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Involute Spur Gear Template Development by Parametric Technique Using Computer Aided Design *(Pp. 415-429)*

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Abstract

There are many methods available for developing profiles of gear and spline teeth. Most of the techniques are inaccurate because they use only an approximation of the involute curve profile. The parametric method developed in this paper provides accurate involute curve creation using formulas and exact geometric equations. In addition, the involute curve by equation technique allows using either Cartesian in terms of X, Y, and Z or cylindrical coordinate systems to create the involute curve profile. Since spur gear geometry is controlled by a few basic parameters, a generic gear can be designed by three common parameters namely the pressure angle (a), the module (m), and the number of teeth (z). Most of the present day CAD systems have no built-in tool for designing such gears. This paper is an attempt in utilizing the concept of parametric technology to develop a template gear. The gear so developed has true involute profile, which is a realistic design. This will allow making changes to the gear design by using *parametric input. If one gear file is developed using this parametric technology, with which, different size and variety of spur gears can be created. The specific objective is to design and develop a template spur gear with 3 module, 30 Teeth, 20° pressure angle based on parametric technique by using CATIA V5R14 package. The later portion it is shown how this model may be retrieved and utilized for developing gears of different modules and number of teeth with change in these input parameters.*

Keywords: Parametric design, Template gear, involute curve, x and y co-ordinates, Laws for x and y co-ordinates, Extrapolated spline, circular pattern, extrusion

Introduction

Template gear development using parametric method means that the dimensions control the shape and size of the gear. The template gear should have the ability to be modified, and yet remain in a way that retains the original design intent. The logical modifications which can be carried out will be the number of teeth and module. Since the design is parametric it is possible to create a variety of spur from one model (Earnest L. Walker and Bruce Cox, 1999). The involute gear is based on an involute curve, which is a mathematical shape. The involute profile is the path traced by unwrapping a string that is wound over a cylinder by maintaining its tension. There are many methods available in creating the involute profile. Method 1 is purely based on geometrical construction and is concerned in preparing the teeth profile individually for all the teeth in the gear, this takes longer time to complete the total profile of the gear and Method 2 is preparing one profile and by keeping this as template the other profiles are created. This method is adequate when ordinary representation of the gear is needed and not an accurate one. The third method and the most accurate system is the graphic method of drawing the involute. Though the procedure is laborious, it can be used for creating the uncorrected and corrected gear profiles. This could be also employed in developing form tools. (Gitin M. Maitra, 2000). Excel Spreadsheet can also be used to draw gears quickly and easily, it will be very useful in creating sets of gears for any projects that require accurate shapes and rapid prototyping of interlocking gears. Excel is a common program. The shortcomings are that any adjustments to the design cannot be immediately reflected in the program where the profile is generated. Instead, the new parameters must be entered into the Excel sheet, and then transferred to a plot file. It also needs to provide a visualization of what the new gear will look like, which needs an extra step in the HPGL/1 file transfer before the design becomes an actual model. (Joseph B. Ferreira, 2002)

Methodology

The methodology starts with study (Olberg, Erik, Jones et al;2000) and tabulating the mathematical relation for generating the involute profile and other parameters for the standard gear (Dudley, Darle W, 1984). The generative shape design work bench in CATIA V5R14 , is selected to create the geometrical set for the gear. The present work bench is configured for relations, parameters and metric units. The ZY plane (front) is selected for geometry creation. The f(x) icon is used to enter the primary generation parameters like module (m), Pressure angle (a), and the number of teeths (z). Followed which the dependant parameters like pitch circle radius (rp), base circle radius (rb), outer circle radius (ra), the root circle radius (rf), root fillet radius (rc) are keyed in. The fog command is activated and the parametric laws of Yd and Zd and entered. The origin point and axis along x direction is created. The Yd and Zd co-ordinates are referred from the parametric laws and a set of points P2 to P5 is created in the ZY plane. Joining these points creates the spline, which then is extrapolated towards the center. The extrapolated spline now is rotated to produce the symmetry of the profile with reference to ZX plane. The semi circle representing the outer and the root cirle is drawn. Create fillet radius at the root using the corner option. The split command is activated to prepare the portion of the profile, for this the outer circle, extrapolated spline and corner is used. Then the involute is mirrored using the symmetry option. The top land and other portions of the profile is created and joined as one profile using join option. Further, the profile is patterned using the circular pattern from the advanced repletion tools. The final gear profile is extruded using the pad option in the part workbench. The bore and keyway if necessary may be created. The table 1 contains the parameters and formulas used in the parametric definition of gear in the software. The gear is developed in the metric system (Dan Marsalek, 2005).

