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Mechanical Transmissions Parameter Modelling

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1. Introduction

In mechanical technique, transmission means appliance which is used as intermediary mechanism between driving machine (e.g. of engine) and working (consumed) machine. The role of transmission is transmitting of mechanical energy from main shaft of driving machine to main shaft of working machine. The selection of transmission is limited by the price of complete appliance, by working environment, by dimensions of the appliance, technical regulations, etc. In mechanical engineering, so as in technique generally, mechanical transmissions are broadly used. Mechanical transmissions are mechanisms which are used for mechanical energy transmitting with the change of angle speed and appropriate change of forces and rotary torques. According to the type of transmitting, mechanical transmissions could be divided into: transmissions gear (sprocket pair), belt transmissions (belt pulleys and belt), friction transmissions (friction wheels) and chain transmissions (chain pulleys and chain). (Repcic & Muminovic, 2007)

In this chapter, the results of the research of three-dimensional (3D) geometric parameter modelling of the two frequently used types of mechanical transmissions, transmissions gear (different types of standard catalogue gears: spur gears, bevel gears and worms) and belt transmissions (belt pulley with cylindrical external surface, or more exactly, with pulley rim) using CATIA V5 software system (modules: *Sketcher, Part Design, Generative Shape Design, Wireframe and Surface Design and Assembly Design*), is shown.

Modelling by computers are based on geometric and perspective transformation which is not more detail examined in the chapter because of their large scope.

It is advisable to make the parameterisation of mechanical transmissions for the purpose of automatization of its designing. Parameter modelling application makes possible the control of created geometry of 3D model through parameters integrated in some relations (formulas, parameter laws, tables and so on). All dimensions, or more precisely, geometric changeable parameter of gear and belt pulley, can be expressed through few characteristic fixed parameters (m , z , z_1 , z_2 and N for the selected gear; d , B_k , d_v and s for the selected belt pulley). Geometry of 3D mechanical transmission model is changed by changes of these parameters values. Designer could generate more designing solutions by mechanical transmission parameterisation.

Because AutoCAD does not support parameter modelling, and command system, that it has, does not make possible simple realization of changes on finished model, parameter

oriented software systems (CATIA V5, SolidWorks, Mechanical Desktop, and so on) which used analytical expressions for variable connection through parameters are used. CATIA V5 (*Computer-Aided Three-dimensional Interactive Application*) is the product of the highest technological level and represents standard in the scope of designing (Dassault Systemes, IBM, 2011). Currently, it is the most modern integrated CAD/CAM/CAE software system that can be found on the market for commercial use and scientific-research work. The biggest and well-known world companies and their subcontractors use them. It is the most spread in the car industry (Daimler Chrysler, VW, BMW, Audi, Renault, Peugeot, Citroen, etc.), airplane industry (Airbus, Boeing, etc.), and production of machinery and industry of consumer goods. The system has mathematical models and programs for graphical shapes presentation, however users have no input about this process. As a solution, it is written independently from operative computer system and it provides the possibility for program module structuring and their adaptation to a user. In the „heart“ of the system is the integrated associational data structure for parameter modelling, which enables the changes on the model to be reflected through all related phases of the product development. Therefore, time needed for manual models remodelling is saved. The system makes possible all geometric objects parametering, including solids, surfaces, wireframe models and constructive elements. (Karam & Kleismit, 2004; Saric et al., 2010) Whole model, or part of model, can be parameterised in the view of providing of more flexibility in the development of new variants designing solutions. Intelligent elements interdependence is given to a part or assembly by parameterising. The main characteristic of parameter modelling in CATIA V5 system is the great flexibility, because of the fact that parameters can be, but do not have to be, defined in any moment. Not only changing of parameter value, but their erasing, adding and reconnecting, too, are always possible. (Karam & Kleismit, 2004) Total *Graphical User Interface* (GUI) programmed in C++ program is designed like tools palette and icons that can be found in Windows interface. Although it was primarily written for Windows and Windows 64-bit, the system was written for AIX, AIX 64-bit, HP-UX, IRIX and Solaris operative system. To obtain the maximum during the work with CATIA V5 system, optimized certificated hardware configurations are recommended (Certified hardware configurations for CATIA V5 systems, 2011).

Parameter modelling in CATIA V5 system is based on the concept of knowledge, creating and use of parameter modelled parts and assemblies. (Saric et al., 2009) Creating of 3D parameter solid models is the most frequently realized by combining of the approach based on *Features Based Design* – FBD and the approach based on Bool's operations (*Constructive Solid Geometry* – CSG). (Amirouche, 2004; Shigley et al. 2004; Spotts et al., 2004) The most frequent parameter types in modelling are: *Real, Integer, String, Length, Angle, Mass*, etc. They are divided into two types:

- internal parameters which are generated during geometry creating and which define its interior features (depth, distance, activity, etc.) and
- user parameters (with one fixed or complex variables) which user specially created and which define additional information on the: *Assembly Level, Part Level* or *Feature Level*.

So, parameter is a variable we use to control geometry of component, we influence its value through set relations. It is possible to do a control of geometry by use of tools palette *Knowledge* in different ways:

- by creating of user parameters set and by their values changing,
- by use of defined formulas and parameter laws that join parameters,
- by joining of parameters in designed tables and by selection of appropriate configured set.

The recommendation is, before components parameterising, to:

1. check the component complexity,
2. notice possible ways of component making,
3. notice dimensions which are going to change and
4. select the best way for component parameterising.

