AKADEMIA GÓRNICZO-HUTNICZA

FACULTY OF MECHANICAL ENGINEERING AND ROBOTICS

FINAL PROJECT

Specification, design and kinematic analysis of an Electric Toothbrush using *CATIA® V5R19*

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1. INTRODUCTION AND OBJECTIVES

Throughout of the present document, an electric toothbrush development will be explained. In the first place, the theoretical introductions about the system designed and its history are narrated along the *Chapters 2*and *3*: *Historical Development of Toothbrush* and *Explanation about basic mechanism.* Besides, in the *Chapter 4* is explained the basic concepts of the modules of *CATIA*® used

Immediately, in the following pages (*Chapter 5* and *6*) are dedicated to describe the model, each and every one of its components and its characteristics. Moreover, it will explain the kinematic features for the model works correctly.

When the *Toothbrush* is finished, start the stage of optimization and analysis. During this step, diverse studies have been made. On the one hand, the main objective is the optimization of *Upper Brush* rotational angle, because for a better brushing, this angle should be the maximum as possible.

On the other hand, the model has been subjected to other studies: test of clashes, calculation of sweep volume of the mobile parts. Furthermore, it is necessary to analyze the behaviour of the gear along the movement transmission, and check the relation between the kinematic parts and the gears movement.

In conclusion, the general objectives of this project are to know the operational mode of several modules from *CATIA*® *V5 R19.* In addition, develop the *Toothbrush* mechanical system for the right kinematical behaviour.

2. TOOTHBRUSH HISTORICAL DEVELOPMENT

Brushing teeth is a normal and everyday activity since 3000 BC, although it may seem strange. Obviously, the brushing techniques have changed largely, from the old Egypt and Babylon where the population used branches of trees called *chewing sticks* until now, where the people use modern and different electric toothbrush. *Chewing stic*ks are used today by African tribes.

Moreover, the primitive *toothpicks* that helped cleaning the teeth and mouth appear in the Ancient Greek and Roman literature. As the years passed, *toothpicks* matured into the chew stick which was about the size of a modern pencil. One end was chewed into and became softened and brush-like while the opposite end was pointed and used as a pick to clean food and debris from between the teeth. The twigs used were carefully chosen from aromatic trees that had the ability to clean and cool the mouth.

The other cultures during that age, including the Greeks, Romans, and Indians, also used twigs to clean their teeth. These people used to fray one end of the twig to facilitate its better penetration between the teeth. The Arabic world called this instrument, made from a twig of the *Salvadora persica* tree, *Miswak* which has antiseptic properties. Rubbing baking soda or chalk against the teeth has also been common practice in history. *(Wikipedia, 2001-2011)*

Picture 2.1. Miswak

(Fotopedia, 2008-2011)

In 1223, Japanese Zen master *Dōgen Kigen* recorded on Shōbōgenzō that he saw monks in China cleaning their teeth with brushes made of horse-tail hairs attached to an ox-bone handle while the Europeans used linen cloth or sponges dipped in sulphur oils and salt solutions for rubbing away all the tooth grime*. (Gargles, 2011)*

The first toothbrush similar to the current was invented in China in 1498 by the Chinese Emperor *Hongzhi*. The Emperor put hair of wild boar like bristles in a handle of bamboo or bone. The Chinese toothbrush was introduced in Europe by the merchants who visited East China, but the Europeans considered that the hair of wild board was too hard and irritating for the gums and it was changed to horse hair.

Picture 2.2. Bone toothbrush

(Gargles, 2011)

The mass-production of the toothbrush started in 1780 in England by *William Addis*. He was a businessman who was jailed in 1770 for causing a riot. While he was in prison he decided that the method used to clean teeth, at the time rubbing a rag with soot and salt on the teeth, could be improved. He took a small animal bone and he drilled small holes in it, he obtained some bristles from a guard, tied them in tufts, passed the tufts through the holes on the bone, and he glued them. Pig bristles were used for cheaper toothbrushes, and badger hair for the more expensive ones. But *Anthony Wood* was the first person who called toothbrush this instrument in 1690.

The first patent for a toothbrush was by *H. N. Wadsworth* in 1857 (US Patent No. 18,653) in the United States, but mass production in the USA only started in 1885. The rather advanced design had a bone handle with holes bored into it for the Siberian boar hair bristles. Animal bristle was not an ideal material as it retains bacteria and does not dry well and the drilling of a gum by the sharp tips of the bristles can cause numerous infections in the mouth. . *(Wikipedia, 2001-2011)*

Animal hair brushes sterilized with boiling water had the disadvantage of excessive softening forever, and even destroy them completely, and brushes made of animal hair were too expensive to allow for frequent replacement.

Picture 2.3. Toothbrush of horse hair

(Gargles, 2011)

The nylon was discovered in the 1930´s by *DuPont*© chemists and with this milestone was started a revolution in the toothbrush industry by the physical properties of nylon. It is hard, rigid but flexible, it is resistant deformation and moisture since it is dried completely and thus, it avoids the bacterial growth.

DuPont© used the *World Wars* to their advantage and supported the war troops as a marketing campaign. The first nylon bristle toothbrush was sold in the United States in 1938 under the *Dr. West's Miracle Tuft Toothbrush* name. *DuPont*© artificial fibbers gave initially the name of *Exton Bristia*.

Picture 2.4. Toothbrush of nylon fibbers

(Colgate-Palmolive Company, 2011)

However, these early nylon bristles were so rigid that they damaged the gums and the dentists did not recommend the use of this kind of toothbrush. In 1950´s, *DuPont*© had perfected a soft nylon that it was shown to the customers with the name toothbrush *Park Avenue*.

The next step in the history of the toothbrush was the invention of the electric toothbrush in Switzerland in 1939, but this invention was not popular until 1954. The *Broxodent*, electric toothbrush invented by *Dr. Philippe-Guy Woog* and it was developed by *Broxo S.A.* ©*.* In United States it was distributed by *Squibb Company*.

The first study to demonstrate its superiority over the manual toothbrush was published in 1956 by Professor *Arthur Jean Held* in Geneva. Electric toothbrushes were initially created for patients with limited motor skills, as well as for patients who will use braces. It is argued that electric toothbrushes are more effective than manual because it gives less possibility for patients to brush incorrectly. *(Wikipedia, 2001-2011)*

Subsequently, *General Electric*© invented the wireless and rechargeable toothbrush, and in 1987 one toothbrush with rotary action was presented.

Actually, it can be found a high variety of electric toothbrushes with different movements, electric alimentation, batteries, designs, types of mechanisms, etc; and they are marketed under a lot of brands.

Picture 2.5. Electric Toothbrush

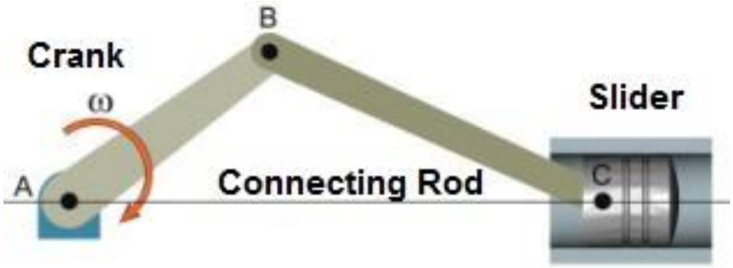
(phpBB Group, 2000-2007)

3. EXPLANATION ABOUT BASIC MECHANISM

3.1. INTRODUCTION

The design of the electric toothbrush mechanism, main objective of this project, is based in a *Slider-Crank* mechanism. It is a system that transforms the circular motion in linear alternative displacement.

The basic *Slider-Crank* mechanism is constituted by a rotating element called *Crank* that is connected with a *Slider* by a rigid stick (*Connecting Rod*).

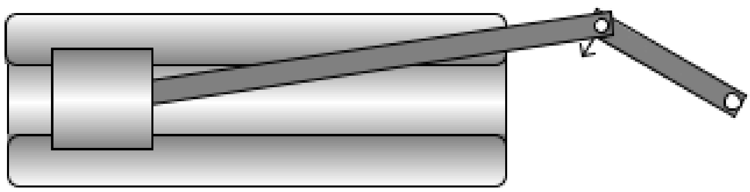


Picture 3.1. Elements of Slider-Crank Mechanism

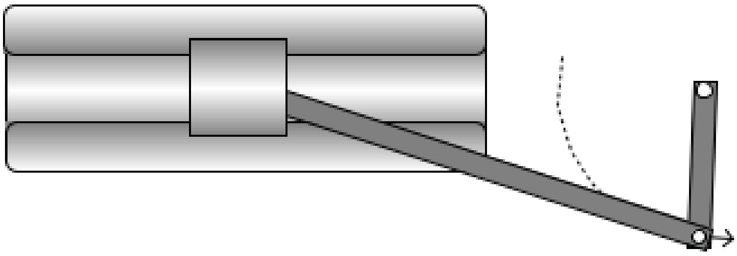
(Universidad Nacional de Colombia, 2011)

When the rotating element is moved, the movement is transmitted to the *connecting rod* by a rotation joint. This element obligates the slider movement by other rotation joint, generating forward and backward movements in it.

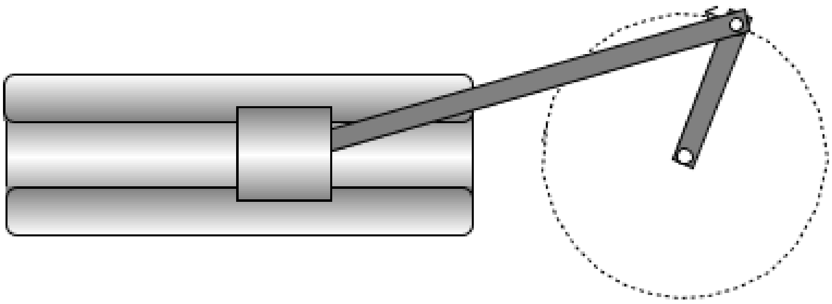
It is a reversible system whereby if turned the *crank* can move the *connecting rod*, and viceversa. If the *connecting rod* produces the input motion, the *crank* is forced to rotate. The movement of *Slider-Crank* mechanism is represented in the next sequence of pictures. *(Xie, 2004-2011)*