S1: Start and configure the generative shape design workshop: **Since the part design workshop is not sufficient for designing parametric curves, select the generative shape design workshop** Generative shape design: Start > Shape> Generative shape Design

S2: **After CATIA program is initiated – select** TOOLS>OPTIONS->infrastructure **> part infrastructure and in** Display select Parameters and Relations**.**

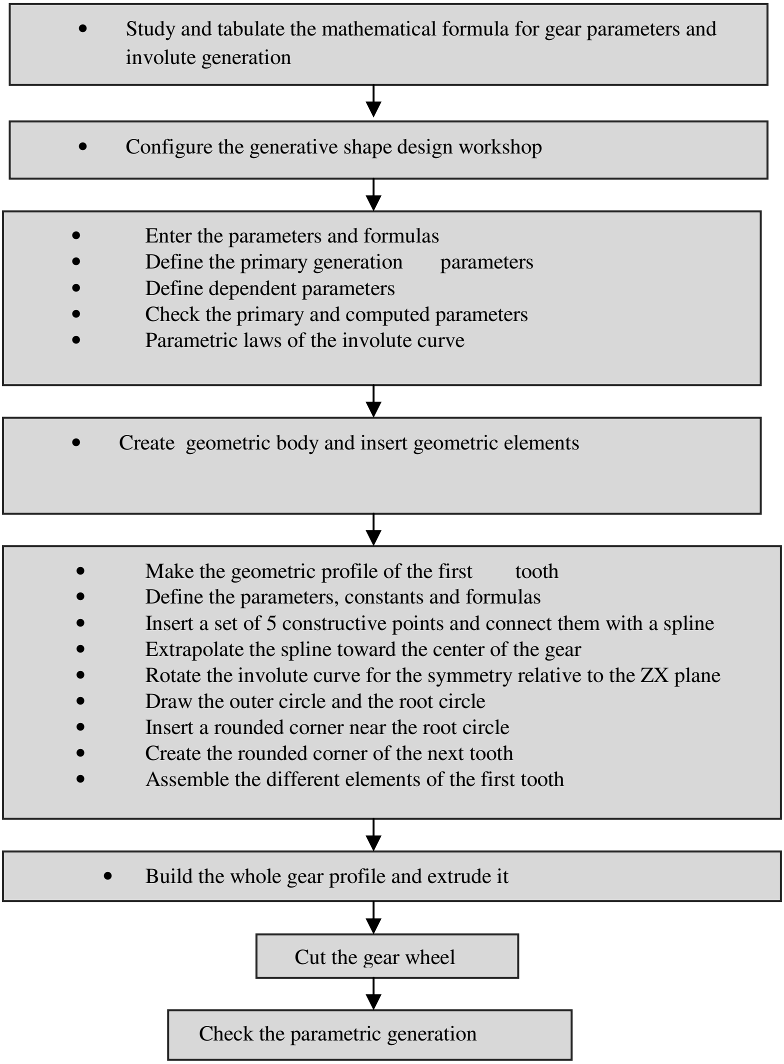
S3: **Then in** Options>General **in** Parameters and Measures **select** with value and with formula in Parameters **Tree View.** Click ok**. Bring the knowledge tool bar outside**

S4: **Click on arrow pointed down near table icon. Fog and f(x) are two most important things you will use for gear design**

S5: Entering the parameters – The Module (m), number of teeth (z), Pressure Angle (a) Enter some basic parameters that define gear. This is done by clicking at f(x) icon **Fig 2**. and then when you see dialog box: Formulas: 3 x 30 Spur gear. In the new parameters tab select (real, length or angle) and click it, and then edit value **Fig 3**. This is done until all parameters are entered.

