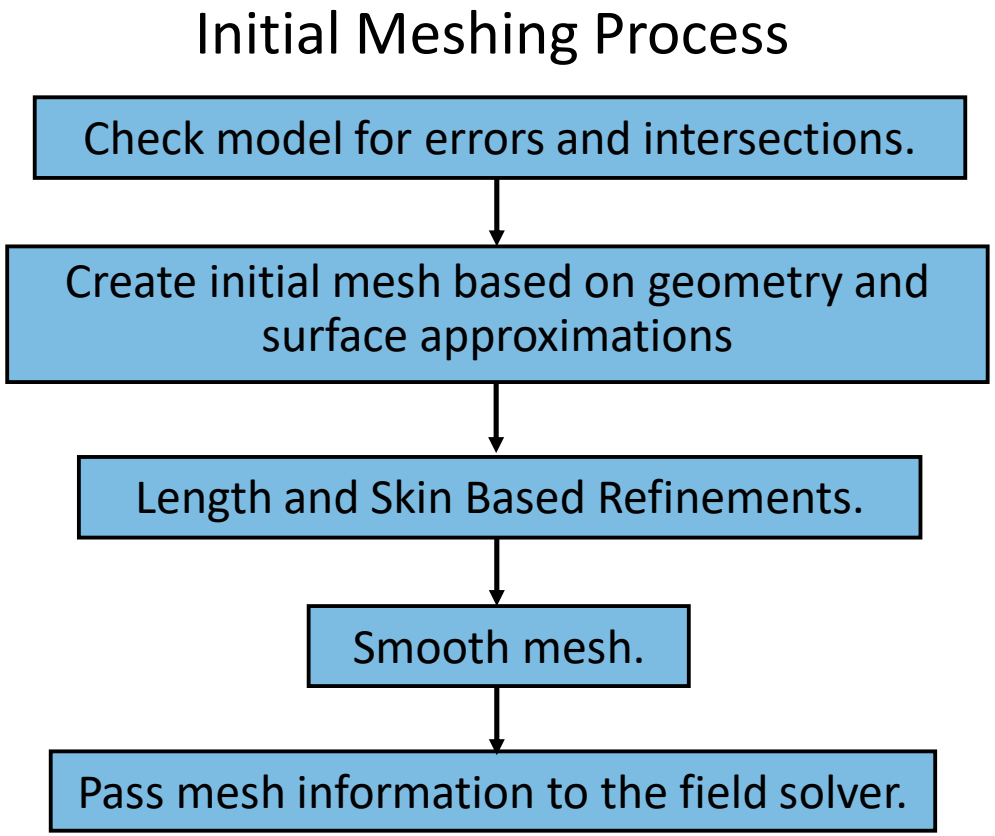
ANSYS Maxwell Advanced Motor Training

# Maxwell Meshing

- About Mesh
  - Maxwell uses the Finite Element Method (FEM) to solve Maxwell's equations.
  - In order to obtain the set of algebraic equations to be solved, the geometry of the problem is discretized automatically into basic building blocks (triangles in 2D, tetrahedra in 3D)
  - The assembly of all triangles or tetrahedra is referred to as the finite element mesh or simply the mesh
  - Mesh plays important role in accuracy of the computed results and thus requires higher mesh resolution in regions where fields are of interest
  - The key point when creating the mesh is to obtain a mesh of sufficient quality and density to represent the phenomena of interest and at the same time not to create an over-meshed model, which could lead to unjustifiably long simulation time
- Meshing in Maxwell
  - Maxwell meshes all model Objects in the geometry automatically before solution process starts
  - In Maxwell's Quasi-Static Solvers, the mesh is automatically refined to achieve the required level of accuracy in field computation. This is referred as Adaptive Mesh Refinement and it is assumed the trainee has already covered this topic in the "Introduction to ANSYS Maxwell" training material
  - Maxwell also offers wide range of mesh operations which can be used to achieve the required accuracy

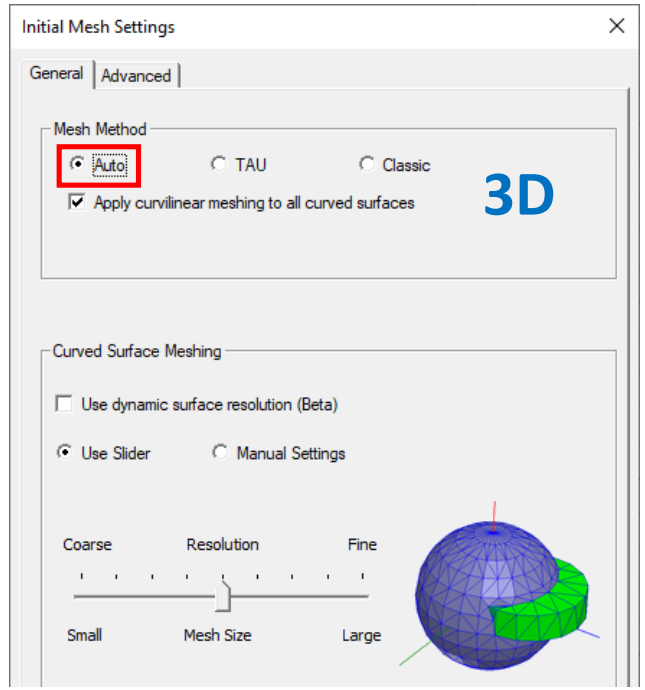
# Initial Mesh

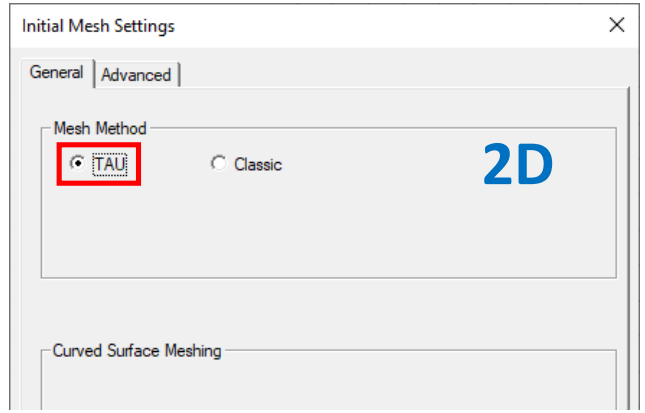
- **Initial Mesh**
  - **When the Solution process is initiated, Maxwell uses an initial mesh to perform field calculations**
  - **Initial mesh is automatically created by Maxwell without any instructions from users prior to performing field calculations**



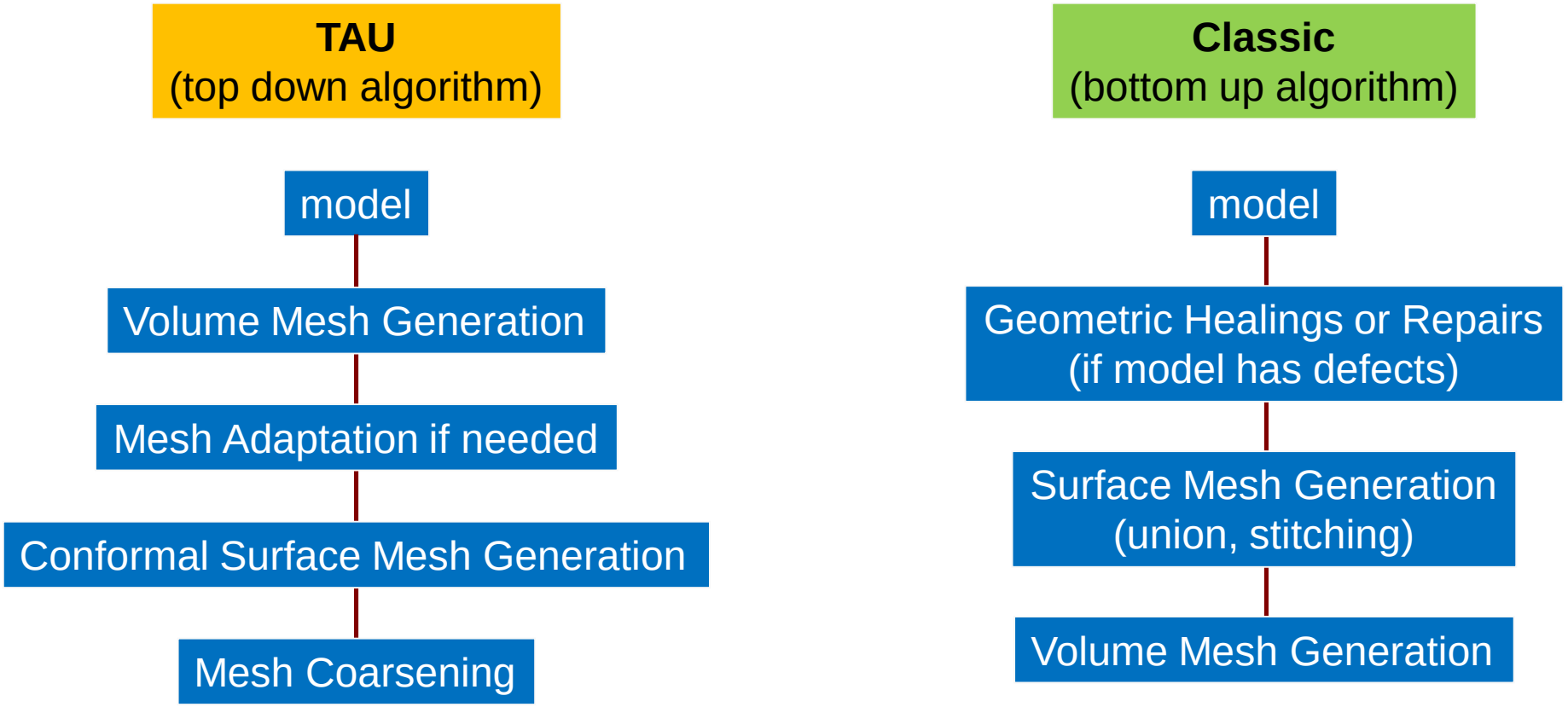
# Initial Mesh Settings

- **Initial Mesh Settings**
  - Default **Initial Mesh Settings** are appropriate for most geometries
  - Initial Mesh settings can be accessed from menu item ***Maxwell 3D → Mesh Operations → Initial Mesh Settings***
- **Meshing Methods**
  - **Auto (3D Only):**
    - Default meshing method in 3D, allowing Maxwell to automatically select the appropriate mesher based on geometry
    - **Apply curvilinear meshing to all curved surfaces:** checking this increases accuracy for curved surfaces, though it costs more memory
  - **Tau Mesh (default in 2D):**
    - Well suited for curved surfaces and transient with movement analysis
    - It creates a fine mesh at the beginning relaxing it by smoothing
  - **Classic Mesh:**
    - Might not be suitable for curved surfaces and requires geometry segmentation but works better for thin, flat objects
    - It creates a coarse mesh at the beginning, refining it by smoothing



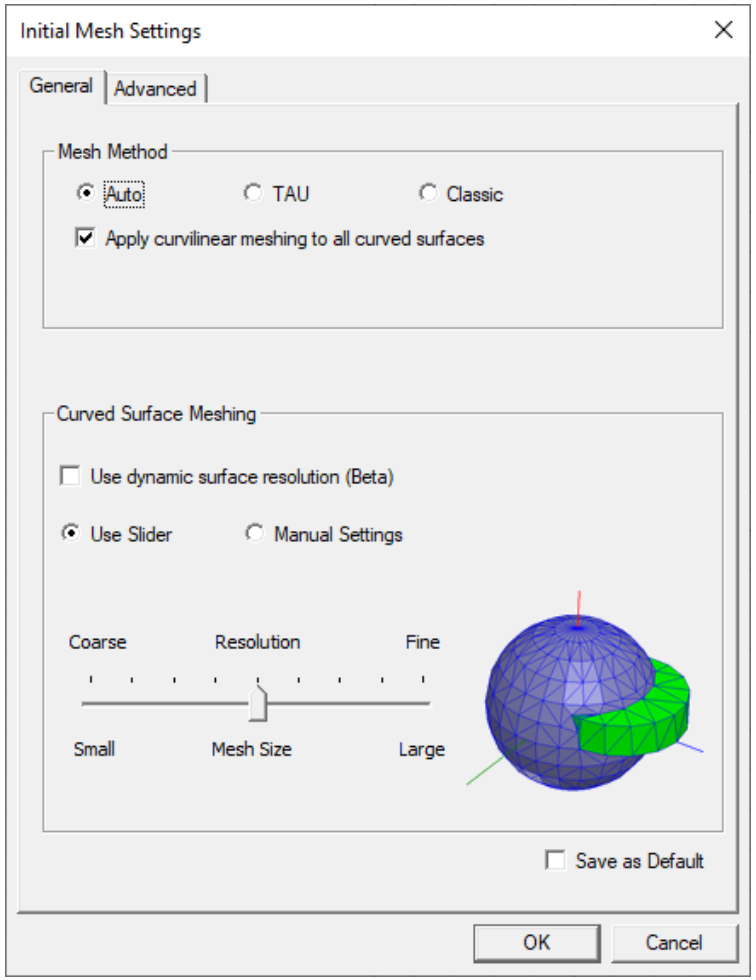
# Classic Mesh versus TAU mesh



# Classic Mesh versus TAU mesh

- **TAU (Tetrahedral Adaptive Uniform)**
  - Create more regular mesh, ideal for transient analysis (no adaptive meshing)
  - Avoid low quality elements (poor aspect ratio)
  - Has many dedicated functions for true surfaces
- **Classic**
  - Works well on geometries with many thin surfaces
  - Works better with geometries of very bad quality
  - Create a smaller mesh with a minimum number of elements (of poor quality), which is ideal as an initial mesh for adaptive process for huge geometries (it limits memory requirement)
  - More flexible to create very optimized meshes