Picture 3.2. Forward Movement of the Slider-Crank Mechanism.1



Picture 3.3. Backward Movement of the Slider-Crank Mechanism



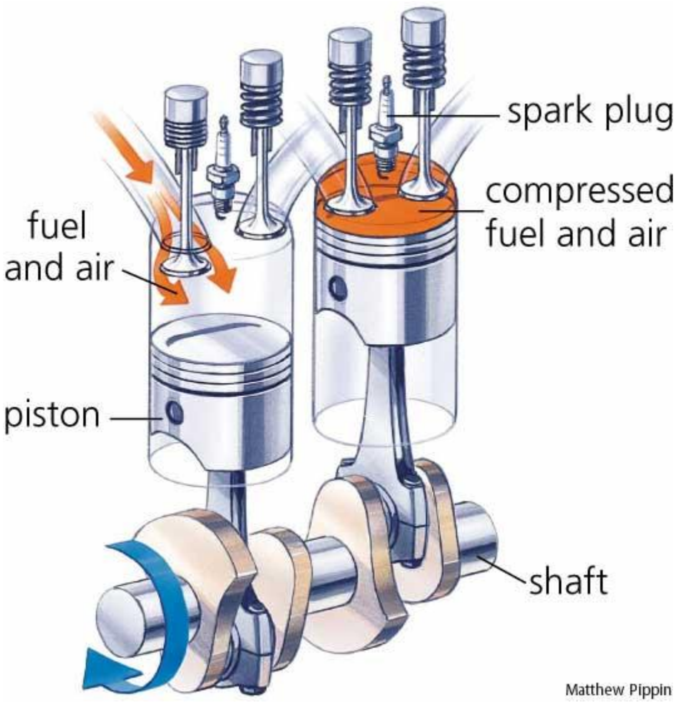
Picture 3.4. Forward Movement of the Slider-Crank Mechanism.2

The length of displacement of the *slider* depends on the *crank* dimensions, when it runs a full circle; the *connecting rod* moves the double of the *crank* length.

$$\boldsymbol{L = 2 \cdot r} \quad (1)$$

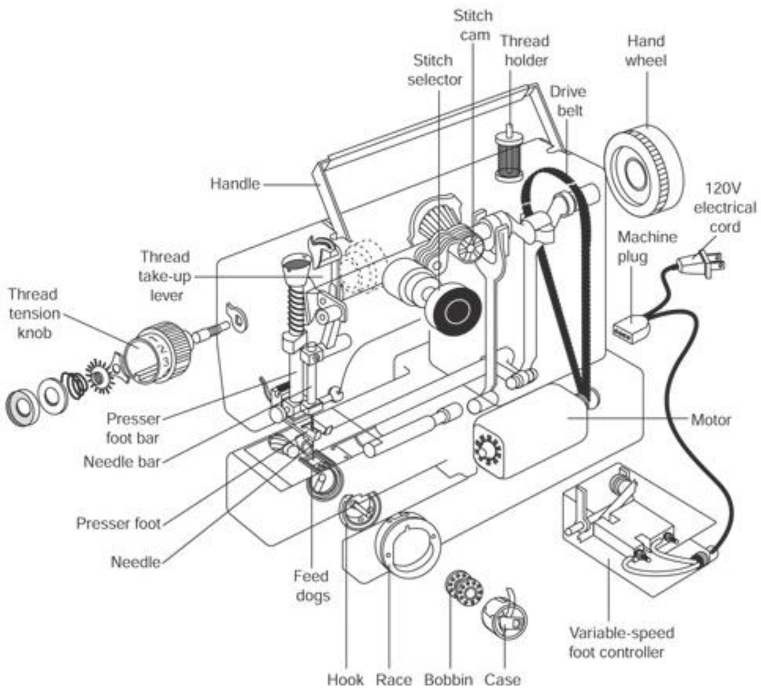
Where *L* is the displacement of the *connecting rod* and *r* is the *crank* length.

The *Slider-Crank* system is used in industrial application such as the piston of the internal-combustion engine, the basic mechanism of the sewing machine, window Regulator Mechanism inside a car, etc. Some examples of the industrial application are shown in the following pictures.



Picture 3.5. Piston

(Martinez, 1999-2011)

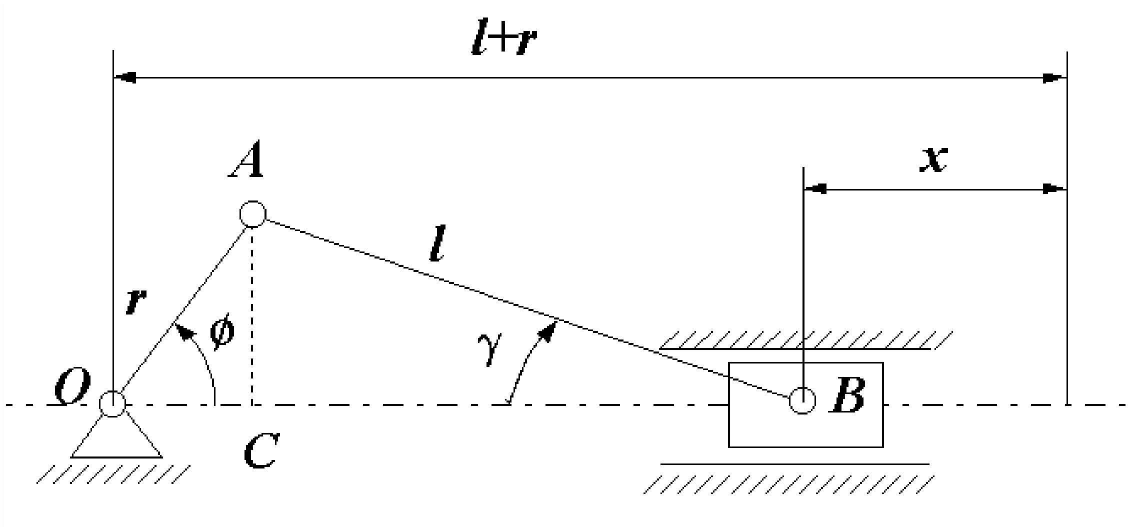


Picture 3.6. Sewing Machine mechanism

(Repair Sewing Machine, 2011)

3.2. KINEMATIC OF SLIDER-CRANK MECHANISM

In this chapter it is going to be explained the kinematic analysis of the slider-crank mechanism. This kind of analysis consists in knowing the positions, velocities and accelerations of all components of the system.



Picture 3.7. Mechanism to analyze

(Monografias.com S.A.)

- ***Analysis of position:***

A structural analysis is necessary before the kinematic analysis to know the dimensions of the mechanism. If all initial values required are obtained, it can be calculated the position of the *slider* in an instant of time with the following expression:

$$x = l + r - (OA \cdot cos\phi + AB \cdot cos\gamma) \quad (2)$$

The angle rotated by the *connecting rod* γ is closely related to the angle ϕ turned by the crank. The same can be calculated by the following expression:

$$\gamma = sin^{-1}\left(\frac{r \cdot sin\phi}{l}\right) \quad (3)$$

- ***Analysis of velocities:***

To find the speed of the slider is enough to take derivative of the displacement expression respect to time:

$$\frac{dx}{dt} = OA \cdot sin\phi \cdot \frac{d\phi}{dt} - AB \cdot sin\gamma \cdot \frac{d\gamma}{dt}$$

$$V_B = \omega_{OA} \cdot r \cdot sin\phi - l \cdot \omega_{AB} \cdot sin\gamma \quad (4)$$

To find the value of *crank* angular velocity ω_{AB}, differentiate the expression that links the angle turned by the crank and the angle turned by the *connecting rod*.

$$\omega_{AB} = \omega_{OA} \cdot \frac{r}{l} \cdot \frac{cos\phi}{cos\gamma} \quad (5)$$

- ***Analysis of accelerations:***

Differentiating the equation of the *slider* velocity, it is possible obtained its acceleration:

$$a_B = \omega_{OA}^2 \cdot r \cdot cos\phi - l \cdot \left(\alpha_{AB} \cdot sin\gamma + \omega_{AB}^2 \cdot cos\gamma\right) \quad (6)$$

Where α_{AB} is:

$$\alpha_{AB} = \frac{r}{l} \cdot \left(\frac{\omega_{OA} \cdot \omega_{AB} \cdot sin\gamma \cdot cos\phi - \omega_{OA}^2 \cdot sin\phi \cdot cos\gamma}{(cos\gamma)^2}\right) \quad (7)$$

4. SOFTWARE USED

CATIA® is a software of integral design, created and developed by the French company *Dassault Systemes*© and it is distributed worldwide by *IBM*©*.* The program begun like a parametric CAD system (Computer Aided Design) and currently, it is one of the most powerful softwares of product lifecycle management. These kinds of products are called *PLM* or Product Lifecycle Management.

The acronym *CATIA*® means *Computer Aided Three-dimensional Interactive Application*. The aim of *Dassault Systemes*© was to create a solution that included the areas *CAD, CAM, CAE, KBE* and *PDM* or in other words, design, machining, calculation of structures and management of the knowledge and product.

Picture 4.1. CATIA V5 R19

(Dassault Systemes, 2002-2011)

CATIA®*V5* is available in different versions and it can be used in diverse operative systems, such as *Microsoft Windows, UNIX (HP-UX and IRIX), IBM AIX* and *Solaris.* This program is conceived to satisfy the requirements of the customers. For this reason, its basic structure is modular and every client can choose the modules more adequate for their work and always they have the possibility of buying and integrating new modules.

The design of the *Electric Toothbrush* was realized by *CATIA®V5R19* (Version 5 Release 19) because it is the version available in the laboratories of the university *Akademia Górniczo-Hutnicza.*

The project has been realized using modules in the following areas: *Mechanical Design* and *Digital Mock Up*. Inside the *Mechanical Design* it has been used *Part Design* for the implementation of the toothbrush components and the unit *Assembly Design* for the union of its parts. Similarly, it has been used the section *Drafting* for generate the drafts of the parts and assembly drawings.

Part Design included the "smart-solid" design kernel that combines feature based design with the flexibility of Boolean approach, offering a highly productive, intuitive solution enabling multiple design methodologies. In this module the parameterization of the values to facilitate possible future changes in the dimensions of the model is possible. Moreover, it is feasible to create sketch and 3D components inside the *Assembly Design* module.

Picture 4.2. CATIA Part Design

(Dassault Systemes, 2002-2011)

In *CATIA Assembly Design* it possible to join the parts created in the above module where only necessary to specify the relationship between the components is using mouse movements or graphical commands, for that reason it is easy to snap into position. Parts and sub-assemblies can be easily reused in the assembly without data duplication. It allows concurrent engineering between the design of the assembly and the design of individual parts.

Picture 4.3. CATIA Assembly Design

(Dassault Systemes, 2002-2011)

The *Drafting* module is easy to use as it includes dynamic sketching co-pilot and variational solving. The drawing co-pilot accelerates the creation of 2D geometry, which auto-detects geometric conditions on existing geometry. It defines and reuses 2D components through management of external catalogs. It is compliant with the latest versions of the most important international standards.

Picture 4.4. CATIA Drafting

(Dassault Systemes, 2002-2011)

Inside *Digital Mock Up* it has been used for carry out the kinematic analysis; specifically, it has been harnessed *DMU kinematic*. This program has several advantages, such as generating directly the mechanical joints from mechanical assembly constraints, it analyzes mechanism motion dynamically with visual feedback by checking limits and interferences, and computing minimal distances, it allows automation of mechanism creation and simulation through Visual Basic macro programming. In addition, reports with the simulations values and other useful information such as traces and swept volumes to be taken account for further design modifications are recorded and generated.