P	Formula	Description/ Units used for construction
a	20deg	Pressure angle: technologic constant (10deg $\leq a \leq$ 20deg) / Angular degree
m	—	Modulue / millimeter
Z	—	Number of teeth ($5 \leq Z \leq 200$) / Integer
p	$m * \pi$	Pitch of the teeth on a straight generative rack / millimeter
e	$p / 2$	Circular tooth thickness, measured on the pitch circle / millimeter
ha	m	Addendum = height of a tooth above the pitch circle / millimeter
hf	if $m > 1.25$ $hf = m * 1.25$ else $hf = m * 1.4$	Dedendum = depth of a tooth below the pitch circle. Proportionally greater for a small modulus (≤ 1.25 mm) / millimeter
rp	$m * Z / 2$	Radius of the pitch circle / millimeter
ra	$rp + ha$	Radius of the outer circle / millimeter
rf	$rp - hf$	Radius of the root circle. / millimeter
rb	$rp * \cos(a)$	Radius of the base circle /millimeter
rc	$m * 0.38$	Radius of the root concave corner. ($m * 0.38$) is a normative formula / millimeter
t	$0 \leq t \leq 1$	Sweep parameter of the involute curve / floating point number
yd	$rb * (\sin(t * \pi)$ $- \cos(t * \pi) * t * \pi)$	Y coordinate of the involute tooth profile, generated by the t parameter / millimeter
zd	$rb * (\cos(t * \pi)$ $+ \sin(t * \pi) * t * \pi)$	Z coordinate of the involute tooth profile / millimeter
ro	$rb * a * \pi / 180deg$	Radius of the osculating circle of the involute curve, on the pitch circle / millimeter
c	$\mathrm{sqrt}(1 / \cos(a)^2 - 1) /$ $PI * 180deg$	Angle of the point of the involute that intersects the pitch circle / angular degree
phi	$\mathrm{atan}(yd(c) /$ $zd(c)) + 90deg / Z$	Rotation angle used for making a gear symmetric to the ZX plane / angular degree

Fig 1 Parametric spur gear – Development Method Table 1:



- Study and tabulate the mathematical formula for gear parameters and involute generation

- Configure the generative shape design workshop

- Enter the parameters and formulas
- Define the primary generation parameters
- Define dependent parameters
- Check the primary and computed parameters
- Parametric laws of the involute curve

- Create geometric body and insert geometric elements

- Make the geometric profile of the first tooth
- Define the parameters, constants and formulas
- Insert a set of 5 constructive points and connect them with a spline
- Extrapolate the spline toward the center of the gear
- Rotate the involute curve for the symmetry relative to the ZX plane
- Draw the outer circle and the root circle
- Insert a rounded corner near the root circle
- Create the rounded corner of the next tooth
- Assemble the different elements of the first tooth

- Build the whole gear profile and extrude it

Cut the gear wheel

Check the parametric generation

S6: Entering the formula r_b - base cylinder radius, rp - Pitch circle radius, ra - outside circle radius, rf - root circle radius, rc – bottom clearance. Enter the formula for, rp, ra, rb, rk and rc by naming them and by clicking Add Formula. Formula editor will appear: Enter: rp = m*z/2, Enter: rb = r*cos(a), Enter: rf = r – 1.25 *m, Enter: ra = r + m*1, After entering all formulas and expanding specification tree and look for the created parameter as in **Fig 4**.

S7: Preparing the Geometric profile of the first gear tooth: Since the whole gear is the circular repletion of the first tooth, the profile of first tooth is developed initially.

