

# Design and Simulation of a Radius Cutting Attachment to a Lathe

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**Abstract** – The radius cutting attachment swings a tool through an arc to make a radius on the end of a cylindrical part. The radius cutting attachment turns an accurate convex or concave shape on a cylindrical work piece machined in a lathe. The pivot pins and tool position are adjustable, so it is capable of cutting either a concave or a convex shape. Unlike conventional radius turning methods that swing the cutting tool parallel to the lathe table, the tool of the radius cutting attachment moves from the top of the part to its centre along a vertical axis to the lathe bed. The most common application of a radius cutter is to turn a radius or ball end on the end of a cylindrical work piece. The use of radius cutting attachment eliminates inaccurate or expensive methods of radius turning by Combination Feed and Form Tool methods. This paper deals with the design and simulation analysis of a radius cutting attachment to a typical lathe. This method of radius turning is found to be an accurate and economical one. If there is a need to make a radius into or onto the end of a part, there is no easier way to do it than with this accessory. It can also cut a complete ball in a two-step operation.

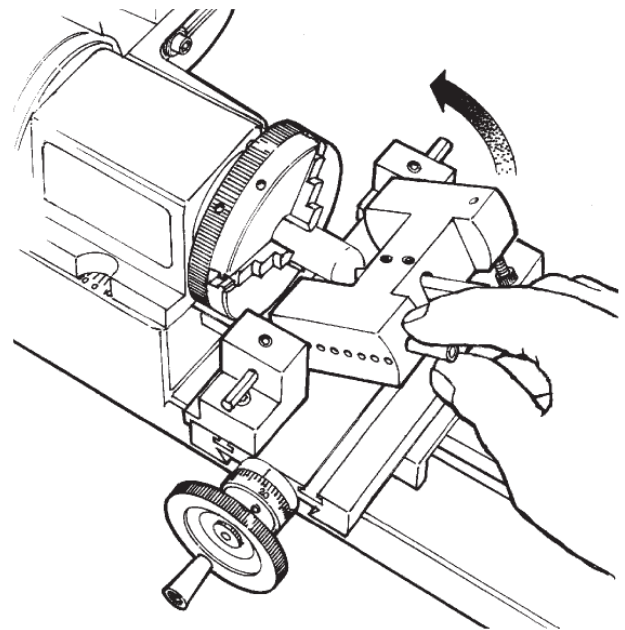


Fig-1. Radius Cutting Attachment cutting a Ball end<sup>6</sup>.

**Key Words:** Radius Cutting Attachment, Lathe, Cylindrical Part, Radius Cut, Design, Solid Works, Modeling, Simulation, etc.

## 1. INTRODUCTION

Normally, the radius turning operation is done by form tool or by combination feed method. Form tool gives correct spherical shape but it requires different tool for different radii, thus making it an expensive method. Combination method on the other hand lacks accuracy in producing convex or concave shape on the work piece<sup>6</sup>. Moreover, the combination feed method demands a highly skilled operator. The radius cutting attachment is relatively simple and easy to operate. It also produces an accurate convex and concave profile on the work piece. Unlike the conventional radius cutting attachments that swing the cutting tool parallel to the lathe table, the tool of this attachment moves from the center of the part to the top as shown in Figure 1.

A ball can also be cut using a two-part process. A handle is provided so that it can be used on operations where the tool faces the long end of the cutter body. On operations where the tool faces the other way, the handle is not used.

### 1.1 Setting up the tool to cut a convex radius or ball end

The most common application of a radius cutter is to put a radius or ball on the end of a part. The process of setting up the attachment is as follows:

- Mount the two radius cutter supports on the cross-slide of the lathe by inserting them through the V-groove of the cross slide and then assembling the radius cutter body into them using the pivot pins. The radius cutter supports are firmly clamped to the cross-slide groove by means of the clamp pieces. The cutter supports are mounted closest to the spindle.
- The quickest way of setting a cutting tool is by first turning a final diameter (twice the radius) on the part, which is to be worked on with a standard lathe tool before mounting the radius cutting attachment. If the part is already turned to the finished diameter to turn a full radius on the end, simply raise the radius cutter body to the vertical position and lower the tool until it touches the top of the part. This will establish the proper radius. It would be safest to set the tool to a slightly larger radius and then coming to the final dimension once most of the material is removed and it can

be seen that how close the final cuts are coming to the desired radius. Move the saddle and then the cross-slide towards the part fixed in the chuck. Rotate the radius cutter support to take a light cut on the top corner. The first series of cuts are accomplished by rotating the tool up and back. Make final adjustments with the cross-slide hand wheel to finish up exactly on center to cut the full radius.

c. The tool will cut the full amount it has advanced at the center but will not reduce the diameter at the top and bottom of the part. If the tool moves past the top center before the tool is cutting at its final position, it will undercut the opposite side of the ball. Thus, it is preferred to stay back 10 degree or so from top center until the tool has reached its final position as in Figure 2.

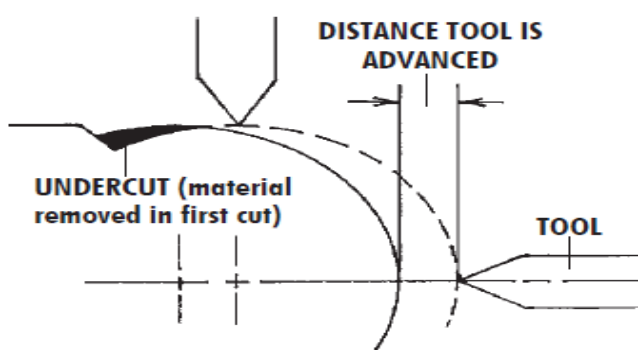


Fig-2. Tool advancement leading to undercut during convex radius cutting operation<sup>6</sup>.

d. Another way to set the tool would be to accurately cut or mill a gauge block to a dimension that is the center height of the part over the table plus the desired radius of the part. Set this gauge block on the table and move the tool to just touch the top of it with the attachment in the vertical position as shown in Figure 3.

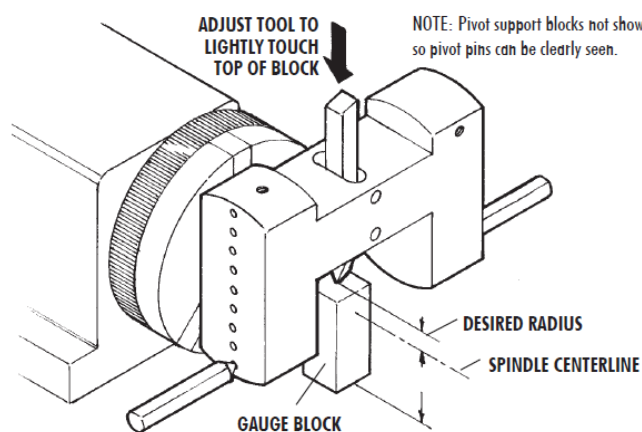


Fig-3. Using a gauge block to set the tool height for a convex radius<sup>6</sup>.

### 1.2 Setting up the tool to cut a concave radius

Full convex radii are easy to measure using a caliper or micrometer. A concave radius is more difficult to measure. It is better to spend the time accurately clamping the tool using a height gauge than trying to check the radius with a template that cannot be viewed accurately Figure 4. Some things in machining have to be controlled with the setup rather than with an inspection method and this is one of them. A simple formula when working with concave shapes:  $r = \frac{(c^2 + 4h^2)}{8h}$ ; where r – radius, c – diameter of pocket and h – height (depth of pocket)<sup>6</sup>.

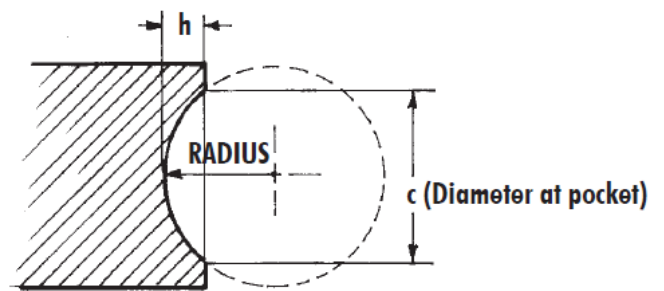


Fig-4. Procedure for cutting a concave radius<sup>6</sup>.

