Drawing an Involute Spur Gear Using DeltaCad®

Written by DCUG member - “i44troll“ - March-April 2011 (‘Part I’ & ‘Part II’)

Getting Two For The Price of One.........

> "To most mechanics a gear is a gear!.....and, in fact the gear is often a gear and nothing more, sometimes barely that. But, if the mechanic will look beyond the tips of his fingers he will find that it is something more....."
>
> *"A Treatise on Gear Wheels", George B. Grant, 1893*

Of all the old, ancient books that I have in my library, I love Grants book the best! To Grant a gear was something MORE than just a gear, and his efforts were set to convince you of that! I hope to use this tutorial to show the reader just what it was that Grant was talking about when referring to a gear as "something more" .....maybe this will be a discovery to some of us and not just a tutorial. We don't just want to draw a gear but understand what it is that we are drawing; otherwise we should be content with what we are able to create with *DeltaCad’s* gear making macro.

To complete this tutorial it is assumed that you have used *DeltaCad* enough to be familiar with the standard features of each tab, specifically the ability to use the "base point" feature within the select tab and the ability to copy and paste selected elements in a CONTROLLED manner (and the ability to run a *DeltaCad* Macro file). To teach the use of these features would be outside of the scope of this tutorial.

The Involute Spur Gear - Defined

In order for us to even begin with this tutorial we'll have to understand exactly what an "involute spur gear" is.

Spur gears have been made in many different ways over the years and for the most part, have just recently begun to settle into a concrete and stable standard of nomenclature, and that only because of the success and failures of previously held ideals.

It shouldn't be too difficult to understand what a "spur" gear is, since the name itself tends to conjure up images of cowboy boots and lasso's, so the only thing left to define is the word "involute", which literally means; "to turn inward or roll inward". In gearing, however, the "involute curve" is best defined by visual example.

Try to visualize this definition......

"An involute curve is a curve that is traced by a point on a taut string unwinding from a circle, which is called a base circle." (See figure 1 for a visual representation of the involute curve based on the above definition.)

If you look intently on the part of the curve created closest to the base circle, you can see that it starts to resemble the contour of a gear tooth.

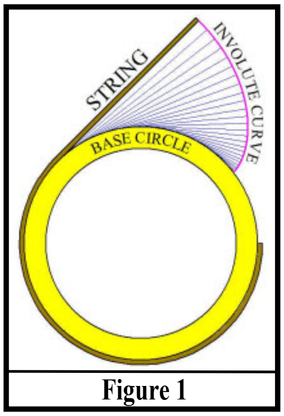


Figure 1

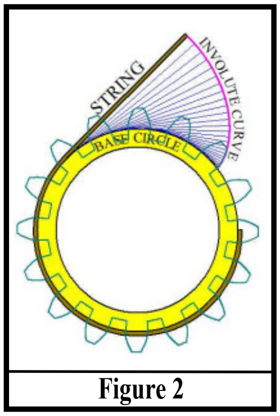


Figure 2

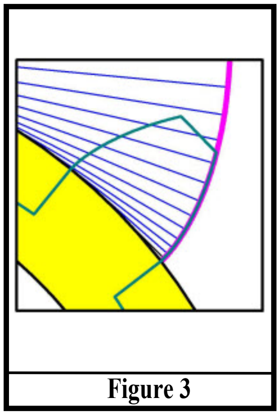


Figure 3

Look now as we superimpose a full involute gear over the top of the last image. (Figure 2) See how this curve creates the geometry of the gear tooth EXACTLY?

And yet a little closer still (Figure 3) to see the exact form that is superimposed.........

Now you know how the involute curve is used in gear geometry. The next step is to define and draw the "Pitch Circle" by which all other computations are made.

The Pitch Circle

If it were possible to transmit power from one circular wheel to another circular wheel continuously and without interruption there would be no need for gears. Gears make it possible for two “Wheel Circles" to interlock together without slipping and losing traction. So, for now, we want to imagine a gear as though it had no teeth, as though it was a simple circular wheel just to see the evolution that must take place that transforms a circular wheel into a multi-toothed gear. We begin with what is called the "Pitch Circle".

By definition... "The pitch circle is the imaginary circle that passes through the contact point between two meshing gears."

It is this "Pitch Circle" that *DeltaCad’s “Gear Maker”* macro draws, along with the gear teeth, each time you generate gears using that macro!

Just so we can understand this a bit easier, we'll create two identical gears using the gear macro supplied by *DeltaCad*.

-- Open the *Gear Maker* macro and use 16 teeth for both gears, then use 1" for the distance between centers. Notice that both circles are joined by one point of contact along their circumference. (See Figure 4) This is exactly the image expressed by the definition above. Those two circles would then represent two wheels running together if all the gear teeth were non-existent.

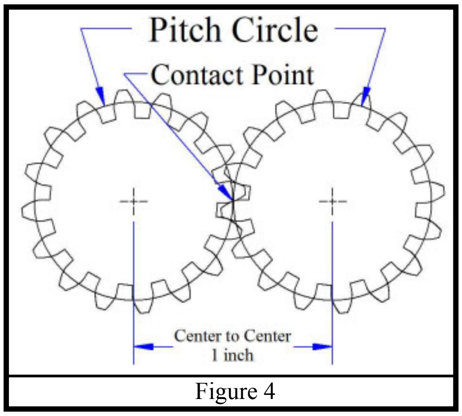


Figure 4

Since we created both gears identical we can assume that both pitch circles each have a 1/2" radius,after all, they each share 1/2 the distance between centers (which has a total length of 1 inch). Therefore we conclude that both pitch circles have a **"Pitch Diameter"** of one inch. (Figure 5)

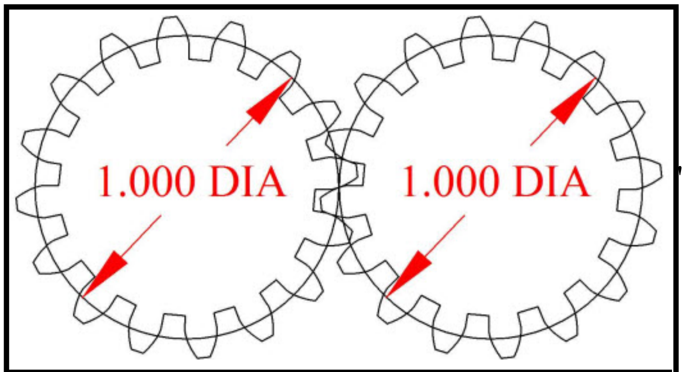


Figure 5

Now then, the real benefit of gearing is that you can transfer motion from the first gear to either "slow down" or "speed up" the resulting motion of the second gear. In order for this to happen, however, there must be a difference in the size of the gears! If this were just a matter of changing the size of two circles (as mentioned above) we could make an immediate adjustment and be done with it, but we already know that gear "teeth" must be implemented otherwise those two circles will slip and the end motion interrupted; So, if gear teeth are to be added to each of these circles they must be placed evenly along the outer circumference in equal distances so that there is no distinguishable difference between the beginning and ending gear teeth, and if that wasn't difficult enough, the second gear, regardless of its size, must be created the same way using the same physical size of gear tooth and gear tooth spacing.

It won't take you long before you realize that the pitch diameter of your gear cannot be a random size but must be drawn according to the physical size of the gear teeth and the amount of teeth to be placed along the circumference of the pitch circle.

We can probably now understand why Grant would say,

"***Look past your finger tips! ....gears are something more!***"

Diametral Pitch

We just discussed in the last post why it is that the pitch diameter of a gear is influenced by the "physical size" of the gear tooth. In this part of the tutorial we'll show how gear tooth size is determined and how that Diametral Pitch (gear size) affects the size of the pitch diameter.

Later on we'll be creating several gears using *DeltaCad*'s **gear-maker** macro and placing each one of them in sequence one after another so that they mesh together into what is called a "gear train".

Those of you who have used this macro have probably thought it was just a novel accessory, paying little or no attention to it after your initial discovery. For the most part, it was created only as a novelty because it does not create gears based on the physical size of the gear tooth but, instead, creates gears with unconventional tooth sizes. Let me assure you that after this tutorial you will consider the **gear-maker** macro a much more useful tool when drawing mechanical gear-laden parts as long as you use it in the way prescribed in this tutorial.