S7a. Parametric laws of Involute curve: Define the formulas defining the (Y, Z) Cartesian position of the points on the involute curve of a tooth. We could as well define a set of parameters Y0, Z0, Y1, Z1, … for the coordinates of the involute's points. Add laws that will define the involute of the gear **Fig 5**. Click on fog icon, name law as yd > select ok > add parameters, t – select real, and x - length select their types and apply > ok. Refer **Fig 6.**

Law yd: yd=rb*(sin (t*PI*1rad)-cos (t*PI*1rad)* t*PI (1)

S7b: Same should be done for zd. This law will helps to create points that define spline for our involute. Involute is line that is trajectory of point belonging to line that is always tangent to base gear cylinder. It is used for tooth profile. If gears had profiles formed by straight lines they wouldn't work.

Law zd:zd= rb*(cos (t*PI*1rad)+sin (t*PI*1rad)*t*PI (2)

S8: Creating geometric profile for the first tooth: The position of each point is defined by the yd (t) and zd (t) parametric laws. 5 points are defined on the YZ plane. **Insert > Wireframe> Point> Select point type**: on plane> **Select YZ plane** > for position Y and Z, right click and Edit formula. In order to ordinate, double click the Relations\Zd .Evalutae(0). Click on the spline icon ∿ and connect all points. Check for the spline profile on the screen.

S8a: Extrapolating the spline towards the center of the gear: The extrapolation is required because the involute curve ends on the base circle of radius rb = rp * cos(20) = 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. **Fig 8.**

Click on the Extrapolate icon in the extrapolate dialog box key in point 2 for the boundary point and extrapolated spline.1. The length of extrapolation is empirically defined as f(x)= 2*m The continuity should be selected as curvature.

S9: The involute curve is rotated for the symmetry relative to the ZX plane: The rotation angle is decided by formula 18, from table. Before this the value of c, the involute parameter is entered from the formula 17. **c=sqrt(1/(cos(a)*cos(a))-1)/PI**, and the unit should be selected as real. **Phi = atan (Relations\yd .Evaluate(c)/Relations\zd .Evaluate(c))+90deg/z.** Rotate the Extrapolated spline through an angle –Phi. **Fig 9.** The points and spline can be hidden by right click on the point menu and select hide/show menu. The outer circle, root circle is drawn.

S9a: Inserting a rounded corner near the root circle: The corner between the extrapolated involute curve and the root circle has a radius defined by the parameter rc. Catia prompts to select an arc (**in red**) out of 4 possible geometric solutions (**in blue**). Refer **Fig 10**

S10: Assemble the different elements of the first tooth: At this assembly stage the extrapolated spline has to be cut, fill and join the different elements of the 1st tooth: Cut the segment of the extrapolated spline between the outer circle and the rounded corner. The symmetric profile is defined relative to the ZX plane, for the other side of the 1st tooth.

S10a: Inserting a new plane: Insert>plane >plane type > Angle/Normal to plane> Select rotation axis > Reference plane as ZX plane > Angle is –PHI>ok. Then the corner fillet radius is mirrored with respect to the plane 1.

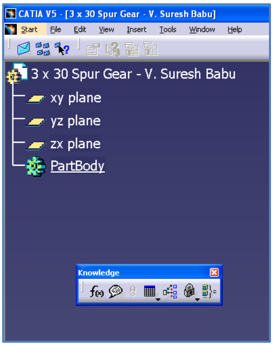
S10b: The profile is trimmed with reference to the outer circle and root circle. The corners are joined by line definition. . The last operation consists in joining all the elements of the 1st tooth. The output looks like **Fig. 11**

S11. To build the whole gear profile and to extrude it: Since the gear profile is just a circular repetition of the 1st tooth, repetition around the X axis is defined. The number of instances is controlled by the Z parameter (number of teeth). Insert > Advanced repetition tools > circular pattern . The circular pattern is defined as in the dialog box of **Fig 12**. The completed gear profile is as seen in **Fig 13.**

The **part design workshop** is opened and the pad option is used to extrude the gear profile. The template output is as seen in the **Fig 14.**