2. Mechanical transmissions parameter modelling

Modelling of selected mechanical transmissions was done in *Sketcher, Part Design* and *Generative Shape Design* modules of CATIA V5 system. As prerequisite for this way of modelling, it is necessary to know modelling methodology in modules *Wireframe and Surface Design* and *Assembly Design* of CATIA V5 system. (Karam & Kleismit, 2004; Dassault Systemes, 2007a, 2007b; Zamani & Weaver, 2007)

After finished modelling procedure, mechanical transmissions can be independently used in assemblies in complex way.

Parameter marks and conventional formulas (Table 1. and 5.) used in mechanical transmissions modelling can be found in references (Repicic & et al., 1998; Repicic & Muminovic, 2007, pgs. 139, 154-155, 160-161). Clear explanations for transmissions gear and belt transmissions can be found in references (Repicic & et al., 1998, pgs. 54-106, 118-151).

2.1 Transmissions gear parameter modelling

Next paragraph is shows 3D geometric parameter modelling of characteristic standard catalogue gears: spur gears, bevel gears and worms.

Gears were selected as characteristic example, either because of their frequency as mechanical elements or because exceptionally complex geometry of cog side for modelling.

Every user of software system for designing is interested in creation of complex plane curve *Spline* which defined geometry of cog side profile.

The control of 3D parameterised model geometry is done by created parameters, formulas and parameter laws shown in the tree in Fig. 1. (Cozzens, 2006) Parameters review, formulas and parameter laws in the *Part* documents tree activating is done through the main select menu (*Tools* → *Options* → *Part Infrastructure* → *Display*).

Spur gear	Bevel gear	Worm
z	$z1, z2$	$z1=1$
m		$m=1,5$
$a=20 \text{ deg}$		
$p=m*PI$		
$r=(z*m)/2$	$r=(z1*m)/2$	$d=20 \text{ mm}$
$rb=r*\cos(a)$	$rb=rc*\cos(a)$	

Spur gear	Bevel gear	Worm
$r_f = r - 1.2 * m$		
$r_a = r + m$		$r_a = d / 2 + h_a$
$r_r = 0.38 * m$		
$h_a = m$		
$h_f = 1.2 * m$		
$x_d = r_b * (\cos(t * PI) + \sin(t * PI) * t * PI)$		$N = 6,5$
$y_d = r_b * (\sin(t * PI) - \cos(t * PI) * t * PI)$		$L = (N + 1) * p$
$0 \leq t \leq 1$		$\text{gama} = \text{atan}(m * z_1 / d)$
	$\text{delta} = \text{atan}(z_1 / z_2)$	$dZ = -L / 2$
	$r_c = r / \cos(\text{delta})$	
	$l_c = r_c / \sin(\text{delta})$	
	$t_c = -\text{atan}(\text{Relations} \setminus y_d.\text{Evaluate}(a / 180\text{deg}) / \text{Relations} \setminus x_d.\text{Evaluate}(a / 180\text{deg}))$	
	$b = 0.3 * r_c$	
	$\text{ratio} = 1 - b / l_c / \cos(\text{delta})$	
	$dZ = 0 \text{ mm}$	