# Auto Mesh in 3D



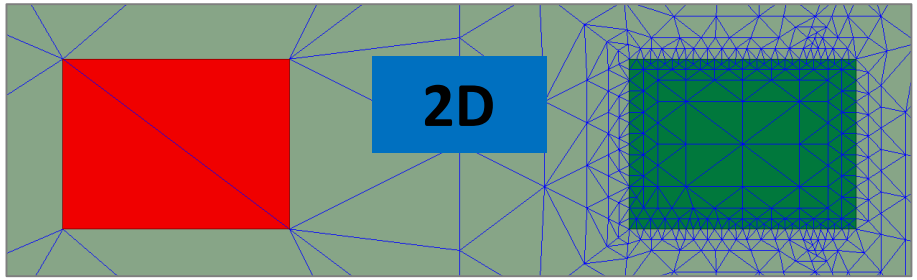

- **Auto (default):**
  - TAU (strict) or Classic (for models with multiple extremely thin layered models)
- **Classic Mesh:**
  - Automatically call TAU (tolerant) if it fails
- **TAU (strict):**
  - Strictly tight tolerance, same as Classic
  - Automatically call TAU (tolerant) if it fails
- **TAU (tolerant):**
  - Model dimension-based tolerance
  - Starting mesh directly from ACIS model
  - If it fails, it fails, and Healing or Geometry analysis may be required

# Mesh Operations

- **Mesh Operations**
  - Maxwell's Adaptive mesh refinement feature can be effectively used to achieve an optimized mesh
  - Transient Solvers do not have the capability to refine the initial mesh. Thus, Transient Solvers require either Mesh Operations to be specified, or use the Link Mesh option to an adaptively refined mesh from a static solver
  - In complex Static problems, it is also recommended to use Mesh Operations
    - To reduce number of passes required to achieve desired accuracy
    - To increase mesh density in areas of interest before the adaptive mesh refinement begins
  - Maxwell offers following mesh operation specifications
    - On Selection/ Length Based
    - On Selection / Skin Depth (Layered) Based
    - Inside Selection / Length Based
    - Surface Approximation
    - Apply curvilinear Meshing
    - Model Resolution
    - Cylindrical Gap Treatment
    - Clone Mesh

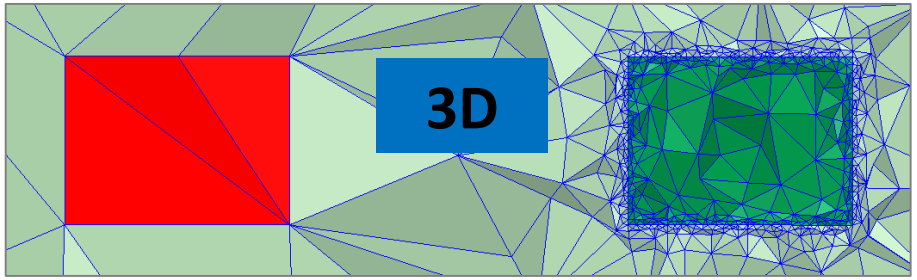
# On Selection

- **Mesh Operation: On Selection/Length Based (both TAU and Classic – 2D/3D)**
  - **The Length-Based On-Selection refinement will limit the edge length of all triangles formed on the surface of a selected object or any selected faces**
  - **Can be added by selecting either the Object or its edges/surfaces and menu item *Maxwell 2D/3D → Mesh Operations → Assign → On Selection → Length Based***
  - **Restrict the length of elements:**
    - **Refines the mesh by controlling maximum elements size on the boundary of assigned object**
  - **Restrict the number of additional elements:**
    - **Refines the mesh by controlling maximum element count on the boundary of assigned object**




Without Mesh Operation

With Mesh Operation




Without Mesh Operation

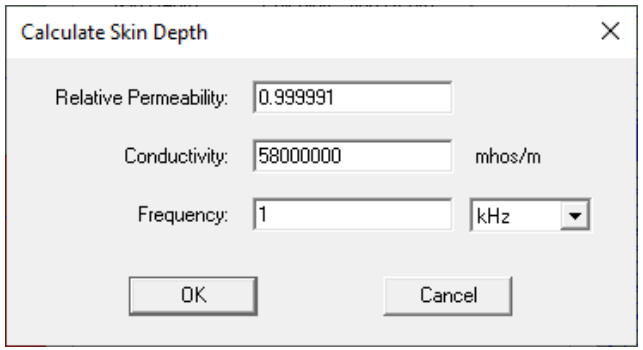
With Mesh Operation

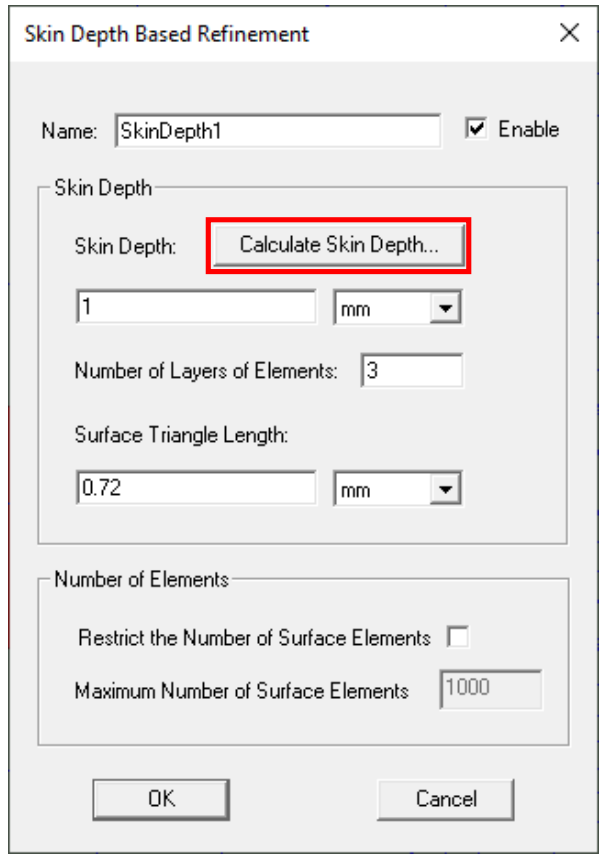
***Note: When both Restrict the length of elements and Restrict the number of additional elements are both selected, mesh refinement will stop when any of the conditions is met***

# On Selection

- **Mesh Operation: On Selection/Skin Depth Based (3D TAU/Classic and 2D Classic)**
  - Skin Depth Based mesh operations are assigned to resolve induced eddy current near conductor surfaces
  - This refinement method creates mesh layers within the selected surfaces of objects
  - Can be added selecting the Object and menu item *Maxwell 2D/3D → Mesh Operations → Assign → On Selection → Skin Depth Based*
  - **Skin Depth:**
    - Skin Depth field allows users to enter known value of the skin depth and number of layers of mesh to be created
  - **Calculate Skin Depth:**
    - Calculate Skin Depth tab allows user to compute resulting skin depth value based on Permeability, Conductivity and Frequency
    - Computed value is automatically assigned in Skin Depth field

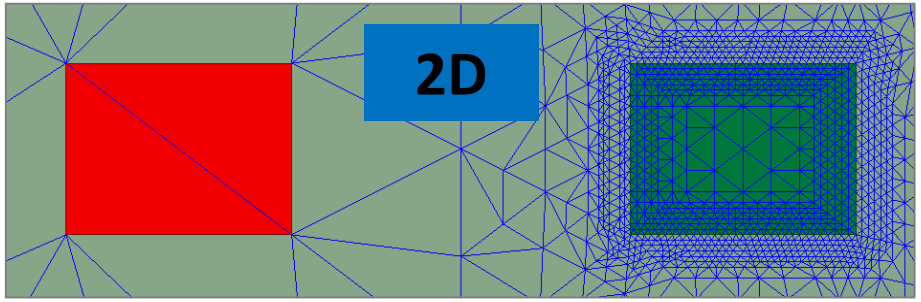
$$\delta = \sqrt{\frac{2}{\omega \mu_0 \mu_r \sigma}} = \frac{1}{\sqrt{\pi f \mu_0 \mu_r \sigma}}$$



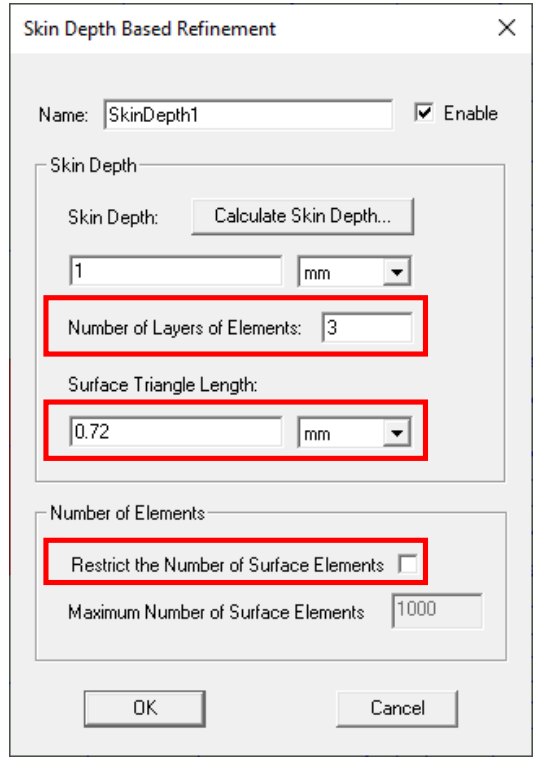
# On Selection

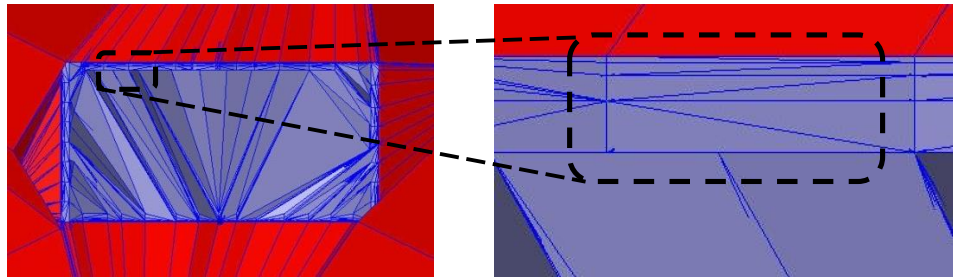
- **Mesh Operation: On Selection/Skin Depth Based**
  - **Number of Layers of Elements:**
    - Sets maximum number of mesh layers created in skin region
  - **Surface Triangle Length:**
    - The solver refines the surface triangle mesh (the faces of the tetrahedra touching the surface) until their edge lengths are less than or equal to the specified value
  - **Restrict the Number of Surface Elements:**
    - Restricts the count of elements to a specified value




Without Mesh Operation

With Mesh Operation



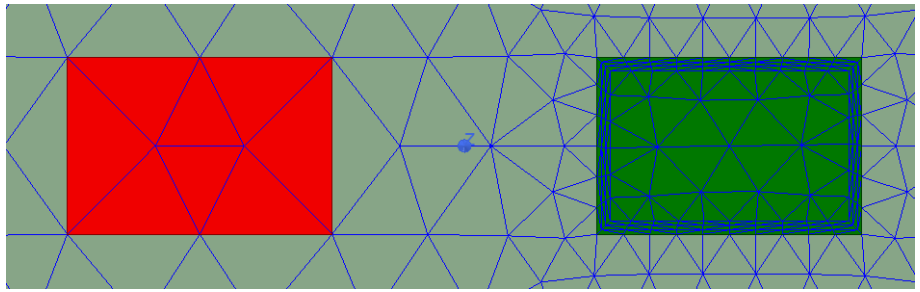



Four Layers of Skin Depth Mesh

***Note: Skin Depth Based mesh operation may result in high aspect ratio tetrahedra, thus it should be used carefully***

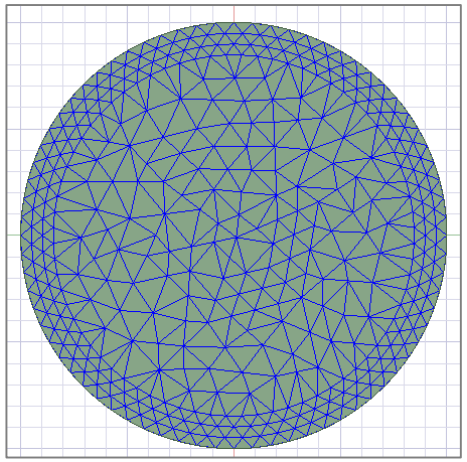
# On Selection

- **Mesh Operation: On Selection/Skin Depth Layered Based (only 2D TAU)**
  - **It works only for 2D models with TAU mesher**
  - **It can be assigned only on the edges of the 2D objects**
  - **Skin Depth:**
    - **Skin Depth field allows users to enter known value of the skin depth and number of layers of mesh to be created**
  - **Number of Layers**
    - **Sets maximum number of mesh layers created in skin region**

