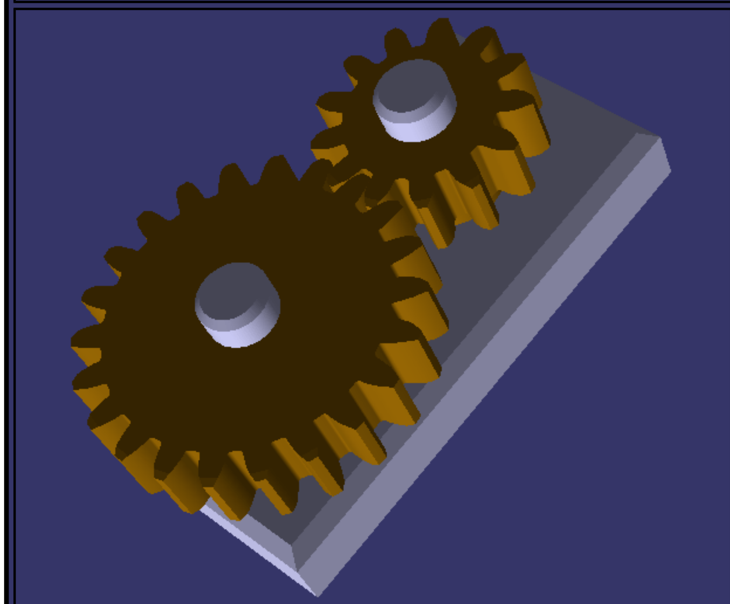
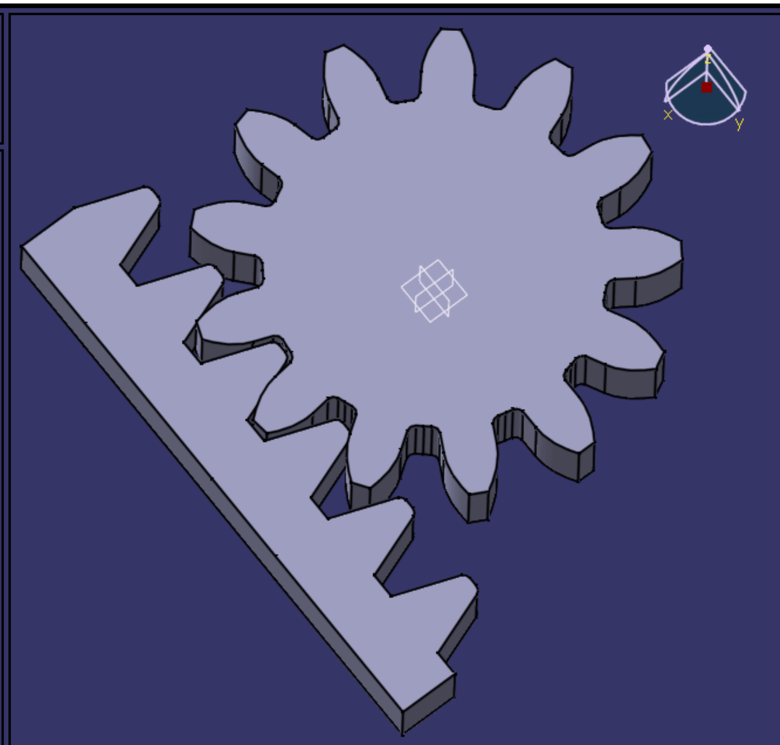
Designing parametric spur gears with Catia V5

Published at http://gtrebaol.free.fr/doc/catia/spur_gear.html
Written by Gildas Tr é baol on June 10, 2005.
Zipped part: spur_gear.zip (256 KB).
Zipped demo: spur_gears.zip (1.25 MB).
VRML97 model: spur_gear.wrl (44 KB).

The powerful CAD system Catia version 5 release 11 has no tool for designing gears. When you are making a realistic design, you may need a template spur gear.





Since the geometry of a spur gear is controlled by a few parameters, we can design a generic gear controlled by the following parameters:

- The pressure angle a.
- The modulus m.
- The number of teeth Z.

This tutorial shows how to make a basic gear that you can freely re-use in your assemblies.

1 Sources, credits and links

- Most of my tutorial is based on a nice tutorial on helical gears in English at http://ggajic.sbb.co.yu/pub/catia/.
- I improved it a little for making an exactly symmetric tooth.
- The mathematic description of the involute curve is visually explained in French at http://serge.mehl.free.fr/courbes/developC.html.
- The gear technology is explained in French at http://casm.insa-lyon.fr/engrenag/.
- The conventional formulas and their names in French come from the pocket catalog Engrenages H.P.C, June 1999 edition.

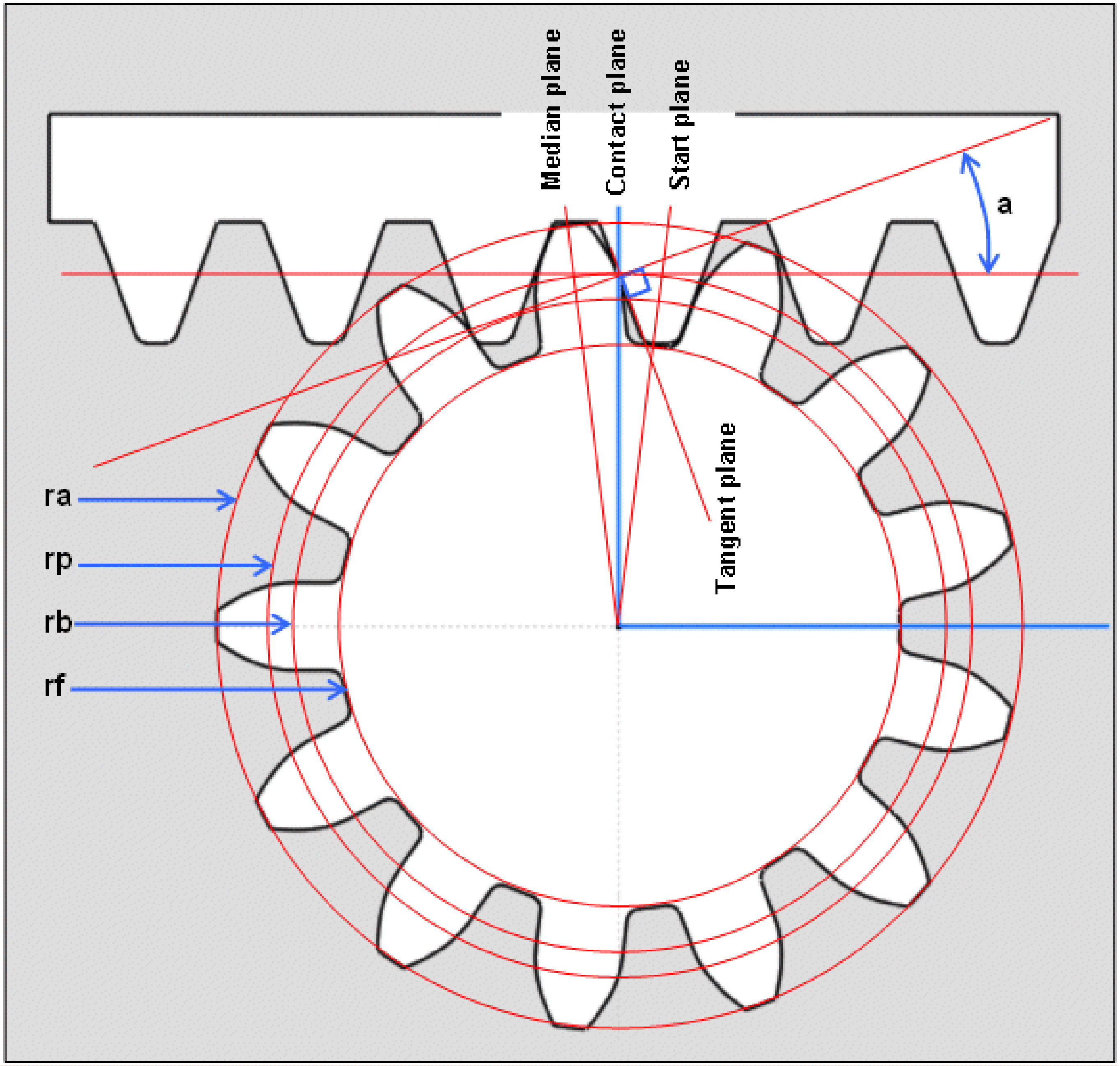
2 Table of gear parameters and formulas

Here is a table containing the parameters and formulas used later in this tutorial.
The table is given first so that you can use it for further copy/paste operations.
All the units are defined in the metric system.

#	Parameter	Type or unit	Formula	Description	Name in French
1	a	angular degree	20deg	Pressure angle: technologic constant (10deg ≤ a ≤ 20deg)	Angle de pression.
2	m	millimeter	—	Modulus.	Module.
3	Z	integer	—	Number of teeth (5 ≤ Z ≤ 200).	Nombre de dents.
4	p	millimeter	m * π	Pitch of the teeth on a straight generative rack.	Pas de la denture sur une cr é maill è re g é n é ratrice rectiligne.

5	e	millimeter	p / 2	Circular tooth thickness, measured on the pitch circle.	Epaisseur d'une dent mesur é e sur le cercle primitif.
6	ha	millimeter	m	Addendum = height of a tooth above the pitch circle.	Saillie d'une dent.
7	hf	millimeter	if m > 1.25 hf = m * 1.25 else hf = m * 1.4	Dedendum = depth of a tooth below the pitch circle. Proportionnally greater for a small modulus (≤ 1.25 mm).	Creux d'une dent. Plus grand en proportion pour un petit module (≤ 1.25 mm).
8	rp	millimeter	m * Z / 2	Radius of the pitch circle.	Rayon du cercle primitif.
9	ra	millimeter	rp + ha	Radius of the outer circle.	Rayon du cercle de t ê te.
10	rf	millimeter	rp - hf	Radius of the root circle.	Rayon du cercle de fond.
11	rb	millimeter	rp * cos(a)	Radius of the base circle.	Rayon du cercle de base.
12	rr	millimeter	m * 0.38	Radius of the root concave corner. (m * 0.38) is a normative formula.	Cong é de raccordement à la racine d'une dent. (m * 0.38) vient de la norme.
13	t	floating point number	0 ≤ t ≤ 1	Sweep parameter of the involute curve.	Param è tre de balayage de la courbe en d é veloppante.
14	xd	millimeter	rb * (cos(t * π) + sin(t * π) * t * π)	X coordinate of the involute tooth profile, generated by the t parameter.	Coordonn é e X du profil de dent en d é veloppante de cercle, g é n é r é par le param è tre t.
15	yd	millimeter	rb * (sin(t * π) - cos(t * π) * t * π)	Y coordinate of the involute tooth profile.	Coordonn é e Y du profil de dent en d é veloppante de cercle.

Draft showing the parameters: a, ra, rb, rf, rp:



2.1 Notes about the formulas (in French)

Formule N ° 11: explication de l' é quation rb = d * cos(a) / 2:

- La crémaillère de taillage est tangente au cercle primitif.
- Au point de contact, a défini l'angle de pression de la ligne d'action.
- La ligne d'action est tangente au cerce de base.
- On a donc un triangle rectangle à résoudre.