Table 1. Parameters and formulas

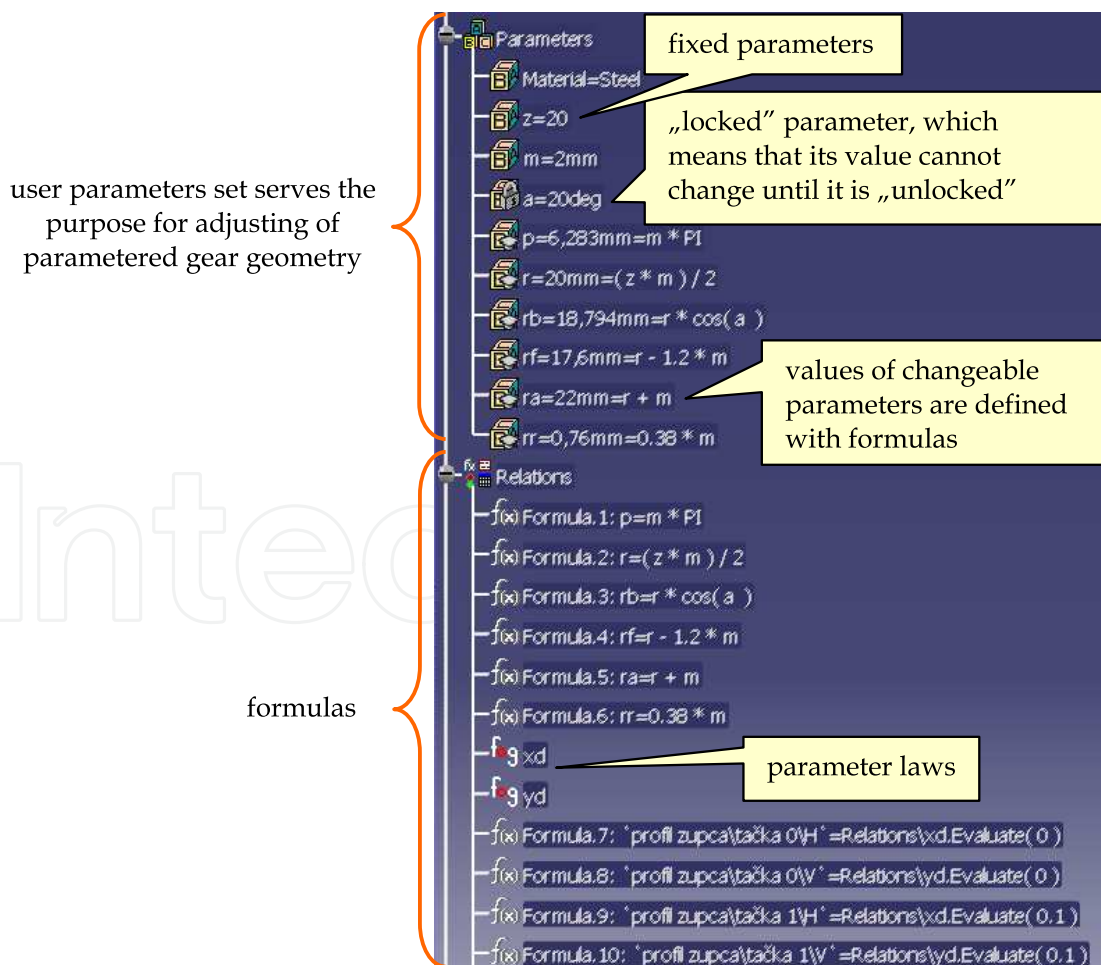



Fig. 1. Gear geometry control

2.1.1 Spur gears parameter modelling

To define fixed parameters (Fig. 2.), we select command *Formula*  from tools palette *Knowledge* or from main select menu. Then, we:

1. choose desired parameter type (*Real*, *Integer*, *Length*, *Angle*) and press the button *New Parameter of type*,
2. type in a new parameter name,
3. assign a parameter value (only in the case if parameter has fixed value) and
4. press the button *Apply* to confirm a new parameter creation.

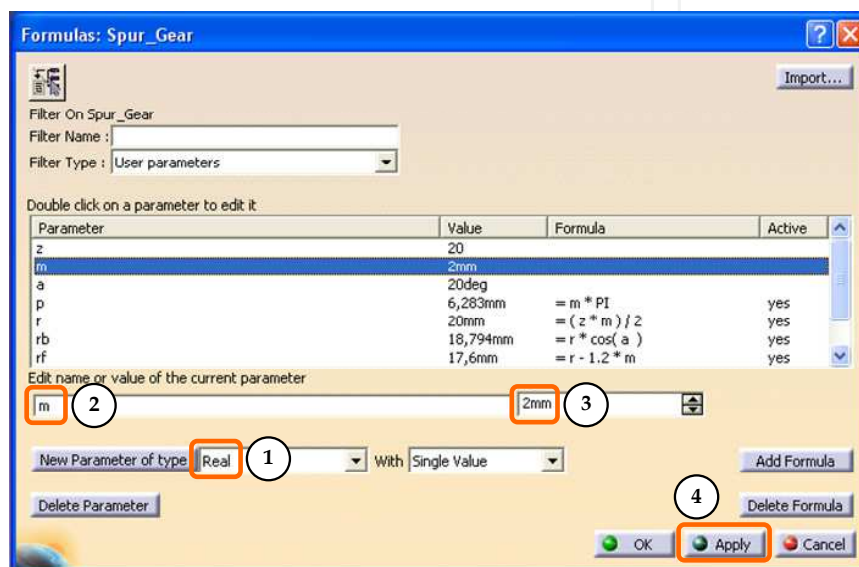


Fig. 2. Fixed parameters defining

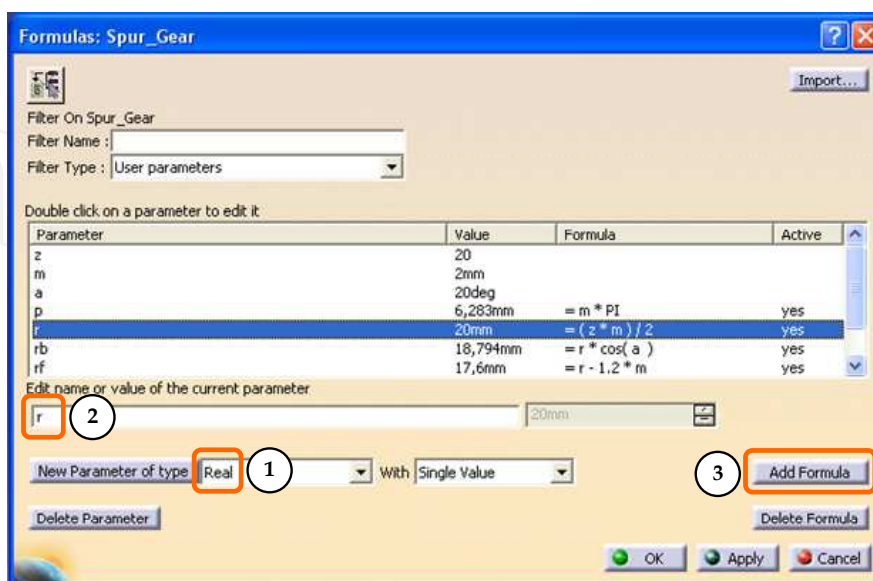


Fig. 3. Changeable parameters defining


Most geometrical gear parameters are changeable and are in the function of fixed parameters m and z (Fig. 3.). We do not need to set values for these parameters, because CATIA V5 system calculates them itself. So, instead of values setting, formulas are defined by choosing the command *Formula*  (Fig. 4.). When formula has been created, it is possible to manipulate with it by the tree, similar as with any other model feature.