Diametral Pitch - Defined

Diametral Pitch is defined as "The number of gear teeth to each inch of pitch diameter"

It is important to note that "Pitch Diameter" and "Diametral Pitch" are two entirely different things!

At the beginning of this tutorial we created two equally sized gears, both had 16 teeth and a pitch diameter of “one inch”. According to our definition we must know two things to define the Diametral Pitch of a gear, the number of teeth and the pitch diameter. We can then say that those two gears have a Diametral Pitch of "16", or "16DP" because they both have exactly 16 teeth- within the first one-inch of pitch diameter.

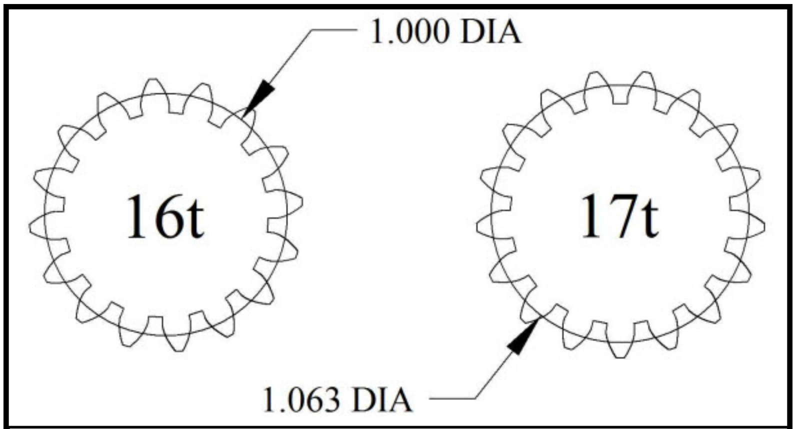


Figure 6

As gears increase in number of teeth so does the need for the pitch diameter to increase as well. This increase is in direct proportion to the Diametral Pitch of the gear, so if our original 16-tooth - 16DP gear were to have 17 teeth, we would have to increase the pitch diameter by an additional 1/16th of an inch (.063) to accommodate the additional tooth. (See Figure 6) ***[Editor’s Note: .0625 is the exact decimal value of 1/16.]***

This is probably the hardest thing for my students to understand when it comes to Diametral Pitch because once they see the first gear example they want to continue to think that ALL 16 toothed gears have a Diametral Pitch of 16, when in fact, the ONLY 16 toothed gear that has a Diametral Pitch of 16 (16DP) is the one that also has a pitch diameter of one inch! (by definition) -- It is imperative that Diametral Pitch be understood in order to draw gear geometry successfully.

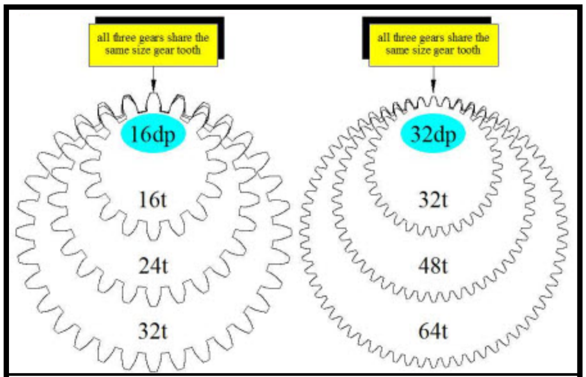


Figure 7 - Gears that share the same Diametral Pitch will run together regardless off the difference of gear diameter or tooth-count because they share the same tooth-size.

Figure 7 clearly shows that the set of gears on the right side have teeth that are much smaller in size than those on the left side making it IMPOSSIBLE for them to mesh together. As stated, **all gears that run together MUST be made using the same Diametral Pitch**, and any two gears, no matter the size, can run together as long as they both share the same Diametral Pitch. Since Diametral Pitch has everything to do with the physical size of the tooth, the actual choice made to determine what Diametral Pitch to use for a given application would then have to be determined based upon the needed strength of the individual gear tooth itself and that, again, would be outside the scope of this tutorial.

Now, a little test to see if "Diametral Pitch" has been clearly understood

(In the following questions "t"="teeth" and "dp"="Diametral Pitch".)

Question #1:
I want to create a 32t 16dp gear, what will the pitch diameter of this gear be?

Question #2:
I have a 12dp gear with a pitch diameter of 1-1/2", how many teeth will my gear have?

Question #3:
I have a 50t gear and a pitch diameter of 10", what is the Diametral Pitch of this gear?

Answers to the above questions:

#1: 2 inches (32 divided by 16=**2**) **#2: 18 teeth** (1-1/2 times 12=**18**) **#3: 5dp** (50 divided by 10=**5**)

Using *Deltacad*'s 'Gear-Maker' Macro to Create True Involute Spur Gears

How Does it Work?

Up to this point we've studied pitch diameter and Diametral Pitch and the relationship each one has with the other. This section is designed to show us how the gear-maker macro processes the information it needs to create random generated gears. We're eventually going to create true-gear forms using this same macro.

I know that I've been saying all this time that the gear-maker macro wasn't really designed with true-to-scale gears in mind, but we can get around that simply by "lying" to the macro. At the moment, however, let's focus on how this macro works!

When you open the macro it prompts you for four bits of information...

- the number of gear teeth of the first gear
- the number of gear teeth of the second gear
- the distance between the two gear centers
- the desired 'backlash' clearance (not always used or allowable in the production of real precision gears)

The way that this macro works is quite interesting! It divides the distance from centers by the total number of teeth in both gears, then it draws a pitch circle for each of the gears outlining each circle with the appropriate number of gear teeth. Even though this is a little unorthodox, it's really pretty cool! Let me show you how this is done by this example.

We'll use these randomly chosen numbers:

- first gear = 13 teeth
- second gear = 17 teeth
- the distance between centers = 5 inches

Follow this step-by-step. Remember, this will work for ANY number combination.

1. draw a horizontal 5" line representing the distance between centers.
2. use "draw mid-points" to find the intersection of the two pitch circles by clicking on both ends and typing "13+17-1" ("-1" to keep you from adding an additional erroneous midpoint)
3. use "draw a circle with a center and a radius" anchoring the center to the line endpoint farthest left and ending the circle radius at the 13th midpoint to the right. (this represents the pitch circle for the 13-tooth gear)
4. use "draw a circle with a center and a radius" anchoring the center to the line endpoint farthest to the right and ending the circle radius at the 17th midpoint to the left. (this represents the pitch circle for the 17-too gear) ***this should also be ending on the same mid-point as the other pitch circle***

Your drawing should now look like figure 8.

5. delete your temp points
6. "split" the 5 inch line at the intersection of the circles circumference to form a radius for both circles.
7. select, copy, and pivot the radius in the left circle so that it equally divides the circle by 13 (you can type 360/13 at the prompt to achieve this)
8. select, copy, and pivot the radius in the right circle so that it equally divides the circle by 17 (you can type 360/17 at the prompt to achieve this)

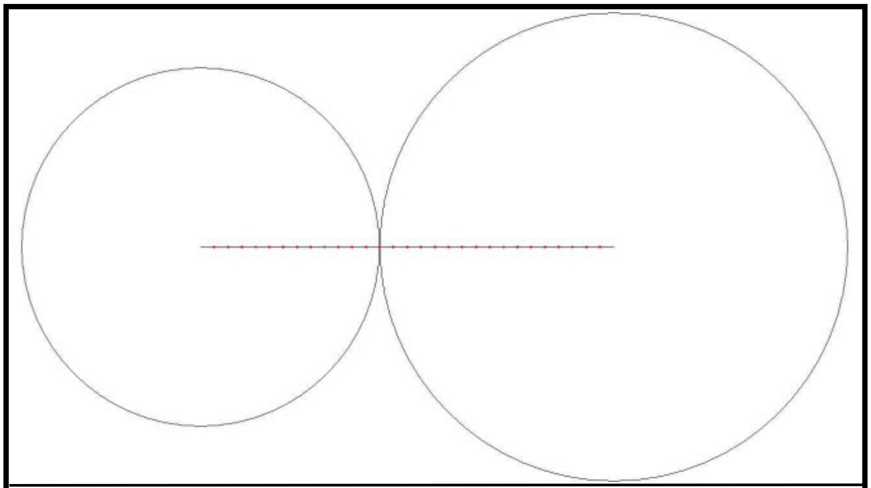


Figure 8

(**NOTE:** I may call the division of each circle the "teeth" of the gear when actually all I intend to do here is show the gear tooth pitch of each circle, so don't think you've missed something if you don't see gear teeth popping up on each pitch circle)

Your drawing should now look like figure 9.