Formule N° 12:

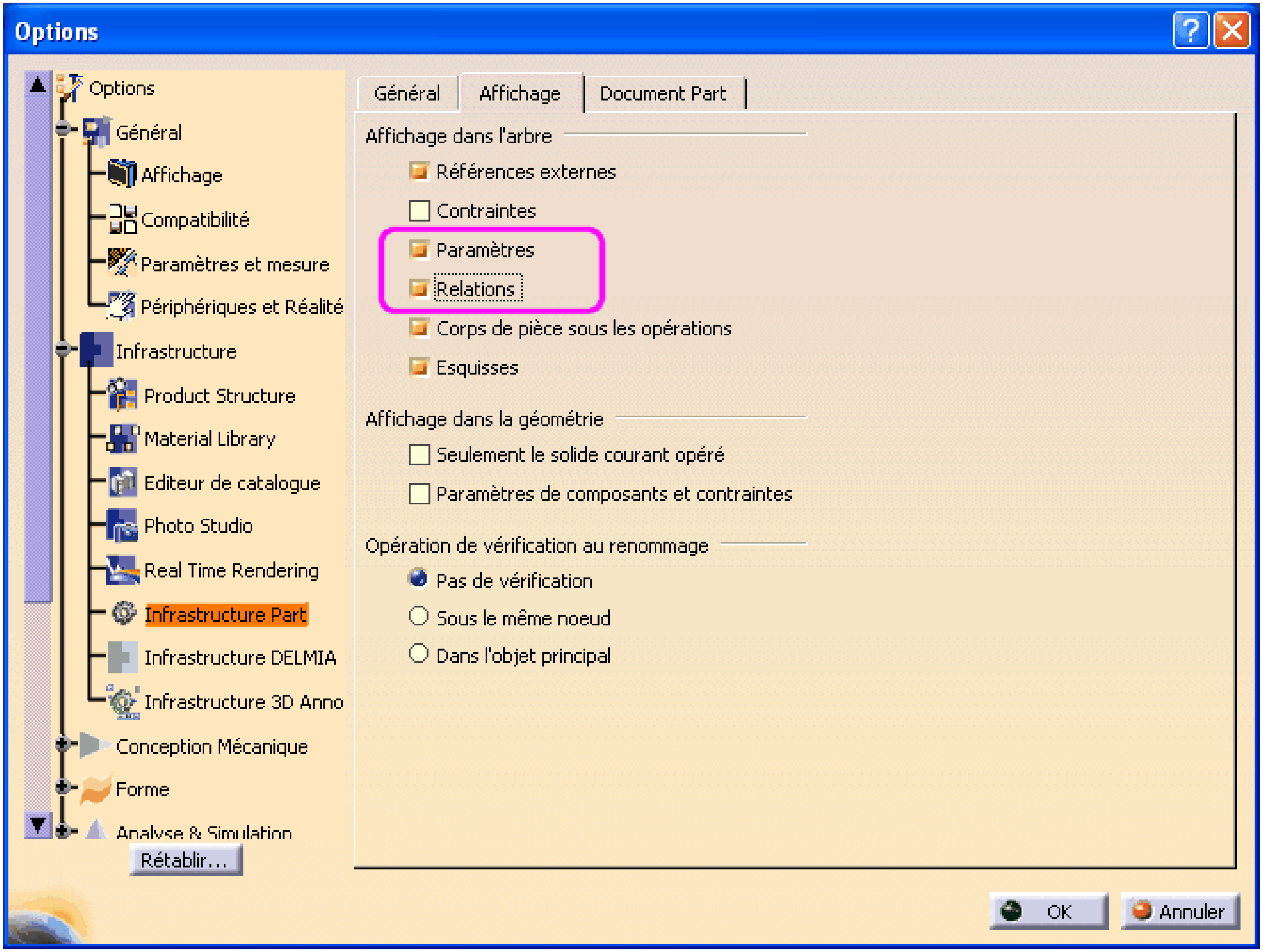
- Entre le cercle de pied et les flancs des dents,
  prévoir un petit congé de raccordement pour atténuer l'usure en fatigue.

Formule N° 14: explication de x = rb * cos(t) + rb * t * sin(t):

- Le premier terme correspond à une rotation suivant le cercle de base.
- Le second correspond au déroulement de la développante.

3 Enable the display of the parameters and formulas

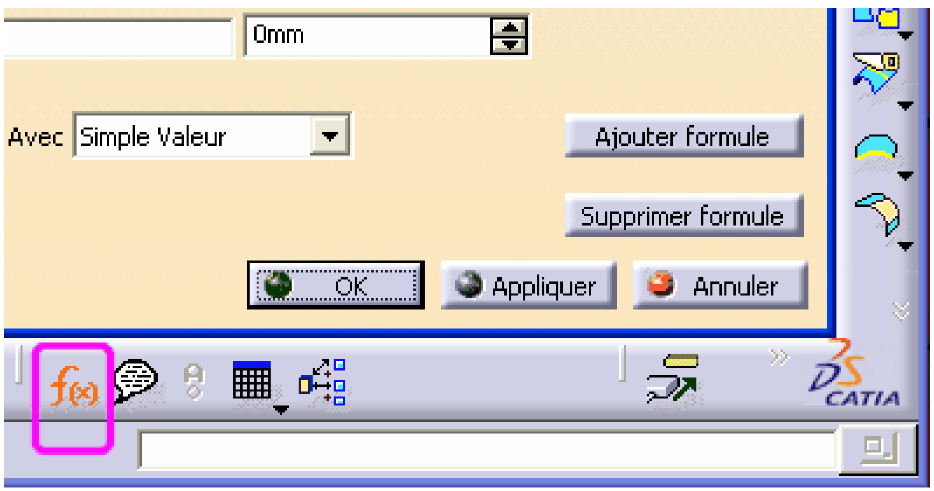
We first need to configure Catia: set the 2 highlighted check boxes:



Now the tree of your part should look like this:

4 Define the generation parameters

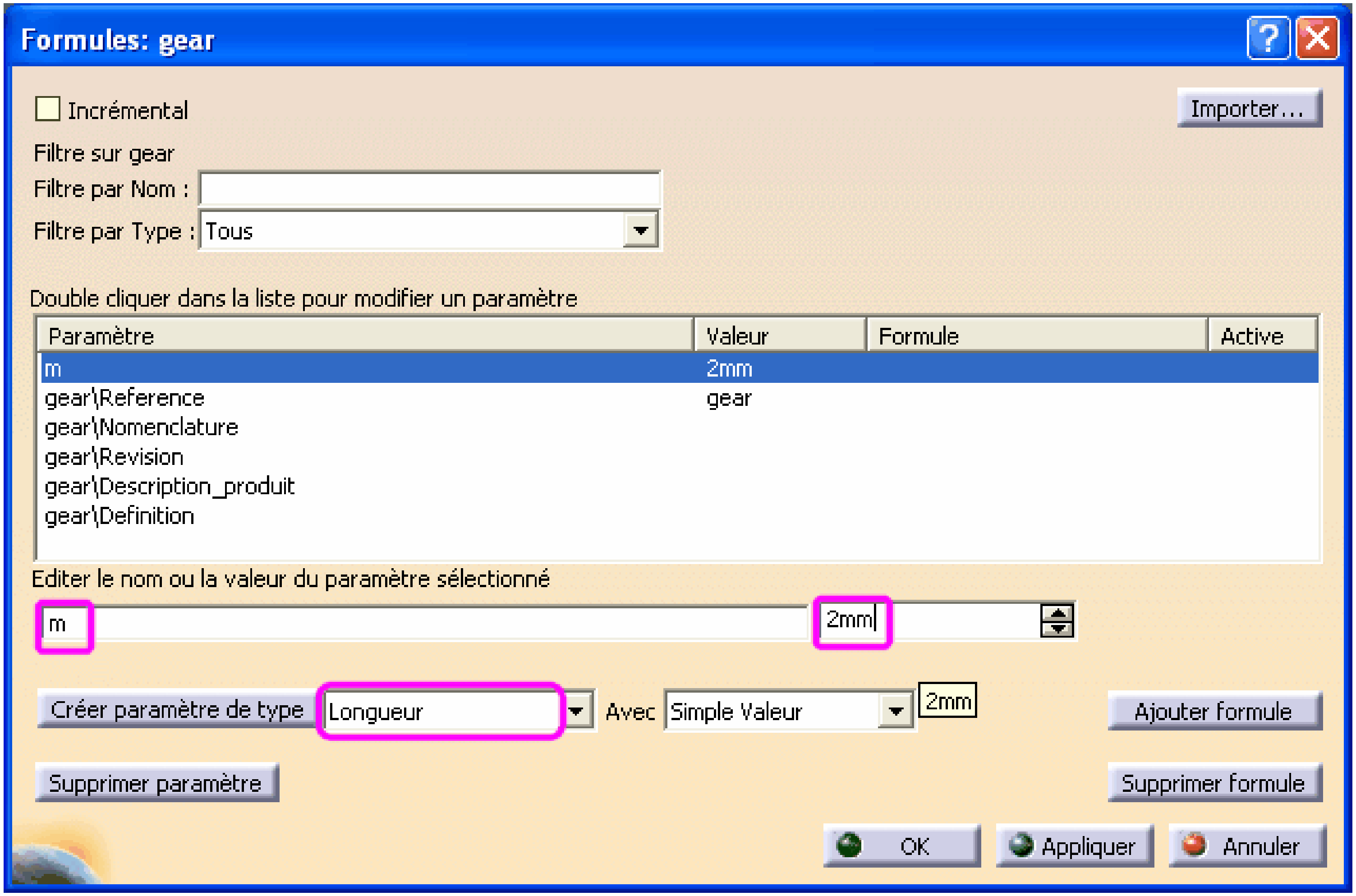
Switch to the Generative Shape Design workshop and click on the f(x) button:



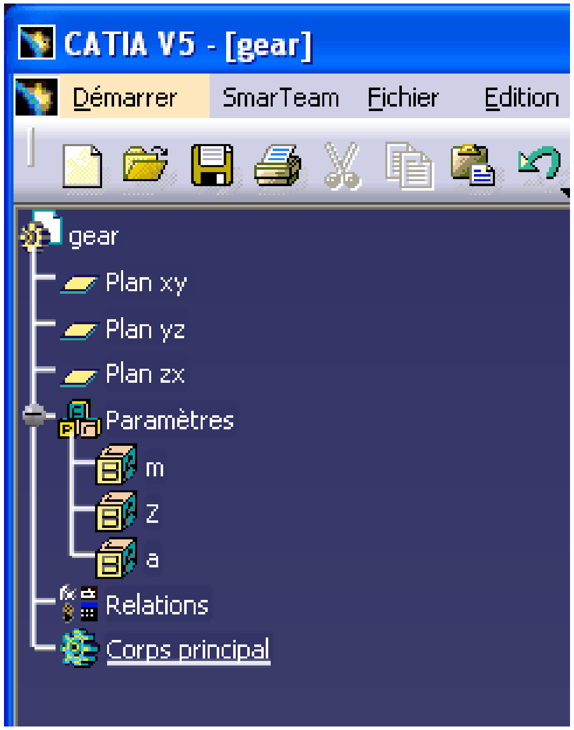
Then you can create the gear generation parameters:

1. Select the unit (integer, real, length, angle, ...).
2. Press the create parameter button.

3. Enter the parameter's name.
4. Set the initial value, used only if the parameter has a fixed value.

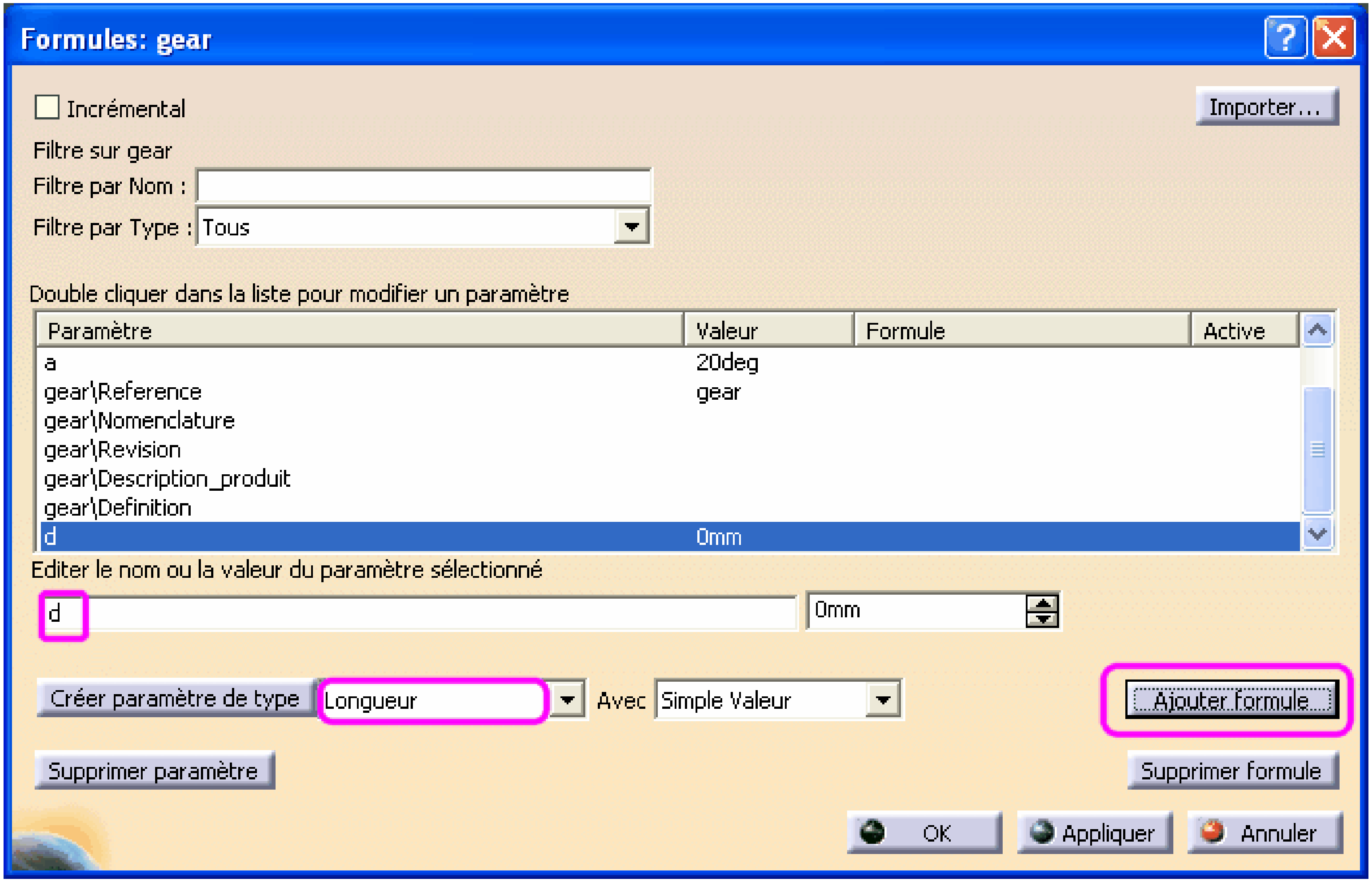


Now your tree should look like this:



5 Define the computed parameters

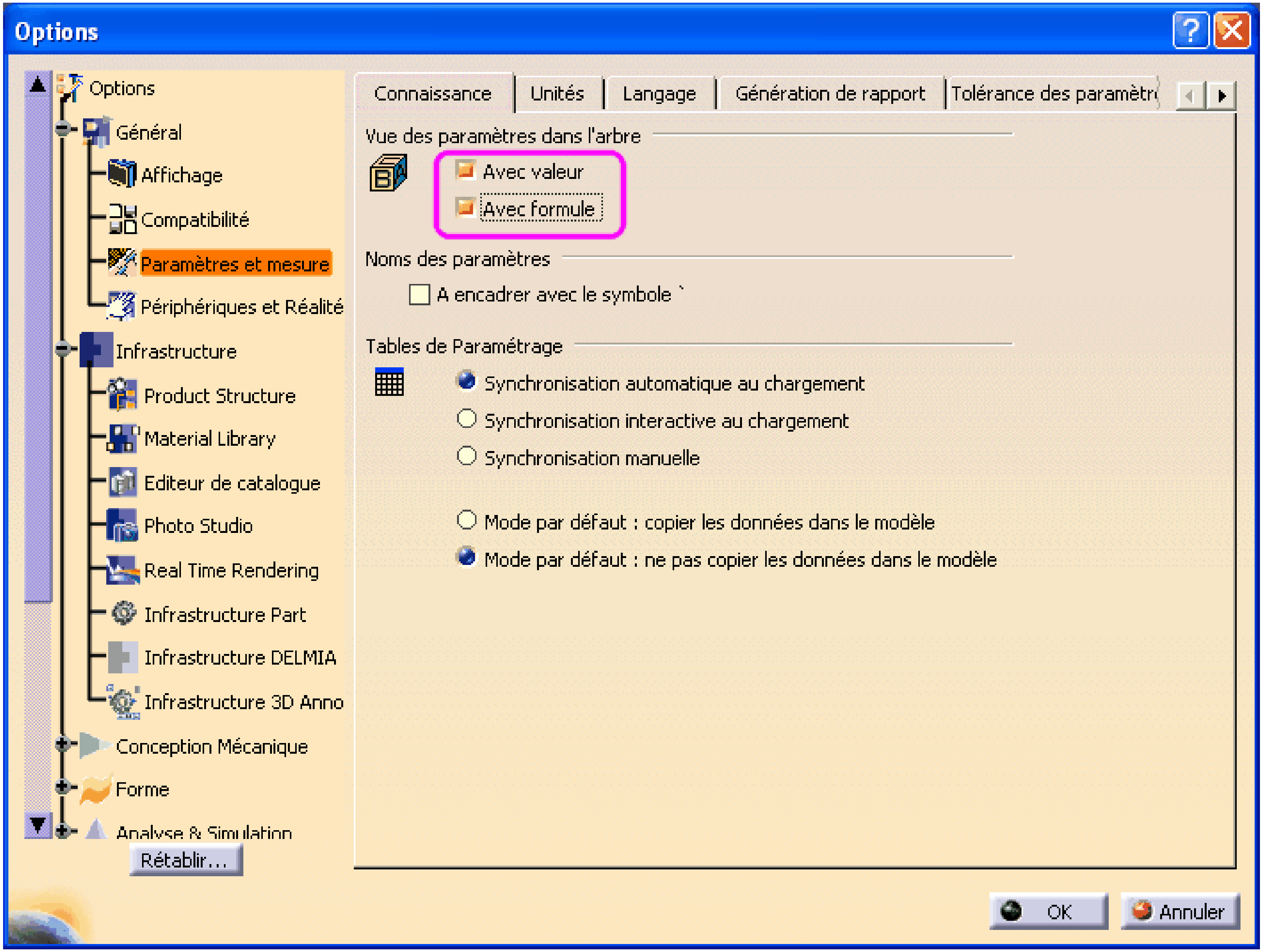
Most of the geometric parameters are related to a, m, and Z.
You don't need to assign them a value, because Catia can compute them for you.
So, instead of filling the initial value, you can press the add formula button:



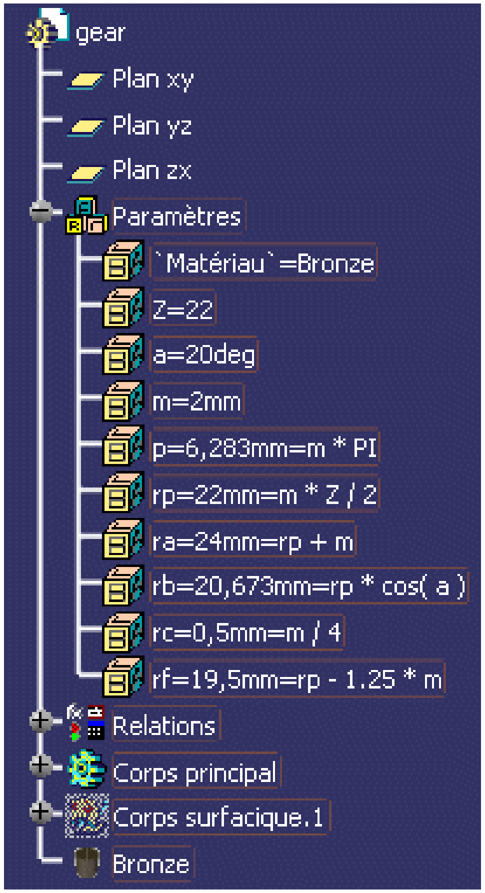
Then you can edit the formula:

6 Check the fixed and computed parameters

Set the following option in order to display the values and formulas of each parameter:



Now your tree should display the following parameters and their formulas:

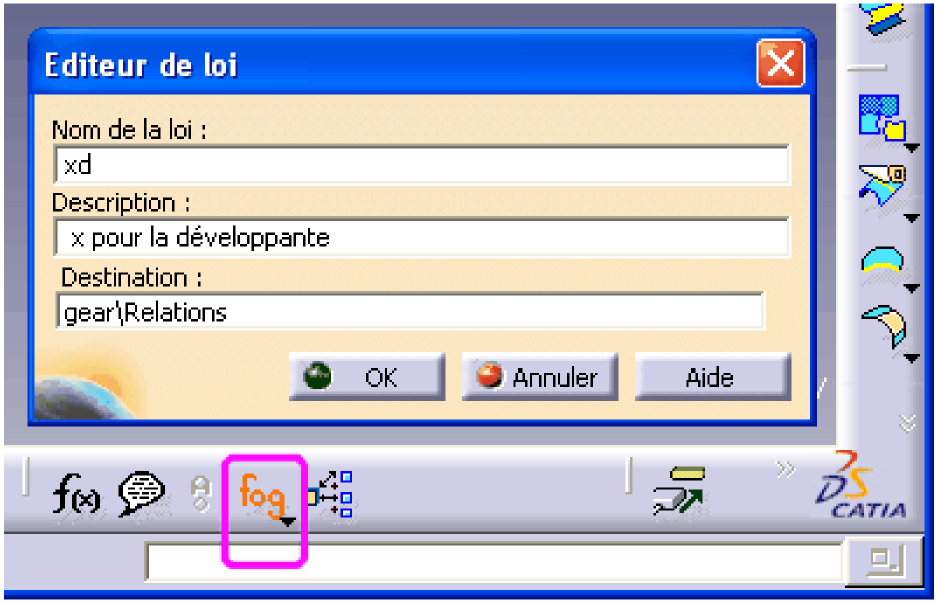


7 Define the parametric laws

Up to now, we have defined formulas for computing parameters.
Now we need to define the formulas defining the {X,Y} position of the points on the involute curve of a tooth.