Fig. 4. Formula setting

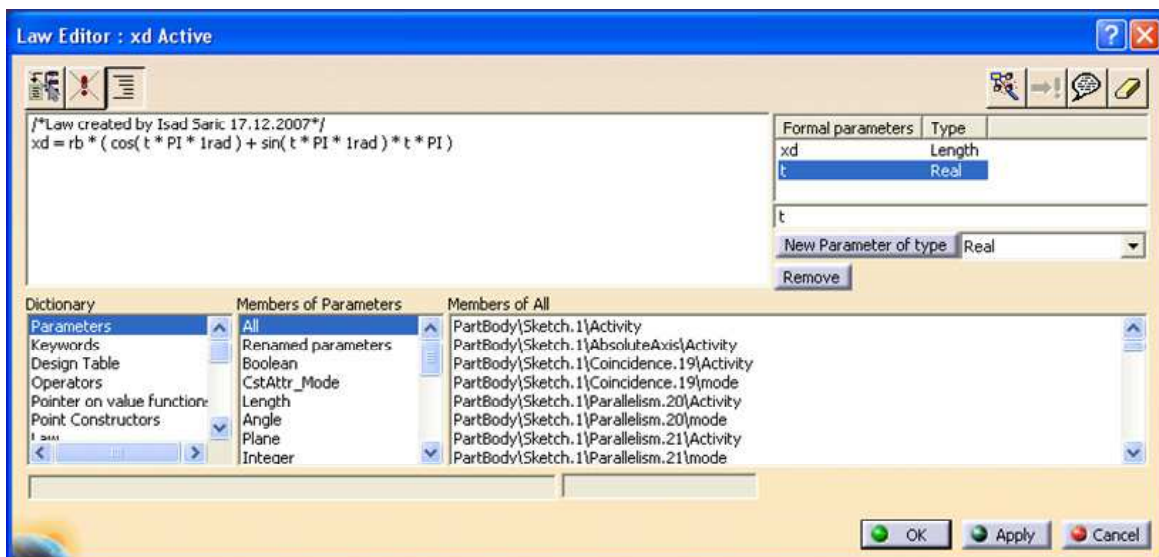



Fig. 5. Setting of parameter laws for calculation of x and y coordinates of involute points

Position of the points on involutes profile of cog side is defined in the form of parameter laws (Fig. 5.). For coordinate points of involute (x_0, y_0) , (x_1, y_1) , ..., (x_4, y_4) we most frequently define a set of parameters. To create parameter laws, we choose the command *Law*  from tools palette *Knowledge*. Then, we give two laws in parameter form, which we are going to be used for calculation of x and y coordinate points of involute

$$xd = rb * (\cos(t * PI * 1rad) + \sin(t * PI * 1rad) * t * PI) \quad (1)$$

$$y_d = rb * (\sin(t * PI * 1rad) - \cos(t * PI * 1rad) * t * PI) \quad (2)$$

While we use law editor, we have to take into account the following:

- trigonometric functions, specially angles, are not considered as numbers, and because of that angle constants like $1rad$ or $1deg$ must be used,
- PI is the value of the number π .

For the purpose of accuracy checking of previously conducted activities, review of formulas, parameter laws and values of all defined fixed and changeable parameters is activated in the tree of *Part* document (*Tools* → *Options* → *Knowledge*).

The example of spur gear parameter modelling is shown in the next paragraph. All dimensions, or more precisely, geometric changeable parameters of spur gear are in the function of fixed parameters m and z . We can generate any spur gear by changing parameters m and z .

Part Number	m	z	d_g	d	b_z	b_g	b_k	t_k
G2-20	2	20	30	15	20	35	5	2,35
G3-40	3	40	60	25	30	50	8	3,34
G4-60	4	60	120	30	40	60	10	3,34

Table 2. Selected spur gears parameters

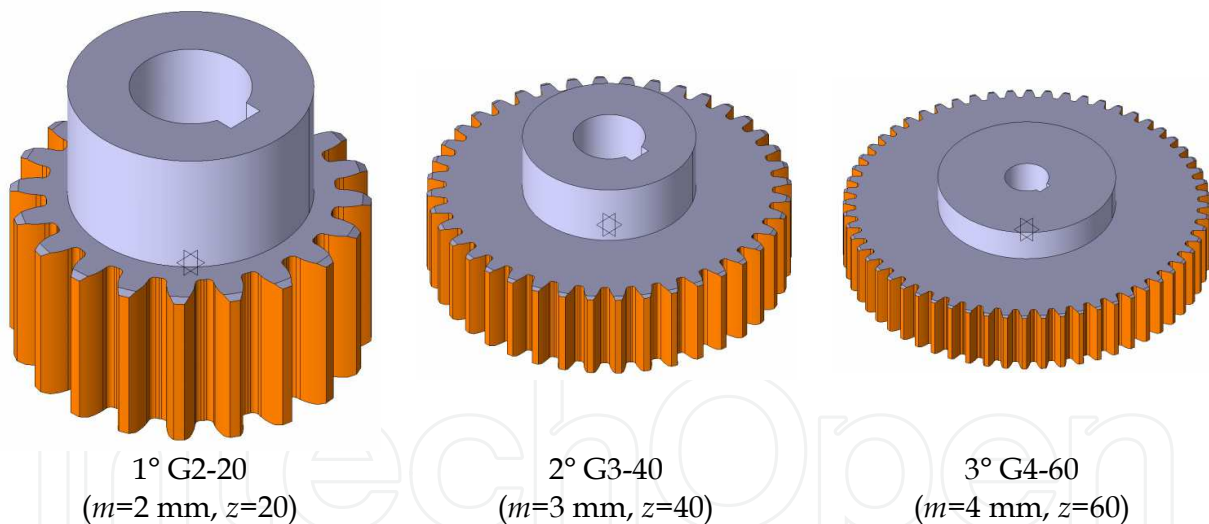


Fig. 6. Different spur gears are the result of parameter modelling

Fig. 6. shows three different standard catalogue spur gears made from the same CATIA V5 file, by changing parameters m and z . (Saric et al., 2009, 2010)

2.1.2 Bevel gears parameter modelling

The example of bevel gear parameter modelling is shown in the next paragraph. All dimensions, or more precisely, geometric changeable parameters of bevel gear are in the function of fixed parameters m , z_1 and z_2 . We can generate any bevel gear by changing parameters m , z_1 and z_2 .