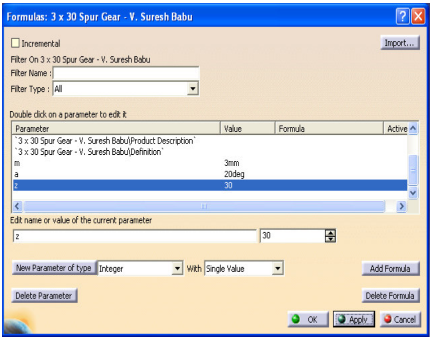
Results and Discussion

This paper has aimed in developing a template spur gear, using parametric design. The template gear is now used to develop Gear models of modules, number of teeth and other parameters. Successfully developed gear is named as template gear. Using this gear, we can generate gears of different parameters, which is tried using case studies. Case 1: In this case we try to model gear with the parameters 2 module 30 teeth with 14.5 degree pressure angle. The template gear tree and the modified gear tree is shown aside each other. The final output generated is shown in **Fig 15**. Case 2: Here 4 module, 30 teeth with 20 degree pressure angle gear is considered for development. As above, the tree is shown and the output is shown in **Fig 16**. From the above two case studies, we could conclude that that the parametric modeling technique helps to shorten the modeling time, and avoids the laborious work carried out in creating the gears. The parametric concept can be extended for developing helical, bevel, and internal gears. Computer-aided machining, inspection, sterolithography, Stress, motion Analysis, and similar such process that can use a three-dimensional part directly from a parametric solid modeled gear file. Since models are developed from the template the time consumed for modeling of gear each and every time based on the parameters assigned is reduced. Infact few entries in the input screen develops the gear in no time. Cost of development of the model is lesser because of time. The human fatigue is also very less. Similar such concept with little modification can be utilized for developing asymmetric profiles and gears.



3 x 30 Spur Gear - V. Suresh Babu
xy plane
yz plane
zx plane
PartBody

Fig 2: knowledge tool bar



☐ Incremental

Filter On 3 x 30 Spur Gear - V. Suresh Babu
Filter Name :
Filter Type : All

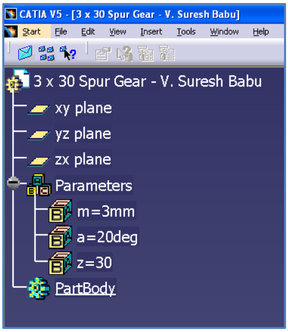
Double click on a parameter to edit it

Parameter	Value	Formula	Active
`3 x 30 Spur Gear - V. Suresh Babu\Product Description`			
`3 x 30 Spur Gear - V. Suresh Babu\Definition`			
m	3mm		
a	20deg		
z	30		

Edit name or value of the current parameter
z 30

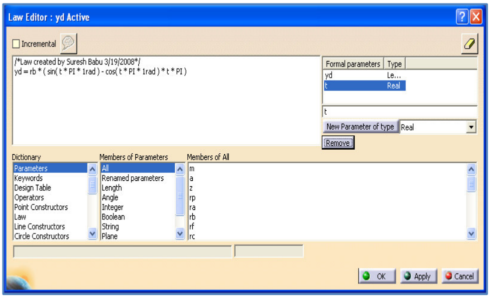
New Parameter of type Integer With Single Value

Fig 3. Entering the parameters



3 x 30 Spur Gear - V. Suresh Babu
xy plane
yz plane
zx plane
Parameters
m=3mm
a=20deg
z=30
PartBody

Fig 4. Display of parameters



☐ Incremental

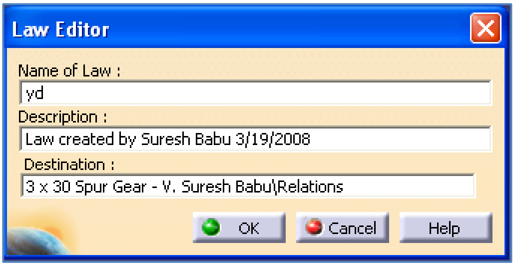
```
/*Law created by Suresh Babu 3/19/2008*/
yd = rb * ( sin( t * PI * 1rad ) - cos( t * PI * 1rad ) * t * PI )
```