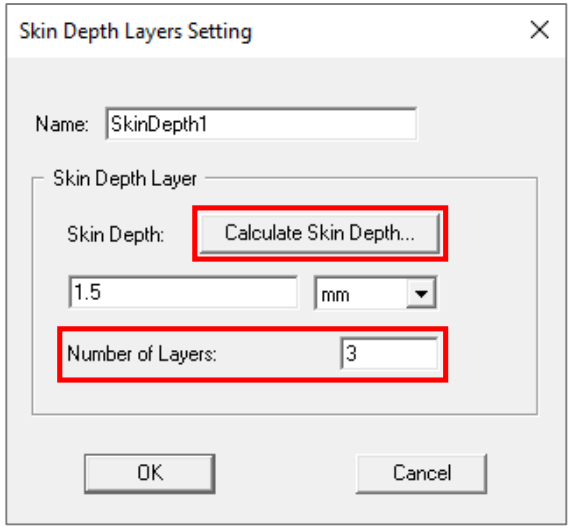


Without Mesh Operation

With Mesh Operation

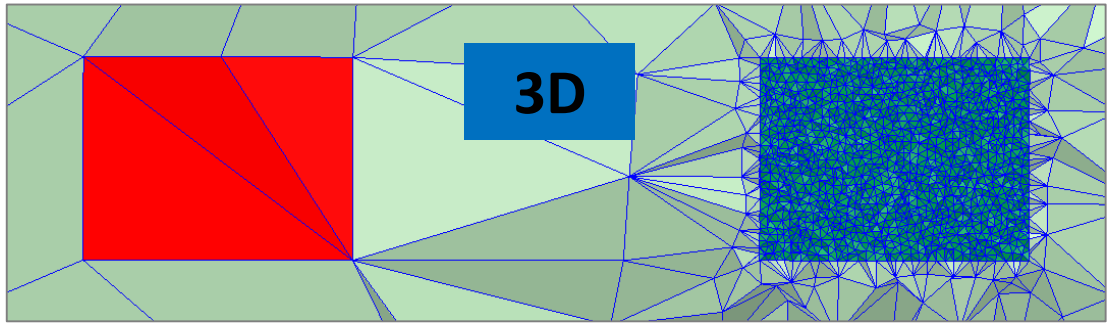


Example for circular section

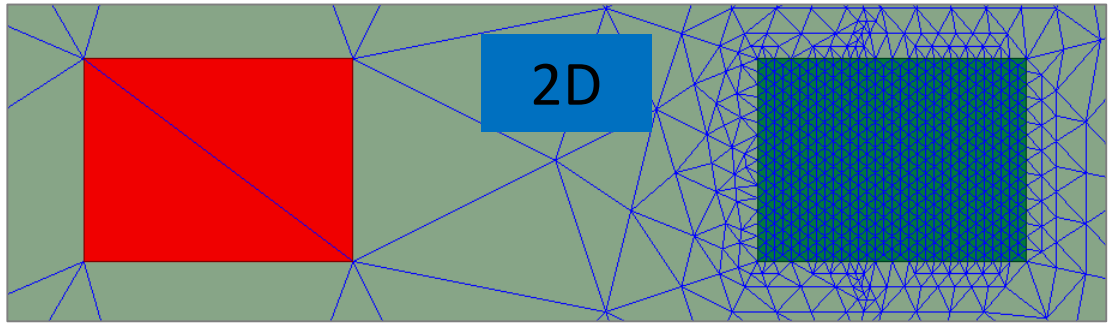


# Inside Selection

- **Mesh Operation: Inside Selection/Length Based**
  - **The Length-based Inside-selection refinement will limit the edge length of all tetrahedrons (or triangles) formed inside a selected solid or sheet object**
  - **Can be added by selecting the Object and menu item *Maxwell 2D/3D → Mesh Operations → Assign → Inside Selection → Length Based***
  - **All the options in the Element Length Based Refinement window are the same as for On Selection mesh operation except that the inside selection refinement will control size or number of elements inside the selected object, forming a homogeneous mesh**



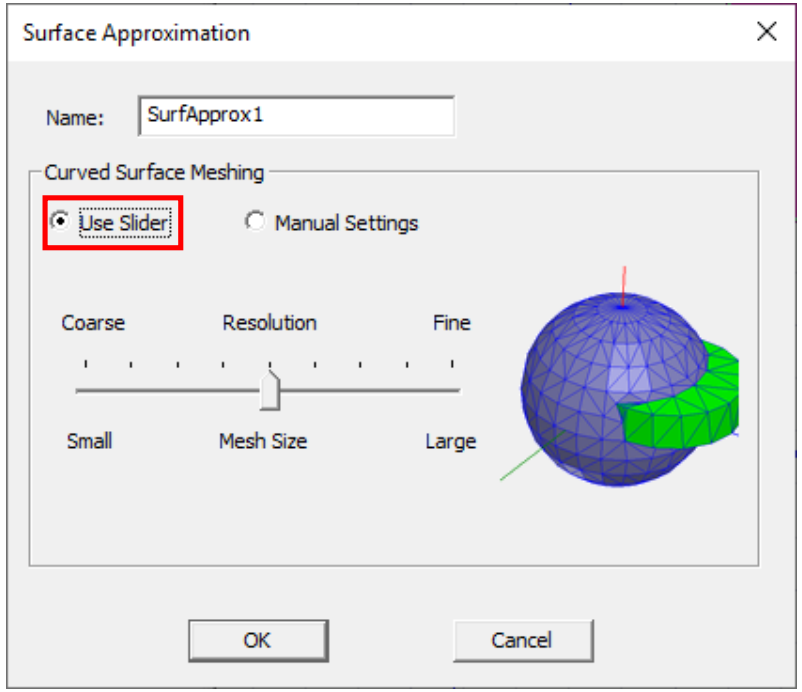

Without Mesh Operation  With Mesh Operation




Without Mesh Operation  With Mesh Operation

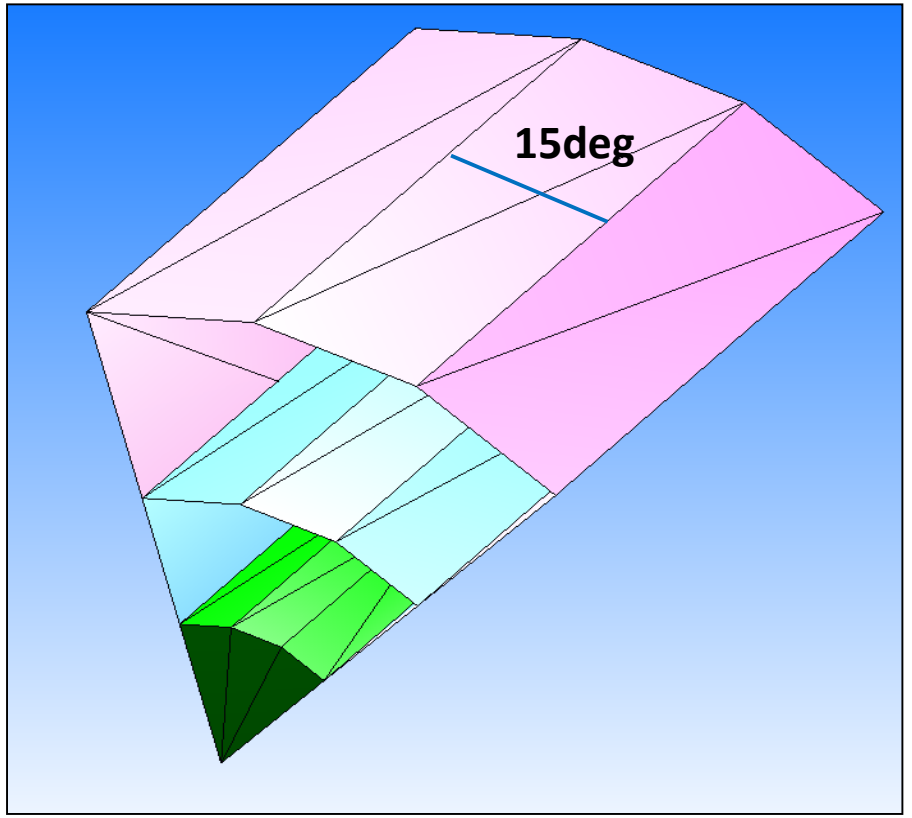
# Surface Approximation

- **Surface Approximation**
  - Surface Approximation Mesh Operations are helpful to resolve curved surfaces with a good quality mesh and can be used to both increase or decrease mesh density on curved surfaces
  - By default, Surface Approximation mesh operation is performed while creating initial mesh using Initial Mesh Settings
  - Can be assigned selecting the Object and menu item *Maxwell 2D/3D → Mesh Operations → Assign → Surface Approximation*
  - The Slider is purposely designed for beginners, to help them to increase/decrease surface resolution with almost no effort
  - In the next slides we will investigate deeper how to properly use the Manual settings to get good mesh where is needed without over-meshing the model



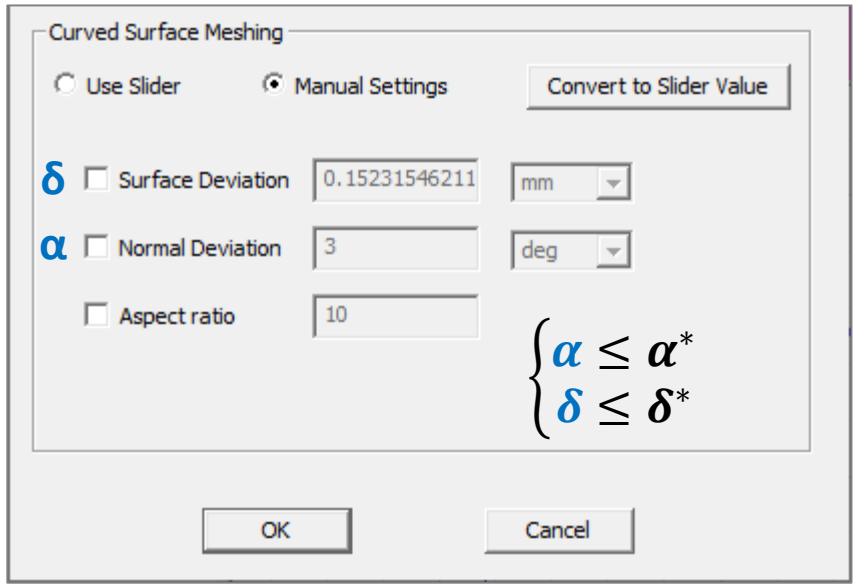
# Default Surface Approximation Mesh settings

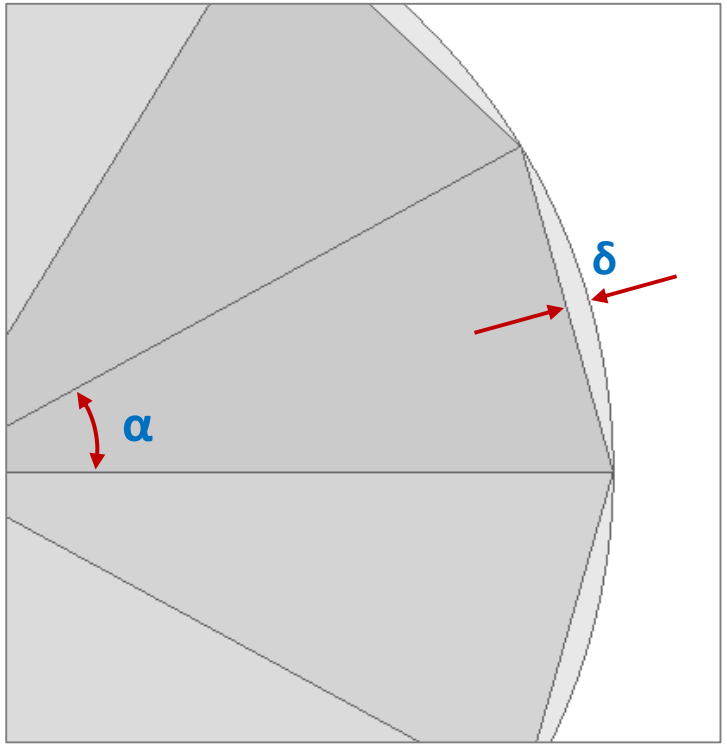
- For Maxwell 3D, 15 deg is the default Normal Deviation for true surfaces, while for Maxwell 2D it is 3 deg
- Classic mesh does not have a minimum aspect ratio constraint while TAU has one
- 15 deg might be fine for other region segmentation, but clearly is not enough for Band
- Maxwell has some automated and manual ways of dealing with true surfaces of different radius of curvature



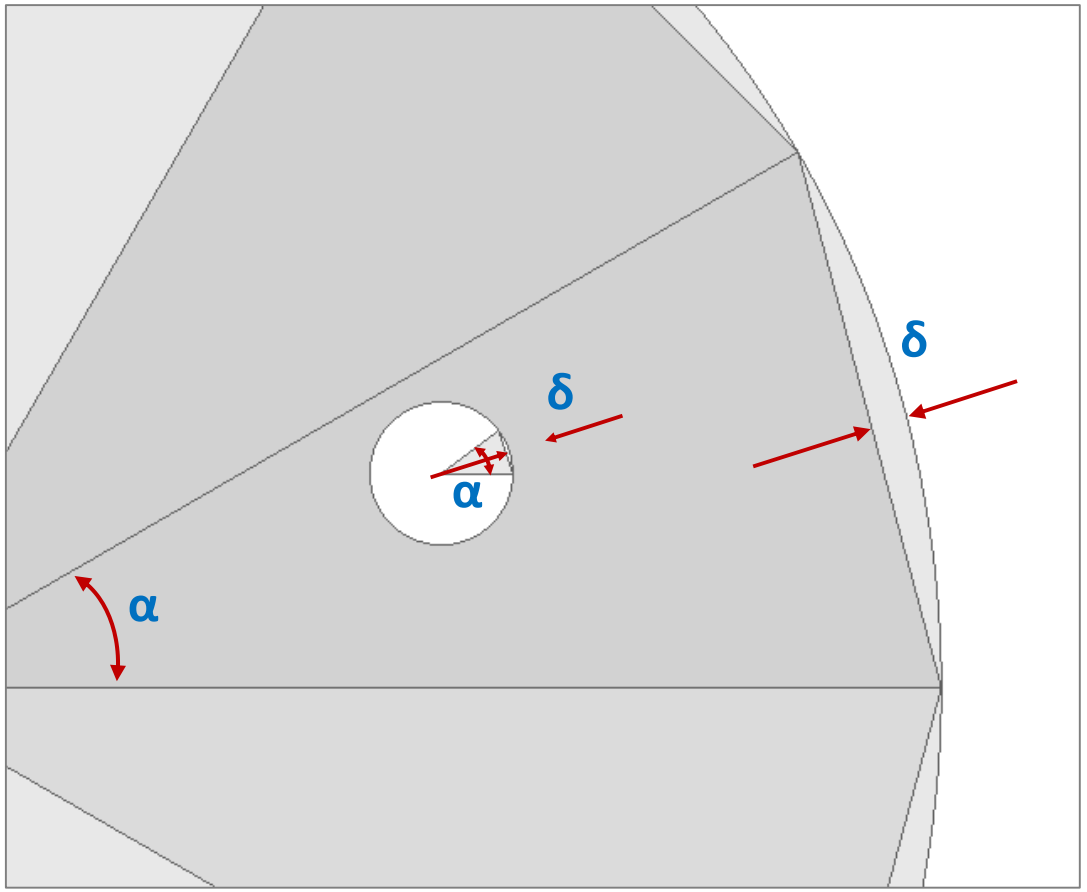
# Manual Settings

- When checking Manual Settings radio button, the Maximum Surface Deviation δ and Maximum Surface Normal Deviation α seem to serve the same purpose, but actually tuning those 2 values is critical to accurately mesh a large variety of geometries.
- If both α and δ are defined, the mesher will refine the surface approximation till satisfying the most constraining condition