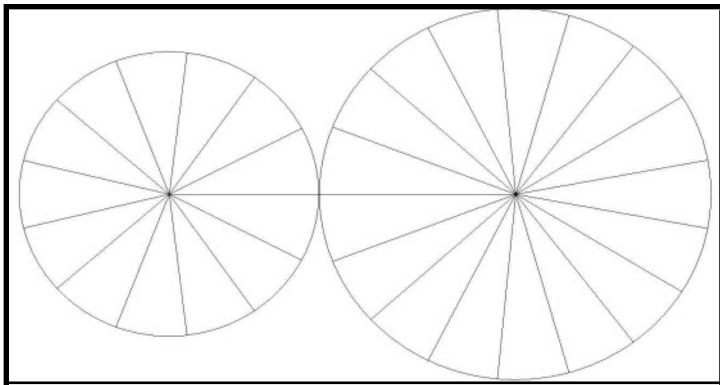


Figure 9

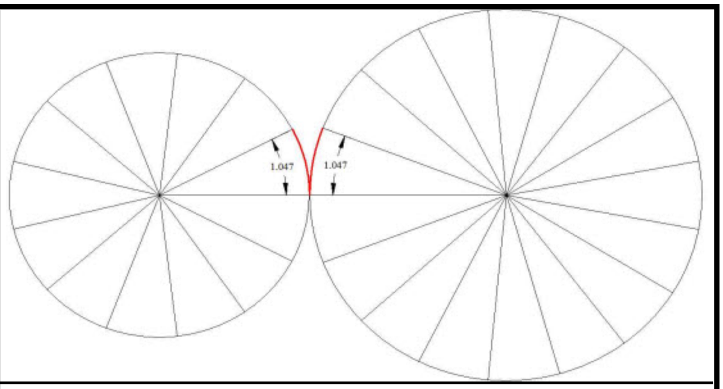


Figure 10

9. on the very first pie-shaped section of both circles change your line color to red and "draw an arc using the center", then dimension both of the arcs. Your drawing should then look like figure 10.

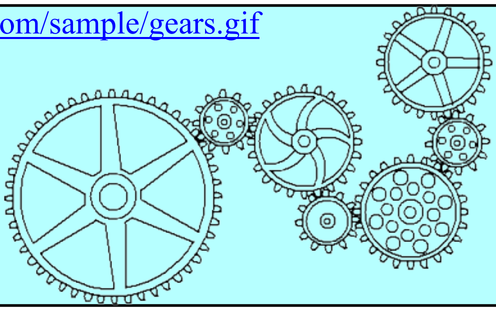
Wow! What an amazing discovery! The gear tooth pitch (1.047) is the same on BOTH pitch circles!

We may or may not have realized it but both these gears share the same Diametral Pitch, and that is just what we said was needed for two gears to share the same size gear teeth so that they mesh. We created that, howbeit unknowingly, by allowing both pitch circles to "share" the same equally placed mid-points of the original 5-inch horizontal line.

This is EXACTLY how the macro uses any random numbers to produce two gears of unequal size, but yet it is able to form gear-tooth-pitches of equal size on BOTH gears!

http://www.deltacad.com/sample/gears.gif

SAMPLE GEARS
DRAWN USING
DELTACAD®



Using DeltaCad's “Gear-Maker” Macro to Create True Involute Spur Gears

How Do You Lie To a Macro?

If you understood how the Diametral Pitch was created in the last couple of examples you'll probably be able to figure this part out on your own, otherwise stay with me....

Let's reflect on the last example for a moment.....

When we divided the 5 inch line by 29 equal mid-points, it was because we had two gears to create; it didn't really matter how many teeth the gears had, just as long as the "horizontal line" (that is, "the distance between centers") was divided evenly by the total number of gear teeth of each gear. If we only want to create ONE gear there wouldn't be much use for mid-points because there wouldn't be any additional gear teeth to mesh. What would be more practical would be to adjust the "distance between centers" to match the Diametral Pitch of a true gear form. Since the macro is usually set up for two gears, the "**Distance between centers**" value entry box will actually process the information as the "sum of the radius of both gears". When you start to realize how this macro processes information you can begin to manipulate the outcome in a more logical way. Since the macro only allows the input of two sets of gear teeth and their distance to centers, let's try the obvious by entering the values of one gear only, the same 16-toothed -16dp gear we made at the beginning.

Open you gear macro and enter the following:

* tooth amount for first gear = 0
* tooth amount for second gear = 16
* distance between centers = .5 (use 1/2 pitch diameter of the gear for the input)
* backlash = 0 (will not be used)

The tooth count for your gear must be put into the text box for the second gear, otherwise the macro will fail to work. As it is, you will still have an error, but it will not affect the outcome of your gear. The picture below (Figure 11) represents what you will see with the exception of the added dimensional call-out.

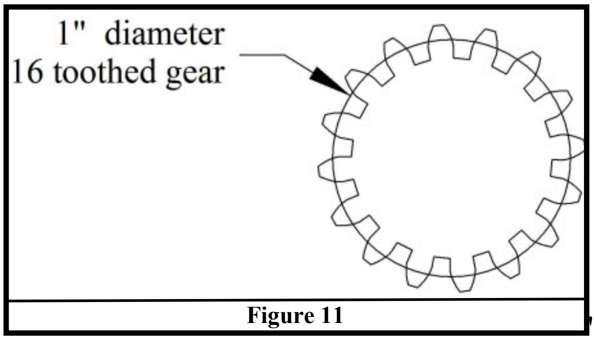


Figure 11

When you enter values for one single gear the macro processes the "distance between centers" as half the pitch diameter because it only takes into account the radial distance of the one gear. What we need to do to create true gear form is to calculate the radial distance needed to define the gear using Diametral Pitch.

In the example above, the macro will generate a true 16-tooth Diametral Pitch gear because the value input of .5 used for the "distance between centers" will actually be interpreted as a one-inch pitch diameter. Therefore, the important thing to remember when using this macro is to enter half the pitch diameter of the gear to be drawn in the "distance between centers" input box.

Believe me, I know how confusing this can be for a beginning student; and it doesn't get any easier when working with formulas because each of these gear terms have closely related symbols as well. To keep it simple, we won't be using the symbols to represent the gear terms, we'll use their abbreviations instead; we will also be using them only when needed.

It’s all about “MESHING TOGETHER”...

Creating a Gear Train

There are four things needed to create our train:

1. (**DP**) Diametral Pitch (remember, this is just the physical size of the gear teeth)
2. (**N**) Number of teeth per gear
3. (**"PD"** for first gear, "pd" for second gear) Pitch Diameter of each gear = (N/DP)
4. (**CD**) Distance from centers = ((PD + pd) / 2) [**Editors Note:** Does NOT mean Compact Disc - LOL]

We'll use the following gears for our train:
(using 16 as our common Diametral Pitch)

1. 16 tooth gear - 1.000 pitch diameter (16N/16DP)
2. 20 tooth gear - 1.250 pitch diameter (20N/16DP)
3. 30 tooth gear - 1.875 pitch diameter (30N/16DP)
4. 18 tooth gear - 1.125 pitch diameter (18N/16DP)
5. 24 tooth gear - 1.500 pitch diameter (24N/16DP)
6. 27 tooth gear - 1.688 pitch diameter (27N/16DP)

Create a grid so that the center-to-center distance will be mapped out for correct gear placement.

Open *DeltaCad* and select "**New**".
Draw a horizontal line 10" long, then draw a vertical line from the left end 2" down. (See figure 12)

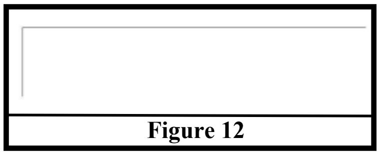


Figure 12

Parallel the vertical line to the right using the "distance from centers" formula for each gear ((PD + pd) / 2).