Picture 4.5. DMU kinematic

(Dassault Systemes, 2002-2011)

5. MODEL DESCRIPTION

5.1. INTRODUCTION

In the following chapter it will be explained in detail the assemblies and parts that composed the model *Toothbrush* and the characteristics of the materials selected in the process of design.

Picture 5.1. Electric Toothbrush

The model of *Toothbrush* (*Picture 5.1*) is composed by 18 parts and is incomplete because the electrical elements are not designed. The materials used are: nylon 66 for the bristles, acetal for the gears and polypropylene for the rest of the set.

The next summary chart shows the model components:

SUBASSEMBLY	PART	QUANTITY	MATERIAL
Fix Part	Casing	1	Polypropylene
	Rear Casing	1	Polypropylene
	Motor	1	-
Upper Brush	External Cylinder Upper Brush	1	Polypropylene
	Hear1	36	Nylon
	Hear2	22	Nylon
Lower Brush	External Part Lower Brush	1	Polypropylene
	Hear1	34	Nylon
	Hear2	19	Nylon
	Internal Cylinder Upper Brush	1	Polypropylene
	Connection Lower Brush with Mechanism	1	Polypropylene
	Connection Between Brushes	1	Polypropylene
	Stick	1	Polypropylene
	Cone	1	Polypropylene
	L	1	Polypropylene
	Connection with Wheel	1	Polypropylene
	Plastic Wheel	1	Acetal
	Plastic Gear	1	Acetal
	Head of Motor	1	Polypropylene
	Axle PW	1	Polypropylene

Chart 5.1. Components of the Toothbrush

5.2. MATERIALS USED

The materials used in the process of creation are: acetal, polypropylene and nylon 66. These materials have been chosen because they are the typically used in such applications.

MATERIAL / PROPERTIES	ACETAL	POLYPROPYLENE	NYLON 66
Density(Kg/m^3)	1410	913,00	1070,00
Modulus of Elasticity (GPa)	3,3	1,10	4,14 (Dry)
			1,66 (Wet)
Ratio of Poisson	0,35	0,35	0,39
Yield Stress (MPa)	70	33,01	42,00
Thermal Conductivity (W/m·K)	0,31	0,22	0,43
Specific Heat (J/mol·K)	-	-	1,67
Elongation (%)	-	-	37
Meltic Point (ºC)	165	164	255
Coefficient of thermal expansion (C^{-1})	$110 \cdot 10^{-6}$	$100 \cdot 10^{-6}$	$80 \cdot 10^{-6}$

Chart 5.2. Properties of materials used

The acetal is a thermoplastic product for the mechanics industry in general. It has a high hardness and good dimensional stability. It is a thermoplastic with high molecular weight that is characterized by high mechanical resistance, almost zero water absorption and good friction properties. The acetal is also called POM or polyoxymethylene.

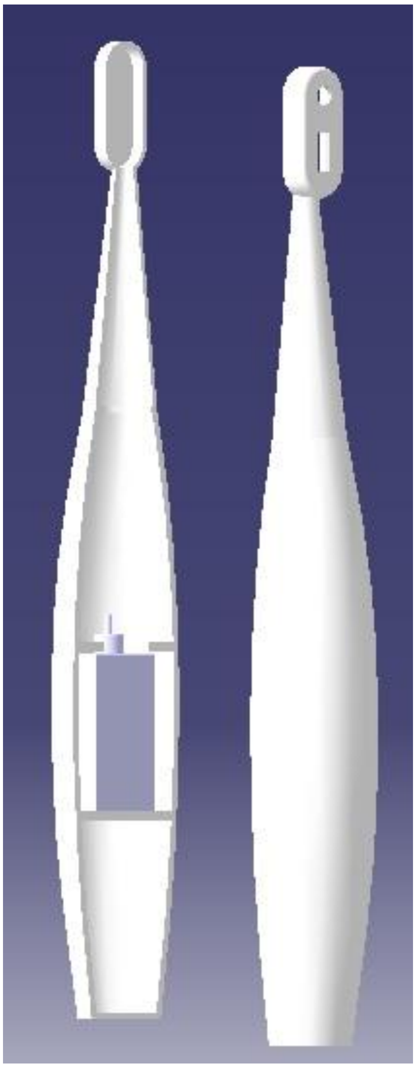
The polypropylene is a commercial thermoplastic polymer, semi-crystalline, white, semi-opaque and currently it is produced in a wide variety of grades and modifications. It is a rigid and hard material which excellent impact resistance, to chemist corrosive products and dielectric.

The nylon 66 is a polyamide with excellent qualities: durability, toughness, high elongation, excellent abrasion resistance, highly resilient the ability of shock absorption, noise and vibration. It is moisture resistant since it is dried completely and thus, it avoids the bacterial growth. *(Plasticbages Industrial S.L.)*

5.3. ELEMENTS OF THE MODEL

The *Toothbrush* designed for this project is the shown in the *Picture 5.1*. The model is composed by the subassemblies and parts, the components are going to be described below.

- ***Fix Part:*** Initially, the fix part of the model is shown, it subassembly is formed by the elements: *Casing, Rear Casing* and *Motor*. The covers were designed in the software *Solid Edge*® of the company *Siemens*© because the difficult of modelled the surface. These three parts are related in the same file due to a designed reason. In the *DMU Kinematick* module*,* for create a Gear joint, is necessary that the gears axes have a common base. In this model, the base of *PlasticGear* is the *Motor* and the other base is the *Casing,* and this method is the only valid for create Gear joints.



Picture 5.2. Fix Part

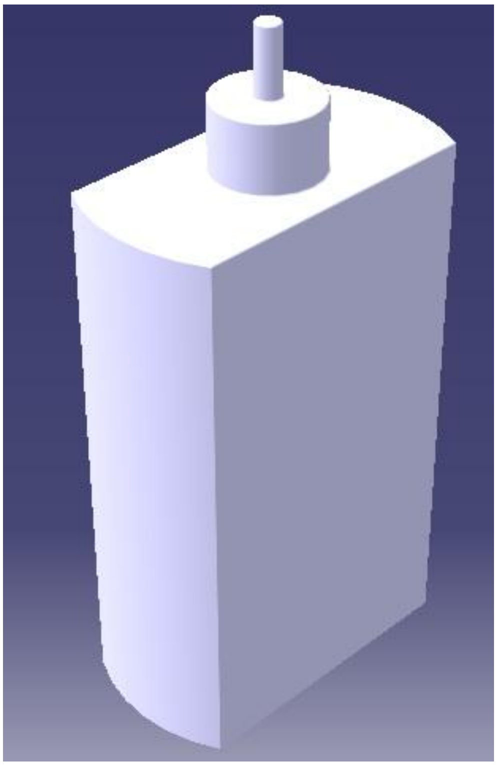
- ***Casing:*** This part is constituted by a head with two holes and the body. The holes of the head are different; one is circular to insert the rotation axis of the *Upper Toothbrush* and the other is rectangular to allow the lineal movement of the *Lower Toothbrush.* The body has two parts, the upper part is an elongated semi cone that covers the *Stick* and the thick part of the body of *Casing* protects the mechanism. Inside the lower section of its body, there is a hole where the *Axle PM* is inserted, and the *Casing* works as the *PlasticGear* rotation base*.* This element has 1mm of thickness in all surfaces except between the lines of change of two parts in the body where it has 2mm to support the *Cone*.

Picture 5.3. Casing

- ***Rear Casing:*** This element has the same external silhouette as the previous part explained but it has some differences. On the one hand, the thickness of the head is lower and it is closed, without holes. On the other hand, it has a kind of box for protect and hold the motor in the middle of the body. Both casings are made of polypropylene and are painted in white.

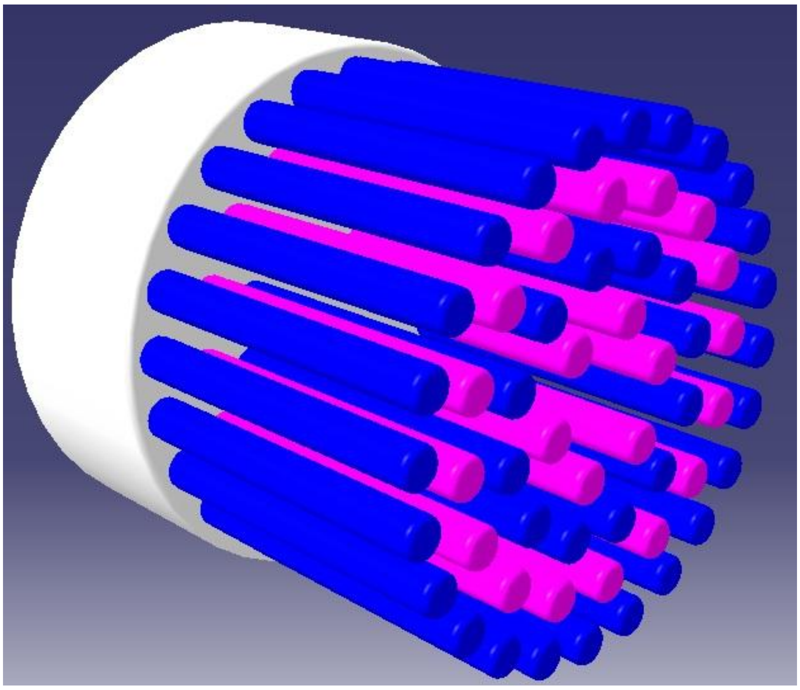
Picture 5.4. Rear Casing

- ***Motor:*** The motor is designed with the dimensions provided in the catalogue of the Chinese company *KINGLY MOTOR*©. The information about the motor is shown in the point 12.2 of this document.



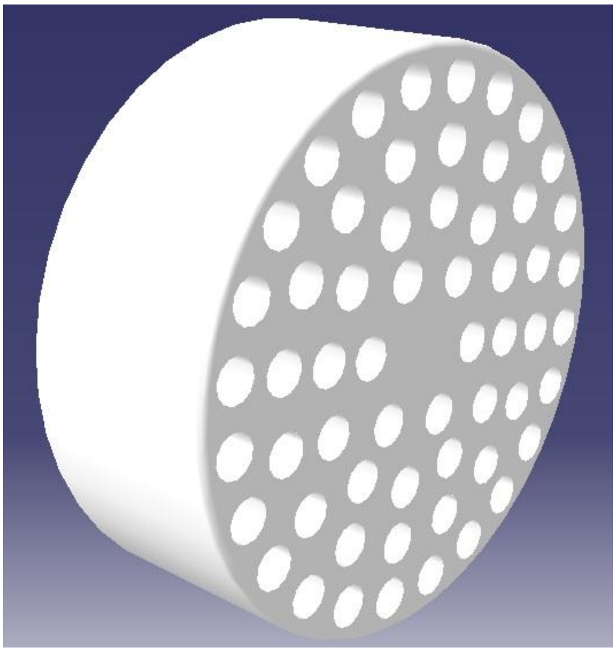
Picture 5.5. Motor

- ***Upper Brush:*** The subassembly *Upper Brush* is composed by the following parts: *External Cylinder Upper Brush* and the *Hair1* and *2.* The first one has little holes situated in a circular form where are inserted the hairs. This element is shown in the *Picture 5.6.*



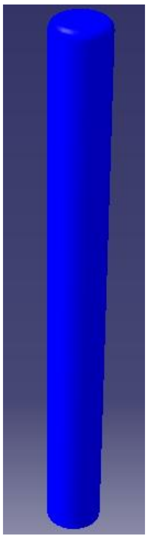
Picture 5.6. Upper Brush

- ***External Cylinder Upper Brush:*** This element has little holes situated in a circular form in the front surface where the hairs or bristles are inserted, as already mentioned above. Besides, in the opposite surface there is a hole to connect the *Upper Brush* with the *Internal Cylinder Upper Brush*.