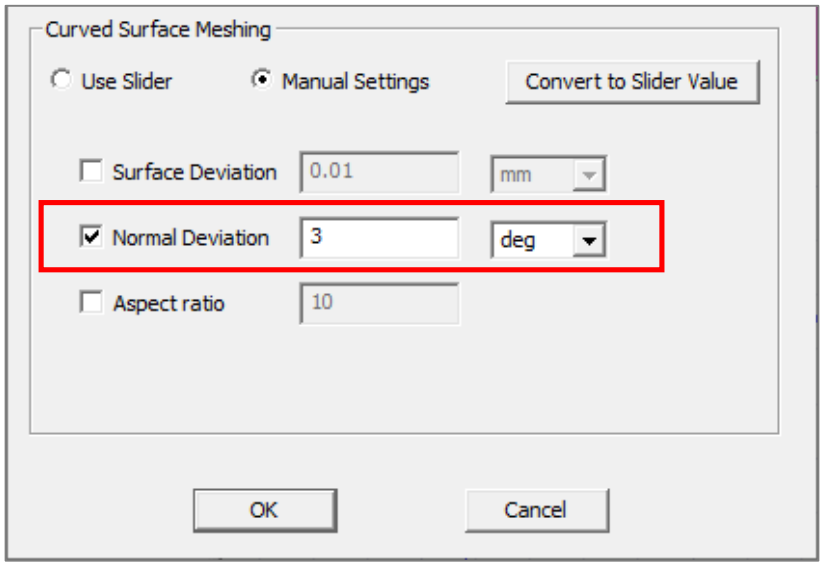



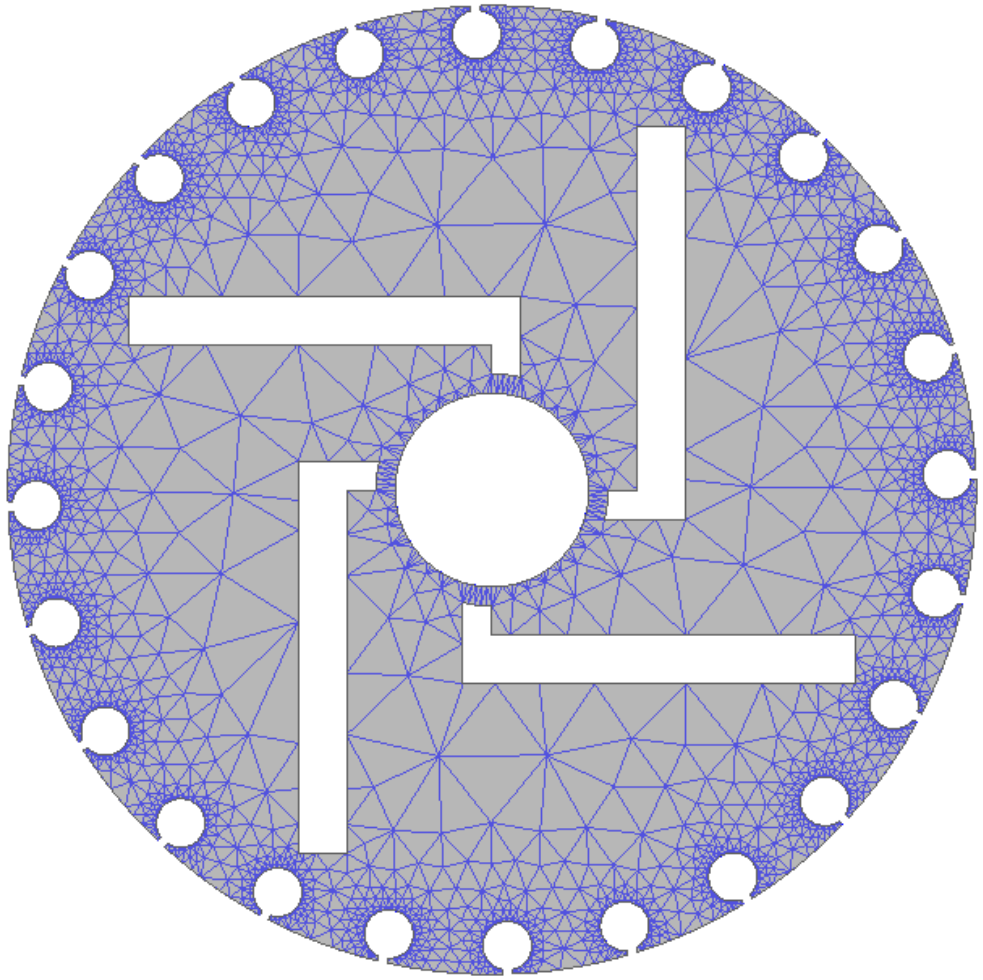
# Meshing Process




- α will be applied the same way on curved surfaces independent of their radius. A small-radius curve and a large-radius curve will be treated the same way
- δ will not have the same effect on all curved surfaces. By setting δ large enough, it is possible to only constrain large-radius curves of the object
- The mesher stops as soon as both the two constraints α AND δ are met

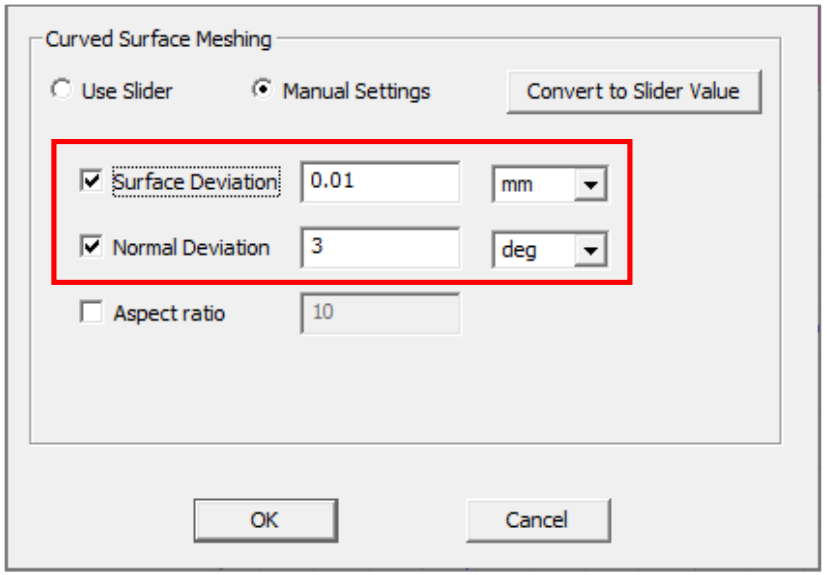
# Example: specifying only a maximum angle

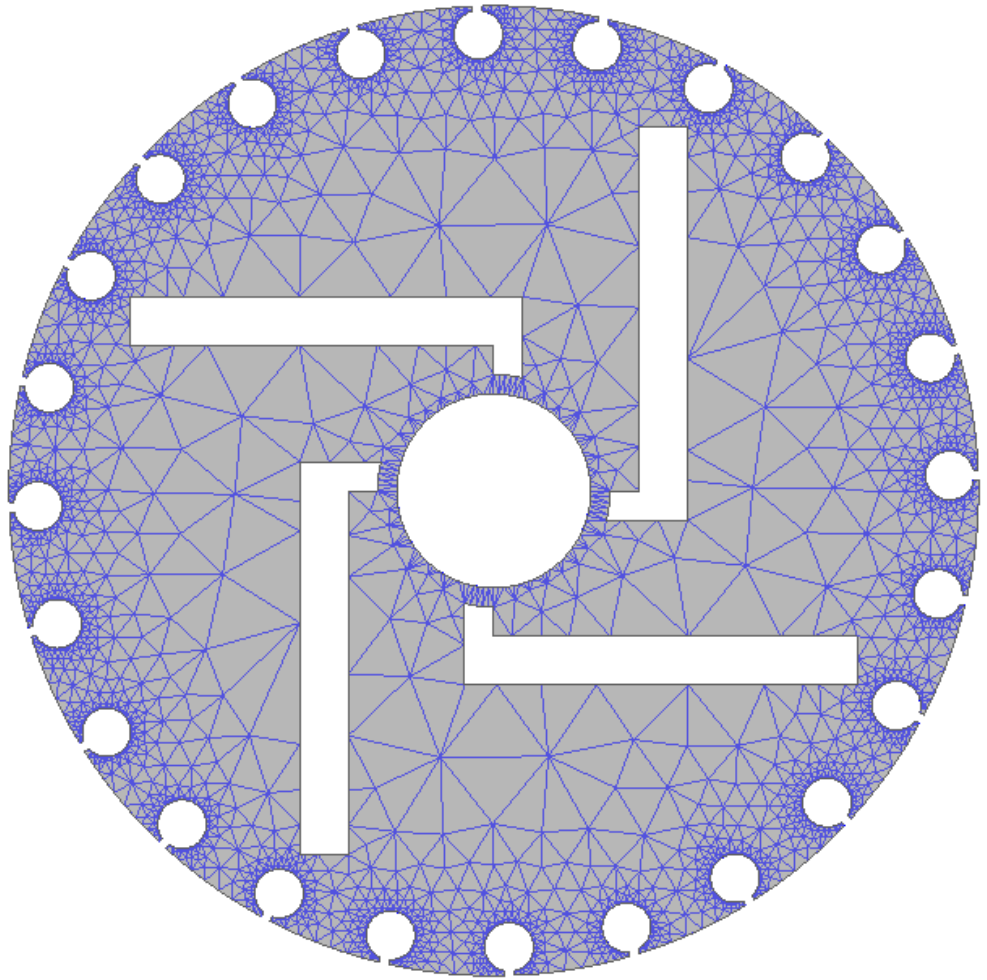


- All curved lines are meshed with 3 deg segmentation
- This is what is needed for the outer part, facing the air gap but the segmentation is way too detailed for the slots and the inner radius

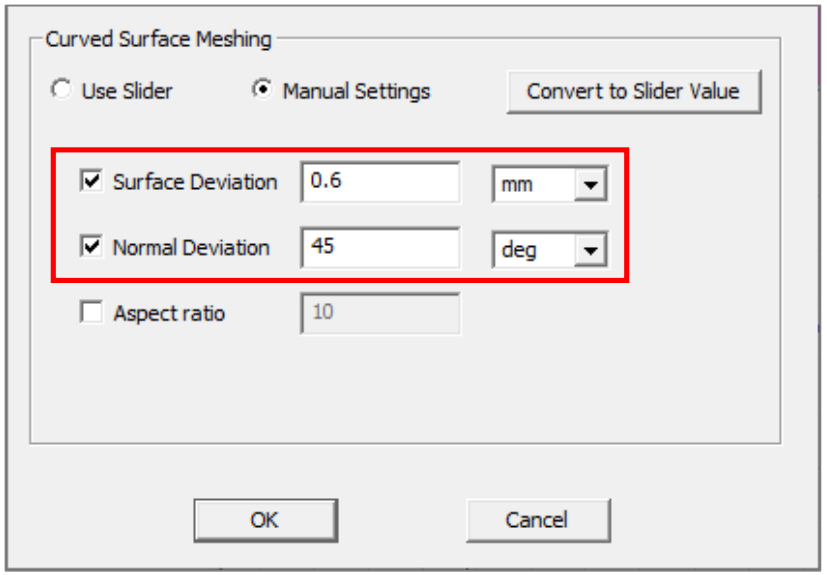
# Example: specifying angle and distance

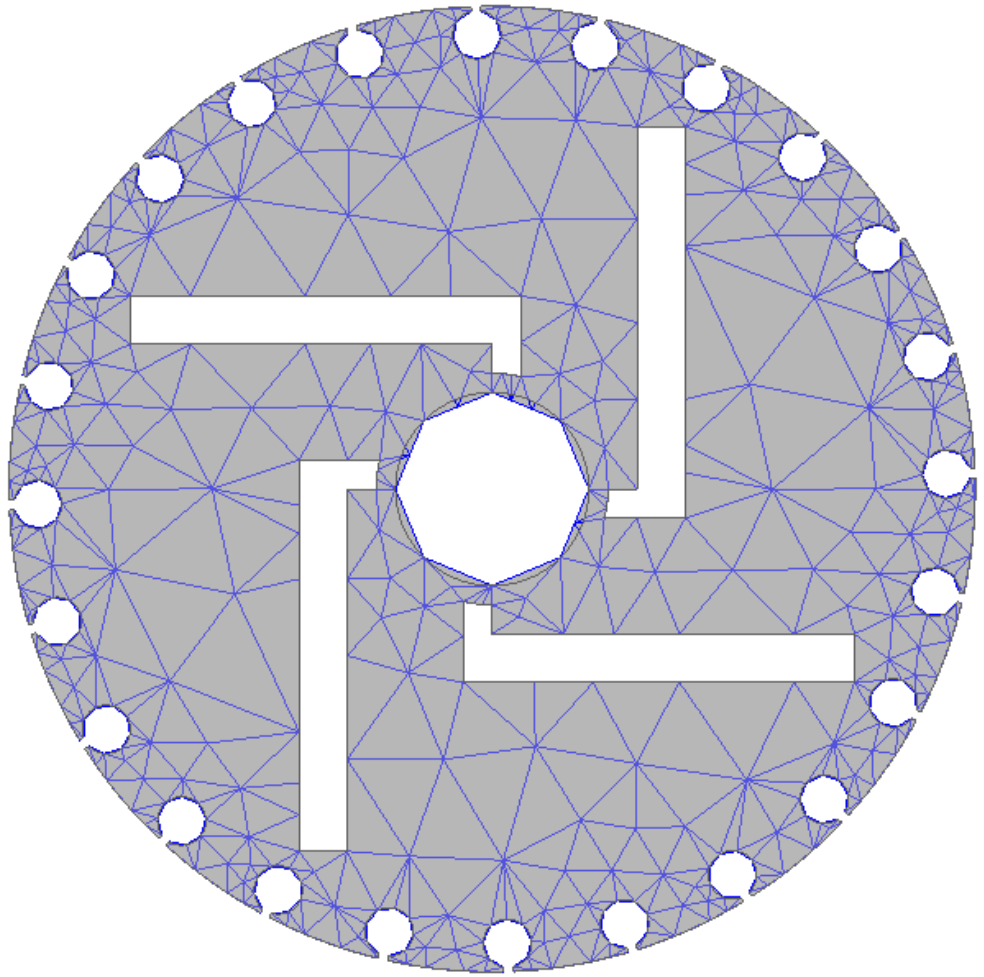


- Despite the maximum distance added, the fact that we impose a very small angle leads to a detailed segmentation of all true surface curves
- The Maximum Surface Deviation is not helpful with this value