1. 16 to 20-tooth gear = (1.000 + 1.250)/2 = 1.125 distance from centers
2. 20 to 30-tooth gear = (1.250 + 1.875)/2 = 1.563 distance from centers
3. 30 to 18-tooth gear = (1.875 + 1.125)/2 = 1.500 distance from centers
4. 18 to 24-tooth gear = (1.125 + 1.500)/2 = 1.313 distance from centers
5. 24 to 27-tooth gear = (1.500 + 1.688)/2 = 1.594 distance from centers
6. 27-tooth gear

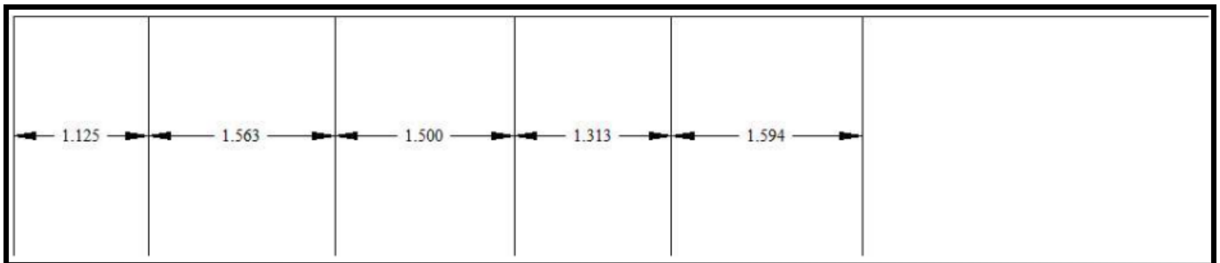


Figure 13

When you are finished the lines should look like figure 13 (dimensions were added to visualize actual distance)

Now we're ready to create the gears.

To start we MUST open a new *DeltaCad* ‘sheet‘to create the gears because the macro will delete everything on the same page used to generate the gears.

****
**** **Please make sure you are not on the same page as your line drawing** ****
**** **when you create the gears or your lines will be erased** ****
****

Create each gear by returning to the new sheet and running the gear-maker macro then "cut-and-paste" the gear into your line drawing on the correct line intersection. Remember, in order to create just one gear you must place a "0" for the first gear but fill in the correct number of teeth for the second gear. In the "distance from centers" prompt you will enter 1/2 the pitch diameter of each gear. Make sure you do this in consecutive order. Each gear MUST be created individually and placed on the intersection of the line starting from the left-hand side. When placed correctly every "even toothed" gear with fit together precisely along the circumference of the pitch circle; any included "odd toothed" gear will have to be rotated to mesh properly.
The following is the list of gears showing 1/2 their pitch diameter

1. 16-tooth gear - 0.500 "1/2 PD" ((16N/16DP)/2)
2. 20-tooth gear - 0.625 "1/2 PD" ((20N/16DP)/2)
3. 30-tooth gear - 0.938 "1/2 PD" ((30N/16DP)/2)
4. 18-tooth gear - 0.563 "1/2 PD" ((18N/16DP)/2)
5. 24-tooth gear - 0.750 "1/2 PD" ((24N/16DP)/2)
6. 27-tooth gear - 0.844 "1/2 PD" ((27N/16DP)/2)

Once finished your drawing will look like this.....(See figure 14)

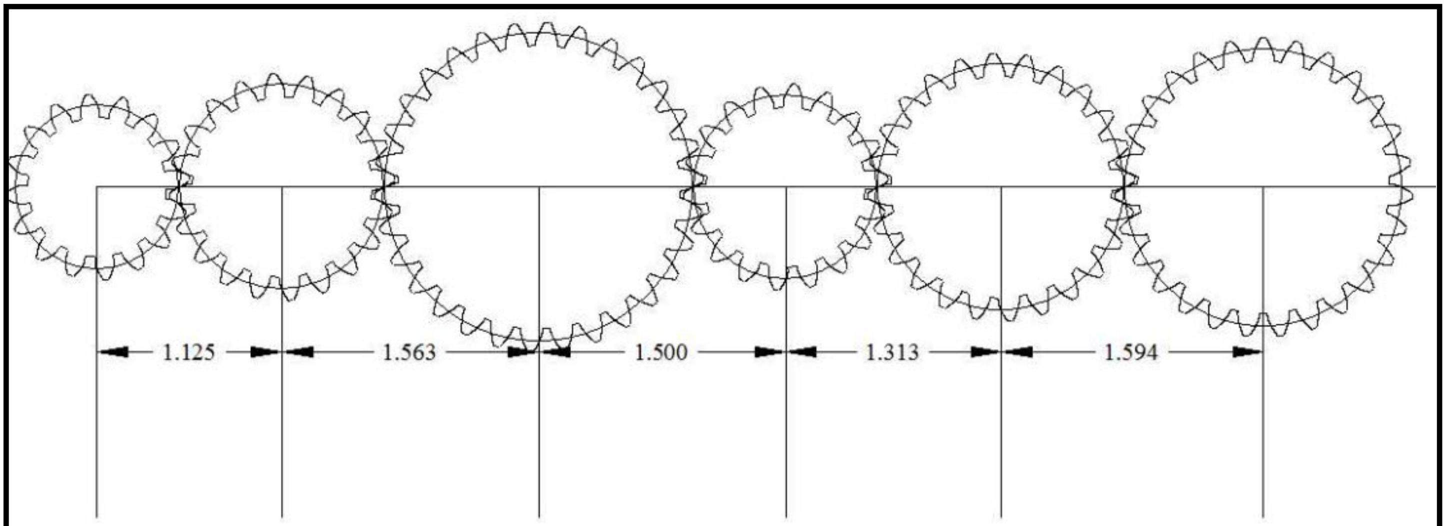


Figure 14

Of course, gear trains rarely run in a straight line but join gears at different angles and countless configurations. Constructing locations for gears that follow a non-linear path is best done using circular construction lines where the radius of the circle is used to represent the distance between centers.

This concludes 'Part-One' of the gear training tutorial.

In the second part we'll concentrate on drawing a gear

without the aid of the gear-maker macro.

Please practice what you've learned thus far.

(Part-Two of this tutorial follows...)

Introduction to "Drawing an Involute Spur Gear" - Part II

"The natural tendency is too often to skip first principles, and begin with more advanced and interesting matter, and the result is a trashy knowledge that stands on no foundation and is soon lost. When a fact is learned by rote it may be remembered, but when it follows naturally upon some simple principle it cannot be forgotten"........

*"**A Treatise on Gear Wheels**", George B. Grant, 1893*

As I stated in the first tutorial "*We don't just want to draw a gear, but understand what it is that we are drawing*". You wouldn't be reading this tutorial if you weren't interested in a deeper understanding of the geometry of gear creation, so let's begin by quickly reviewing some of the "simple principles" that were taught in the first tutorial.

1st things 1st.......

Gears come in various sizes, from the very small found within wrist-watches to the enormous mechanical monsters that transmit the power needed to rotate a cruise-ship's propeller. Both of these, regardless of their obvious size differences share the same principles of construction. The VERY FIRST consideration is to determine the physical size of the gear tooth needed for the application. If you studied the first tutorial you will have learned that the size of any gear tooth is based entirely upon the Diametral Pitch of the gear. If you remember we also mentioned in the first part of this tutorial that Diametral Pitch was the most difficult for the machining student to understand when studying gear geometry. You may find it interesting that around the turn of the century Diametral Pitch was not so easily adopted as the basis of gear size selection, but rather "Circular Pitch" was more commonly used, after all it is circular pitch that defines the diameter of the "invisible" pitch circle while Diametral Pitch just defines the size of one single tooth. This misdirection was clearly understood by Grant but he takes a bit of a turn to show how simple it is to use the Diametral Pitch unit over the Circular Pitch unit even though it might not have been understood as the most reasonable method at that time.

Quoting from Grant again, he says....