Part Number	m	z_1	z_2	d_g	d	b_z	b_g	Connection between hub and shaft
B2-25	2	25	25	40	12	10,6	25,52	M5
DB3-15	3	15	30	36	18	17	36,26	M6
FB4-15	4	15	60	48	20	34	59,9	M8

Table 3. Selected bevel gears parameters

Fig. 7. shows three different standard catalogue bevel gears made from the same CATIA V5 file, by changing parameters m , z_1 and z_2 . (Saric et al., 2009, 2010)

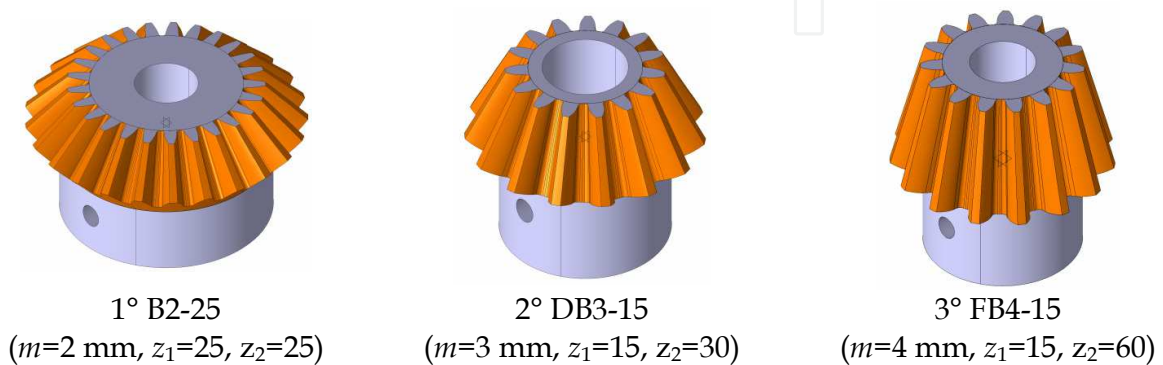


Fig. 7. Different bevel gears are the result of parameter modelling

2.1.3 Worms parameter modelling

The example of worm parameter modelling is shown in the next paragraph. All dimensions, or more precisely, geometric changeable parameters of worm are in the function of fixed parameters m , z_1 and N . We can generate any worm by changing parameters m , z_1 and N .

Part Number	m	z_1	d_g	d	L	L_g	Connection between hub and shaft
W1,5-1	1,5	1	23	10	35	45	M5
W2,5-2	2,5	2	35	15	45	60	M6
W3-3	3	3	41	20	55	70	M8

Table 4. Selected worms parameters

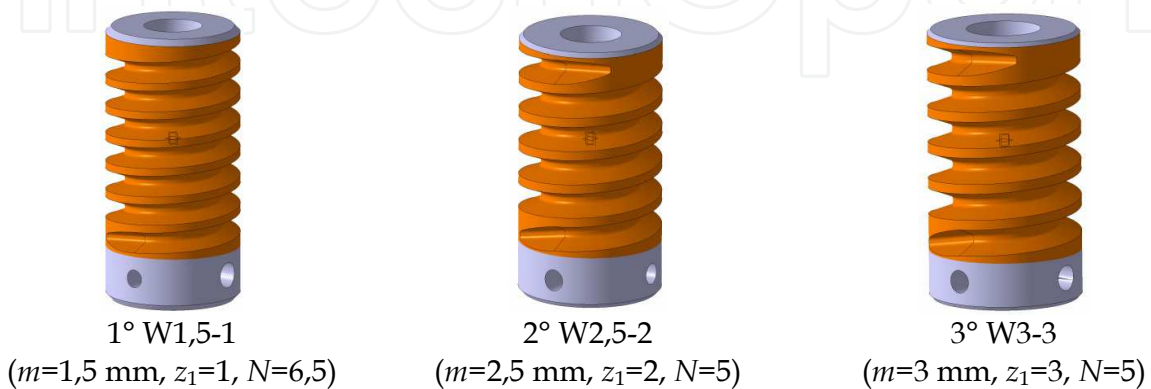


Fig. 8. Different worms are the result of parameter modelling

Fig. 8. shows three different standard catalogue worms made from the same CATIA V5 file, by changing parameters m , z_1 and N . (Saric et al., 2009, 2010)

2.2 Belt transmissions parameter modelling

This application includes wide area of the industry for the fact that belt transmitting is often required. Generally, belt transmitting designing process consists of needed drive power estimate, choice of belt pulley, length and width of belt, factor of safety, etc. Final design quality can be estimated by efficiency, compactness and possibilities of service. If engineer does not use parameter modelling, he/she must pass through exhausting phase of design, based on learning from the previous done mistakes, in order to have standard parts like belt pulleys and belts, mounted on preferred construction. This process is automatized by parameter modelling. In such process, characteristics that registered distance between belt pulleys, belts length, etc., are also created. Such characteristics, also, register links, belt angle speeds and exit angle speed. The results for given belts length can be obtained by the feasibility study. Few independent feasibility studies for the different belts lengths are compared with demands for compactness. In such a way, several constructions of belt transmitting can be tested, and then it is possible to find the best final construction solution.