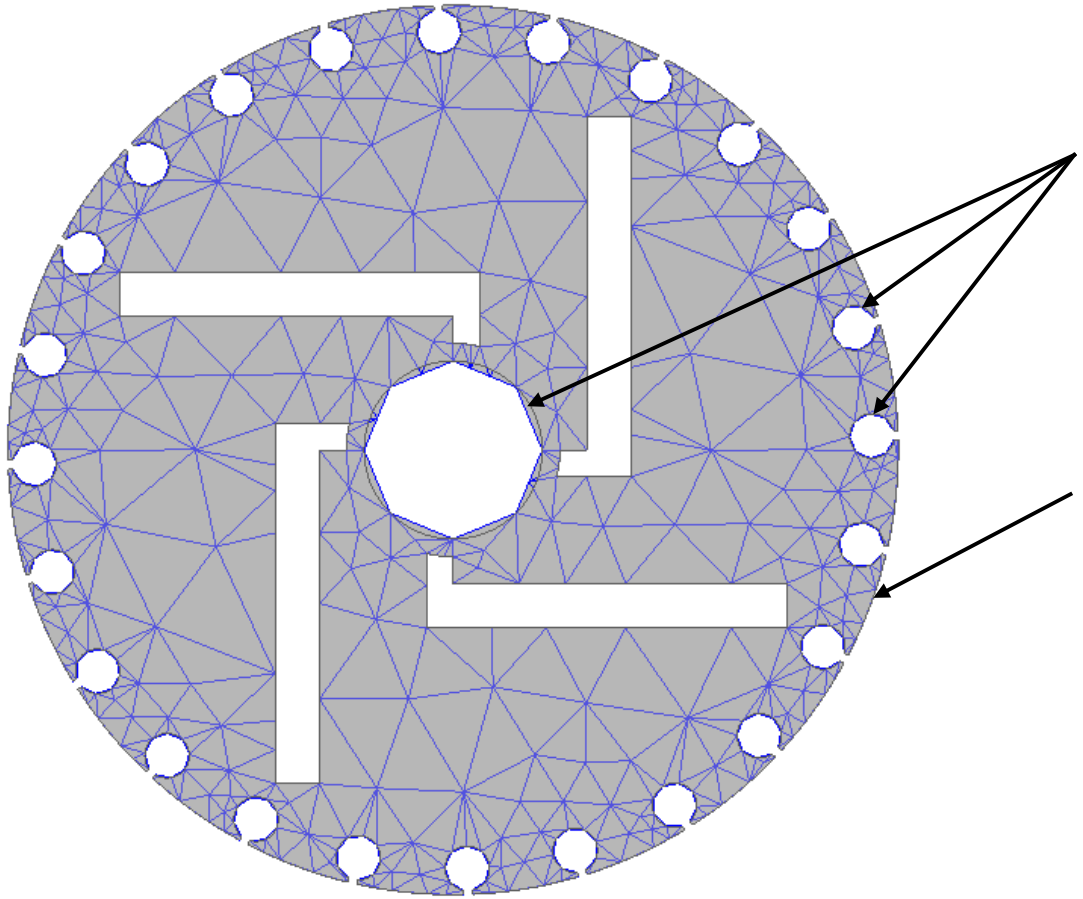
# Example: specifying angle and distance



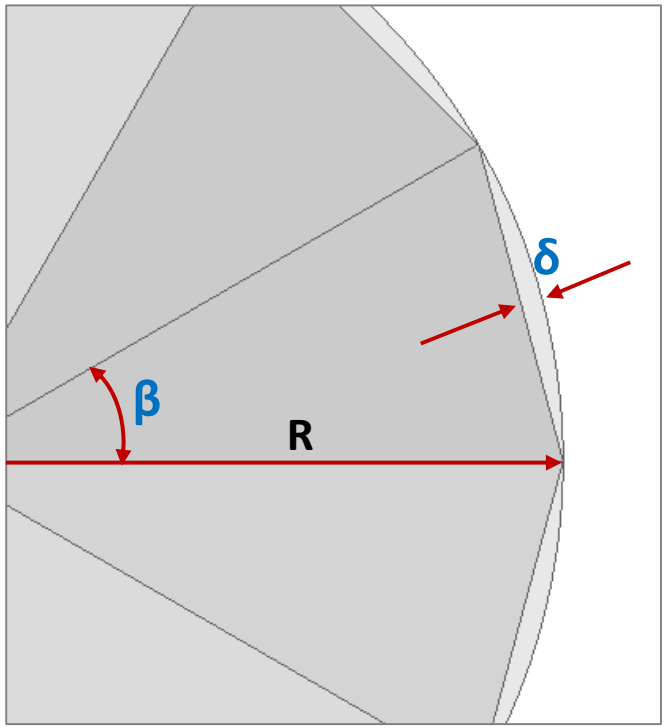
- It sounds counter intuitive, but setting a very large angle limits the segmentation of the smaller curves, exactly what is needed (slots, shaft side)
- The maximum surface deviation of 0.6 mm ensures that the segmentation of the large curve (air gap side) is correct

# Example: motor parts



- Tuning α and δ helps achieving a very good initial mesh:
- α determines the segmentation of the smaller curves. For instance, if you wish to have 8 segments for a slot/shaft, set α to 45 deg
- δ will impose the meshing process not to apply α on the large curves, adding more elements on the air gap side
- α controls small curve faces
- δ controls large curve faces

# Example: motor parts



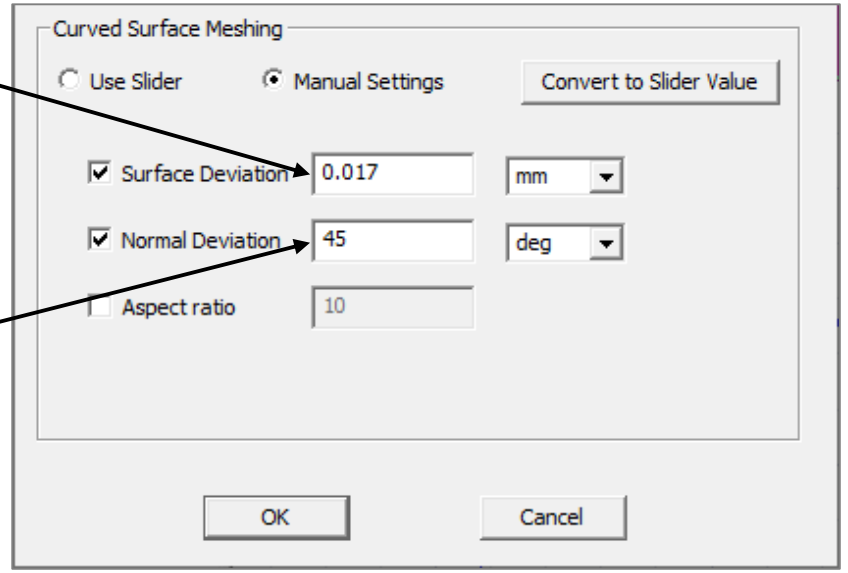

- If the user wants to have an air gap side with an equivalent β = 3 deg segmentation, how to determine δ?
- Use the formula:

  $$\delta = R\,(1 - \cos(\beta/2))$$

- For a 50 mm radius rotor, δ = 0.017mm

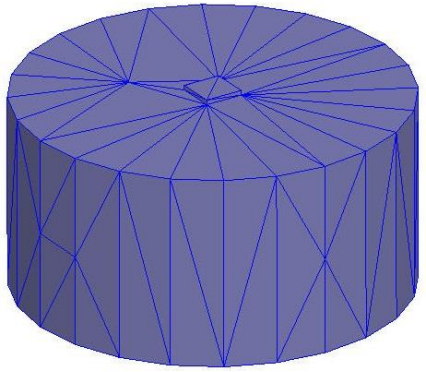
Controls the air gap segmentation (δ)

Controls the small curves segmentation (α)

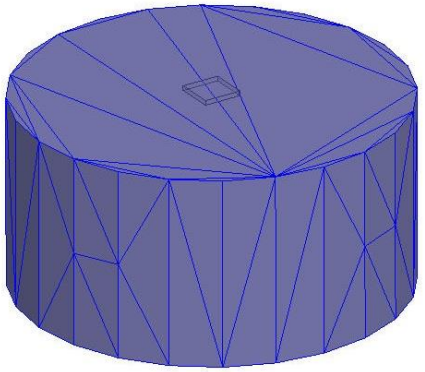


# Model Resolution

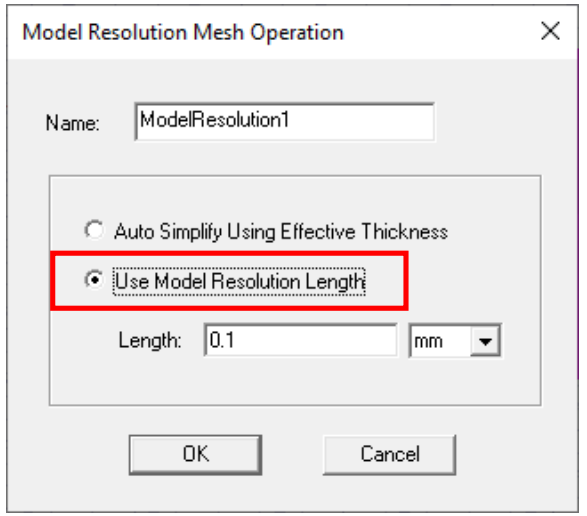
- **Model Resolution (3D Only)**
  - **Model Resolution enables users to ignore small features of geometry which might not be important for simulation**
  - **Users can specify the maximum length of geometry features which will be ignored by mesh**
  - **Default Option is set to Auto Simplify, which automatically calculates the minimum feature length**
  - **Can be assigned from menu *Maxwell 3D → Mesh Operations → Assign → Model Resolution***



Without Model Resolution



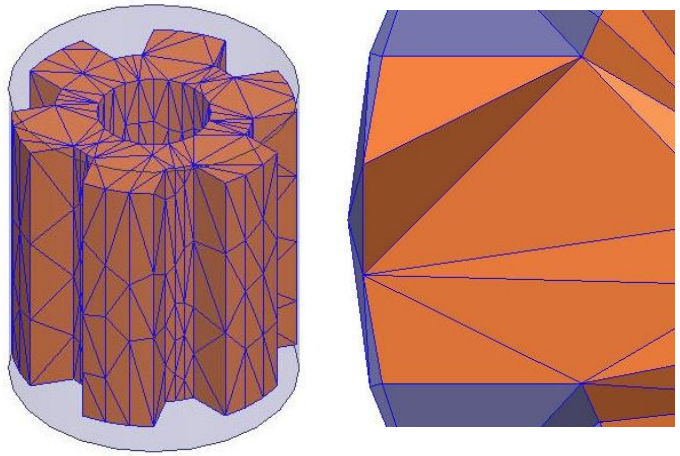
With Model Resolution



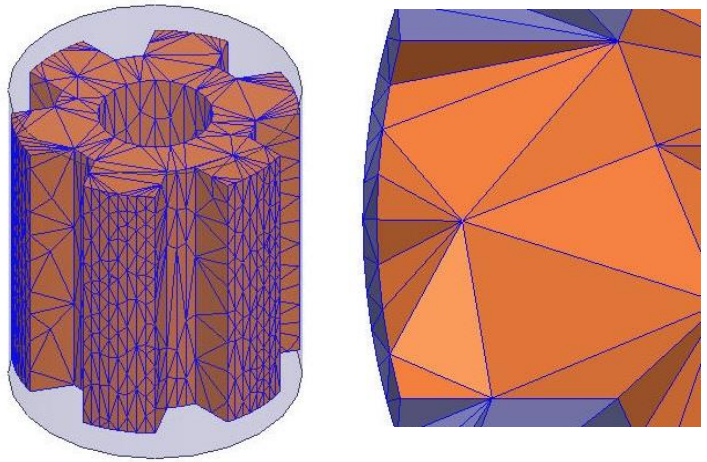

***Note: Model resolution must be used with caution as sometimes mesh might not be able to represent geometry correctly***

# Cylindrical Gap Treatment

- **Cylindrical Gap Treatment**
  - **Cylindrical Gap Treatment mesh operation is a 3D-only proximity based mesh refinement and specifically assigned to Band objects for rotational motion. It works only for TAU (tolerant) mesh**
  - **Refinement is done on the applied objects based on the closeness of the geometry lying inside it**
  - **For Transient Solver involving rotational motion, this mesh operation is automatically created once the rotational motion is defined in order to resolve air gap between Stator and Rotor parts**
  - **Mesh Operation can be assigned from menu item *Maxwell 3D → Mesh Operations → Assign → Cylindrical gap Treatment***
  - ***Cylindrical gap Treatment is the way to activate Clone Mesh in 3D***