*" **The Diametral Pitch -** This is not a measurement, but a ratio or proportion. It is the number of teeth in the gear divided by the pitch diameter of the gear. Thus, a gear of 48 teeth and twelve inches pitch diameter is of 4 pitch. The advantages of the Diametral Pitch unit are so apparent that it is fast displacing the circular pitch unit, and has almost entirely displaced it for cut gearing. **It is so simple that a table of pitch diameters is entirely useless**, although such useless tables have been published".*

Section #36 - "***The Diametral Pitch***", page 15-16

-- And "useless" they must have been since these tables haven't been found in current publications or in countless Internet searches....... **they simply no longer exist!** (although a small section of this chart is used for example purposes - Section #35 *"The Circular Pitch"* page 15) So, even though the "circular pitch unit" was used 120 years ago in Grants day it has long since been replaced with the Diametral Pitch Unit that we commonly use today. This is not to say that Diametral Pitch runs independent of Circular Pitch, rather it is used to "define" the circular pitch of the gear.

The Three Major Spur Gear "Identifiers"

If *Walmart* sold gears on one full store isle, how would you know where to go on that isle to get the gear you want? If then you still couldn't find the one you wanted, how would you explain to the sales associate what gear you were searching for? Suppose you BOTH knew what those three identifiers were, what do you suppose the conversation would be like?..............

Customer: "Hello! I need to replace this worn out gear"
Associate: "What is the Diametral Pitch"
Customer: "I think it is a 12 Diametral Pitch gear"
Associate: "What is the pressure angle.... 14.5, 20, or 25?"
Customer: "It's 20pa"
Associate: "How many teeth does it have?"
Customer: "36 teeth"
Associate: "Right over here Sir......."

Notice, the LAST consideration is the amount of teeth that the gear has, after-all, there is a 36 tooth gear for every Diametral Pitch AND pressure angle! Asking for a 36 tooth gear before considering the Diametral Pitch and pressure angle would be like going to a car dealership and telling the salesman that you are interested in test driving all of their "RED" vehicles! You would probably get a confused look before the salesman narrowed your search down by asking you if you were looking for a "Car,Truck, or Van". This is no different, but because there are so many more 36 toothed gears available your search should be focused mainly on the Diametral Pitch FIRST and then the Pressure Angle and then finally, when your search has been narrowed to a more reasonable amount, the number of teeth. Other parts of the gear are just as important, such as the "base circle", the "addendum", the "dedendum", the "root fillet, etc... but these parts offer very little to the general identification of a gear, so, even though you may not get any hits if you ***Googled*** "gear identifiers" you can be certain that the Diametral Pitch, pressure angle, and number of teeth will give you enough information to either purchase or machine a suitable replacement.

Selecting a Spur Gear

We'll use the three above identifiers to start our gear geometry....

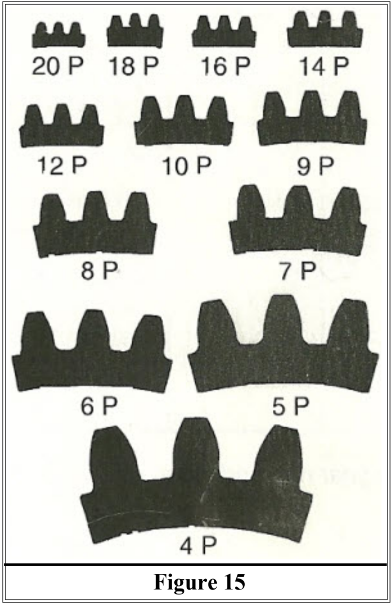


Figure 15

Since "Diametral Pitch" is understood as the physical size of our gear tooth we can decide on any size we want! Text book examples show the differences in size by placing comparative views of each Diametral Pitch. (Figure 15)

We'll use a relatively large toothed gear for our tutorial

- **8 Diametral Pitch**
- **20° Pressure Angle**
- **12 Gear Teeth**

From this information we will now be able to draw the geometry of a single involute gear. In the following posts I will be drawing individual parts of a gear in the order of importance. Certain parts of the gear, such as the addendum and dedendum, will not be included. Only the parts of a gear that are needed for the creation of this drawing will be included. (example: we will use the formula for the "whole depth" of a gear tooth which is the same as adding the addendum, dedendum, and tooth clearance together; an easier route, I must say)

Drawing the Pitch Circle

"The pitch circle is the imaginary circle that passes through the contact point between two meshing gears."

Formula:
pitch diameter=number of teeth/Diametral Pitch.

Draw the pitch circle first using the diameter listed below.
pitch diameter = 12/8 or **1.500 dia** (Figure 16)

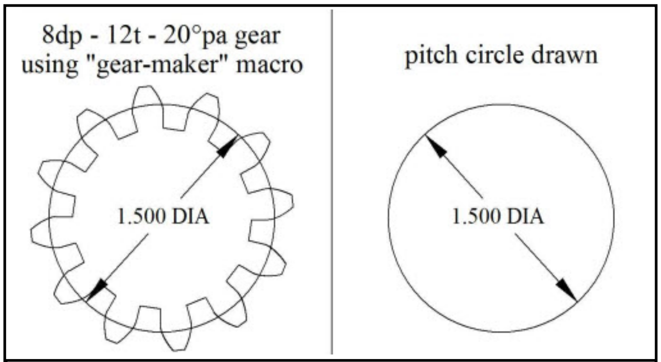


Figure 16

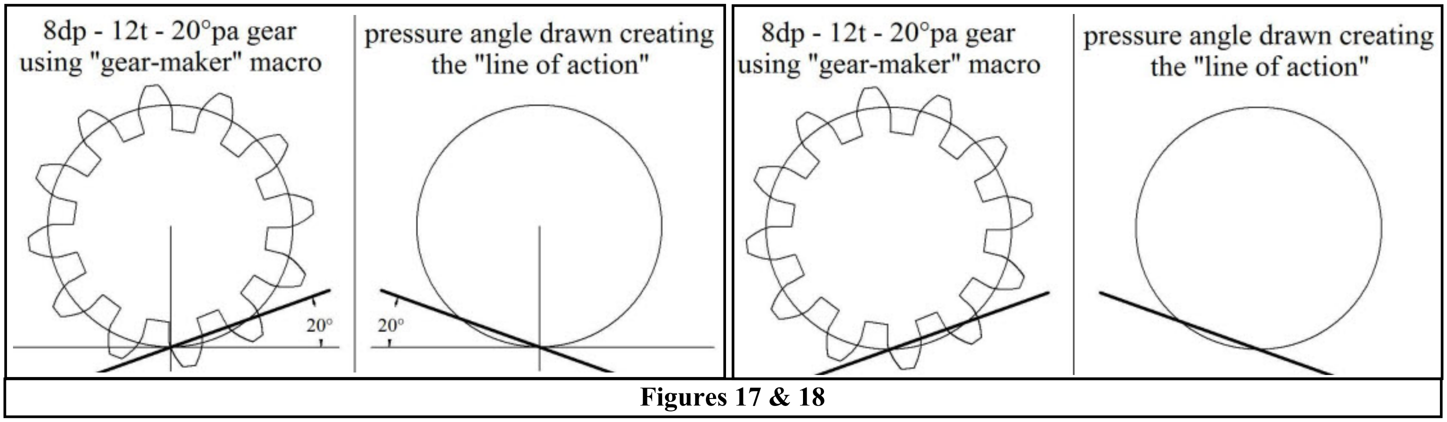
Drawing the Pressure Angle

I haven't elaborated on the pressure angle previously in this tutorial because this angle was automatically generated when using the ‘gear-maker’ macro. The pressure angle is used to create two things:

1. **The "line of action"**
2. **The "base circle"**

We'll concern ourselves about these two items later on, but for now we want to concentrate on creating the angled line. -- If you look at the drawings below (Figures 17 & 18), you'll be able to see how this angle is formed.

- **Draw a vertical line from the center of your pitch circle through the lower circle circumference.**
- **Draw a horizontal line that is tangent to the bottom circumference of the circle.**
- **Copy and rotate the horizontal line 20° using the tangent point as your pivot point.**
- **Erase all construction lines leaving only the 20° diagonal line.**



Figures 17 & 18

Drawing the Base Circle

The "base circle" is the circle by which the actual involute curve is created. It is concentric with the "pitch circle", which means that it shares the same circle center-point.

Formula:
base circle = pitch circle diameter x the cosine of the pressure angle

------------------------------------ This Can Be Accomplished Two Different Ways --------------

1st Way - Using The Formula -- ***DeltaCad*** will do all the math if you enter the formula correctly.