The example of belt pulley parameter modelling is shown in the next paragraph. The belt pulley K is shown in the Fig. 9., and it consists of several mutual welded components: hub G , pulley rim V , plate P and twelve side ribs BR . All dimensions, or more precisely, geometric changeable parameters of belt pulley are in function of fixed parameters d , B_k , d_v and s . We can generate any belt pulley with cylindrical external surface by changing parameters d , B_k , d_v and s .

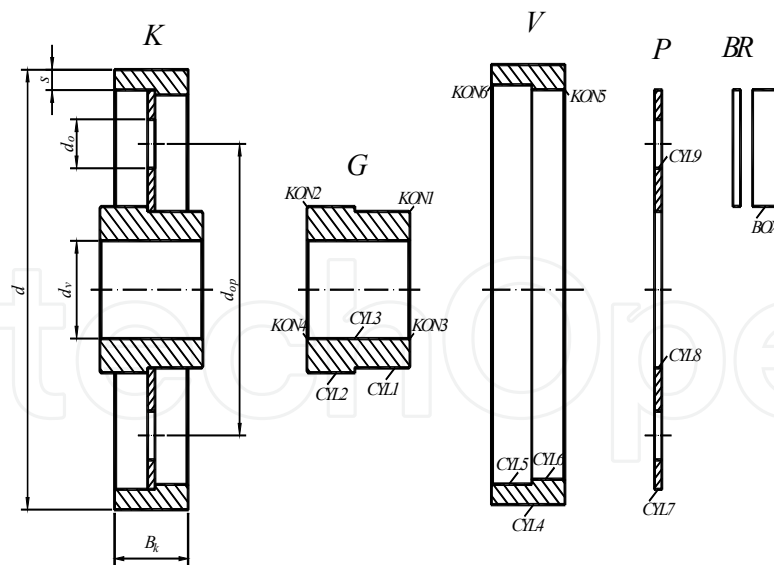


Fig. 9. Modelling of belt pulley parts with cylindrical external surface

Dimensions of hub depends from diameter of shaft d_v , on which hub is set. Shaft diameter is the input value through which the other hub dimension are expressed.

Hub shape can be obtained by adding and subtraction of cylinders and cones shown in the Fig. 9.

$$G = CYL1 + CYL2 - CYL3 - KON1 - KON2 - KON3 - KON4 \quad (3)$$

Pulley rim of belt pulley depends from diameter of belt pulley d , pulley rim width B_k , diameter of shaft d_o and minimal pulley rim thickness s .

$$V = CYL4 - CYL5 - CYL6 - KON5 - KON6 \quad (4)$$

Plate dimensions depend from diameter of belt pulley d , minimal pulley rim thickness s and diameter of shaft d_o .

$$P = CYL7 - CYL8 - 6 \cdot CYL9 \quad (5)$$

Side ribs are side set rectangular plates which can be shown by primitive in the form of prism.

$$BR = BOX \quad (6)$$

Whole belt pulley is obtained by adding of formed forms.

$$K = G + V + P + 6 \cdot BR \quad (7)$$

Belt pulley with cylindrical external surface	
CYL1: $D=1,6 \cdot d_o$, $H=0,75 \cdot d_o$	CYL9: $H=0,1 \cdot d_o$
CYL2: $D=1,7 \cdot d_o$, $H=0,65 \cdot d_o + 2 \text{ mm}$	KON1: $D=1,6 \cdot d_o$, $H=1 \text{ mm}$, angle 45°
CYL3: $D=d_o$, $H=1,4 \cdot d_o + 2 \text{ mm}$	KON2: $D=1,7 \cdot d_o$, $H=1 \text{ mm}$, angle 45°
CYL4: $D=d$, $H=B_k$	KON3: $D=d_o$, $H=1 \text{ mm}$, angle 45°
CYL5: $D=d-2 \cdot s$, $H=B_k/2+0,05 \cdot d_o+1 \text{ mm}$	KON4: $D=d_o$, $H=1 \text{ mm}$, angle 45°
CYL6: $D=d-2 \cdot s-0,1 \cdot d_o$, $H=B_k/2-0,05 \cdot d_o-1 \text{ mm}$	KON5: $D=d-2 \cdot s-0,1 \cdot d_o$, $H=1 \text{ mm}$, angle 45°
CYL7: $D=d-2 \cdot s$, $H=0,1 \cdot d_o$	KON6: $D=d-2 \cdot s$, $H=1 \text{ mm}$, angle 45°
CYL8: $D=1,6 \cdot d_o$, $H=0,1 \cdot d_o$	BOX: $A=[(d-2 \cdot s)-1,8 \cdot d_o]/2$, $B=0,35 \cdot B_k$, $C=0,1 \cdot d_o$