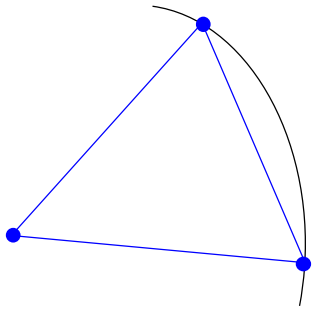
Without Cyl. Gap Treatment



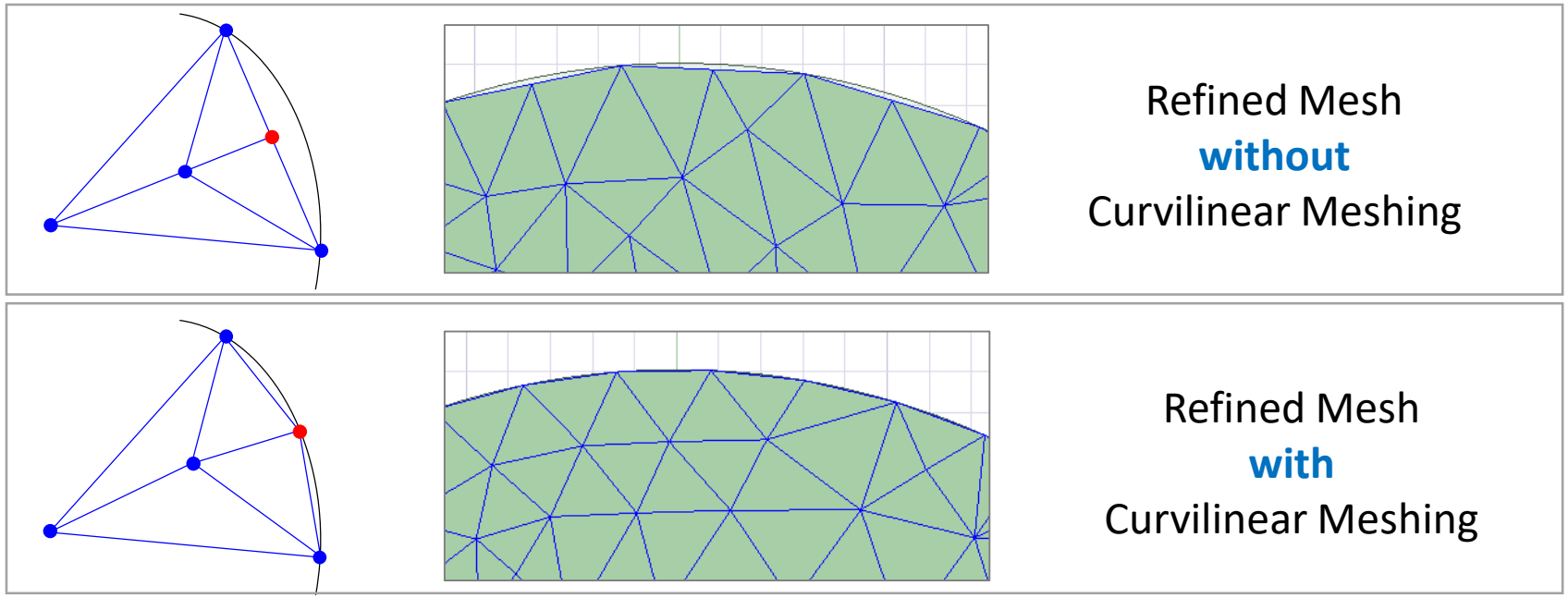
With Cyl. Gap Treatment

# Apply curvilinear Meshing

- **Apply Curvilinear Meshing forces the mesh nodes to be on the surface of a curved object**
  - **When dealing with complex geometries and multiple true surfaces along different selections, it does force the meshing process to have the mesh points on the true surfaces when refining the initial mesh**
  - **Advantage is the better accuracy, drawback is that the mesh becomes larger, more difficult to create and the process can be long**
  - **It is possible to apply this mesh operation either everywhere (initial mesh settings) or to a particular object/surface**



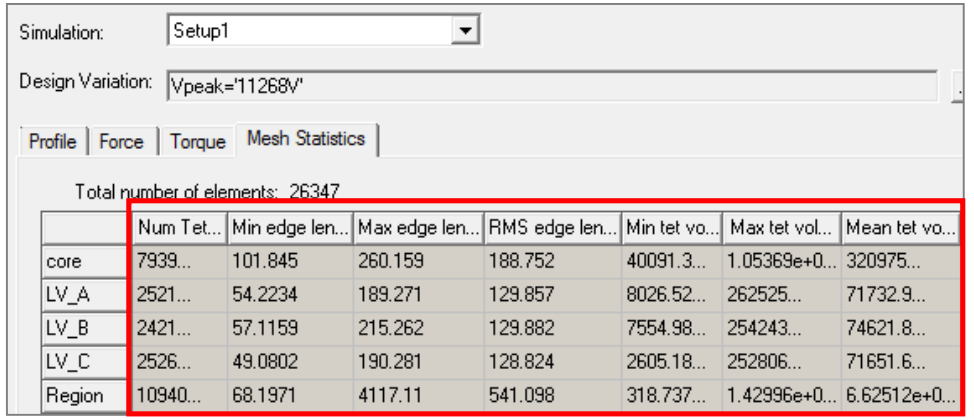
Initial Mesh



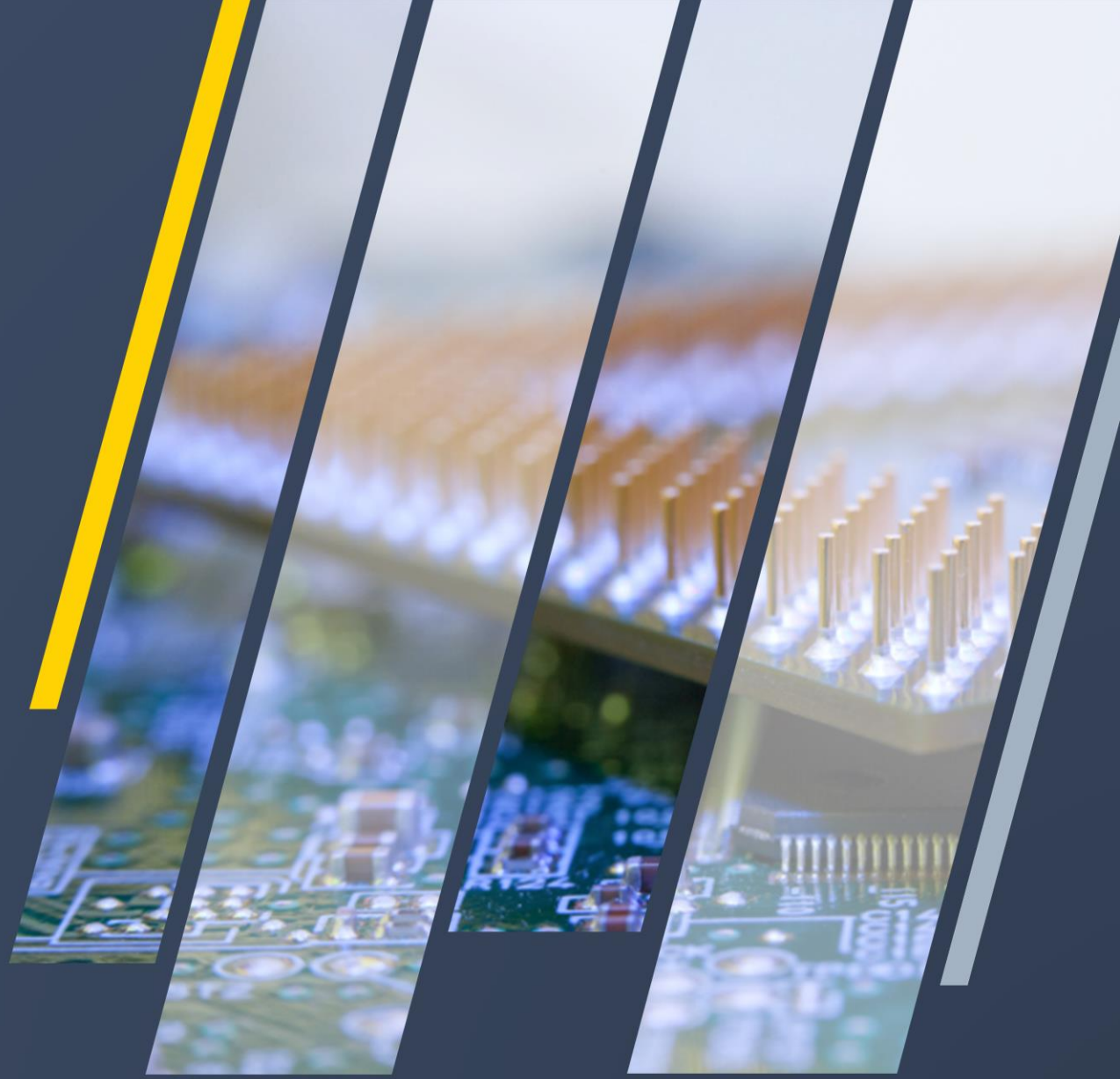
# Applying Mesh Operations

- **Apply Mesh Operations**
  - When Analysis Process is started mesh operations are automatically applied on initial mesh
  - It is advisable to verify mesh quality and element count before starting the solution process by inspecting both the Mesh Statistics, and visual inspection of Mesh plots.
  - Mesh Operations can be assigned from menu item *Maxwell 2D/3D → Analysis Setup → Apply Mesh Operations or RMB on Analysis Setup → Apply Mesh Operations*
  - If the mesh is not satisfactory, it is possible to come back to initial mesh using *Maxwell 2D/3D → Analysis Setup → Revert to Initial Mesh or RMB on Analysis Setup → Revert to Initial Mesh* and then applying again modified mesh operations

- **Mesh Statistics**
  - Once Mesh Operations are applied, mesh quality and element count can be verified from the *Maxwell 2D/3D → Results → Solution Data*
  - In Solutions window, select Mesh Statistics tab




| | Num Tet... | Min edge len... | Max edge len... | RMS edge len... | Min tet vo... | Max tet vol... | Mean tet vo... |
|---|---|---|---|---|---|---|---|
| core | 7939... | 101.845 | 260.159 | 188.752 | 40091.3... | 1.05369e+0... | 320975... |
| LV_A | 2521... | 54.2234 | 189.271 | 129.857 | 8026.52... | 262525... | 71732.9... |
| LV_B | 2421... | 57.1159 | 215.262 | 129.882 | 7554.98... | 254243... | 74621.8... |
| LV_C | 2526... | 49.0802 | 190.281 | 128.824 | 2605.18... | 252806... | 71651.6... |
| Region | 10940... | 68.1971 | 4117.11 | 541.098 | 318.737... | 1.42996e+0... | 6.62512e+0... |



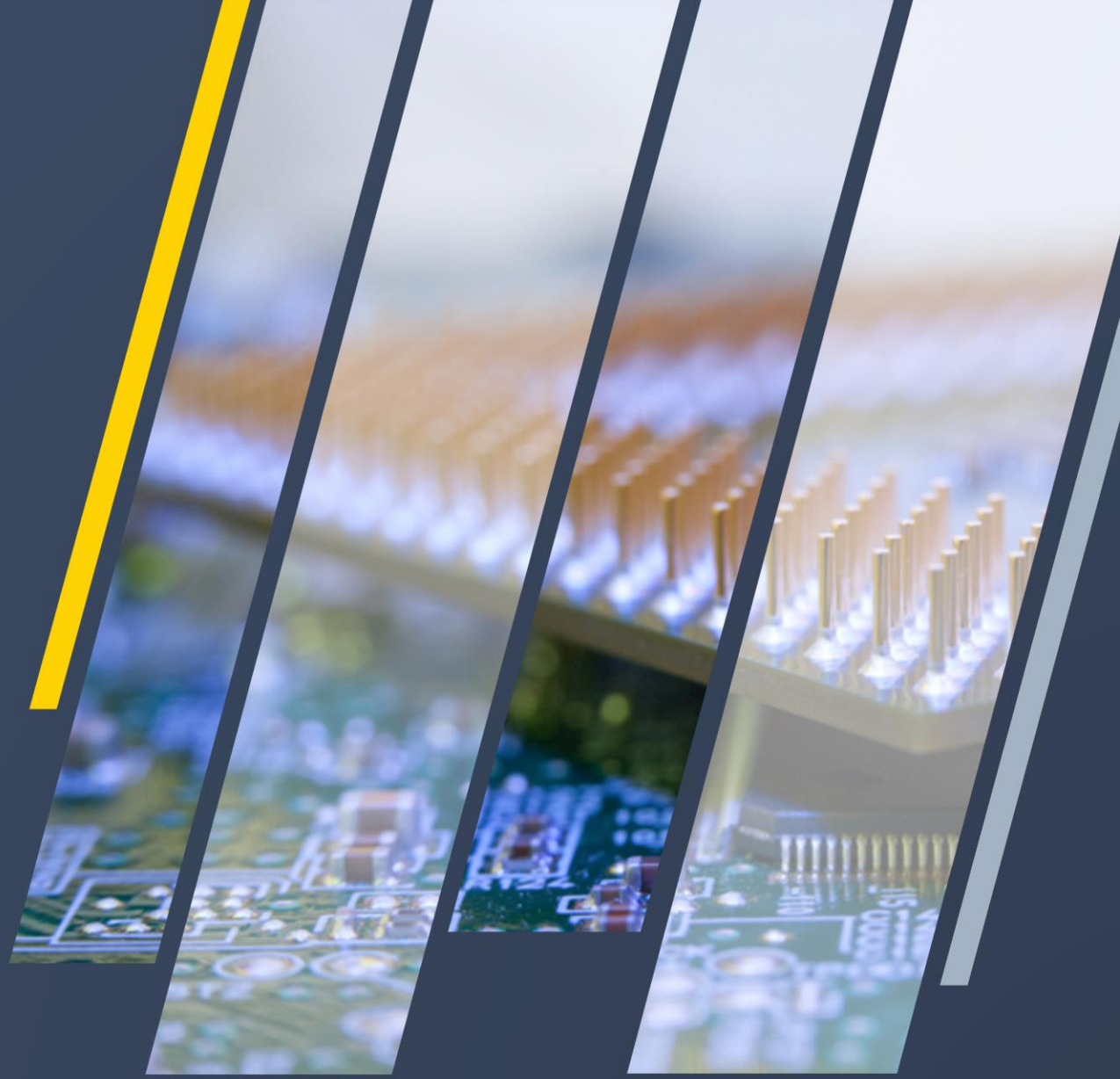
# Specific Mesh Operations for Rotational Machines