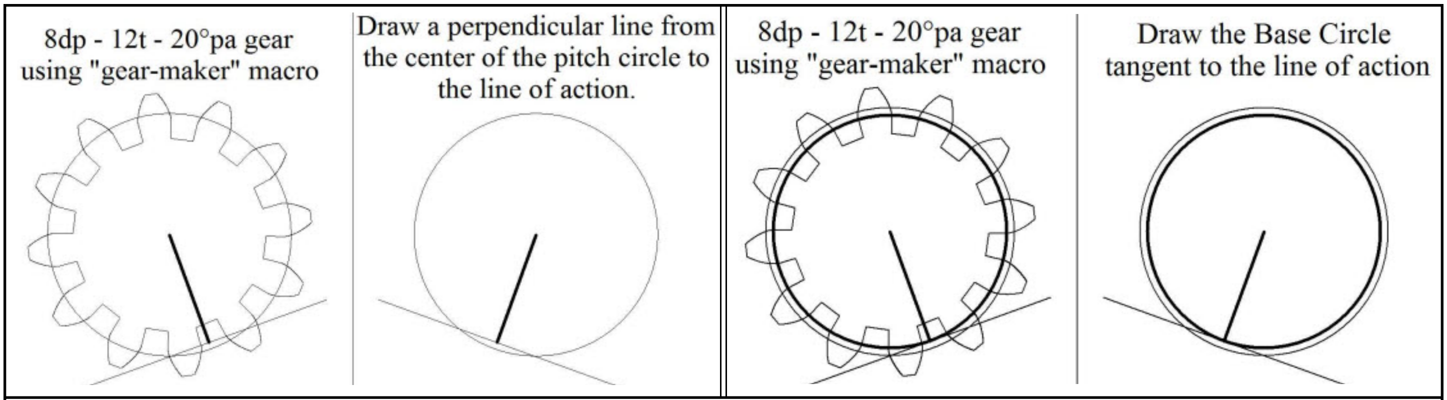
- Begin placement of your circle, but don't finish it with a second mouse-click -- Enter the formula below before the circle is finalized.
- **Enter exactly as follows:** (1.500/2)*cos(20) -- Press "*Enter*" on your keyboard. (YES! ***DeltaCad*** recognizes trigonometry functions as well!)

-- This is the same formula as above except that the pitch diameter is first divided by two. The reason for this is that the prompt requires a radial value instead of a diametral value.

2nd Way - Drawing the Base Circle Tangent to The Line of Action

Step 1: Draw a perpendicular line joining the line of action to the center of the pitch circle....(Figure 19-page 12)

Step 2: Draw the Base Circle tangent to the line of action...(Figure 20-page 12)


8dp - 12t - 20°pa gear using "gear-maker" macro

Draw a perpendicular line from the center of the pitch circle to the line of action.

8dp - 12t - 20°pa gear using "gear-maker" macro

Draw the Base Circle tangent to the line of action

Figures 19 & 20

Drawing the Outside Diameter

The outside diameter is drawn to show the boundary of the gear teeth. This will be the maximum outside diameter of the gear. It is concentric with the "pitch circle" AND the "base circle", which means that it shares the same circle center-point.

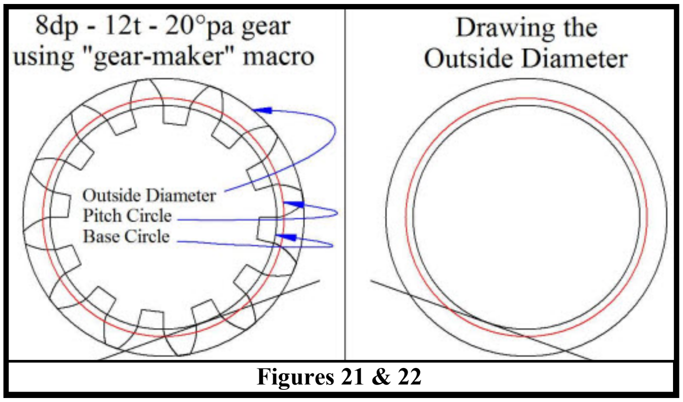
Formula:

Outside Diameter = (Number of teeth + 2) / Diametral Pitch

Using The Formula: (Figures 21 & 22)

- Begin placement of your circle but don't finish it with a second mouse-click. Enter the formula below before the circle is finalized.
- **Enter exactly as shown:** ((12+2)/8)/2 -- then press "Enter".

-- **NOTE:** This is the same formula as was used above except that the result is divided by two. The reason for this is that the prompt requires a **radial value** instead of a diametral value.


8dp - 12t - 20°pa gear using "gear-maker" macro

Drawing the Outside Diameter

Figures 21 & 22

Drawing the "Whole Depth" of the Tooth

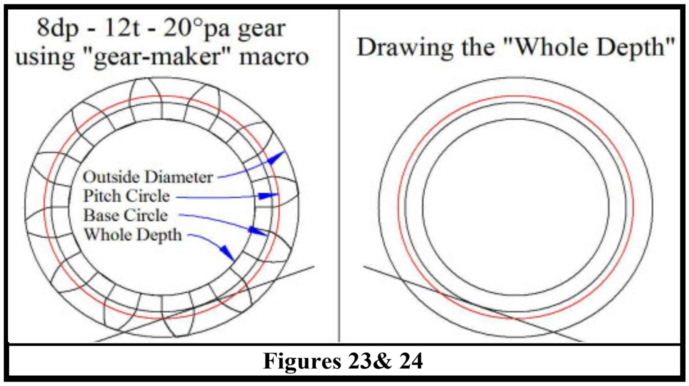
The "whole depth" is the depth of cut taken to ensure the proper clearance needed for mating with other gears. This also represents the smallest of all the circles drawn.

Formula:

Whole Depth = 2.250 / Diametral Pitch

Using The Formula:

- Use the "Draw a Parallel Circle" function and select the outside circle. Drag the circle to the inside of the original circle but don't finish it with a second mouse-click. Enter the formula below before the circle is finalized.
- **Enter exactly as shown:** 2.250/8 -- then press "Enter".


8dp - 12t - 20°pa gear using "gear-maker" macro

Drawing the "Whole Depth"

Figures 23& 24

-- **NOTE:** You will see a little mismatch with the circle that was created over the circle generated by *Deltacad's* gear-maker macro. This is because the macro produces "straight" lines to join the gear teeth. We are using an "arc" to join the gear teeth, which is actually more correct when drawing our gear geometry.

(Remember, *DeltaCad* will do all of the math for you if you enter the formulas correctly.)

Drawing the "Involute Curve"

So far all that has been accomplished has been to create circles with four different diameters, however, each of these circles play a VITAL role in the creation of gear geometry.

Drawing the involute curve will not be as easy to draw, as were those circles, since the curve cannot be drawn by simply selecting a function that creates that type of curve. Instead, we have to draw the curve using small independent lines whose endpoints represent a reasonable involute shape. It is not necessary to create an involute curve using a "spline" as these small independent lines will be sufficient enough to create the curve without the worry of jagged corners.

(**NOTE:** To make the gear drawing (right-side gear) line up correctly with our macro-created gear (left-side gear) I had to rotate the macro-created gear to the right by .854°. I did this so that when we produce each part of the gear we can mirror the right hand side to the left hand side to show how it lay's perfectly over the lines and arcs of the macro-created gear. So far, you should be able to see by the lay-out of the circles that the gear on the right will soon be identical to the one on the left.)

Start by drawing a line to the right from the center of the circle ending it at the base circle, then select that line, choosing the circle center as the base point, and rotate/copy the line counterclockwise twelve times using 3.6° (360/100) as the common angle. Your drawing should look similar to figure 25. (FYI: The red lines, shown in figure 25, are added later.)