Table 5. Parameters and formulas

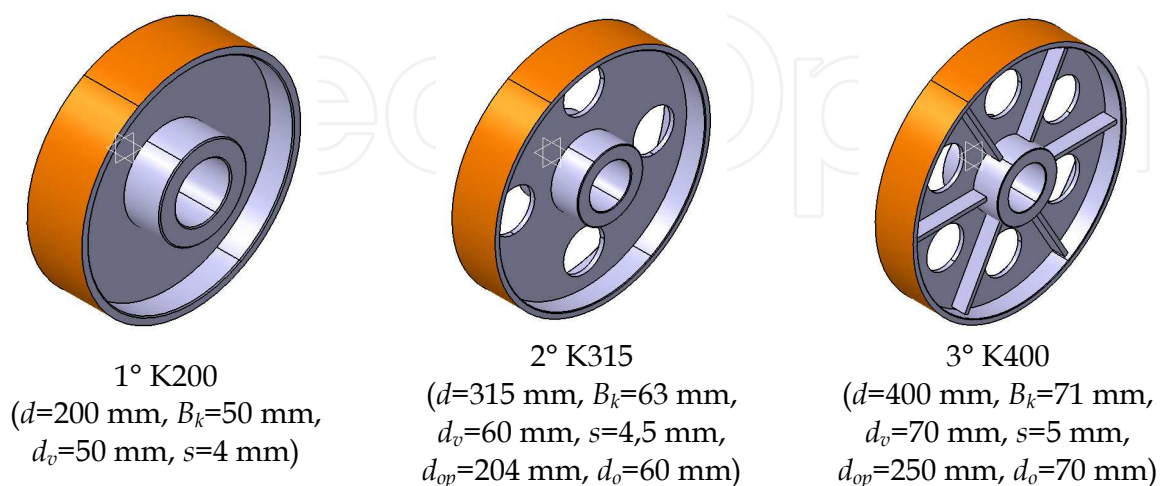


Fig. 10. Different belt pulleys with cylindrical external surface are the results of parameter modelling

Fig. 10. shows three different standard belt pulleys with cylindrical external surface made from the same CATIA V5 file, by changing parameters d , B_k , d_v and s . (Saric et al., 2009)

Use of side ribs that are posed between holes on the plate is recommended during modelling of belt pulleys with longer diameter (Fig. 10.).

Rotary parts of belt pulley shown in the Fig. 9., can be modelled in a much more easier way. More complex contours, instead of their forming by adding and subtraction, they can be formed by rotation. In the first case, computer is loaded with data about points inside primitive which, in total sum, do not belong inside volume of component. In the second case, rotary contour (bolded line in the Fig. 11.) is first defined, and, then, primitive of desired shape is obtained by rotation around rotate axis.

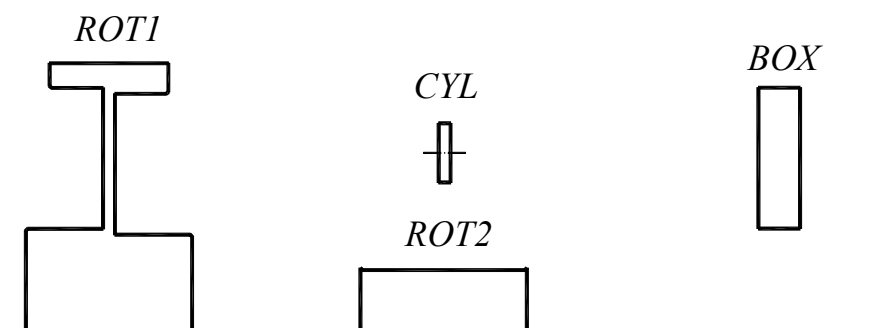


Fig. 11. Modelling of rotary forms

For primitives, shown in the Fig. 11., final form is obtained after the following operations

$$K = (ROT1 - ROT2 - 6 \cdot CYL) \cup 6 \cdot BOX \quad (8)$$

3. Conclusion

Designer must be significantly engaged into the forming of the component shape. Because of that reason, once formed algorithm for the modelling of the component shape is saved in computer memory and it is used when there is need for the modelling of the same or similar shape with similar dimensions. (Saric et al., 2009)

Parts which are not suitable for interactive modelling are modelled by parameters. In the process of geometric mechanical transmission modelling in CATIA V5 system, we do not have to create shape directly, but, instead of that, we can put parameters integrated in geometric and/or dimensional constraints. Changing of characteristic fixed parameters gives us a 3D solid model of mechanical transmission. This way, designer can generate more alternative designing samples, concentrating his attention on design functional aspects, without special focus on details of elements shape. (Saric et al., 2010)

For the purpose of final goal achieving and faster presentation of the product on the market, time spent for the development of the product is marked as the key factor for more profit gaining. Time spent for process of mechanical transmissions designing can be reduced even by 50% by parameter modelling use with focus on the preparatory phase (Fig. 12.).