### 1.3 Making a complete ball

Using the radius cutter it is possible to cut past the vertical point to make more than a half of a circle. However, because the cutter body will eventually hit the chuck, steady rest or some other part of the setup, a complete ball cannot be cut. It is a problem for conventional horizontal-swing radius cutters too. A complete ball can still be made using this tool but it requires two steps.

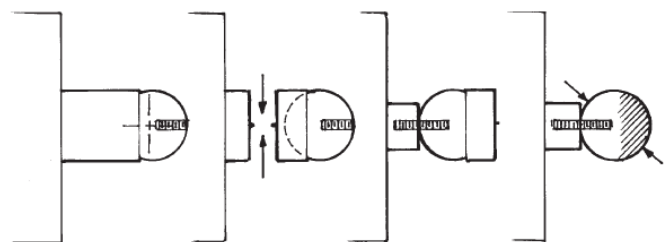


Fig-5. Procedure for cutting a complete ball using a threaded stud<sup>6</sup>.

First, turn half or a little more than half of the ball to the final radius and cut it off leaving enough material to form the opposite side. Drill and tap a hole in the end of the half-completed ball. Using a cut off tool, part off the piece from the stock leaving sufficient material to complete the ball. Make a mandrel with a diameter about 2/3 of the final diameter of the ball with a threaded stud centered on the end and screw the part into it. Place the mandrel in the chuck and use the radius cutting set up to complete the rest of the ball<sup>6</sup>.

## 2. DESIGN OF THE RADIUS CUTTING ATTACHMENT

### 2.1 The radius cutting attachment

It consists of:

- Radius Cutter Body
- Radius Cutter Support
- Clamp Piece
- Pivot Pin
- Handle
- M-6, M-8, M-10 Bolts

### 2.2 Lathe Characteristics & Specifications

The Lathe has the following characteristics and specifications:

- High Precision.
- Pedal cut off.
- Quick changing of the tool post.
- Inter Locking Safety Device.
- Overload protection to lead screw and feed rod.
- Conveniently good operating controls.
- Dynamically balanced main spindle supported at two points with adjustable pre-loaded precision taper roller bearing.
- Torque transmission by hardened gears sliding on spindle shafts with precision bearings.

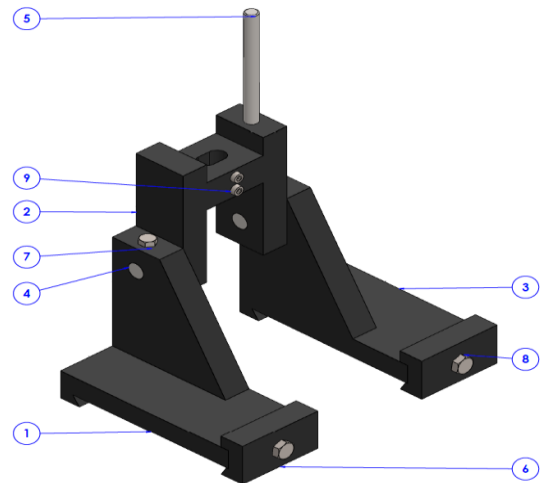
**Table-1:** Specifications of the Lathe<sup>4</sup>

Technical Features	Specifications with Unit
Height of Centers	200mm
Swing over bed (diameter)	420mm
Swing over cross slide	220mm
Swing in gap (diameter)	550mm
Width of Gap	115mm
Distance between centers	1000/1500mm
Spindle Bore (diameter)	53mm
Spindle speed (8 nos.)	32-1200 rpm
Travel of cross slide	225mm
Travel of tail stock spindle	150mm
Main Motor Power	3 KW
Approximate Net Weight	1250-1550 kg

### 2.3 Modeling and Assembly of the Radius Cutting Attachment

Modeling of the different parts of the attachment was done using Solidworks based on drawings and design dimensions of the Lathe cross-slide dimensions where the Radius Cutting