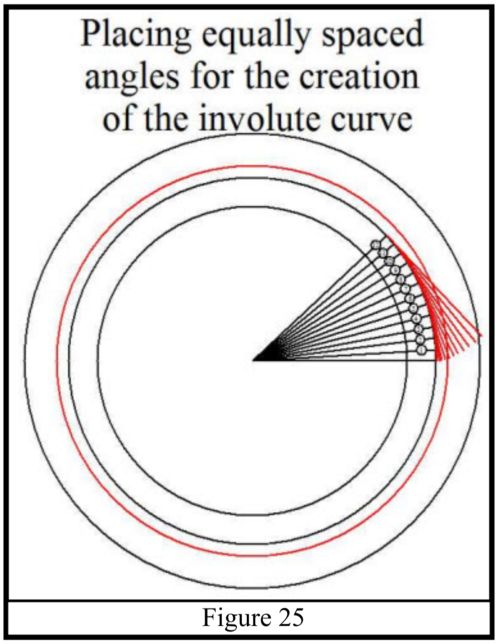


Figure 25

The next step is to find the length of the individual arc that was produced along the base circle for each 3.6° angle. - The way this is done is to draw a single arc over the base circle so that the arc starts and ends within the same 3.6° span. After this is accomplished, that single arc can be dimensioned using the "arc length dimension" feature. Figure 26 shows what your drawing will look like at that single location. (Zoomed-in)

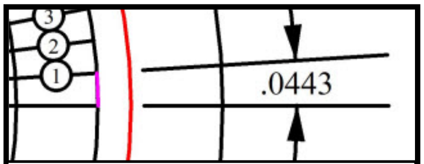
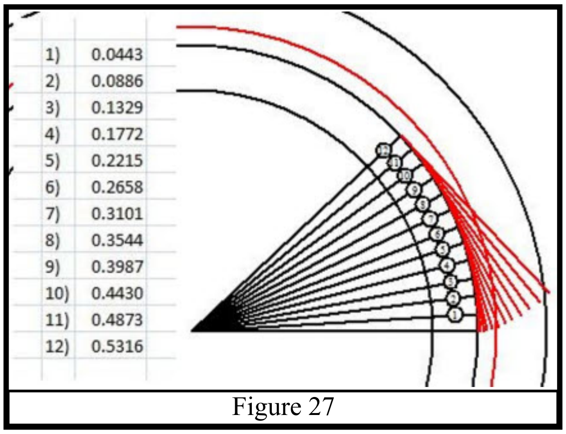


Figure 26

Once the arc length (.0443) has been found, perpendicular lines must be drawn at each angled line endpoint so that the length of each subsequent line is exactly .0443 longer than the last. This is what simulates the "unwinding" of the 'taught string' as explained in the very beginning of this tutorial. (*I used a spreadsheet to add the numbers that were needed and inserted those results in the drawing.*) Your drawing should now resemble figure 27 with the inclusion of the red lines as shown (but not with the spreadsheet table.)



1)	0.0443
2)	0.0886
3)	0.1329
4)	0.1772
5)	0.2215
6)	0.2658
7)	0.3101
8)	0.3544
9)	0.3987
10)	0.4430
11)	0.4873
12)	0.5316

Figure 27

Join all the perpendicular line endpoints together with a continuous line, then trim the end to the outside circle as shown in this picture. (figure 28)

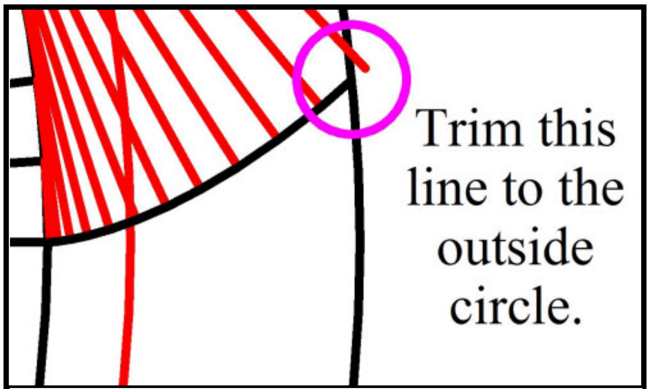


Figure 28

Clean-up the drawing by deleting everything except the lines and circles... Cleaned-up, it should resemble figure 29.(Zoomed-in)

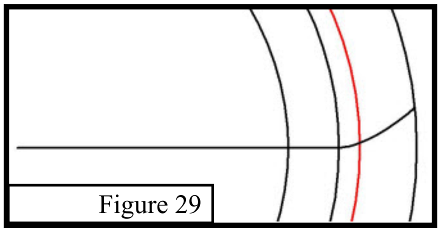


Figure 29

GEAR DESIGN IS FUN!

Drawing the "Thickness of the Tooth"

The "tooth thickness" is the linear distance from one side of the gear tooth face to the opposite side of the tooth face at the pitch diameter.

Formula:
Tooth Thickness = 1.5708 / Diametral Pitch

Using The Formula:

The best way to draw this distance is by using a circular radius with the circle-center point anchored at the intersection of the "involute curve" and the **pitch diameter** (NOT the base diameter!). The circumference of the circle will then mark off the needed distance by intersecting the pitch diameter on the opposite side of the tooth to be drawn. Enter **1.5708/8** for the circle radius. Your circle should now look like figure 30.

Using the radius of a circle to mark the location of the opposite side of the tooth.

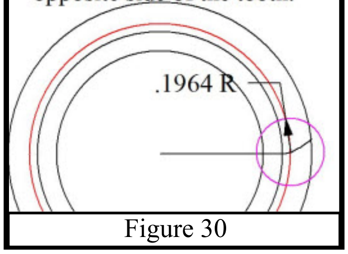


Figure 30

Now, draw a line from the center of that same circle to the intersection of the pitch diameter/circle circumference, place a point in the very center of that line, then draw a line from the center of the main concentric circles through the mid-point of that line. We will call this the "mirror" line.

Your drawing should now look like figure 31.

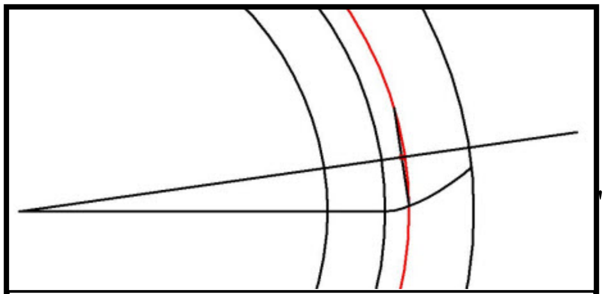


Figure 31

Select only the horizontal line and the involute curve and mirror them to the other side of the mirror line as shown in figure 32.

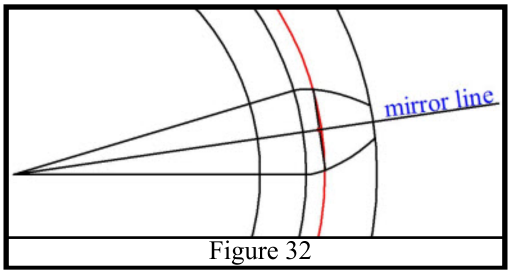


Figure 32

"Trimming and Rotating the Tooth"

It is important to trim as much unneeded lines and arcs as possible so that you aren't left with a drawing that looks like a kaleidoscope of geometric prisms and circles. This operation is best done right after the gear tooth form has been created.

Here is what needs to be done...

- Create a permanent point in the center of the concentric circles
- Delete the pitch diameter and base circle
- Delete the mirror line
- Delete the line between the gear tooth at the pitch circle
- Delete all temporary points
- Break the outside circle into two parts
- Trim the outside circle to the gear tooth curve creating the very edge or tip of the gear tooth then delete the remaining outside circle fragments.

Your drawing should now look like figure 33.

Trimming the lines and arcs to form one single tooth

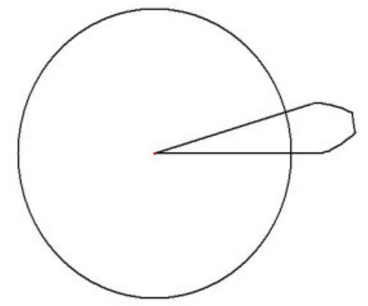


Figure 33

Then...

- Slide the endpoints of the horizontal and diagonal lines so that they end at the remaining circle.
- Delete the remaining circle.

Your drawing should now look like figure 34.