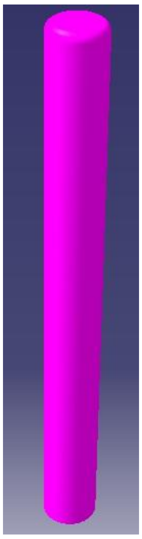


Picture 5.7. External Cylinder Upper Brush

- ***Hair1 and Hair2:*** These bristles are inserted in the holes of the previous part. Hairs are slender sticks or in other words, cylinders of little diameter with the length upper than the diameter. The difference between the *Hair1* and *Hair2* is the colour, the first one is blue and the second one is pink. The hairs are shown in the following pictures.

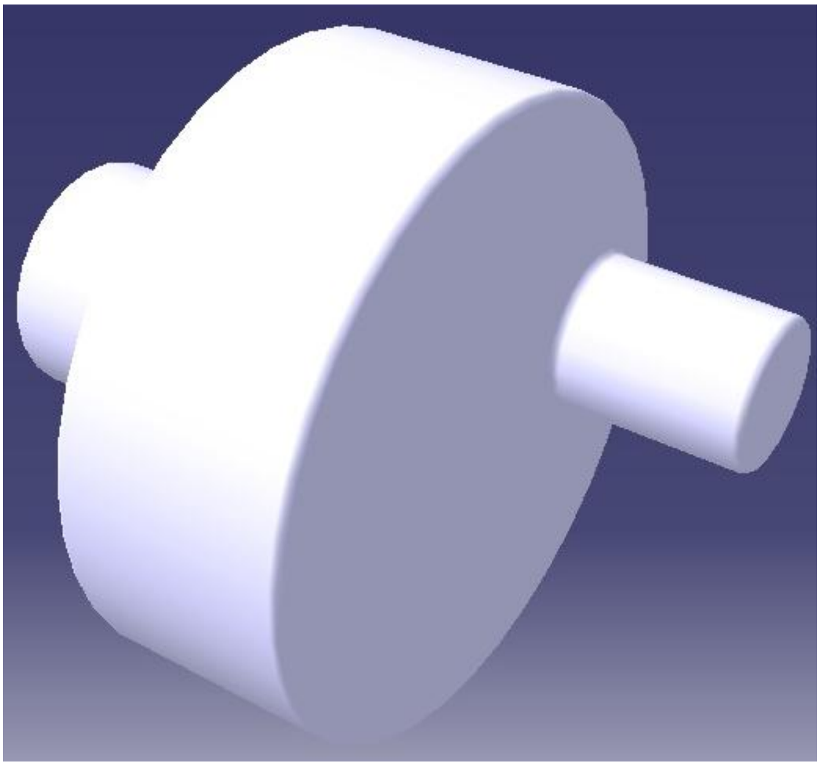


Picture 5.8. Hair1



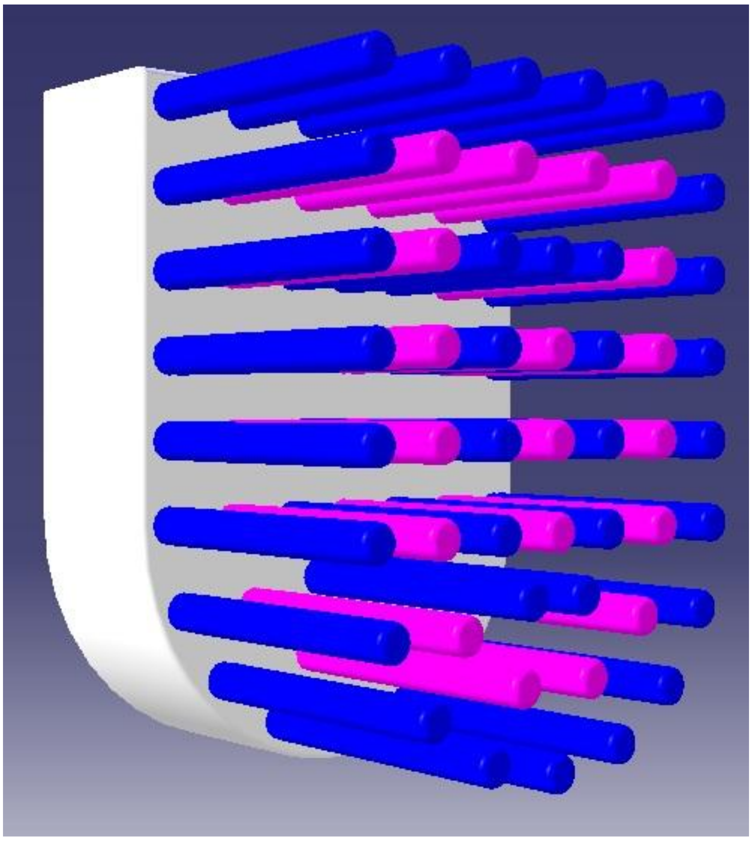
Picture 5.9. Hair2

- ***Internal Cylinder Upper Brush:*** The *Internal Cylinder Upper Brush* is the connector between the subassembly *Upper Brush* and the rest of the mechanism. It is formed by three cylinders: external, central and internal. The external cylinder is joined to the Upper Brush to transmit the movement and is concentric with it, the central cylinder work as its own support and the internal cylinder is eccentric and is adhered to the part *Connection Between Brushes.* Because of this eccentricity, the movement of rotation is possible.



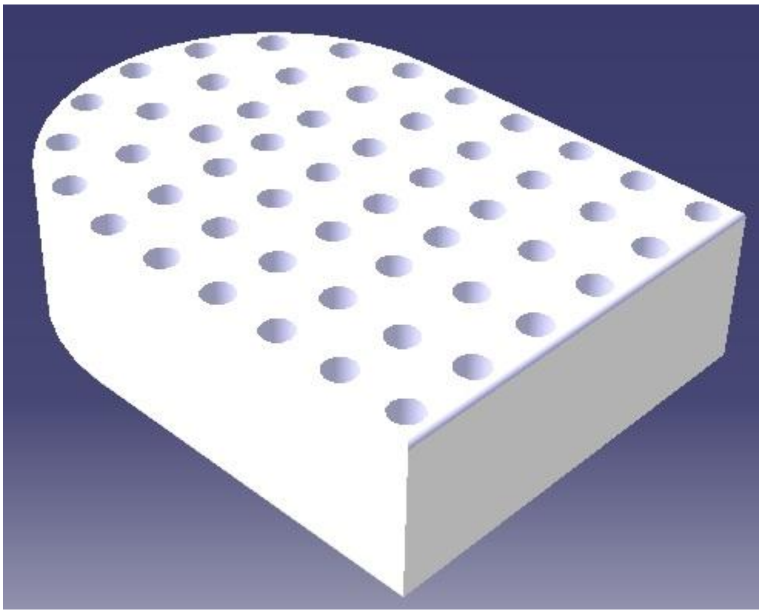
Picture 5.10. Internal Cylinder Upper Brush

- ***Lower Brush:*** The subassembly *Lower Brush* is composed by the next parts: *External Part Lower Brush* and the *Hair1* and *2.* The first one has little holes in its external surface where are inserted the hairs. The hairs are assembled in alternant form, in others words, one line is formed by a group of *Hair1* and the following line by a group of *Hair2* and so on. This element is shown in the *Picture 5.11.*



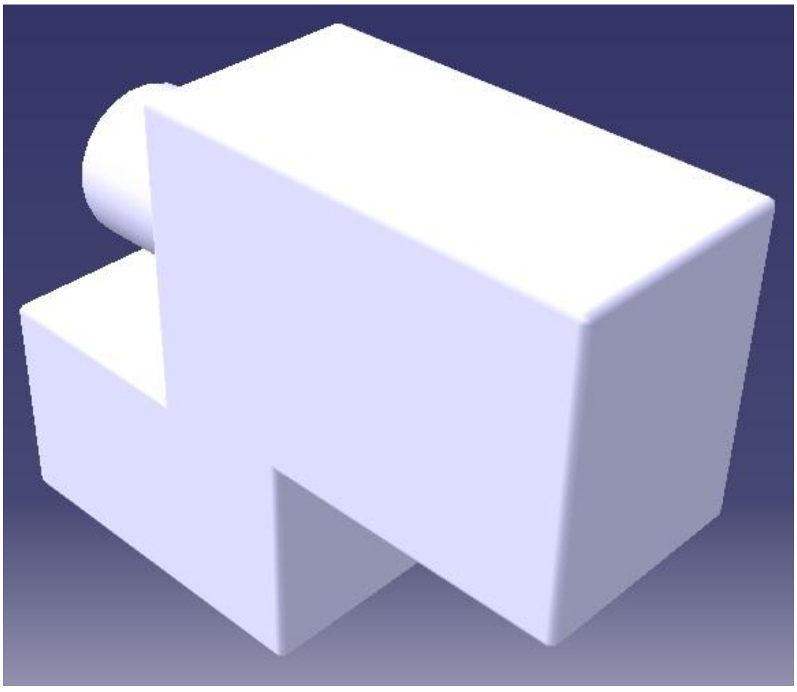
Picture 5.11. Lower Brush

- ***External Part Lower Brush:*** This component has little holes situated in the front surface where are inserted the hairs or bristles, as already mentioned above. Besides, in the opposite surface there is a rectangular cavity for connect the Low*er Brush* with the *Connection Lower Brush with the Mechanism*.