ANSYS Maxwell Advanced Motor Training

# Clone Mesh for Rotating Machines

- **Maxwell 2D:**
  - Without using any Mesh Operations, simply apply Initial Mesh Settings (by using the Slider or the Manual Settings) to achieve desired mesh density
  - A clone mesh should be automatically used if the geometry is symmetric

- **Maxwell 3D:**
  - Use the Clone Mesh checkbox on the Cylindrical Band mesh operation (assigned to the Band)
  - Define the Mapping Angle for the mesh on the Band
  - Assign the number of layers for both Moving Side and Static Side of the airgap (Default is 1 for both)
  - Without using any additional Mesh Operations, simply apply Initial Mesh Settings (by using the Slider or the Manual Settings) to achieve desired mesh density
  - If mesh density is not satisfactory, it is possible to insert additional Clone Mesh Density mesh operation, to increase number of layers both axially and radially



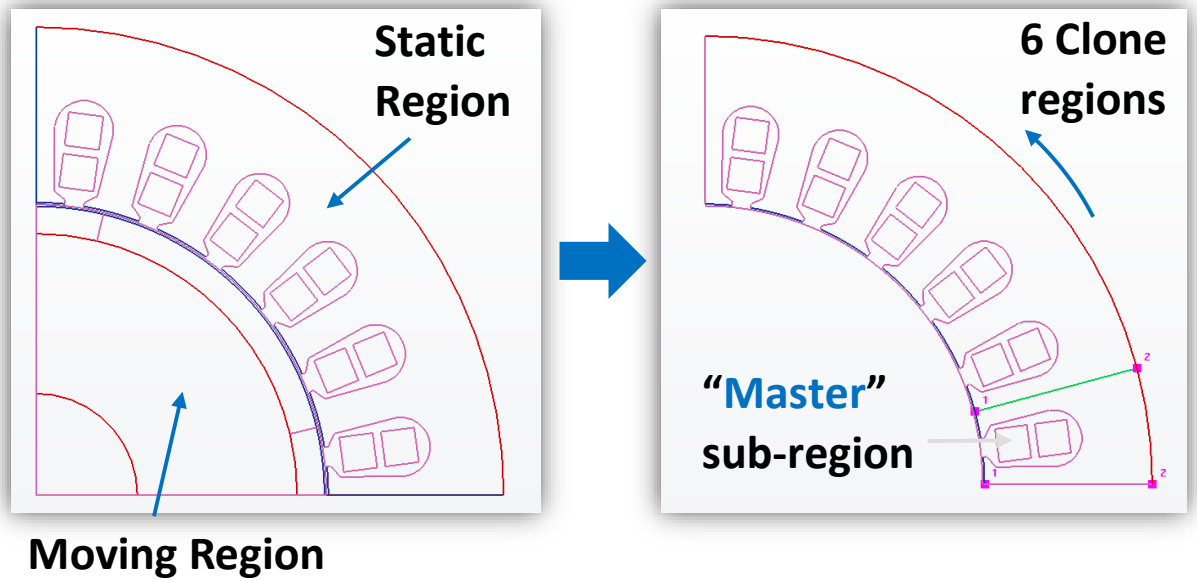
# Clone Mesh

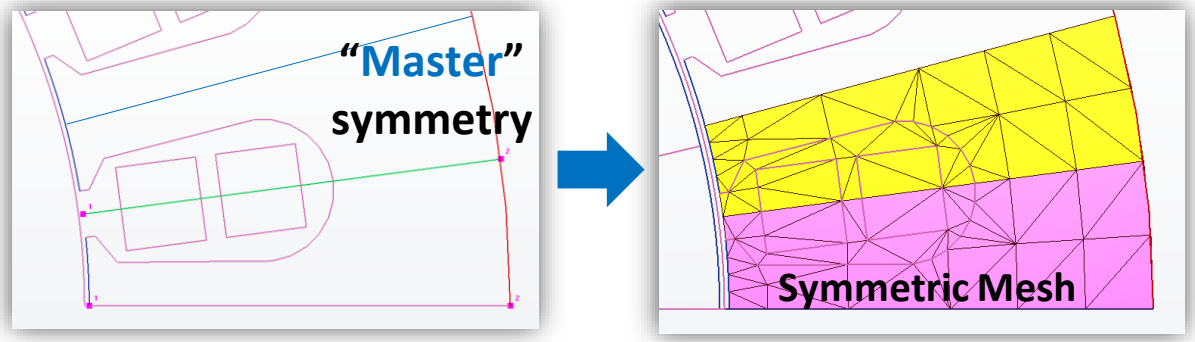
ANSYS Maxwell Advanced Motor Training

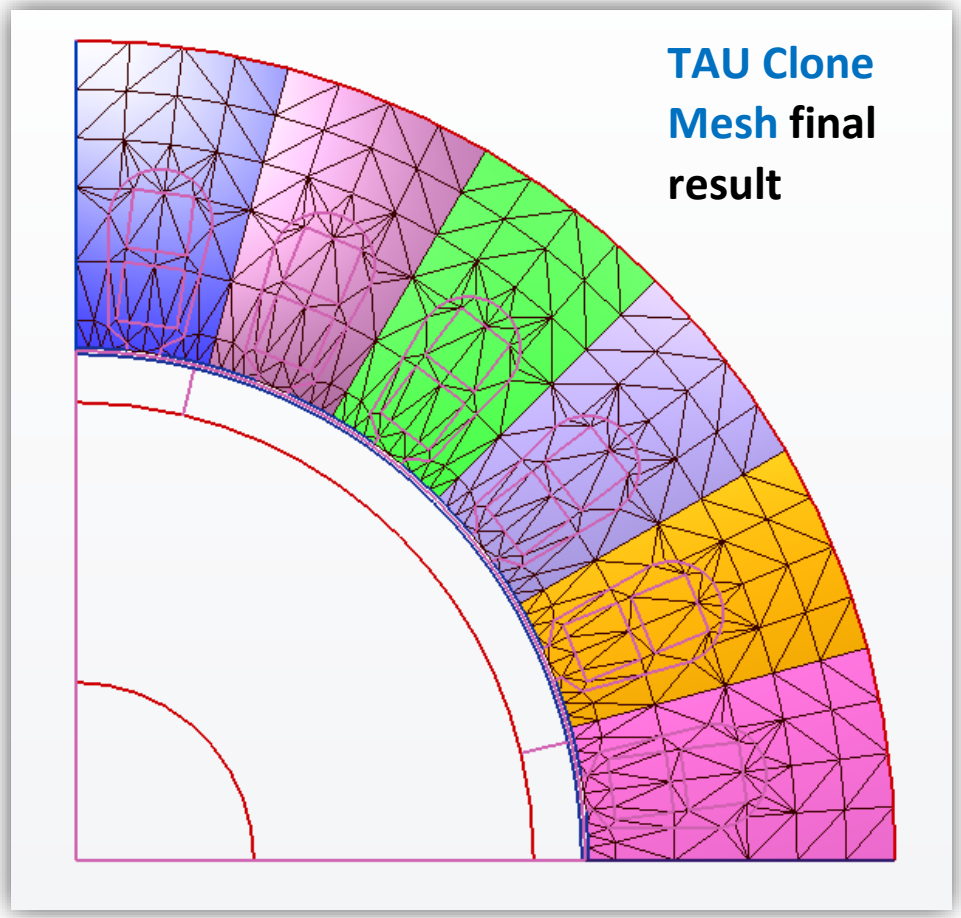
# TAU Clone Mesh and TAU Rotational Sweep Mesh

- **2D Models – TAU Clone Mesh**
  - If TAU method is on, the mesher checks the geometry and can determine if the model is rotational
  - This is done calculating the curves around the origin of the coordinate system
  - If the mesher identifies a rotational model, it “splits” the geometry into two major regions: a Static Region and a Moving Region
  - The Band object is the border element between those two regions
  - The mesher determines whether the regions have multiple duplicate sub-regions and if yes, the TAU Clone Mesh is automatically activated
  - The TAU Clone Mesh generates the mesh for the first “Master” sub-region and then duplicates the created mesh so that all the sub-region show an identical mesh
  - In case the “Master” sub-region has symmetric feature, the symmetric mesh is generated

# TAU Clone Mesh Example



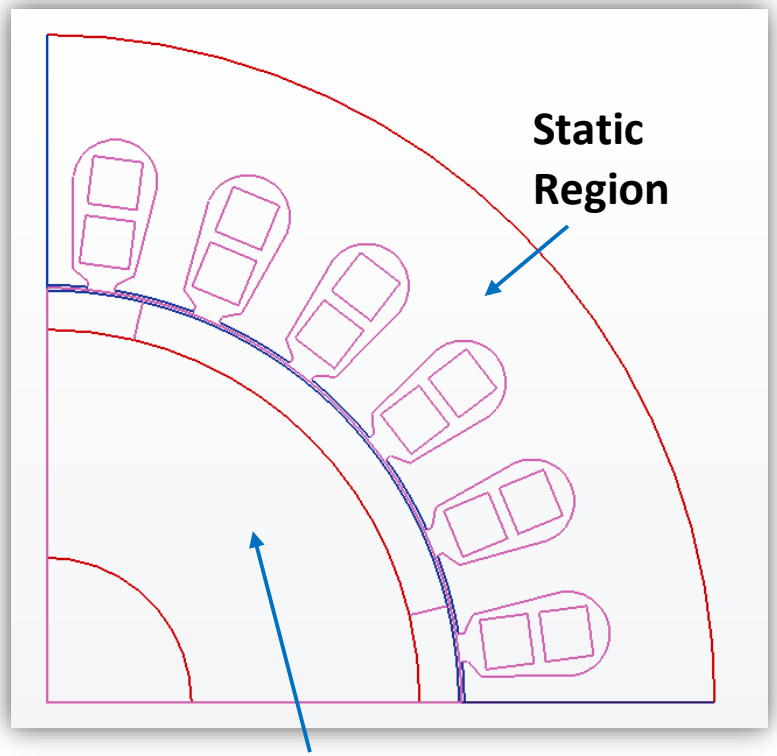



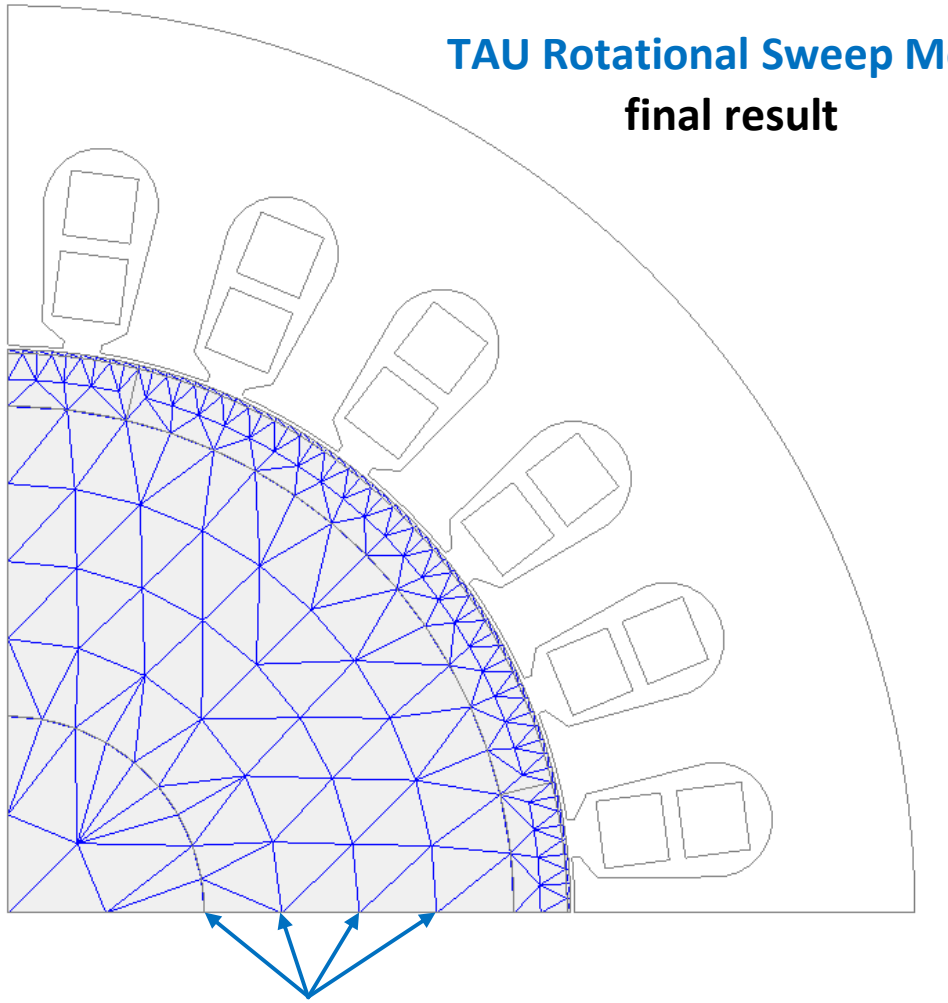
# TAU Clone Mesh and TAU Rotational Sweep Mesh