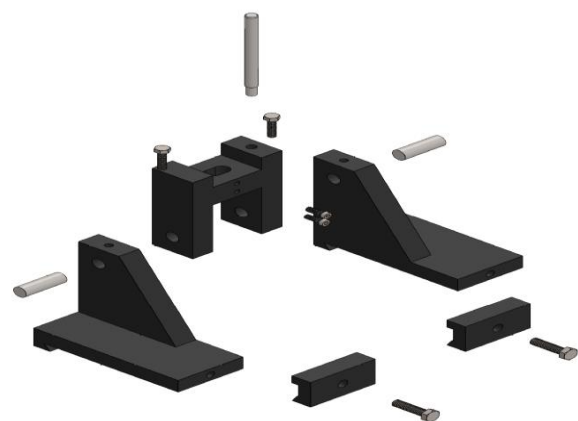
Attachment was to be assembled. Later Sub-Assemblies were created and finally the assembly of the Radius Cutting Attachment was done using Solidworks Assembly Tools. The Assembly drawings are as shown in the following Figure 6. The Material List of the Radius Cutting Attachment is as per Table 2. The exploded view of the attachment is shown in Figure 7.



**Fig-6.** Radius Cutting Attachment Assembled View.

**Table-2:** Parts Description List

Item No.	Part Name	Material	Qty.
1	Radius Cutter Support Left	C.I	1
2	Radius Cutter Body	C.I	1
3	Radius Cutter Support Right	C.I	1
4	Pivot Pin	C.S	2
5	Handle	C.S	1
6	Clamp Piece	C.I	2
7	ISO 4015 - M8 x 30 x 30-S		2
8	ISO 4015 - M10 x 40 x 40-S		2
9	ISO 14580 - M6 x 20 x 18 - 4.8-S		2



**Fig-7.** Radius Cutting Attachment Exploded View.

### 3. SIMULATION OF THE RADIUS CUTTING ATTACHMENT

The simulation was carried out with the help of Solid Works Simulation. Linear, Static and Isotropic analysis being performed on the attachment, which included Material selection, Fixing Degrees of Freedom, applying loads, meshing, running the analysis and post processing. The material was assigned to the attachment from the material library of Solid Works Simulation.

#### 3.1 Material Properties

The parts of the radius cutting attachment considered for the simulation are the pivot pins and the handle. Carbon Steel is the material under consideration. The properties of which are given in Table 3.

Table-3: Material Properties

Sl.No	Properties of Carbon Steel	Value with unit
1	Yield Strength	220.94 MPa
2	Tensile Strength	399.82 MPa
3	Elastic Modulus	210 GPa
4	Poisson's Ratio	0.28
5	Mass Density	7800 kg/m <sup>3</sup>
6	Shear Modulus	79 GPa

#### 3.2 Loading Conditions

Forces acting on the radius cutting attachment was considered on the basis of material chosen for machining which in this case was 0.2% Carbon Steel. Accordingly, the forces acting on the radius cutting attachment were the following:

1. Tangential Component of cutting force ( $F_t$ ), which is acting on the support walls and the sides of the cutter body.
2. Radial Component of cutting force ( $F_r$ ), which acts on the pivot pins as shear force.
3. The axial component of cutting force ( $F_a$ ), which acts on the handle.

For the simulation, however the tangential component is considered safe for the material chosen for the Radius Cutter Body and the supports. The ultimate shear strength of Grey Cast Iron is 173 MPa and the working stress or the design stress was calculated to be 43.25 MPa that will yield a Factor of Safety (FOS) of four, making the design safe. The working shear stress value,  $f_s \ll 43.25$  MPa, this can be attributed to the reason that the design dimensions were taken with respect to the cross-slide dimensions where the radius cutting attachment is to be assembled. The dimensions of which are: Length = 300mm, Width = 165mm, Height of the lathe axis from the top of cross-slide = 115mm.