Picture 5.12. External Part Lower Brush

- ***Connection Lower Brush with Mechanism:*** The *Lower Brush* Connection *with the Mechanism* is a Z form part with three union points. On the one hand, it has a rectangle in the right side, as it can seen in the *Picture 5.11* that it is inserted in the back hole of the *External Part Lower Brush*. On the other hand, it has a cylinder in the left side, as it can seen in the following image, where *Connection Between Brushes* is assembly and finally, in the under surface it has a hole for join the part *Connection Lower Brush with Mechanism* with the *Stick.*

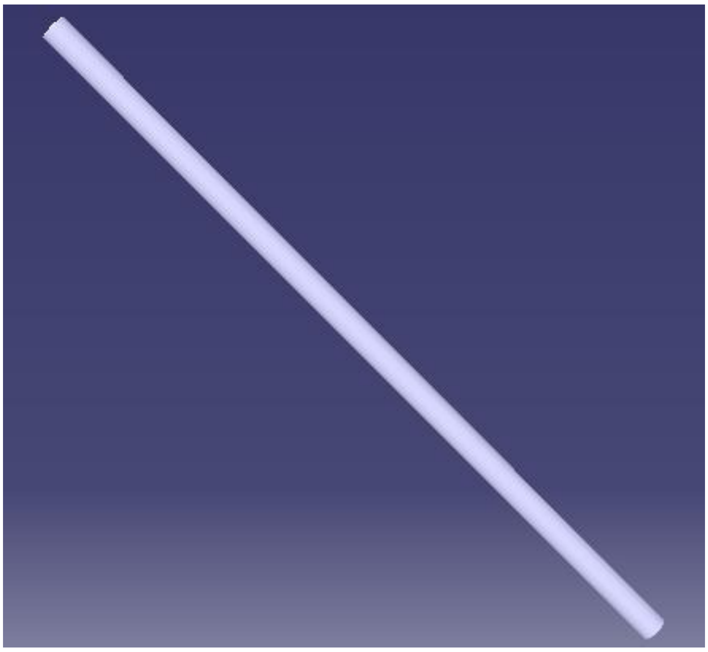


Picture 5.13. Connection Lower Brush with Mechanism

- ***Connection Between Brushes:*** This element which function is transmit the linear movement of the *Lower Brush* to circular motion in *Upper Brush* has a form of symmetric connecting rod. The holes of its ends are inserted in the *Internal Cylinder Upper Brush* and in the *Connection Lower Brush with Mechanism.*

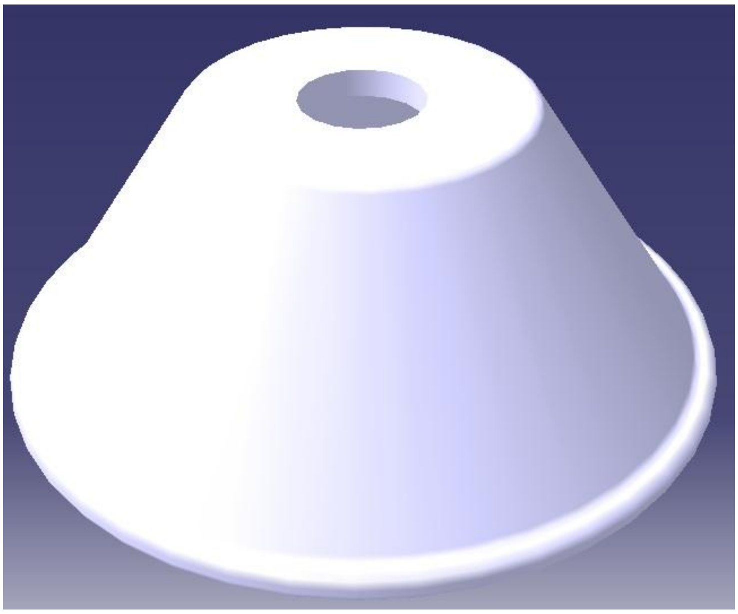
Picture 5.14. Connection Between Brushes

- ***Stick:*** The *Stick* is a slender bar which function is transmit the rotation motion generated by the motor and that is changed to lineal movement by the bevel gears, to the system of brushes.



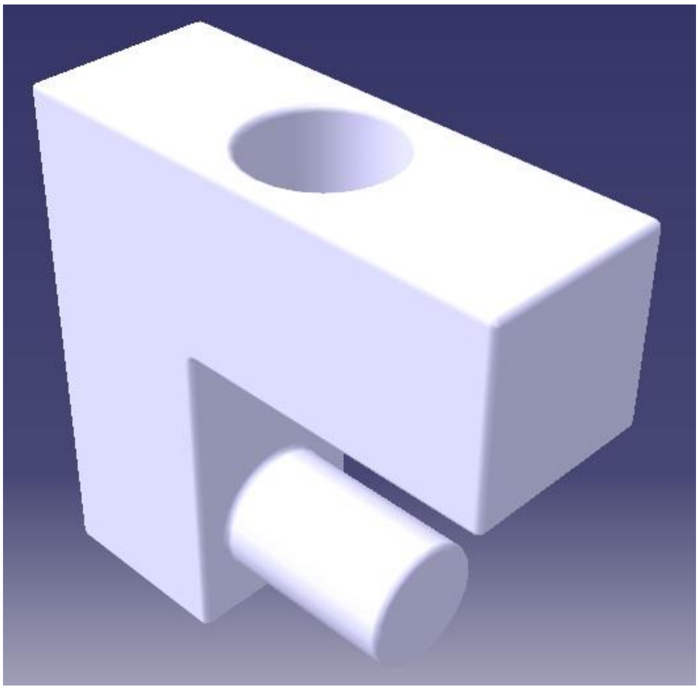
Picture 5.15. Stick

- ***Cone**:* The element *Cone* is, as its own name indicates, a small part with cone form. It is located in the middle of the body of the casings and its function is the support of the *Stick.*



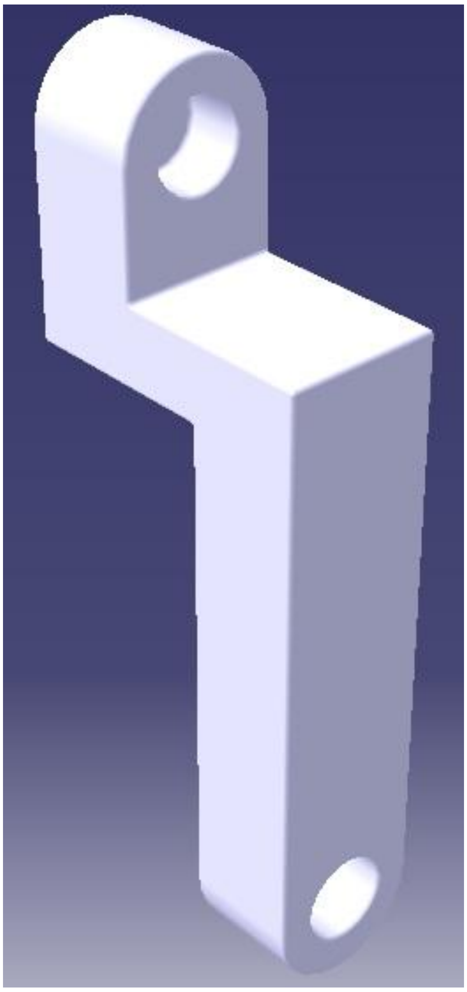
Picture 5.16. Cone

- ***L:*** It is a part with L form, as its own name indicates, which is located between the *Stick* and the *Connection with Wheel.* The first one is inserted in the hole of the upper surface and the second one has the axis of rotation the cylinder of the right side. The *L* is showed in the following picture.



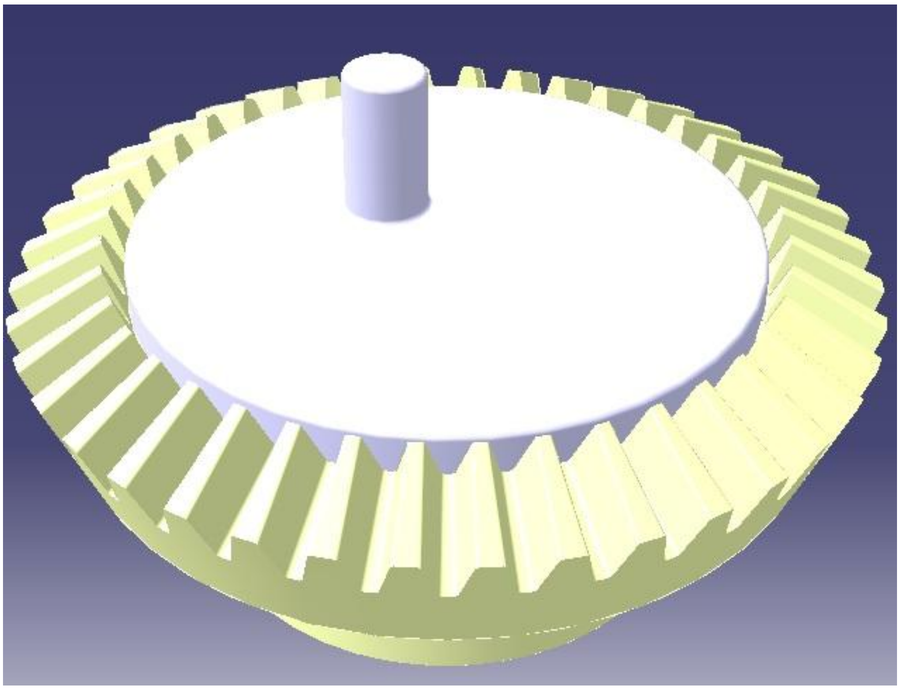
Picture 5.17.L

- ***Connection with Wheel:*** This part connects the *Plastic Wheel* with the rest of the system and is the key to change the kind of movement, for this reason, it is very important inside the model. Besides, the part looks like an eccentric connecting rod to avoid the crash with the teeth of the wheel. *Picture 5.18.*