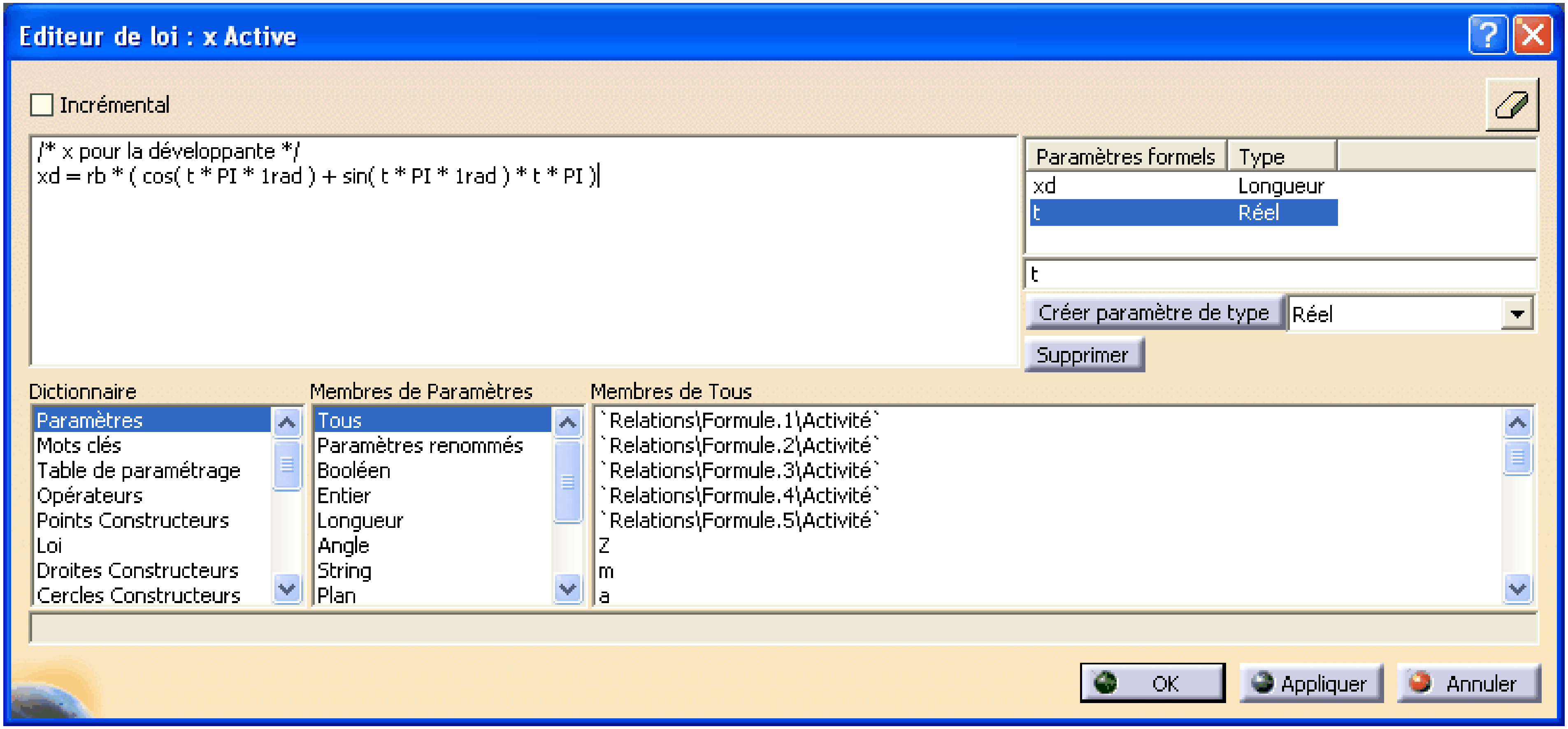
We could as well define a set of parameters x0, y0, x1, y1, ... for the coordinates of the involute's points.
However, Catia provides a more convenient tool for doing that: the parametric laws.

In order to create a law, press the fog button and enter the law name as follows:



Then edit the formula of the 2 laws used for the X and Y coordinates of the involute curve:

- xd = rb * (cos(t * PI * 1rad) + sin(t * PI * 1rad) * t * PI)
- yd = rb * (sin(t * PI * 1rad) - cos(t * PI * 1rad) * t * PI)



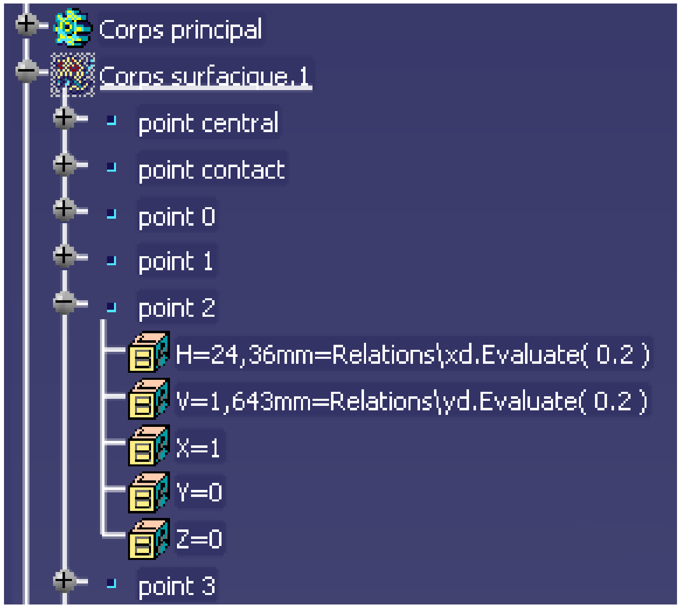
Notes about the formula editor of Catia:

- The trigonometric functions expect angles, not numbers, so we must use angular constants like 1rad or 1deg.
- PI stands for the π number.

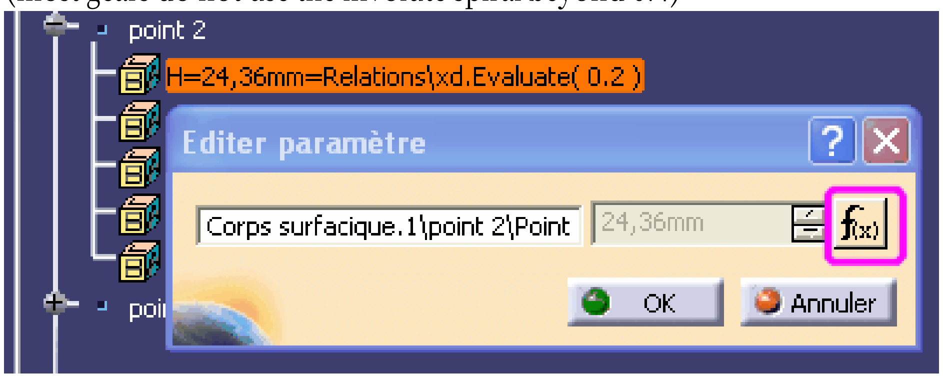
8 Make the geometric profile of a single tooth

The whole gear is a circular repetition of the tooth pattern.
The following steps explain how to design a single tooth:

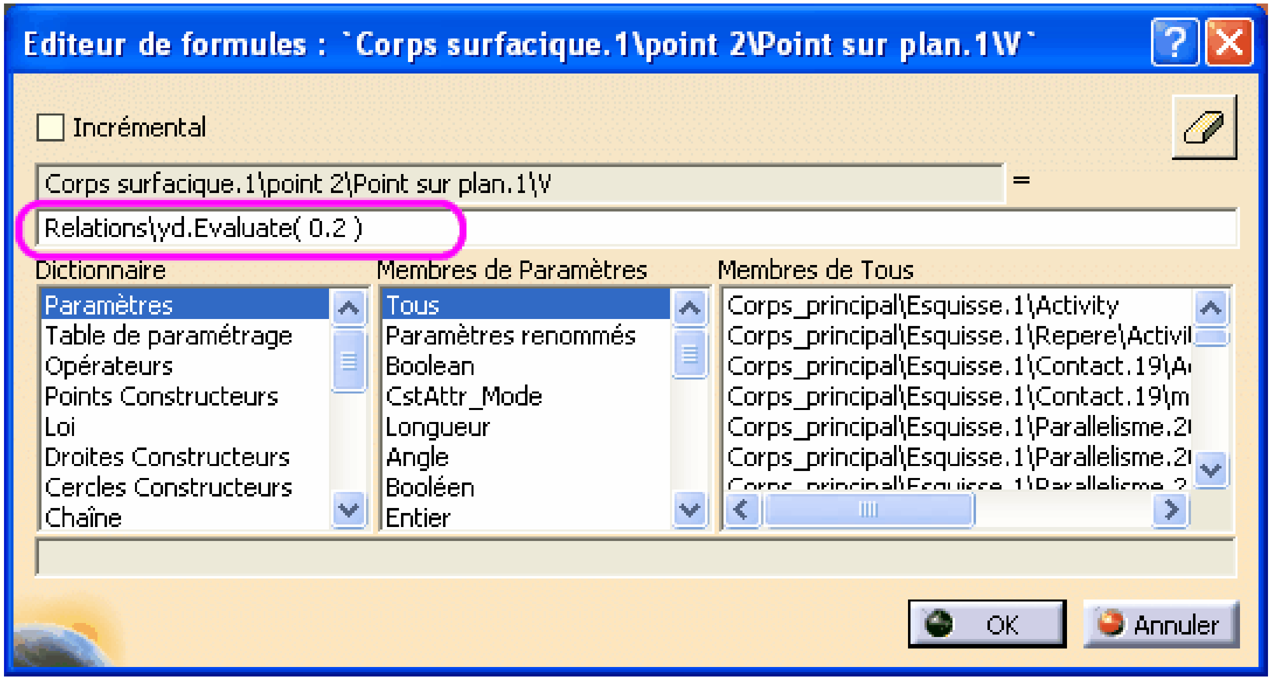
1. Define the parameters, constants and formulas (already done).
2. Insert a set of 5 constructive points, having a position defined by the xd(t) and yd(t) laws:
    - Define 5 points anywhere on the XY plane:



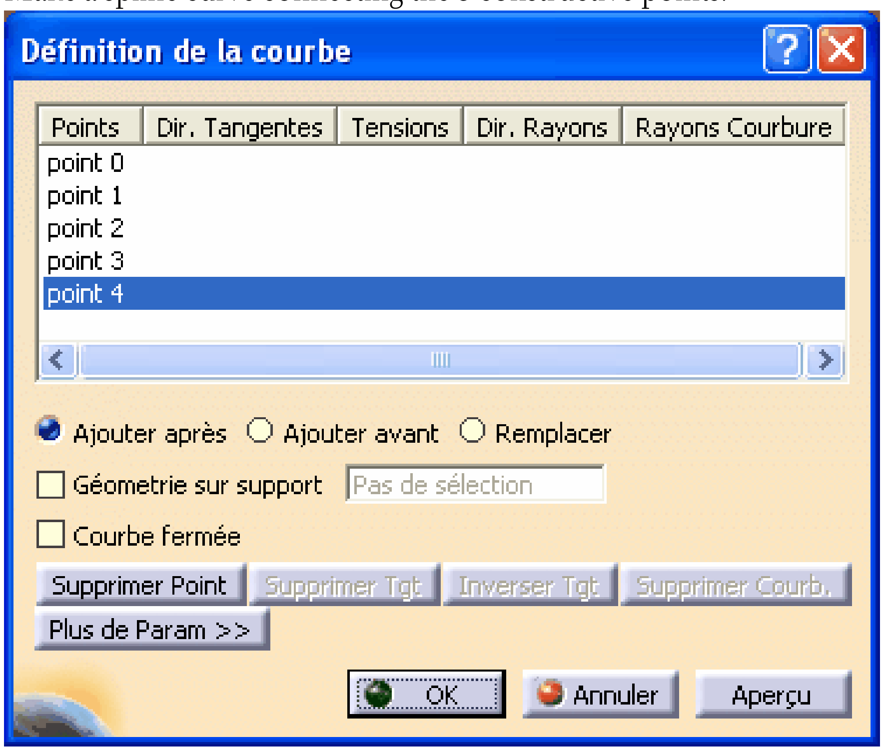
- Edit the H and V coordinates of the points for t = 0 to t = 0.4 (most gears do not use the involute spiral beyond 0.4)



- Compute the H and V coordinates of each point with a different value of the sweep parameter t.
- For example, for the V coordinate of the involute's point corresponding to t = 0.2:



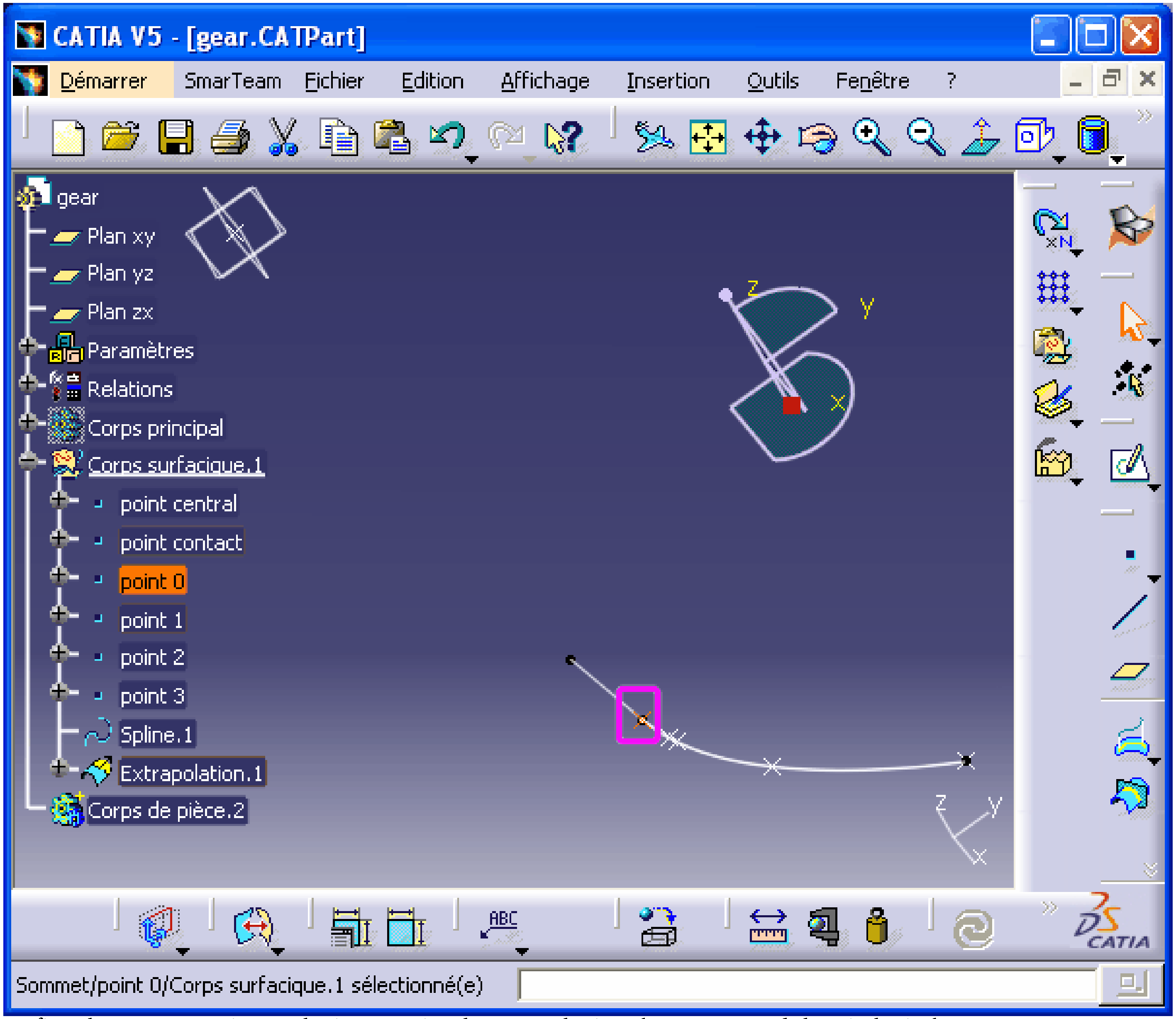
3. Make a spline curve connecting the 5 constructive points:



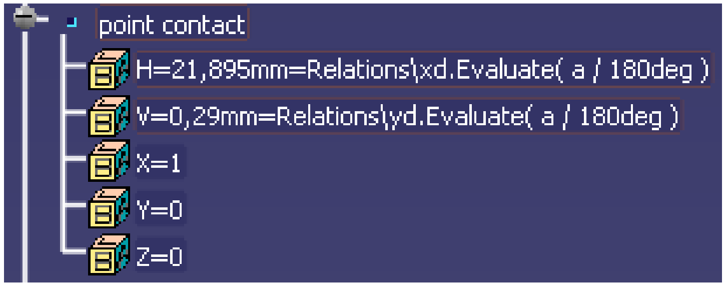
4. Extrapolate the spline toward the center of the gear:
   - The involute curve ends on the base circle of radius $rb = rp * \cos(20) \approx rp * 0.94$.

- When $Z < 42$, the root circle is smaller than the base circle. For example, when $Z = 25$:
  $rf = rp - hf = rp - 1.25 * m = rp * (1 - 2.5 / Z) = rp * 0.9$.
- So the involute curve must be extrapolated for joining the root circle
  (the length to extrapolate is empirically defined by the formula $f(x) = 2 * m$):

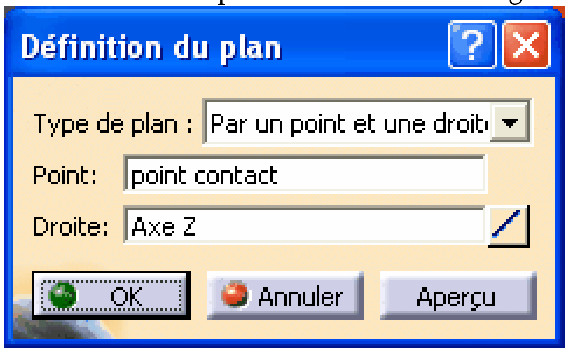
5. Check the extrapolation near the point zero of the involute spline:



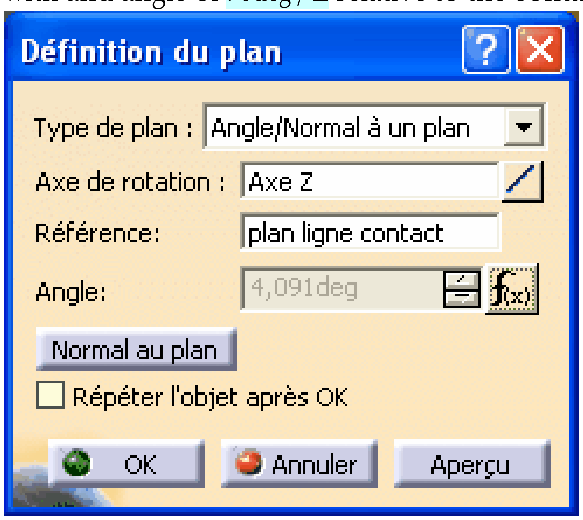
6. Define the contact point, at the intersection between the involute curve and the pitch circle:
    - By principle, on that point the polar angle equals the pressure angle.
    - At the contact point we have the sweep parameter t = a / 180deg
    - So we can compute it like the previous constructive points p0 ... p3:



7. Define a contact plane that contains the gear axis and the contact point:



8. Define the median plane of a tooth:
   - On a symmetric gear, the angular width of each tooth is 180deg / Z.
   - So the angle between the median plane and the contact plane is twice smaller: 90deg / Z.
   - The median plane is defined as a plane containing the rotation axis, with and angle of 90deg / Z relative to the contact plane:



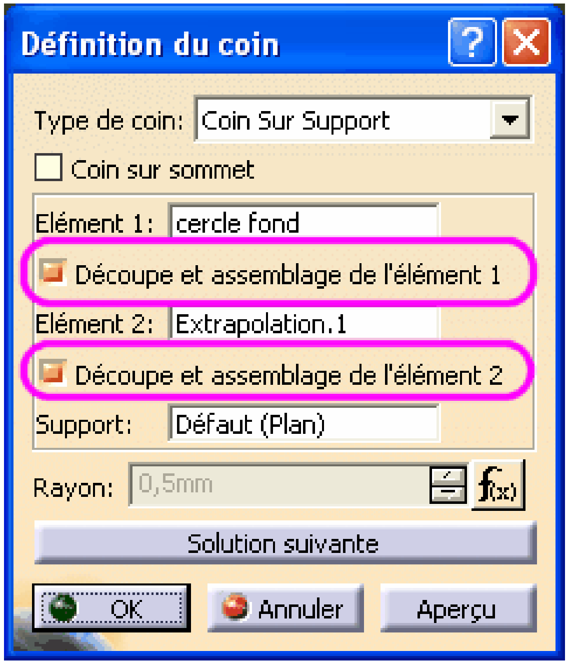
9. Define the start plane of a tooth:
   - We are designing a single tooth.
   - The profile of each tooth starts on the root circle, at the midpoint between two consecutive teeth.

- The start plane is defined as a plane containing the rotation axis, with and angle of -90deg / Z relative to the contact plane.
- As you can see, it is symmetric to the median plane, relative to the contact plane.

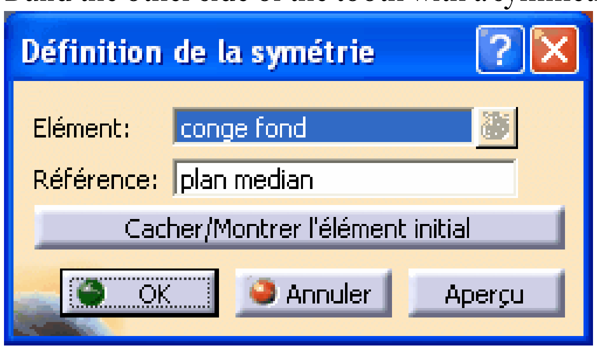
10. Draw the root circle:
    - On the start plane, define the start point of the root circle :
        - V = 0
        - H = - rf = -(rp - hf) = -rp + 1.25 * m
          (or the opposite, depending on the normal direction on that plane)
    - Define the root circle with the "Center-Point" dialog box:
        - Center = 0,0,0
        - Point = the start point defined above.
        - Sweep angle = 0 to 90deg.

    - 

11. Insert a round corner between the root circle and the extrapolated spline:
    - Set the cut and assemble check boxes, so that the resulting shape is a single curve that contains the root circle, the round corner and the extrapolated spline:

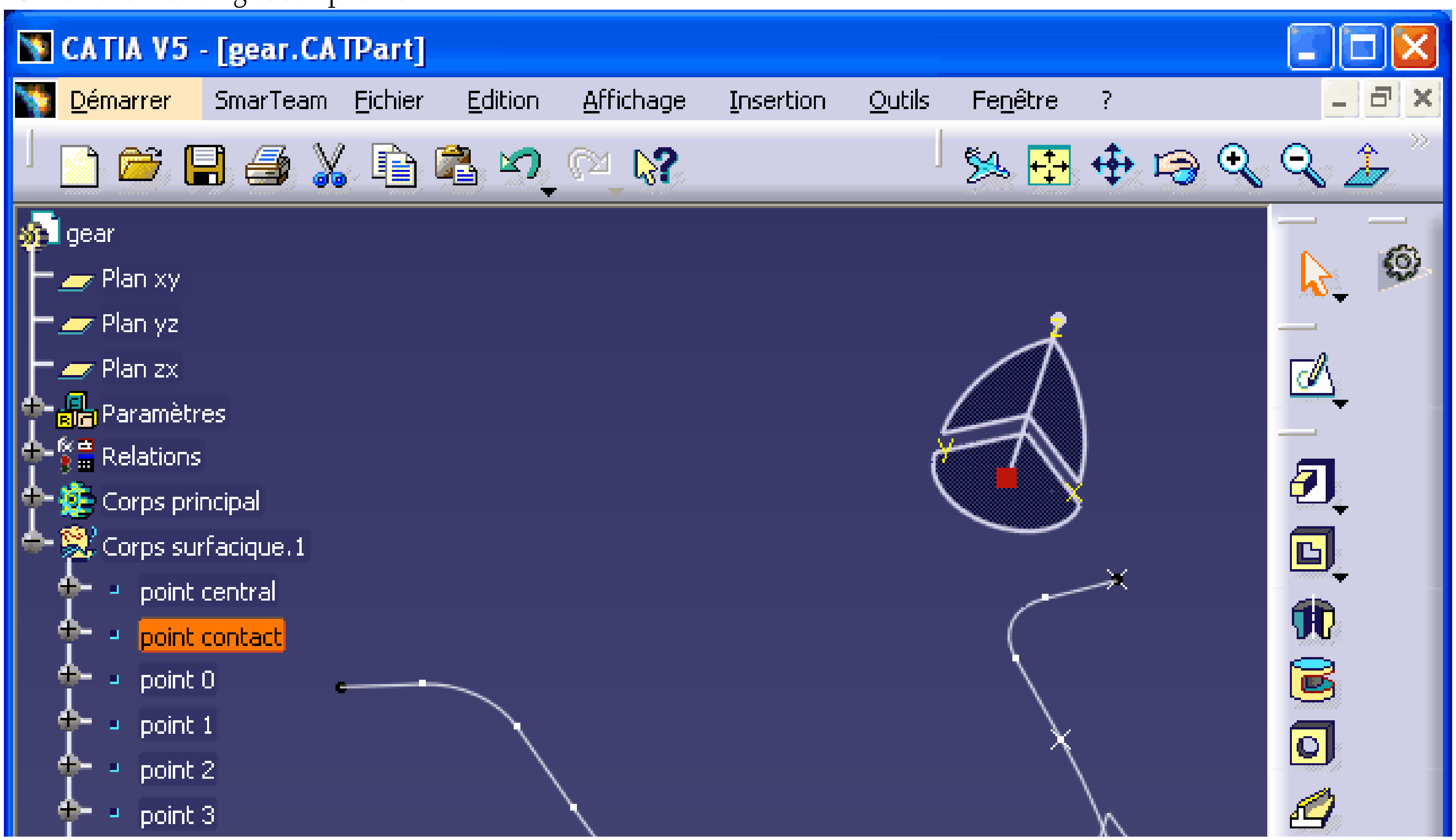
- 

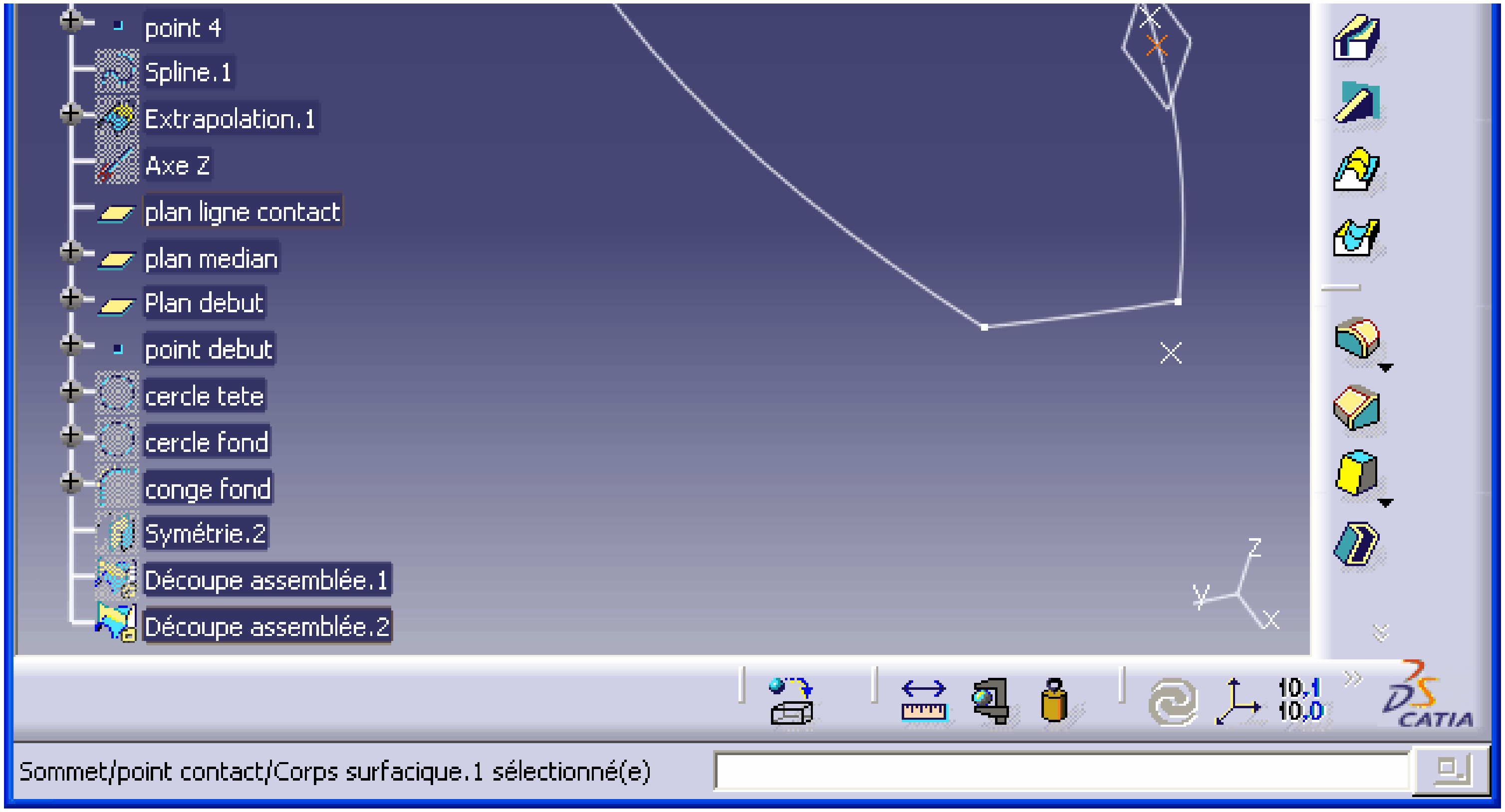
12. Draw the outer circle with the Center-Radius dialog box:
    - Center = 0,0,0
    - Support = XY plane
    - Radius = ra = rp + ha = rp + m
    - Sweep angle = 0deg to 90deg.
13. Build the other side of the tooth with a symmetry of the corner curve:



14. Glue both symmetric profiles and the outer circle with 2 successive cut and assemble operations:

15. Check the resulting tooth profile:



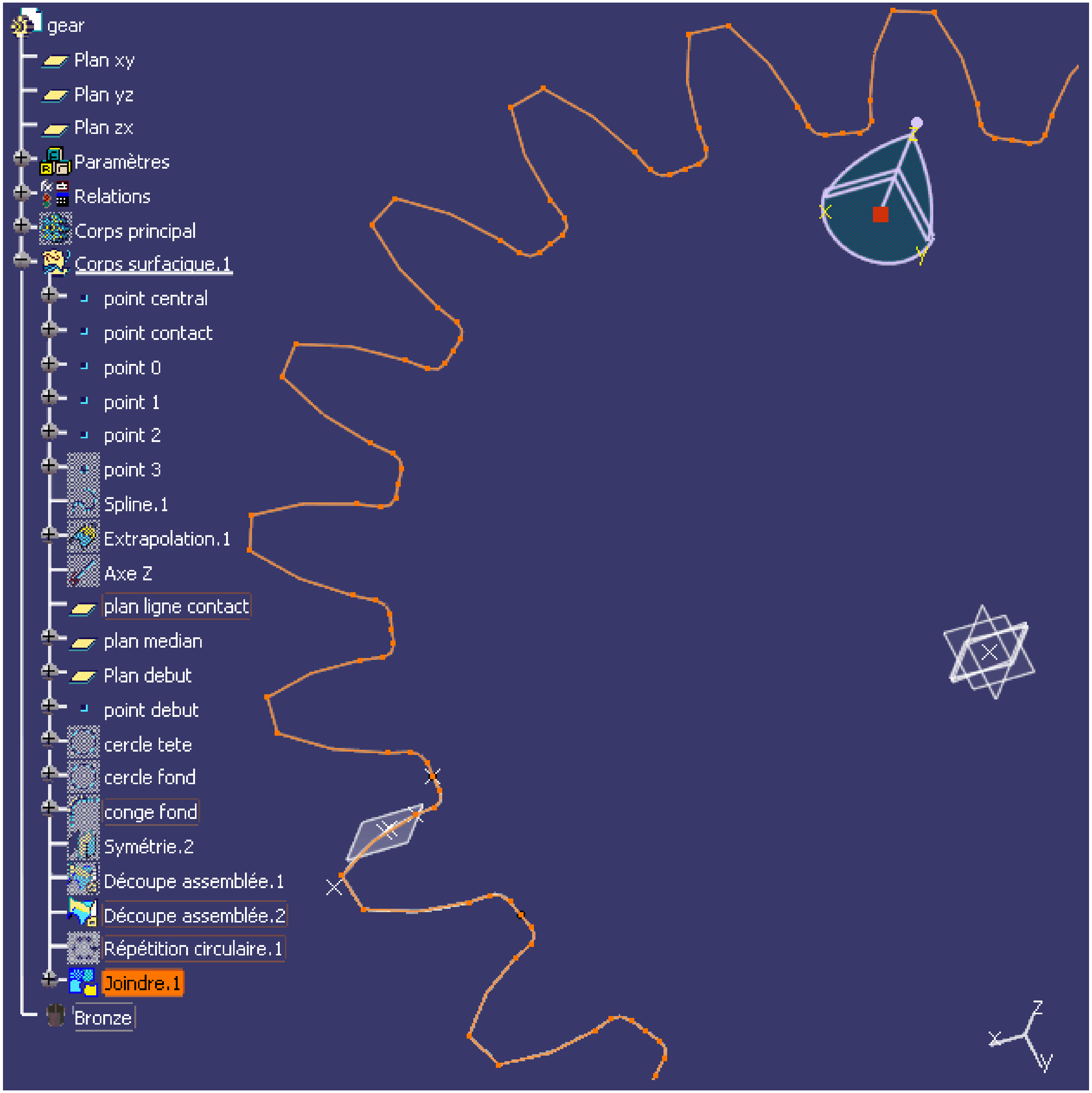


9 Build the whole gear profile

The gear profile is just a circular repetition of the tooth:

- Repetition mode: whole circle or whole crown.
- Rotation axis : Z.
- Number of instances: f(x) = Z.

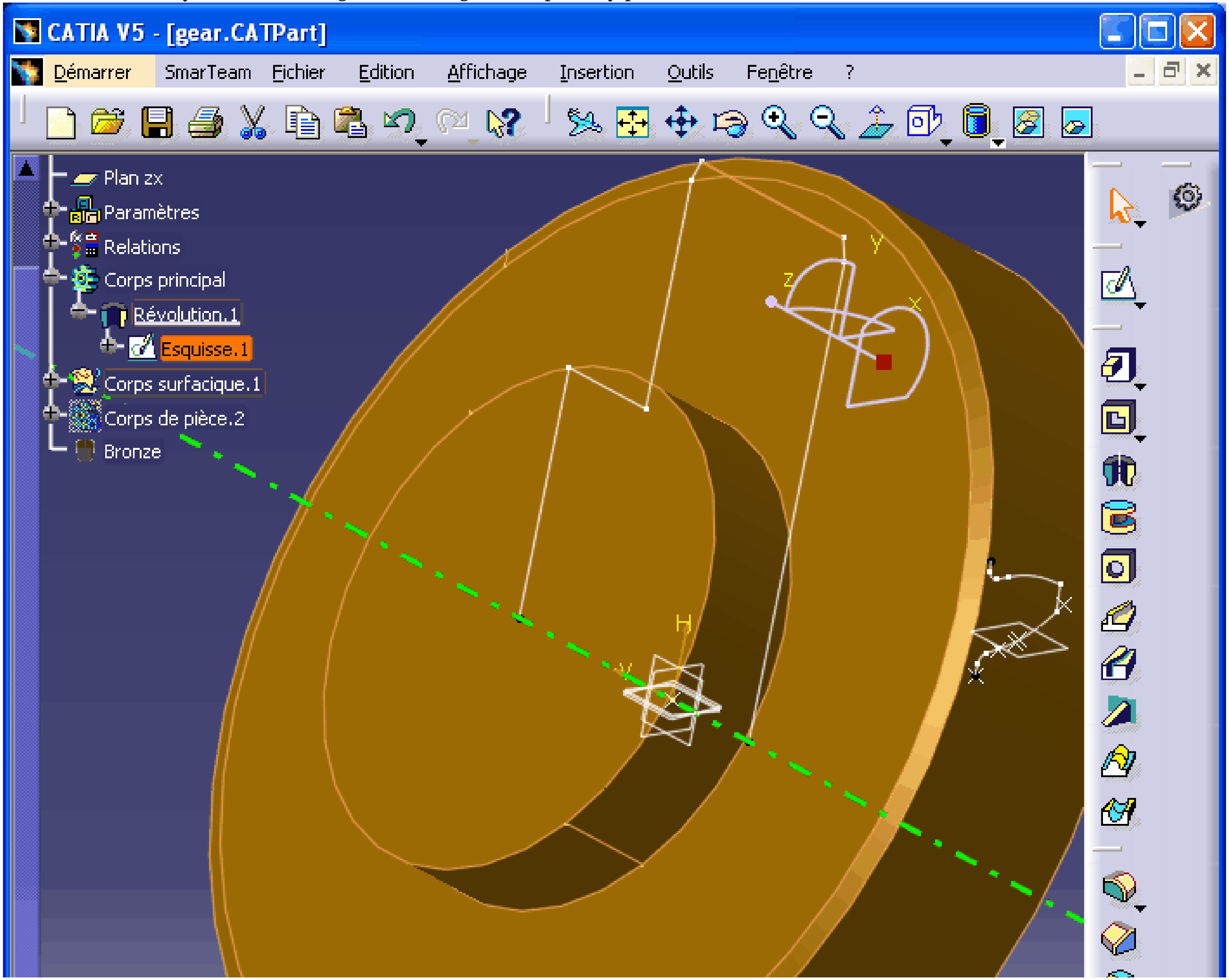
Then you can merge together the repeated profile and the tooth base profile.
The following tree shows the completed geometry, ready for the extrusion:

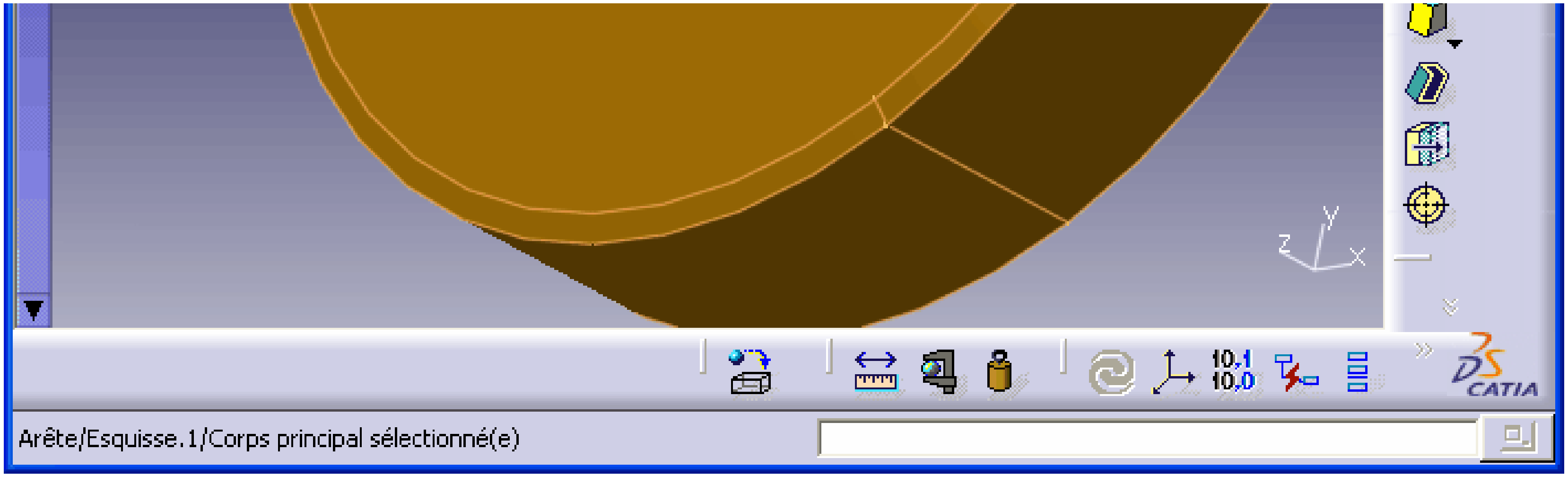

gear
Plan xy
Plan yz
Plan zx
Paramètres
Relations
Corps principal
Corps surfacique.1
point central
point contact
point 0
point 1
point 2
point 3
Spline.1
Extrapolation.1
Axe Z
plan ligne contact
plan median
Plan debut
point debut
cercle tete
cercle fond
conge fond
Symétrie.2
Découpe assemblée.1
Découpe assemblée.2
Répétition circulaire.1
Joindre.1
Bronze

10 Build the gear part body

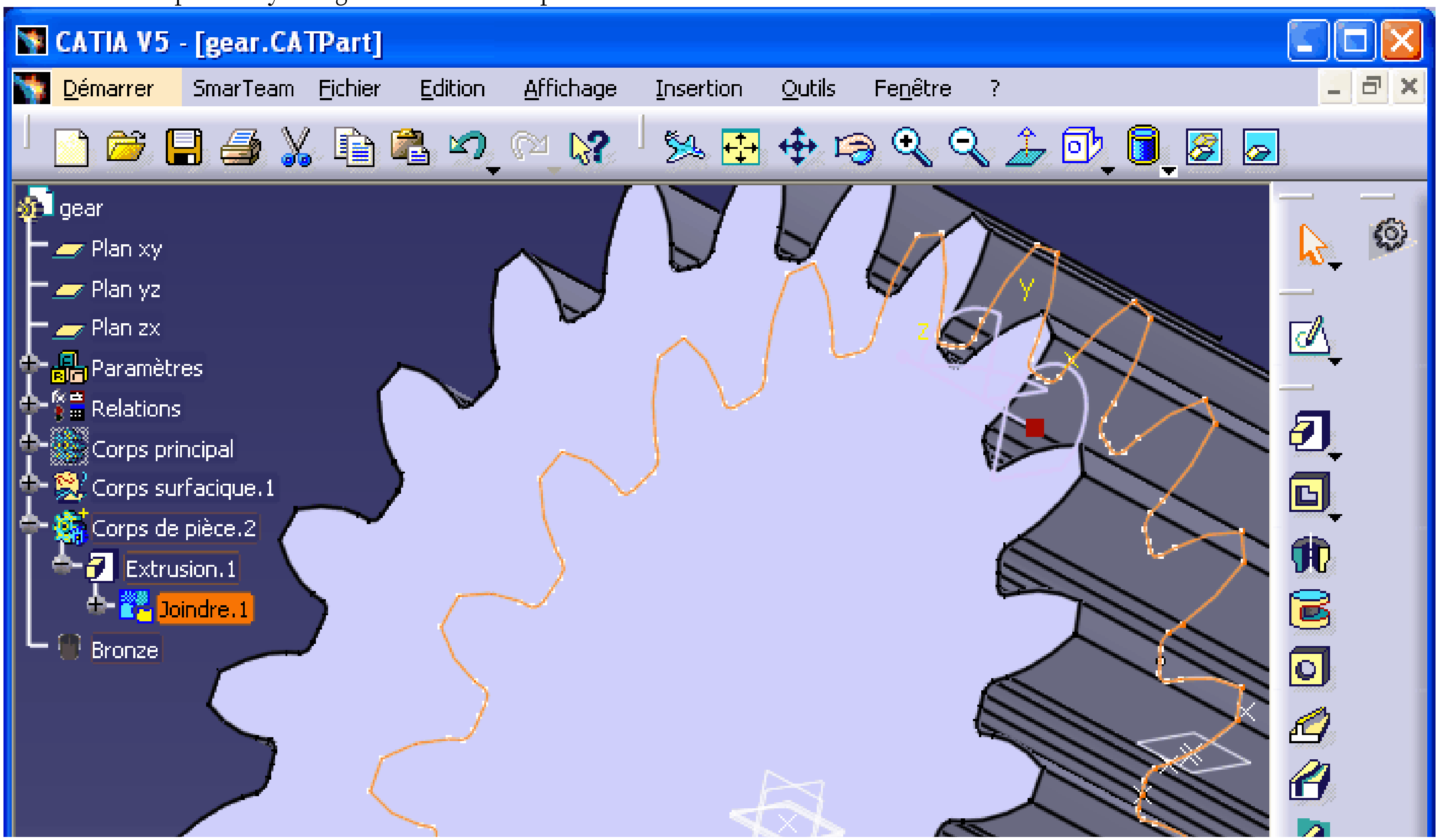
Switch to the Part Design workshop.

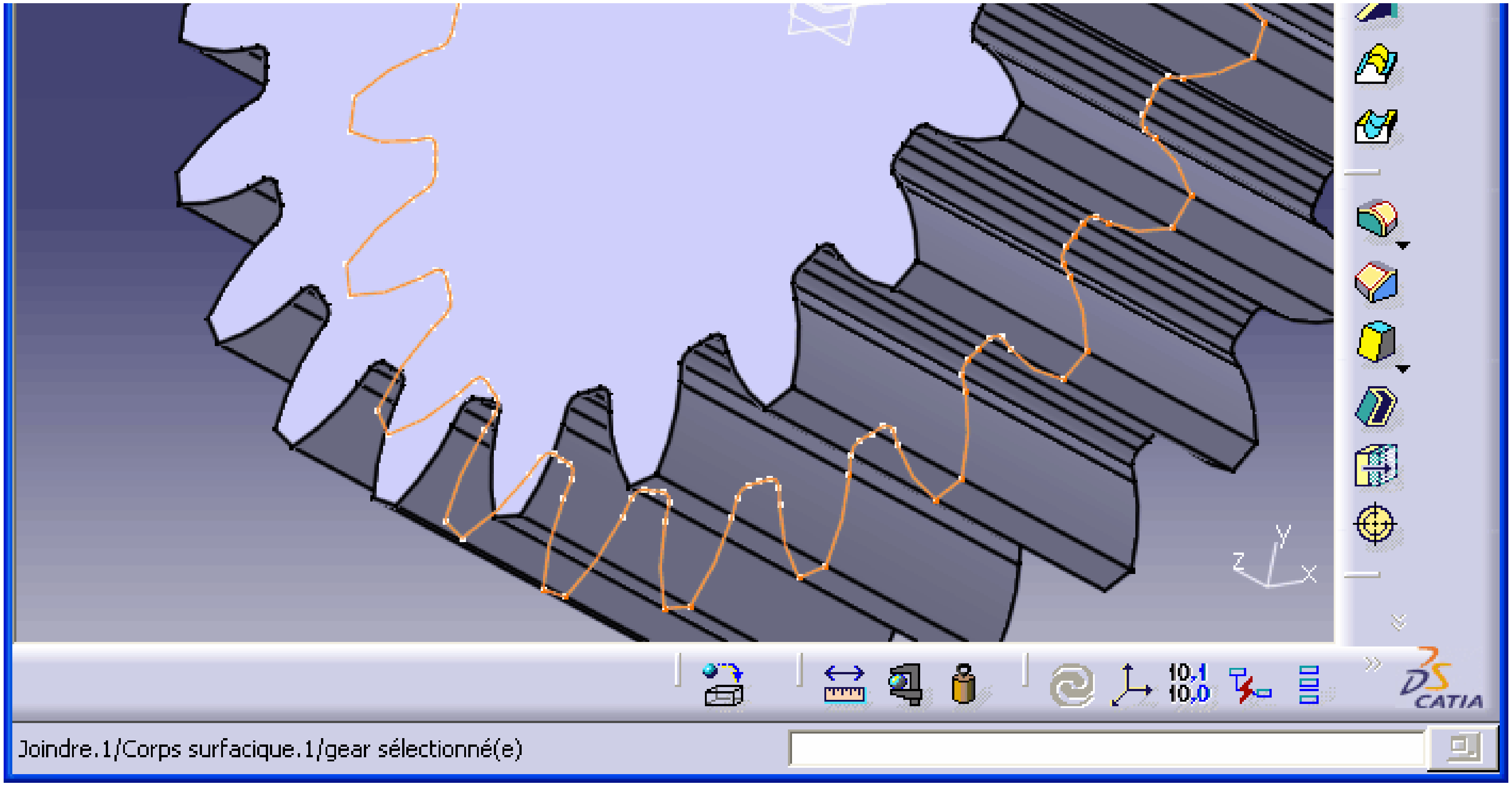
Build the main body with a revolving sketch that gives the primary part to be machined on a lathe:



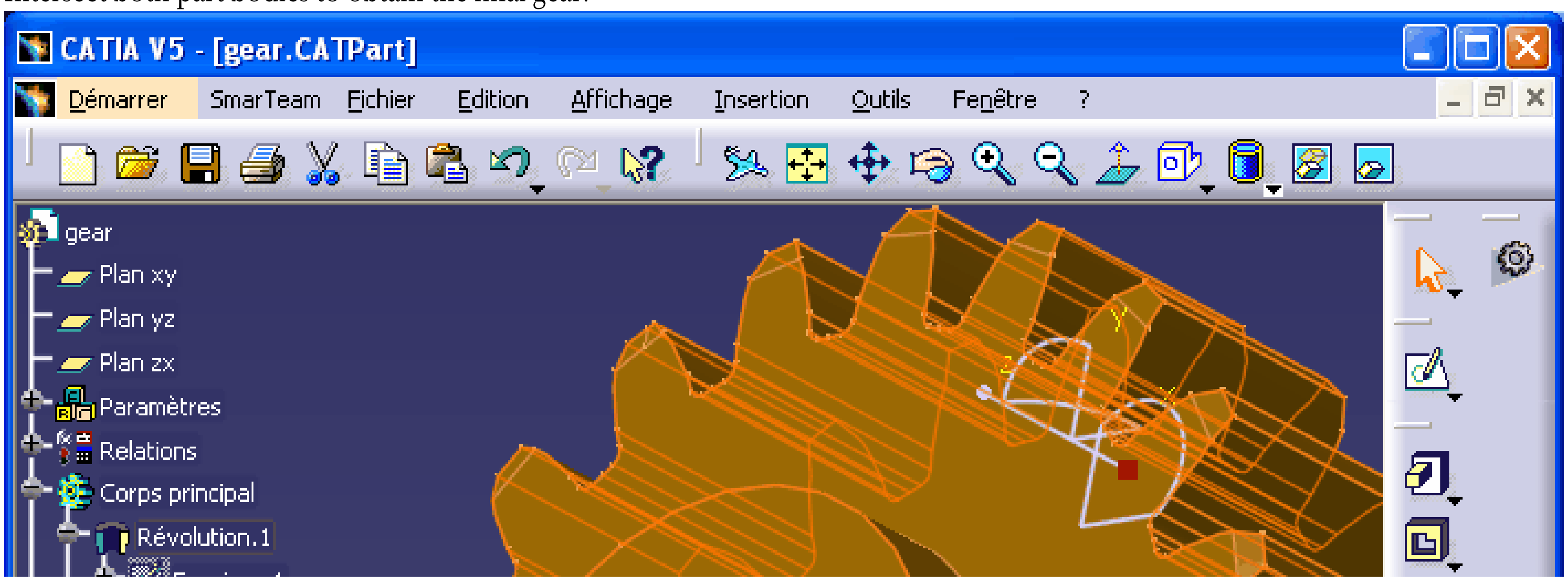


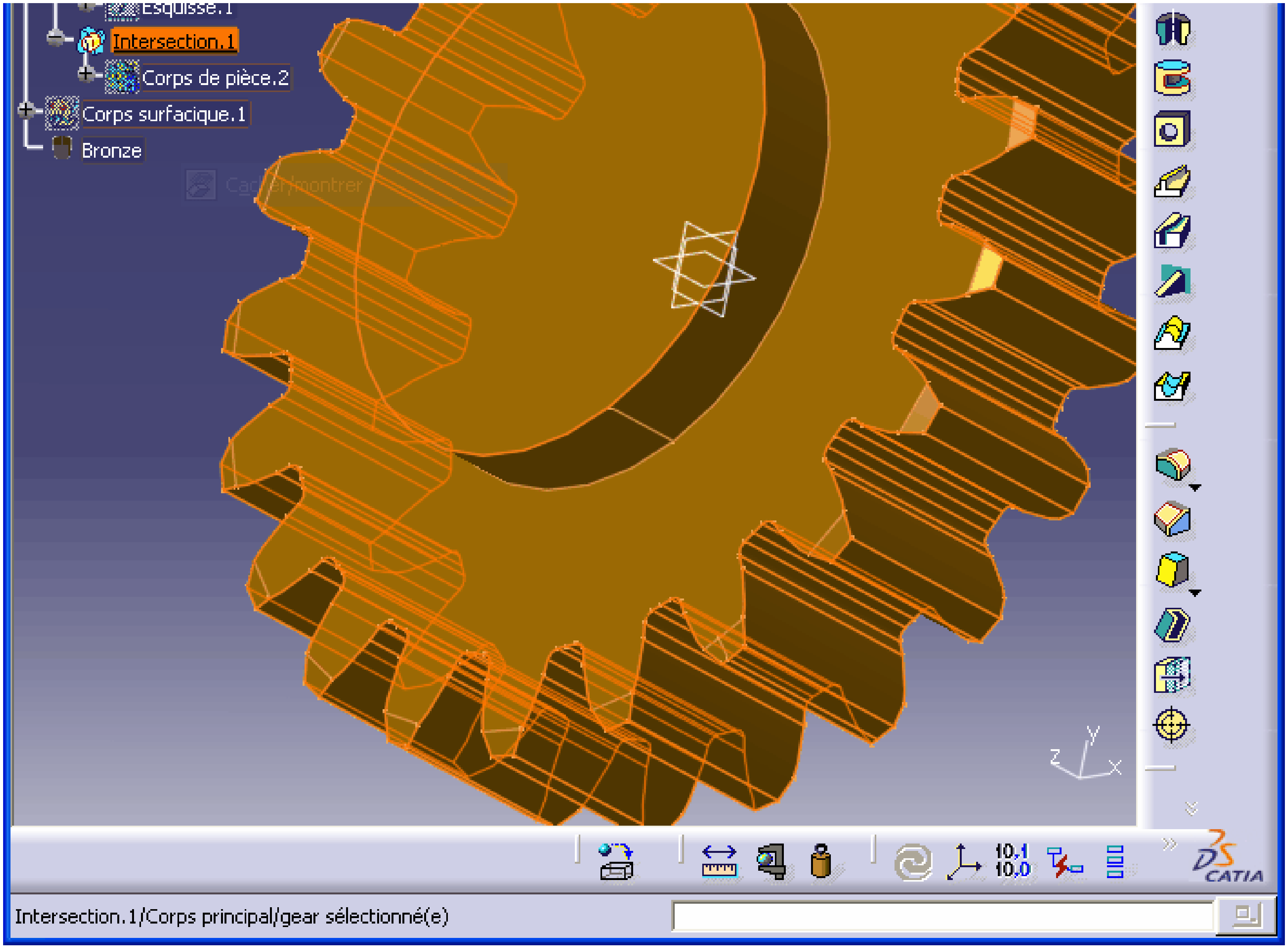
Insert a second part body that gives the extruded profile of the teeth:



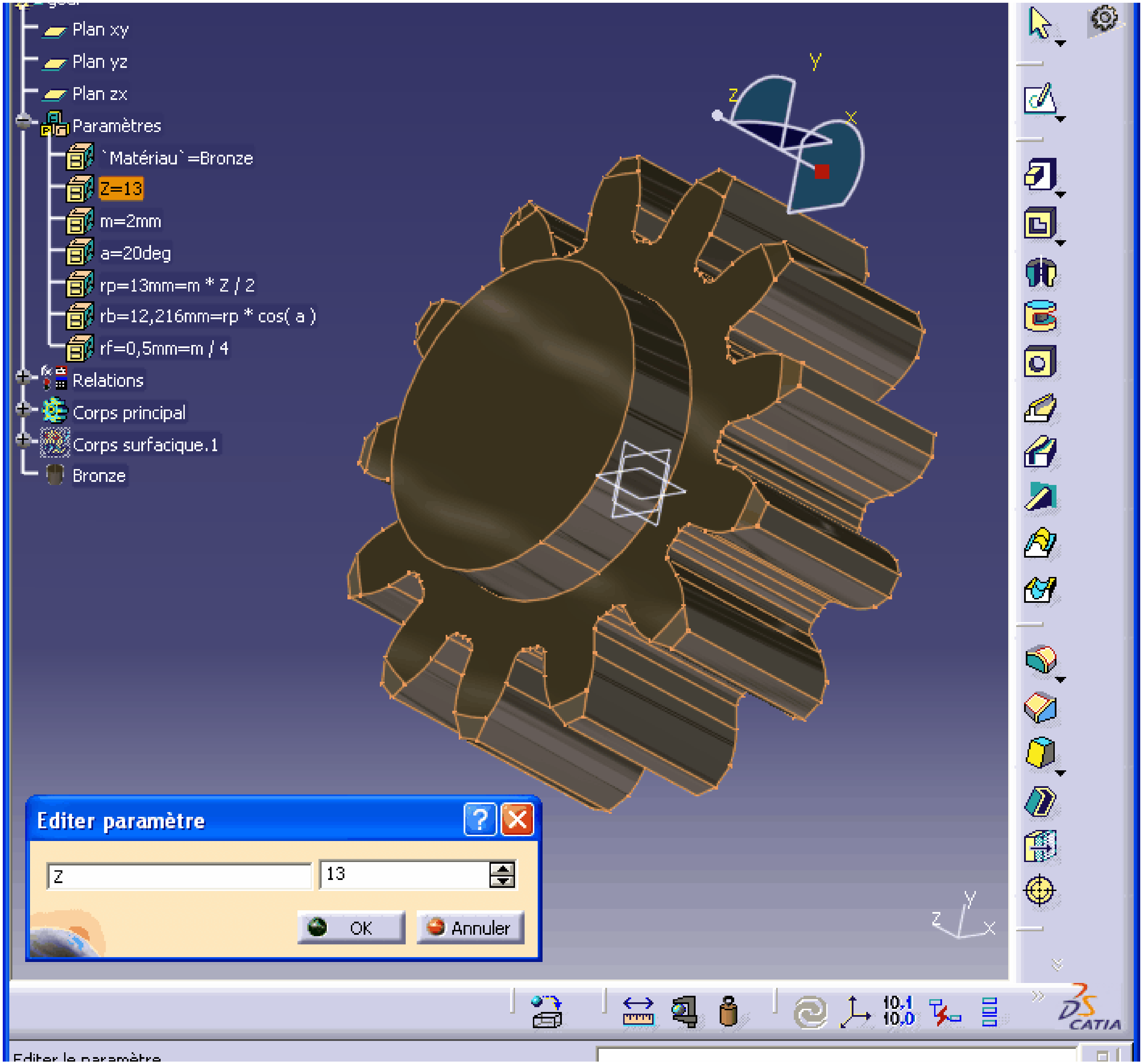


Intersect both part bodies to obtain the final gear:





Now you can play with the Z and m parameters and generate any spur gear:


Plan xy
Plan yz
Plan zx
Paramètres
`Matériau`=Bronze
Z=13
m=2mm
a=20deg
rp=13mm=m * Z / 2
rb=12,216mm=rp * cos(a)
rf=0,5mm=m / 4
Relations
Corps principal
Corps surfacique.1
Bronze
Editer paramètre
Z
13
OK
Annuler
CATIA

End of File