- **2D Models – TAU Rotational Sweep Mesh**
  - If the regions do not have duplicate sub-regions, then TAU Clone Mesh is not applied and a further analysis is performed to verify whether the region is "rotational"
  - One region can be defined "rotational" if it has two or more rotational curves around the rotational center
  - In case the region is "rotational", the TAU Rotational Sweep Mesh method is used, creating uniform layers in radial direction and uniform sweep elements in tangent direction
  - This method controls the Aspect Ratio in radial direction

# TAU Rotational Sweep Mesh Example

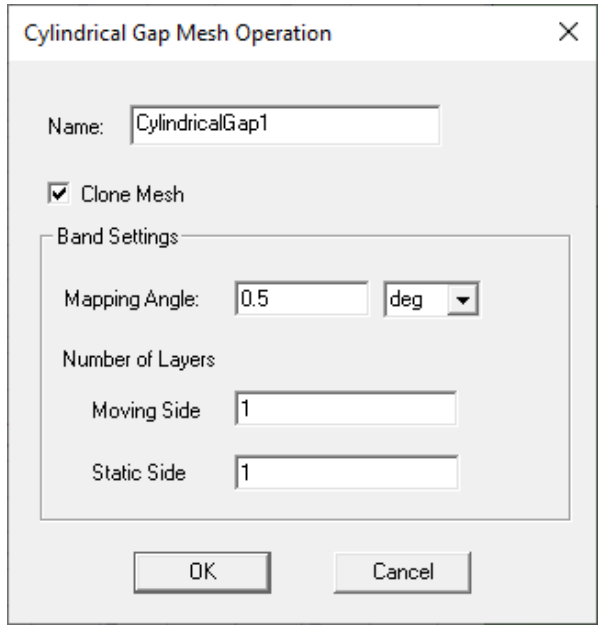



**TAU Rotational Sweep Mesh**
**final result**



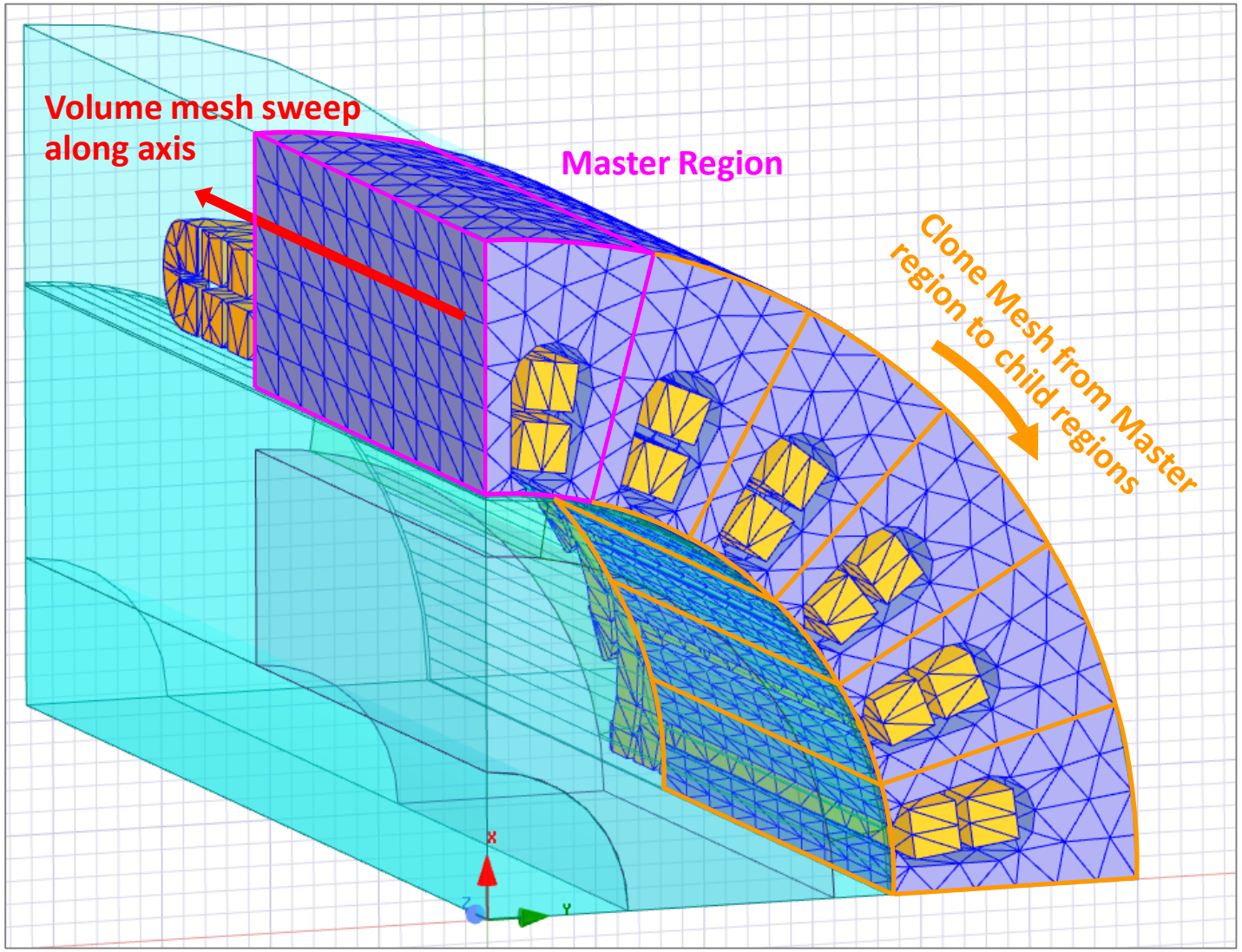
# 3D Clone Mesh

- 3D Models
  - Once a Cylindrical Gap Treatment has been assigned, Maxwell offers the possibility to turn on the Clone Mesh checkbox
  - The stator must be not skewed*
  - The stator must have a repeatable geometry as we have seen for the 2D case
  - The identification of the Static region follows the same rules as in 2D, with additional verification concerning possible skew
  - If the "Master" region is identified, then it is possible to create a symmetric mesh as well as in 2D
  - Once done, the mesh is then swept along the third direction and finally duplicated along the tangent direction (see next slide)



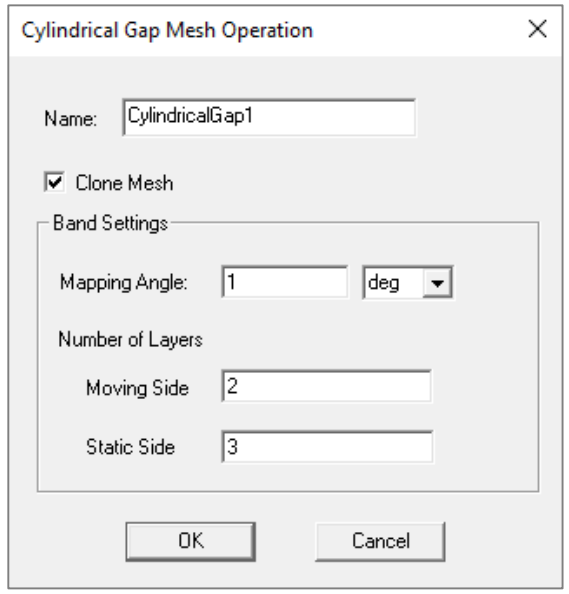

* Clone Mesh works also for skewed geometries, but the model must be complete (360 deg); it is not possible to use Clone Mesh for skewed models together with periodical boundaries (Master-Slave)

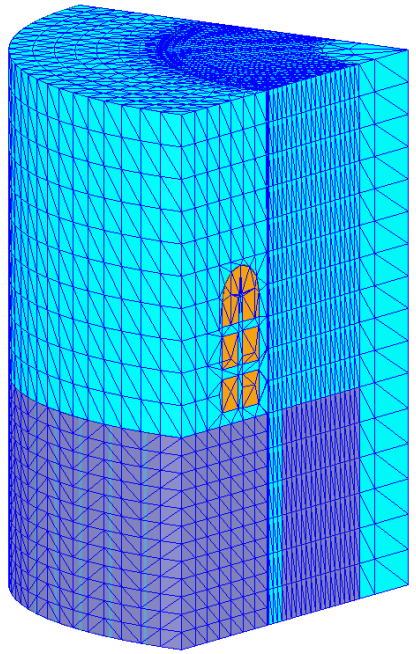
# 3D Clone Mesh Example

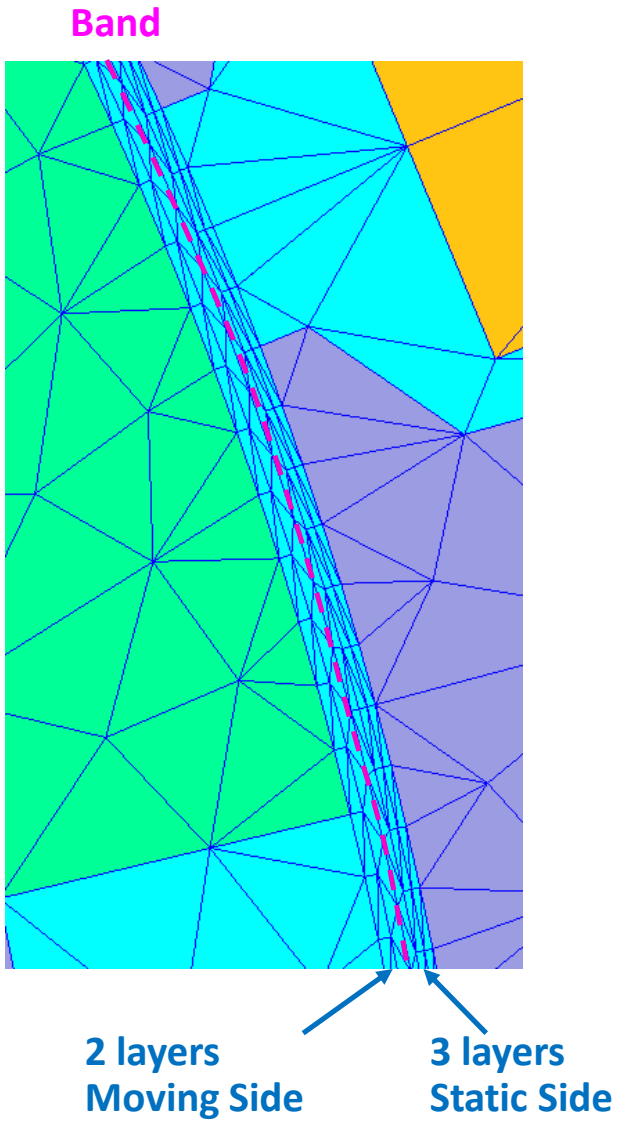


# 3D Clone Mesh

- Once the Clone Mesh checkbox is active, the user can:
- Insert the Mapping Angle, which controls the Band segmentation. Suggested and most often used values are 0.5 deg and 1 deg
- Under the section Number of Layers it is possible to specify the number of layers between the band and the rotor (Moving Side) and between the Band and the Stator (Static Side)
- The default values are both 1, but they can be 2, 3,… and also different among them

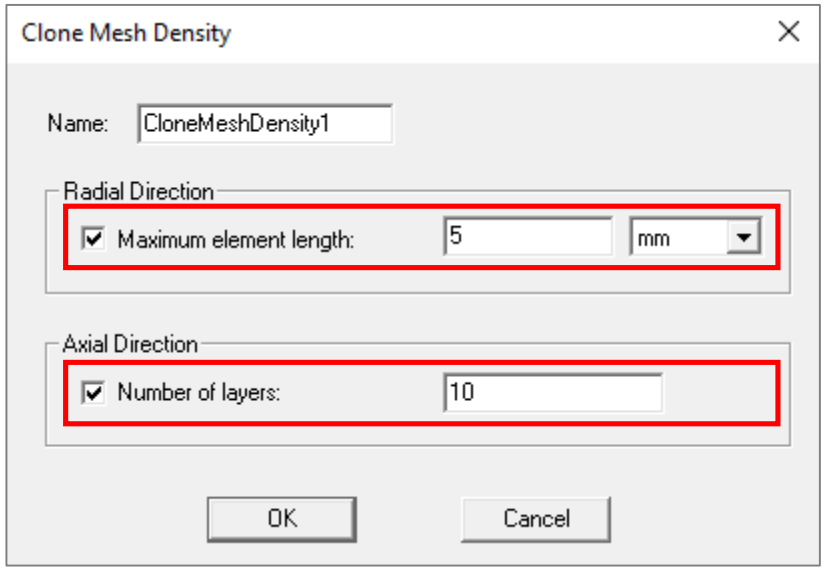




# 3D Clone Mesh

- **Additional Clone mesh refinement**
  - **It is possible to change the mesh density in both radial and axial direction**
  - **To do so, it is needed to select the object of interest and then *Maxwell 3D → Mesh → Assign Mesh Operations → Inside Selection → Clone Mesh Density***
  - **Under Radial Direction it is needed to specify the Maximum element length in millimeters**
  - **Under Axial Direction it is needed to specify the Number of layers**
  - **It is recommended to specify the same umber of layers for both static side and moving side**



# 3D Clone Mesh

- **Tips for successful Clone Mesh:**
  - **Create inner object tangent to the external face of the rotor. Be sure it is a true surface**
  - **Create the Band in the middle of the airgap. It is mandatory that the Band is true surface and not segmented**
  - **Use true surfaces as much as possible for both moving and static objects**
  - **Combine the clone mesh with surface approximations and/or Clone Mesh Density. If there are many small surfaces/segments around the band and the master/slave surfaces, reduce the usual 45deg surface normal deviation to a smaller angle**
  - **Note that when meshing a machine model with coil terminals, the placement of the coil terminals may alter the clone mesh along the Z-axis (in plane with the terminals) and could result in a difference in the rotor and stator mesh along the Z-axis. In such a case additional Clone Mesh Density mesh operation can be very helpful**

# Workshop 3.1 – Mesh Operations for Rotational Machines