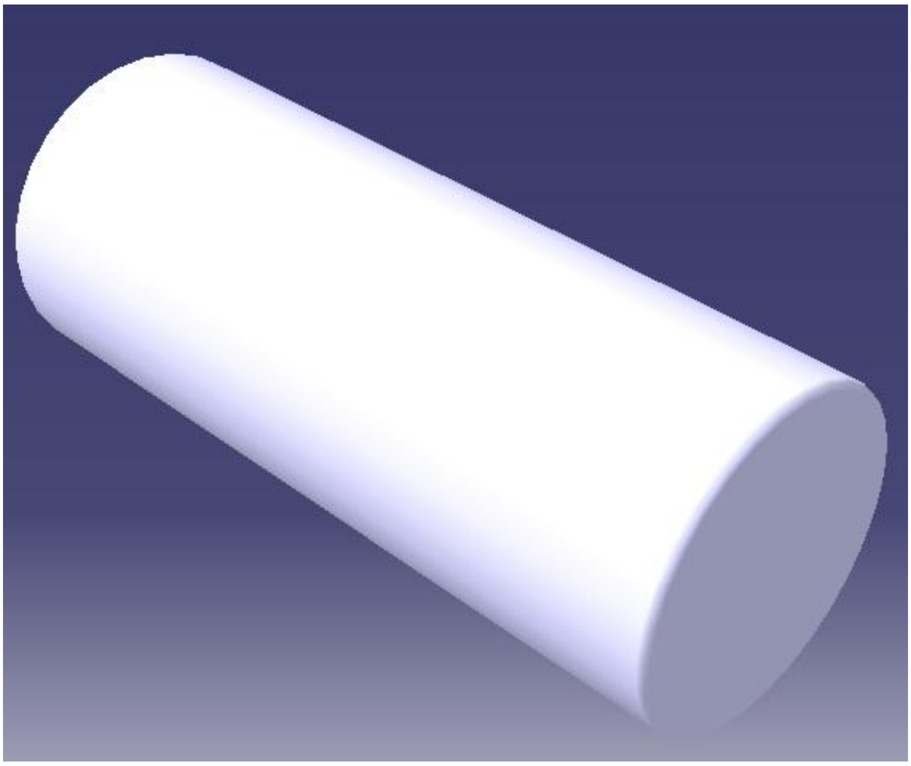
Picture 5.18. Connection with Wheel

- ***Plastic Wheel:*** The part denominated *Plastic Wheel* is a component of the couple of bevel gears chosen in the catalogue of the company *SDP/SI*© (*Stock Drive Products/ Sterling Instrument*) which characteristics are gathered in the annexe 12.1. Otherwise, it is joins with *Connection with Wheel* due to a plastic component inserted concentrically with it. *Picture 5.19.*



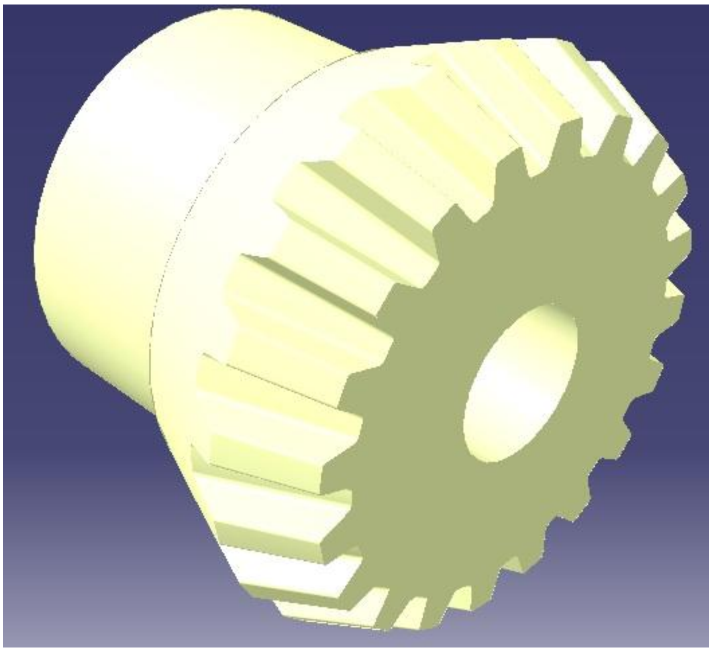
Picture 5.19. Plastic Wheel

Axle PW: Axle PW is a cylindrical element that connect *Plastic Wheel* with a hole in the inside surface of the body. Its function, as its own noun indicates, is operating as an axle between *Casing* and *PlasticWheel* for allow the rotational movement of the last part mentioned.



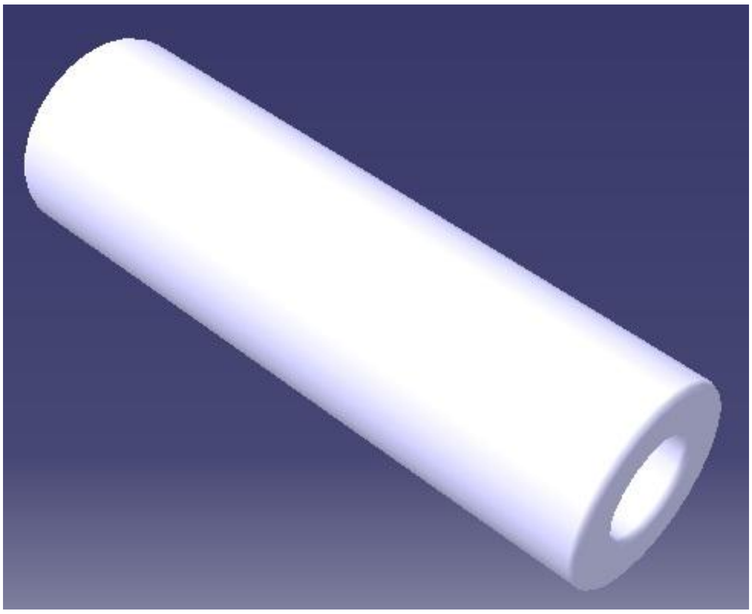
Picture 5.20. Axle PW

- ***Plastic Gear:*** The *Plastic Gear* is the second component of the couple of bevel gears chosen in the catalogue of the company *SDP/SI*© (*Stock Drive Products/ Sterling Instrument*) which characteristics are gathered in the annexe 12.1. It is linked to a motor by the axis that it has in the centre of its body. *Picture 5.21.*



Picture 5.21. Plastic Gear

Head of Motor: The element *Head of Motor* is the axle of the gear *PlasticGear*. This part is inserted inside of the hole of the gear and is connected with the *Motor* due to its internal hole. *Picture 5.22.*



Picture 5.22. Head of Motor

6. MODEL PERFORMANCE

The next step to the explication about the basic components of the toothbrush is explains how it works. In the following chapter, the *Toothbrush* characteristics related with its movements will be explained. Moreover, the mechanism designed will be compared with the basic mechanism (*Slider-Crank mechanism*) commented in the *Chapter 3*.

6.1. KINEMATIC MODEL CHARACTERISTICS

First of all, the kinematic description of the mechanism *Toothbrush* must be introduced; in the first order, the mechanism can be simulated because it has *0 DOF* (Degrees of Freedom) and all its movements are determinate when an input speed is defined. The name of the mechanism aim of study in *CATIA*® is also *Toothbrush.*

Null *DOF* are got in the mechanism due to the composition of several factors. On the one hand, the designer should define the joints and a fix part (mechanical part), and on the other hand, is necessary to indicate the commands and the laws.

Mechanism name:	Toothbrush
Mechanism can be simulated:	Yes
Number of joints:	23
Number of commands:	1
Degrees of freedom without command(s):	1
Degrees of freedom with command(s):	0
Fixed part:	Fix Part.1

Chart 6.1. Mechanism Characteristics

Within the model under consideration, the element denominated *Fix Part* is, as its own noun indicates, the fix part of the model. This subassembly is formed by three immovable components, as: *Casing, Rear Casing* and *Motor.*

For the simulation, a command is required; in this case, the rotation angle of the *PlasticGear* is the chosen. Initially, for the previous experiments the angle is *1440deg* (4 revolutions). In addition, the law related the angle turned with the time, specifically: the gear turns 36deg per second.

*Formula.2=Toothbrush\Commands\Command.1\Angle.1=Toothbrush\KNTime\1s*36deg*

In the second order, it may be interesting to mention the joints available in the module *DMU Kinematic*, because the *Toothbrush* can be simulated due to the right combination of several joints. The next chart summarizes these.

V4 NAME	JOINTTYPE	DEGREES OF FREEDOM	COMMAND TYPE
revolute	Revolute	1 Rotation	Angle
prismatic	Prismatic	1 Translation	Length
actuator	Cylindrical	1 Rotation 1 Translation	Length + Angle AND/OR Angle or Length
pt/pt	Spherical	3 Rotations	–
planar	Planar	2 Translations 1 Rotation	–
rigid	Rigid	–	–
roll/crv	Roll Curve	1 Rotation 1 Translation	Length
slid/crv	Slide Curve	2 Rotations 1 Translation	–
pt/crv	Point Curve	3 Rotations 1 Translation	Length
pt/surf	Point Surface	2 Translations 3 Rotations	–
u jnt	U Joint	1 Rotation	–
gear	Gear joint	1 Rotation	Angle1 or Angle2 (exclusive)
rack	Rack Joint	1 Rotation or 1 Translation	Length1 or Angle2 (exclusive)
cable	Cable Joint	1 Translation	Length1 or Length2
screw	Screw Joint	1 Rotation or 1 Translation	Angle or Length (exclusive)
cv joint	CV Joint	–	–

Chart 6.2. Joint Types

(Scribd Inc., 2011)

For the kinematic definition of the model, the following joints have been used: revolute, cylindrical, planar, gear and rigid. In general, 22 joints have been used, as shown in the *Chart 6.3.*

Joint	**Type**	**Part**	**Geometry**	**Geometry Type**
Rigid.1	Rigid	ToothBrush/ Axle PW.1		
		ToothBrush/ PlasticWheel.1		
Rigid.2	Rigid	ToothBrush/ Cone.1		
		ToothBrush/ Fix Part.1		
Cylindrical.3	Cylindrical	ToothBrush/Stick.1	Stick/PartBody/Pad.1/Axis	Line
		ToothBrush/ Cone.1	Cone/PartBody/Shaft.1/Axis	Line
Revolute.4	Revolute	ToothBrush/ Connection between brushes.1	Connection between brushes/PartBody/Pad.1/ Axis	Line
			Connection between brushes/PartBody/Pad.1/ Face	Plane
		ToothBrush/ Connectuon lower brush-mechanism.1	Connection lower brush-mechanism/PartBody/Pad.2/ Axis	Line
			Connection lower brush-mechanism/PartBody/Pad.1/ Face	Plane
Planar.5	Planar	ToothBrush/Internal Cylinder Upper Brush.1	Internal Cylinder Upper Brush/PartBody/Pad.1/Face	Plane
		ToothBrush/ Connection between brushes.1	Connection between brushes/PartBody/Pad.1/ Face	Plane
Revolute.6	Revolute	ToothBrush/ Connection with wheel.1	Connection with wheel/PartBody/Pocket.1/Fa ce	Plane
			Connection with wheel/PartBody/EdgeFillet.2/ Axis	Line