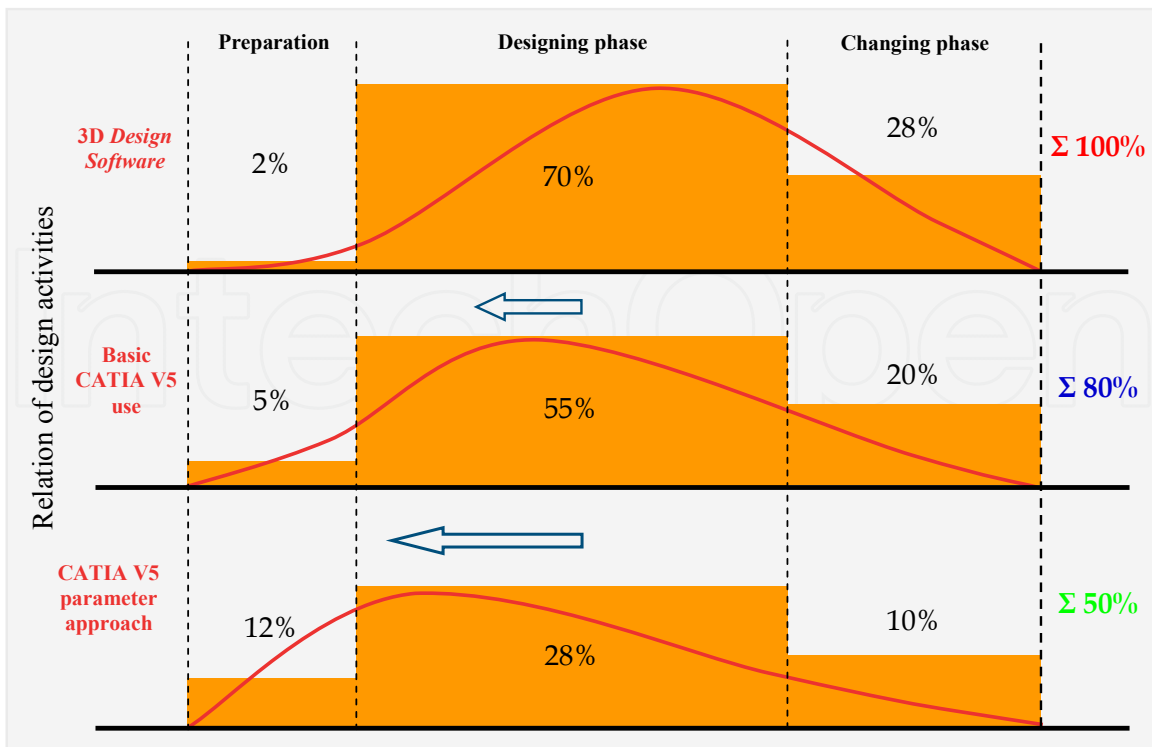


Fig. 12. Relation of design activities and reducing of time spent for design by parameter modelling

These are the advantages of parameter modelling use:

- possibility to make family of parts with the same shape based on one created model,
- forming of libraries basis of standard mechanical elements which take up computer memory, similar to the classic approach of 3D geometric modelling, is not necessary,
- use of parameters enables global modification of whole assembly (automatic reconfiguration),
- development of the product is faster, etc. (Saric et al., 2009)

We can conclude that CATIA V5 system offers possibility of geometric association creation defined by relations established between parameters. Therefore, components parameterisation must obligatory apply in combination with today's traditional geometric modelling approach. Direct financial effects can be seen in production costs reduction, which increases the productivity. Therefore profit is bigger and price of products are lower. (Saric et al., 2010)

Obtained 3D model from CATIA V5 system is used as the base for technical documentation making, analysis of stress and deformation by *Finite Element Method* (FEM), generating of NC/CNC programs for production of the parts on machine (CAM/NC), *Rapid Prototyping* (RP), etc.

4. Acknowledgment

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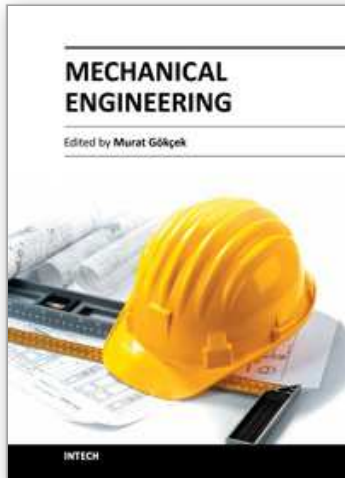
5. Nomenclature

A	mm	side rib length
a	°	line of contact angle
B	mm	side rib width
B _k	mm	pulley rim width
BR	-	side rib
b	mm	cog width
b _g	mm	hub width
b _k	mm	keyway width
b _z	mm	gear width
C	mm	side rib thickness
CYL	-	cylinder
D	mm	appropriate diameter of belt pulley components
d	mm	gear pitch circle; diameter of the hole for shaft; diameter of belt pulley
d _g	mm	interior diameter of hub
d _o	mm	diameter of the hole on the plate
d _{op}	mm	diameter on which holes on plate are set
d _v	mm	diameter of shaft
delta	°	a half of an angle of front cone
dZ	mm	translation of geometry over z axis; translation of worm surface over z axis
G	-	hub
gama	°	angle of helix
H	mm	appropriate length of belt pulley components
ha	mm	addendum part of cog height
hf	mm	root part of cog height
K	-	belt pulley
KON	-	cone
L	mm	helix length
L _g	mm	hub length
lc	mm	cone axis length
m	mm	module
N	-	number of helix
P	-	plate
PI	-	value of number π
p	mm	step on pitch circle
ROT	-	rotation
r	mm	pitch radius
ra	mm	addendum radius
ratio	-	factor of scaling exterior to interior cog profile
rb	mm	basic radius
rc	mm	length of generating line of back (additional) cone
rf	mm	root radius
rr	mm	radius of profile root radius
s	mm	minimal pulley rim thickness

t	-	involute function parameter
t _k	mm	keyway depth
tc	°	cutting angle used for contact point putting in zx plane
V	-	pulley rim
xd	mm	x coordinate of involute cog profile generated on the base of parameter t
yd	mm	y coordinate of involute cog profile generated on the base of parameter t
(x,y)	mm	coordinates of involute points
z	-	cog number
z ₁	-	cog number of driver gear; number of turn of a worm
z ₂	-	cog number of following gear

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