Formal parameters	Type
yd	Le...
t	Real

t
New Parameter of type Real

Dictionary	Members of Parameters	Members of All
Parameters	All	m
Keywords	Renamed parameters	a
Design Table	Length	z
Operators	Angle	rp
Point Constructors	Integer	ra
Law	Boolean	rb
Line Constructors	String	rf
Circle Constructors	Plane	rc

Fig5: Law editor yd



Law Editor

Name of Law :
yd

Description :
Law created by Suresh Babu 3/19/2008

Destination :
3 x 30 Spur Gear - V. Suresh Babu\Relations

Fig 6: Law editor yd active

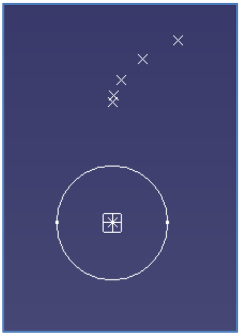


Fig 7. Point Definition

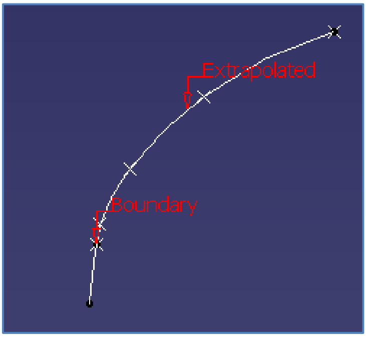


Fig 8. Extrapolated spline

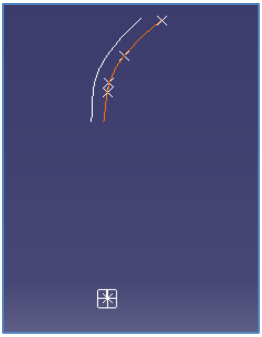


Fig 9. Rotated spline

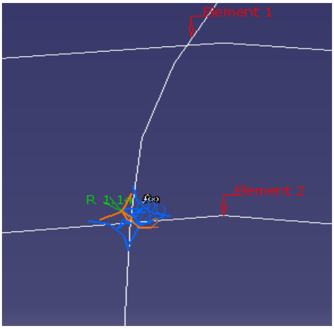


Fig 10. Rounded corner

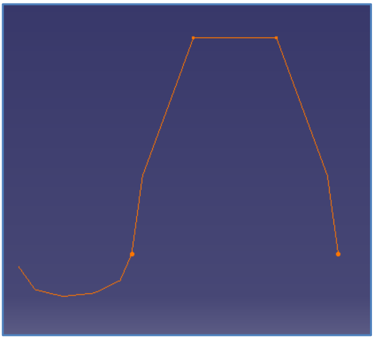


Fig 11. The output of S10

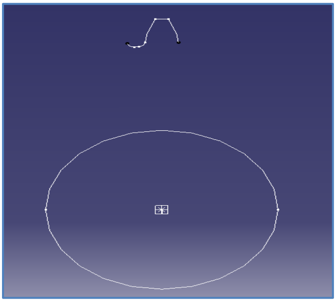
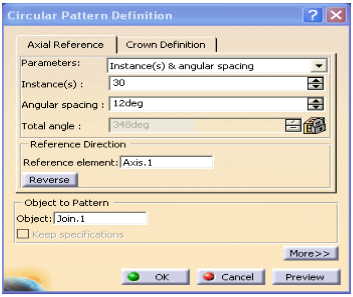


Fig 12. Circular pattern



Parameters: Instance(s) & angular spacing
Instance(s) : 30
Angular spacing : 12deg
Total angle : 348deg
Reference Direction
Reference element: Axis.1
Object to Pattern
Object: Join.1
☐ Keep specifications

Fig 13: The total Gear profile

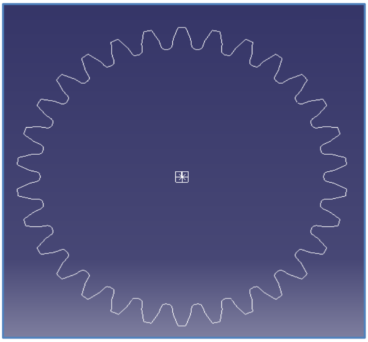


Fig 14: The template Gear (Extruded output)