The radial and axial components of cutting force acts on the pivot pins in the form of torque. The maximum diameter of the work which can be turned by the Radius Cutting Attachment is  $D = 50$ mm as per design with respect to cross-

slide dimensions. Based on these considerations the loading conditions were chosen for the simulation as shown in the following Table 4:

Table-4: Loading Conditions

Sl.No	Loads	Value with unit
1	Torque	14.7 N-m
2	Tangential component of cutting force	1790.3 N

#### 3.3 Meshing Information

The mesh was created using the create mesh option available in the simulation environment. Moderate meshing was employed and the details of the meshing operation is summarized in Table 5. Refined mesh was used at areas of high stress concentration to yield better results. The meshing information is as per the following Table 5.

Table-5: Meshing Information

Sl.No	Details	Information
1	Mesh Type	Solid Mesh
2	Mesher Used	Standard Mesh
3	Element Size	5.89389 mm
4	Tolerance	0.294695 mm
5	Mesh Quality Plot	High
6	Total Nodes	81673
7	Total Elements	53214
8	Maximum Aspect Ratio	5.5115

#### 3.4 Simulation Results

The simulation results focused mainly on the Shear Stress plot and analysis related to the pivot pins, where the stress concentration was more. Several iterations were performed with refined mesh at the areas of high stress concentrations especially focusing on the pivot pins. As shown in the shear stress plot (Figure 8), the maximum shear stress was found to be 13.781 MPa.

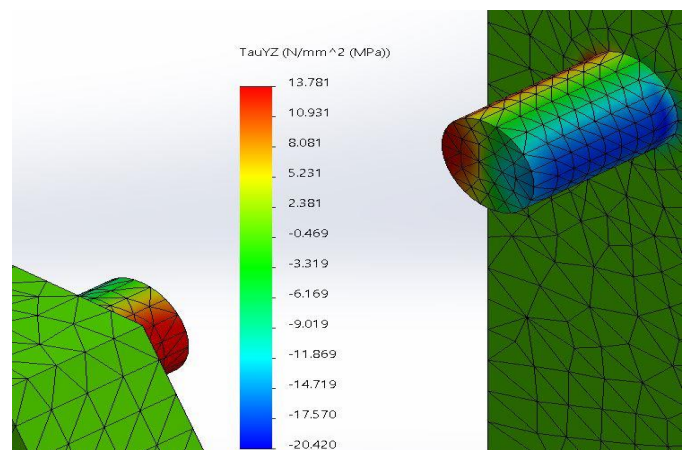


Fig-8. Shear Stress Plot.

The Yield Strength for the material of the pivot pins (Carbon Steel) is 220.94 MPa. The design simulation thereby yielded a Factor of Safety of 16, which clearly indicated that the design was safe. In addition, the resultant force acting on the handle was estimated to be about 37.94 N due to the cutting forces. The analytical value of the force on the handle to resist the Torque was 43.6 N. Therefore, the simulation results were approximately close to the analytical results, with an error of 13%, with the Mesh Control applied. Simulation results are summarized in Table 6.

**Table-6:** Simulation Results

Sl.No	Name	Type	Min.	Max.
1	Stress	Shear in Z Dir. on XZ Plane	-13.781 MPa Node: 13797	13.781 MPa Node: 18866
2	Strain	Shear in Z Dir. on XZ Plane	-0.00025 Node: 13797	0.00025 Node: 18866
3	Reaction Force	Resultant Force	-	37.9925 N

#### 4. CONCLUSION

The radius cutting attachment further extends the capabilities of a Lathe machine tool. An accurate and professional touch can be given to the parts, which are radially turned, thereby once more increasing the versatility of the Lathe. The Radius Cutting Attachment can be a part of any type of Lathe with provisions of providing the hand wheel for giving the feed with adequate graduations on the wheel. Using the Radius Cutting Attachment an accurate convex and concave profile, as well as a complete ball profile can be turned out on a cylindrical work piece with relative ease and maximum accuracy. Use of the attachment eliminates inaccurate or expensive methods of radius turning by combination feed method or form tool methods. The attachment was safely and properly designed to avoid forces on the handle as can be seen from the simulation results. The attachment can also be designed in such a way that it can be clamped to the cross-slide T-slot of certain type of Lathes making this attachment viable to flexibility as well.

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#### BIOGRAPHY



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