		ToothBrush/L.1	L/PartBody/Pad.2/Face	Plane
			L/PartBody/Pad.2/Axis	Line
Planar.7	Planar	ToothBrush/ Connection with wheel.1	Connection with wheel/PartBody/Pad.1/Face	Plane
		ToothBrush/Plastic Wheel.1	PlasticWheel/PartBody/Pad.1 /Face	Plane
Planar.8	Planar	ToothBrush/ Connection lower brush-mechanism.1	Connection lower brush-mechanism/ PartBody/Pad.1/Face	Plane
		ToothBrush/Fix Part.1	Fix Part/Casing/PartBody/ Body/Face	Plane
Rigid.9	Rigid	ToothBrush/Lower Brush.1		
		ToothBrush/ Connection lower brush-mechanism.1		
Revolute.11	Revolute	ToothBrush/Fix Part.1	Fix Part/Casing/PartBody /Solid/Axis	Line
			Fix Part/Casing/PartBody /Body/Face	Plane
		ToothBrush/ Internal Cylinder Upper Brush.1	Internal Cylinder Upper Brush/PartBody/Pad.1/Axis	Line
			Internal Cylinder Upper Brush/PartBody/Pad.1/Face	Plane
Planar.12	Planar	ToothBrush/Fix Part.1	Fix Part/Casing/PartBody /Body/Face	Plane
		ToothBrush/Lower Brush.1	Lower Brush/External Part Lower Brush/PartBody/pad.1/Face	Plane
Revolute.15	Revolute	ToothBrush/Fix Part.1	Fix Part/Casing/PartBody/ Solid/Axis	Line
			Fix Part/Casing/PartBody/ Solid/Face	Plane
		ToothBrush/Upper Brush.1	Upper Brush/External Cylinder Upper Brush/ PartBody/Pad.1/Axis	Line

			Upper Brush/External Cylinder Upper Brush/ PartBody/Pad.1/Face	Plane
Rigid.16	Rigid	ToothBrush/Head of Motor.1		
		ToothBrush/Plastic Gear.1		
Rigid 17	Rigid	ToothBrush/Upper Brush.1		
		ToothBrush/Internal Cylinder Upper Brush.1		
Rigid 18	Rigid	ToothBrush/Stick.1		
		ToothBrush/L.1		
Gear.18	Revolute (13)	ToothBrush/Fix Part.1	Fix Part/Motor/PartBody/ Pad.2/Axis	Line
			Fix Part/Motor/PartBody/ Pad.3/Face	Plane
		ToothBrush/Plastic Gear.1	PlasticGear/Geometrical Set.1/TRM_SRF23/Axis	Line
			PlasticGear/Geometrical Set.1/TRM_SRF21/Face	Plane
	Revolute (14)	ToothBrush/Plastic Wheel.1	PlasticWheel/Geometrical Set.1/TRM_SRF126/Axis	Line
			PlasticWheel/Geometrical Set.1/TRM_SRF130/Face	Plane
		ToothBrush/Fix Part.1	Fix Part/Casing/PartBody/ Pad.1/Axis	Line
			Fix Part/Casing/PartBody/ Pocket.1/Face	Plane
Planar.17	Planar	ToothBrush/Internal Cylinder Upper Brush.1	Internal Cylinder Upper Brush/ PartBody/Pad.1/Face	Plane
		ToothBrush/ Connection between brushes.1	Connection between brushes/PartBody/Pad.1/ Face	Plane

Planar.18	Planar	ToothBrush/ Connection lower brush-mechanism.1	Connection lower brush-mechanism/ PartBody/Pad.1/Face	Plane
		ToothBrush/ Connection between brushes.1	Connection between brushes/PartBody/Pad.1/ Face	Plane
Revolute.20	Revolute	ToothBrush/ Connection lower brush-mechanism.1	Connection lower brush-mechanism/ PartBody/EdgeFillet.3/Axis	Line
			Connection lower brush-mechanism/ PartBody/Pad.1/Face	Plane
		ToothBrush/Stick.1	Stick/PartBody/Pad.1/Axis	Line
			Stick/PartBody/ Pad.1/Face	Plane
Revolute.21	Revolute	ToothBrush/Plastic Gear.1	PlasticGear/Geometrical Set.1/TRM_SRF23/Axis	Line
			PlasticGear/Geometrical Set.1/TRM_SRF21/Face	Plane
		ToothBrush/Fix Part.1	Fix Part/Motor/PartBody/ Pad.2/Axis	Line
			Fix Part/Motor/PartBody/ Pad.3/Face	Plane
Revolute.22	Revolute	ToothBrush/Plastic Wheel.1	PlasticWheel/Geometrical Set.1/TRM_SRF126/Axis	Line
			PlasticWheel/Geometrical Set.1/TRM_SRF130/Face	Plane
		ToothBrush/Fix Part.1	Fix Part/Casing/PartBody/ Pad.1/Axis	Line
			Fix Part/Casing/PartBody/ Pocket.1/Face	Plane
Revolute.23	Revolute	ToothBrush/Plastic Wheel.1	PlasticWheel/ PartBody/Pad.1/Axis	Line
			PlasticWheel/ PartBody/Pad.2/Face	Plane
		ToothBrush/Conne ction with Wheel.1	Connection with Wheel/PartBody/Pocket.2 /Axis	Line
			Connection with Wheel/PartBody/Pad.1 /Face	Plane

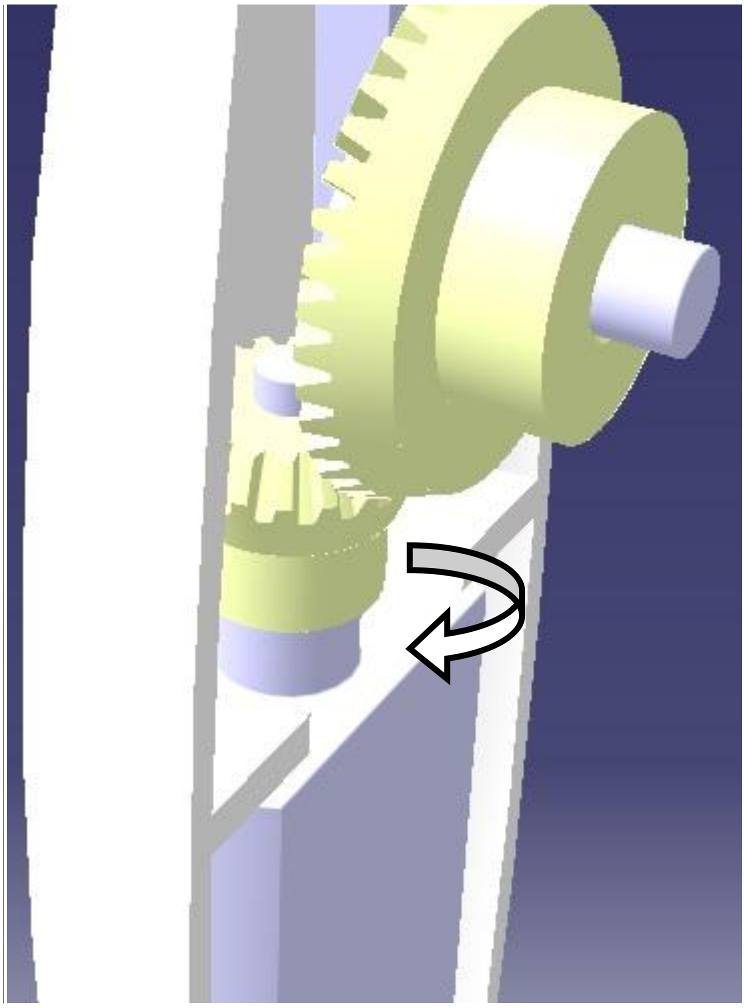
Revolute.24	Revolute	ToothBrush/Connection between brushes.1	Connection between brushes/PartBody/Pad.1/Axis	Line
			Connection between brushes/PartBody/Pad.1/ Face	Plane
		ToothBrush/Internal Cylinder Upper Brush.1	Internal Cylinder Upper Brush/.PartBody/Pad.3/Axis	Line
			Internal Cylinder Upper Brush/.PartBody/Pad.1/Face	Plane

Chart 6.3. Toothbrush Joints

6.2. PERFORMANCE EXPLANATION

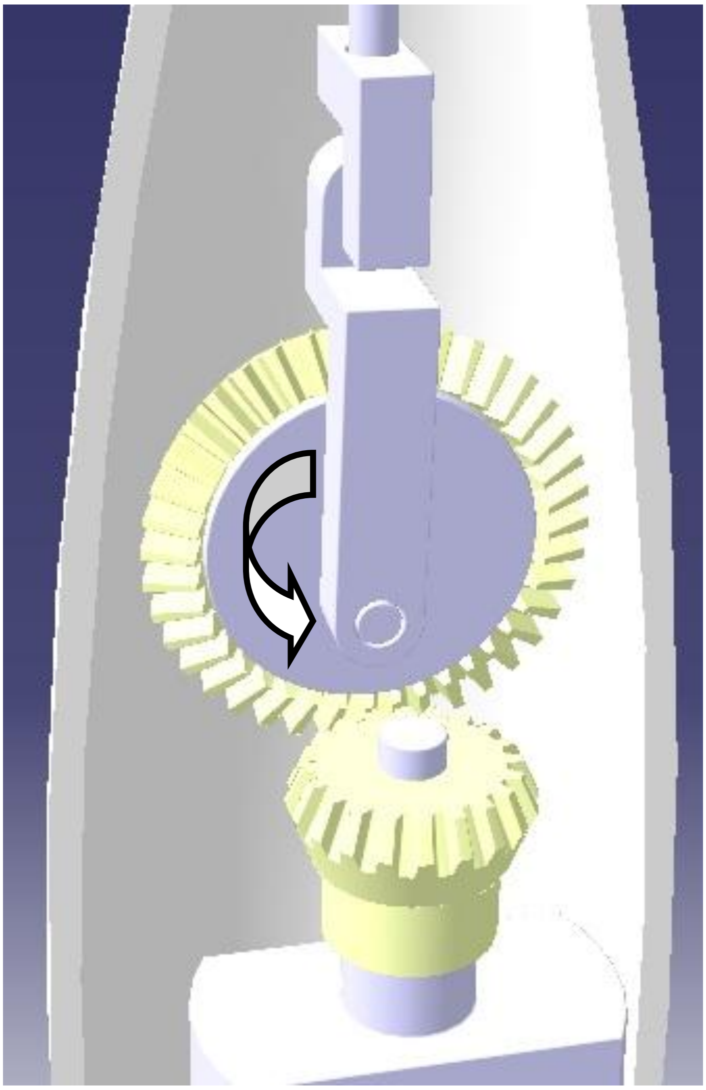
Throughout of this chapter has told in detail the movements and its transmission, in every part of the mechanism.

In the first place, the rotational motion is generated by the *Motor* that due to *PlasticGear* is joined with it for the part *Head of Motor* that it is inserted in its cylinder end. This connection transmits the movement to the rest of the mechanism.