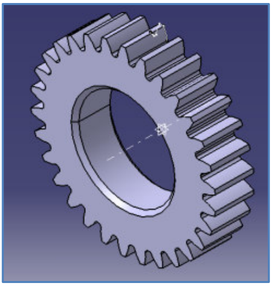
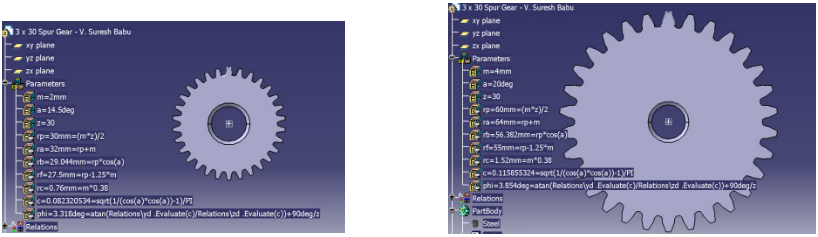


Fig 15: Development of gear with 2 module



3 x 30 Spur Gear - V. Suresh Babu
xy plane
yz plane
zx plane
Parameters
m=2mm
a=14.5deg
z=30
rp=30mm=(m*z)/2
ra=32mm=rp+m
rb=29.044mm=rp*cos(a)
rf=27.5mm=rp-1.25*m
rc=0.76mm=m*0.38
c=0.082320534=sqrt(1/(cos(a)*cos(a))-1)/PI
phi=3.318deg=atan(Relations\yd .Evaluate(c)/Relations\zd .Evaluate(c))+90deg/z
Relations

3 x 30 Spur Gear - V. Suresh Babu
xy plane
yz plane
zx plane
Parameters
m=4mm
a=20deg
z=30
rp=60mm=(m*z)/2
ra=64mm=rp+m
rb=56.382mm=rp*cos(a)
rf=55mm=rp-1.25*m
rc=1.52mm=m*0.38
c=0.115855324=sqrt(1/(cos(a)*cos(a))-1)/PI
phi=3.854deg=atan(Relations\yd .Evaluate(c)/Relations\zd .Evaluate(c))+90deg/z
Relations
PartBody
Steel

Fig 16: Development of gear with 4 module, 30 teeth gear with 14.5degree pressure angle 30 teeth gear with 20 degree pressure angle

Conclusion and Limitations

This paper has attempted for how template gear could be developed. As such, template gear development is time consuming and it warrants sufficient skill and through understanding of the gear terminology. The developed template has limitations that it can be utilized only in places where the gears are uncorrected. When the gear design has modifications such as addendum, dedundum or proturberance etc., it would further complicate the template modeling.

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Table 1: t-test analysis of the pretest scores of students taught with linguistic-stylistic technique and traditional method.

Method	N	$\bar{X}$	S.D.	DF	t-cal.	t-critical	Decision at P<.05
Linguistic-stylistic	153	10.24	3.96	308	0.96	1.96	NS
Traditional	157	10.68	4.08				

NS = Not Significant

Table 2: t-test of the posttest mean scores on the academic achievement of students in poetry taught with linguistic-stylistic technique and traditional method.

Method	N	$\bar{X}$	S.D.	DF	t-cal.	t-critical	Decision at P<.05
Linguistic-stylistic	153	42.65	4.12	308	13.44	1.96	*
Traditional	157	36.47	3.98				

*= Significant

Table 3: t-test of the retention test mean scores on the academic achievement of students in poetry taught with linguistic-stylistic technique and traditional method.

Method	N	$\bar{X}$	S.D.	DF	t-cal	t-critical	Decision at P<.05
Linguistic-stylistic	153	43.86	4.08	30.8	16.27	1.96	*
Traditional	157	36.54	3.87				

*= Significant

Table 4: t-analysis of academic achievement of male and female students taught with linguistic-stylistic technique.

Gender	N	$\bar{X}$	S.D.	DF	t-cal.	t-critical	Decision at P<.05
Male	75	42.20	4.02	151	1.34	1.96	NS
Female	78	43.10	4.22				

NS = Not significant