Trimming the horizontal and diagonal lines to the remaining circle

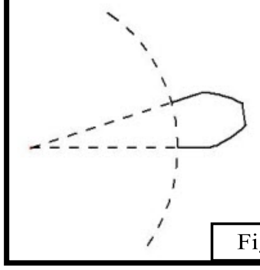


Figure 34

- Select the gear tooth profile.
- Enable "COPY". (it will turn **RED**)
- Set a base point at the same location as your "permanent point". (center of circle)
- Rotate the selection 30° (360°/12t) until all twelve gear teeth are in a circular array.

Your drawing should now look like figure 35.

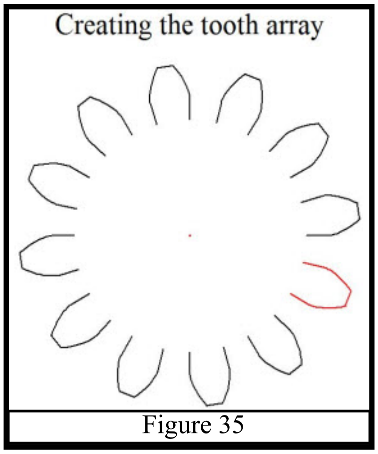

Creating the tooth array

Figure 35

Creating the "Gear Tooth Root”

The "Root" is the deepest "cut" of the profile of the gear. This is what enables the adequate clearance needed to allow the adjacent gear to be engaged without binding. It is what is called the "whole depth" of the gear profile which is the sum of these three parts.

1. Addendum
2. Dedendum
3. Clearance (tooth clearance)

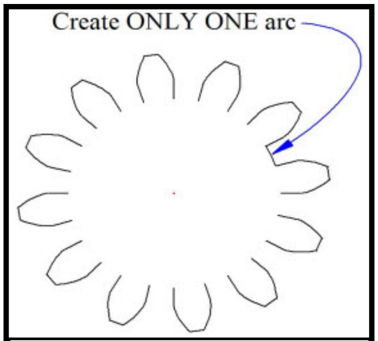

Create ONLY ONE arc

Figure 36

Since we had already trimmed the lines to the "whole depth" already, all we need to do to finish the gear is to connect each tooth together by drawing an arc that joins each tooth. It will be much easier to draw a single arc and paste it in an array rather than to draw each individual arc.
Follow these steps:

- "Draw a circular arc using the center" and connect one gear tooth to an adjacent gear tooth. (See figure 36)
- Select and rotate the arc to complete the gear. Use the "permanent point" as your base point.
- The rotation angle is 30° (360°/12t).

-- Make sure **COPY** mode is selected.

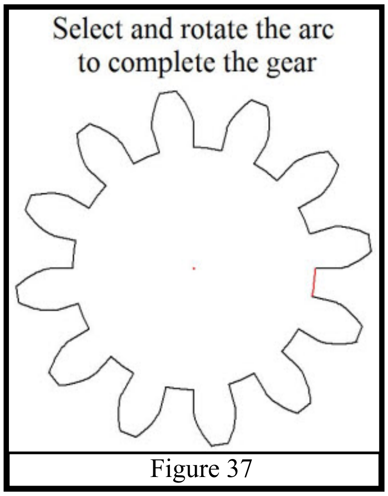
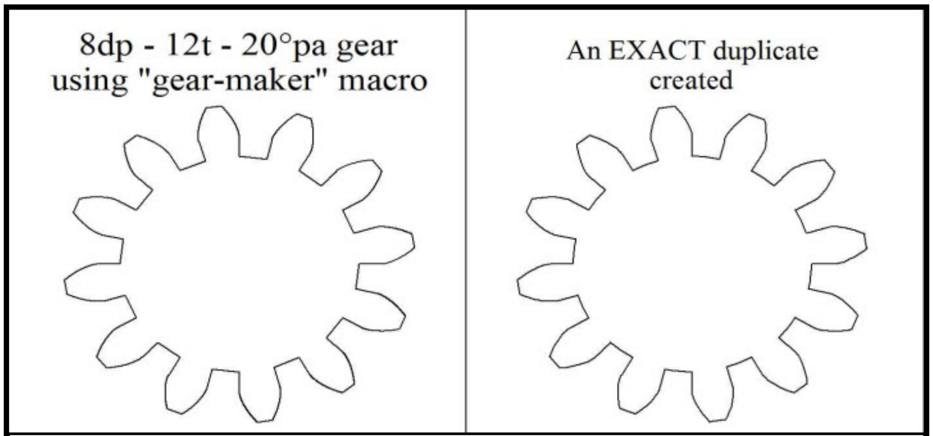

Select and rotate the arc to complete the gear

Figure 37

We have just created an EXACT duplicate of the gear created with the “Gear-Maker” macro..... ***Congratulations!!***

The ONLY difference, as mentioned before, is that we use **arcs** instead of **lines** to represent our "root" and gear tooth "tip" (the outside diameter), but because these arcs are so short, they look almost "straight" when comparing the two gears. (see figure 38)


8dp - 12t - 20°pa gear using "gear-maker" macro

An EXACT duplicate created

Figure 38 (comparison)

Creating the "Root Fillet"

The "Root Fillet" is present in all spur gears, without it the gear would be considered weak at its root and susceptible to cracks and breakage. ***DeltaCad's*** ‘Gear-Maker’ macro does not generate this fillet, even though it is not good practice to exclude it.

-- The formulas needed for this fillet are as follows:

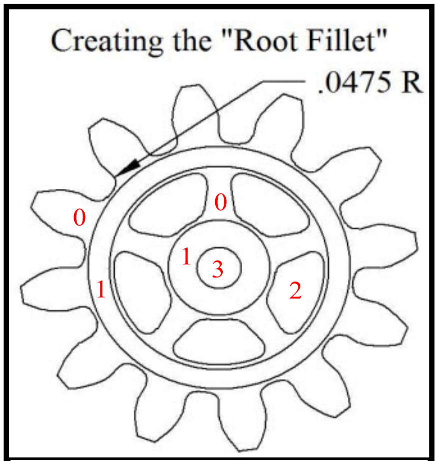


Figure 39

Formulas:

Root Fillet = 1.519 x the clearance (for 20°pa)
Clearance = .250/Diametral Pitch

Using the formulas in our design:

Clearance calculation: **.250/8=.0313**
Root fillet calculation: **1.519x.0313=.0475**

Use the "***Create a radius***" function within the **Edit** tab to change the root of your gear to include this fillet. The finished gear [**0**] (along with some added features -- [**1**] Raised areas (for strength & stability), [**2**] Cut-outs (to reduce weight) and [**3**] a Shaft hole) -- will look like figure 39.

Conclusion

I hope this tutorial was a rewarding experience for those who participated in it. Now that you are knowledgeable in how gears are drawn you probably won't want to do that again, seeing that it requires a bit of time and patience and is really not practical when we know that any gear can be drawn within seconds using the gear-maker macro. The point is that you now have a more intimate knowledge of gears! Who knows where that will lead you, eh! Smile

A big "Thanks" to all of you who took part in this tutorial!

Definitions:

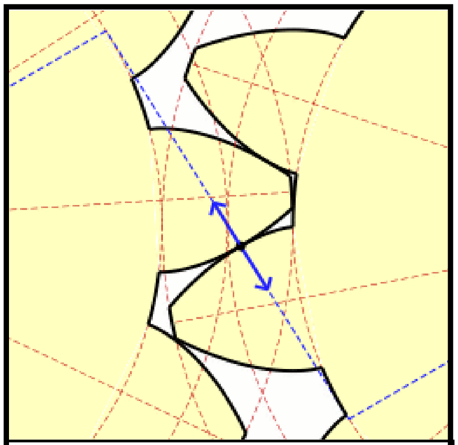


Figure 40

Addendum: [uh-den-duhm] -- *As relating to Machinery:*

a. The radial distance between the tip of a gear tooth and the pitch circle of a gear or the pitch line of a rack.
b. Also called addendum circle - an imaginary circle touching the tips of the teeth on a gear.

Dedendum: [dih-den-duhm] -- *(on a gear or rack)*

The radial distance between the pitch circle or line and the root circle or line.

Diametral: [dahy-am-i-truhl]

Located on or forming a diameter: 'diametral plane' or ‘diametral pitch’

Involute: [in-voe-loot]
As pertaining to gears, is best described, with animation, on Wikipedia. (Figure 40)