Picture 6.1. Transmission of the Motor motion to the Plastic Gear

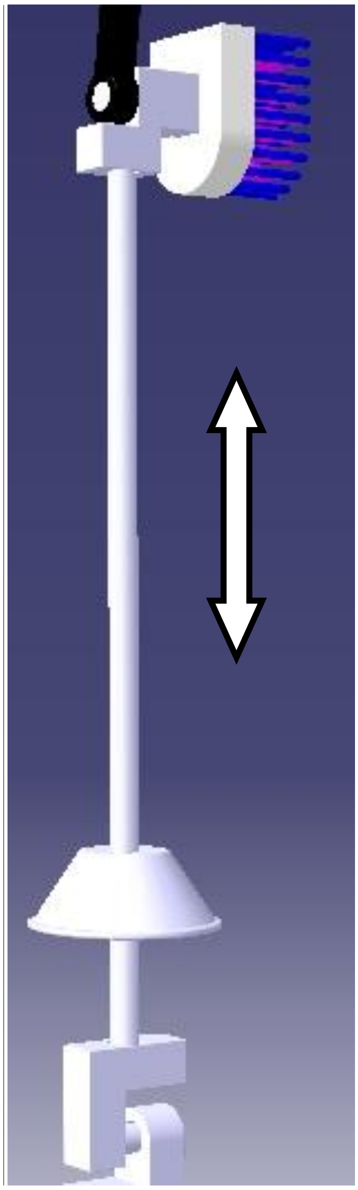
The kind of movement is changed in the couple of bevel gears, the rotational motion transmitted by the *Motor* is turned to linear movement when it through these parts. The *PlasticWheel* has a plastic cylinder fit coaxially with it that has a little cylinder with is inserted the part *Connection with Wheel*. This cylinder is eccentric 2mm to the centre of the *Plastic Wheel* for allow the *Lower Brush* alternative movement. The *Plastic Wheel* works as a crank of this model.



Picture 6.2. Bevel Gears change the kind of movement

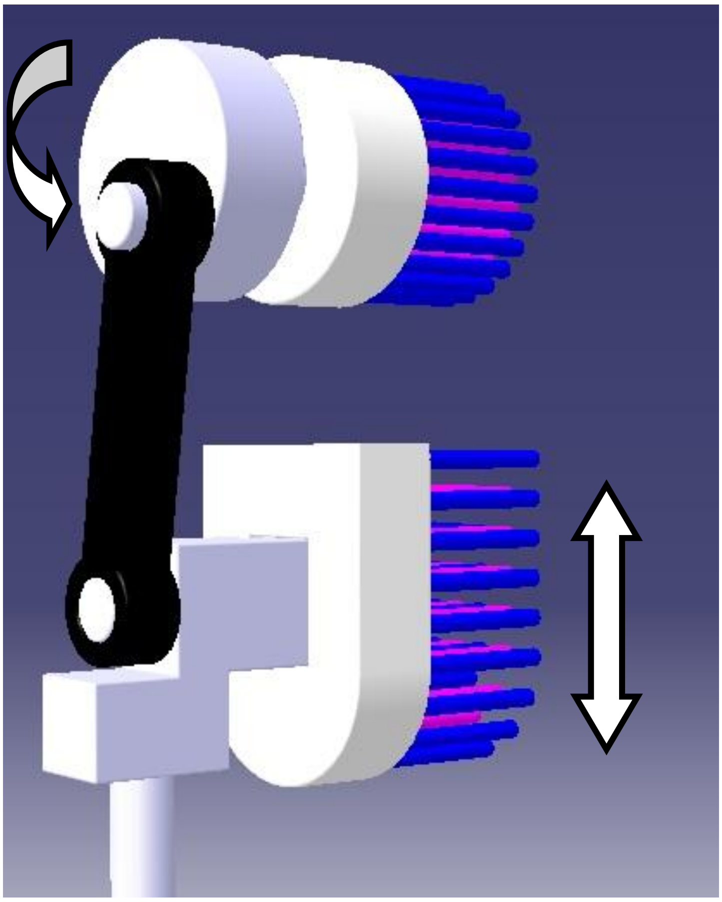
The component *Connection with Wheel* works as a connecting rod between the bevel gears and the rest of the system. This element is linked to *L* in the other end that is considered the beginning of the slider.

The slider of the toothbrush aim of study of this project is formed by the following parts: *L, Stick, Connection Lower Brush with Mechanism* and the subassembly *Lower Brush.* This set of parts transmits the linear movement.



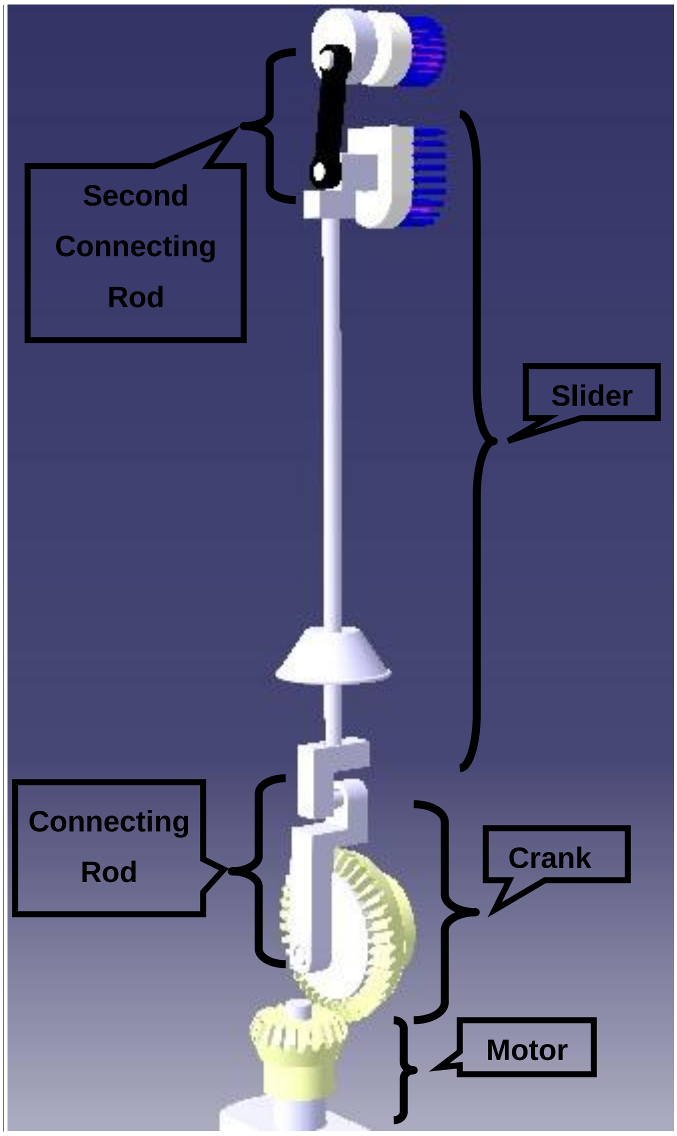
Picture 6.3. Slider

Due to *Connection Between Brushes* is possible the circular motion of the subassembly *Upper Brush.* This element has a form of symmetric connecting rods which ends are inserted in the *Internal Cylinder Upper Brush* and in the *Connection Lower Brush with Mechanism.* It works as a second connecting rod that changed other time the kind of movement. *Picture 6.4.*



Picture 6.4. Transmission of motion between brushes

As a summary, in the *Picture 6.5* are represented the different parts: *crank, connecting rod* and *slider* that form the mechanism *Toothbrush.*



Picture 6.5. Parts of Toothbrush

7. KINEMATIC ANALYSIS

This project is divided in three important parts; the first one is the specification of the model and mechanism object of study, the second one is its design in the *CATIA*® modules abilities for it, and the drawings specifics where the dimensions of the constitutive elements are represented. Finally, the mechanism will be characterized kinematically.

In addition, the module used for this stage is *DMU kinematic,* where the program allows define the kinematic characteristic such as: joints, commands, laws (determine the inputs, inside this case the angular speed of the *PlasticGear*), fix part, sensor for analyze the movement, speed and acceleration and export the results. Moreover, it allows record videos with the motion, make analysis of clashes, draw the sweep volume for each part and the assembly.

For this last part is important study several parameters, as can be:

- ***Optimization of rotation angle Upper Brush***

The rotation angle *Upper Brush* should be maximum for a better brushing, but in an alternative motion (lower than 360º).

- ***Relation of movement between gears***

For a well design, the relation between the motions of the gear must be considered, because this relation is not ideal and it should affect to the final dimensions of the model or parameters.

- ***Other analysis: Lower Brush Displacement.***

The *Lower Brush* displacement is a design condition and should be checked.

- ***Model Sweep Volume***

The mechanism and parts sweep volume is important checked because is necessary know the free space between parts and the space required in the design of the covers.

- ***Clashes***

Other essential analysis is the study of collisions between the parts in movement, because the software not recognize if the designer assembly a part over other part in the assembly stage, for know this stuff is necessary done this analysis.

8. RESULTS

8.1. INTRODUCTION

In the present section will be explained the results obtained in the kinematic analysis realized to the mechanical system designed along this document.

As it has been told previously, the next results are determined from these studies:

- ***Optimization of rotation angle Upper Brush***
- ***Relation of movement between gears***
- ***Other analysis: Lower Brush Displacement.***
- ***Model Sweep Volume***
- ***Clashes***

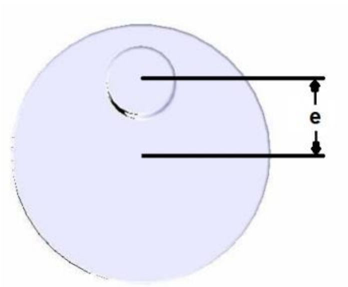
Therefore, the structure of this chapter is based in this sketch.

8.2. OPTIMIZATION OF ROTATION ANGLE UPPER BRUSH

The main aim in this project is find the optimal *Upper Brush* rotation angle with certain conditions of design. In this case, the principal condition is the displacement of the *Lower Brush,* it value should be 4mm. This parameter has the same value that the eccentricity in the connexion between *PlasticWheel* and *Connection with Wheel.*

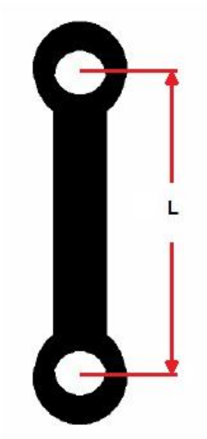
Besides, the circular movement of the *Upper Brush* is achieved when the diametric eccentricity in the connexion between *Internal Cylinder Upper Brush* and *Connection Between Brushes* is higher than 4mm. Given this specification and the clashes between the parts of the model, the following parameters have been modified:

- The eccentricity *e* of the appendix cylinder located in the internal surface of the part *Internal Cylinder Upper Brush. Picture 8.1.*



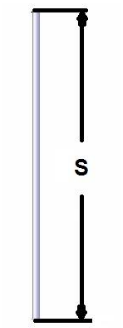
Picture 8.1.e Definition

- The longitude *L* between the centres located in the ends of the element *Connection Between Brushes. Picture 8.2.*



Picture 8.2. L Definition

- The longitude *S* of the *Stick. Picture 8.3.*



Picture 8.3. S Definition

The modifications procedure is the next: in the first place, change the eccentricity *e* with the rest of parameters constants; in the second place, with the new *e* change *L*, and if is necessary in each case, change *S* to avoid collisions. All this information is summarizes in the *Chart 8.1* where are collected the data of the test realized and the results obtained.

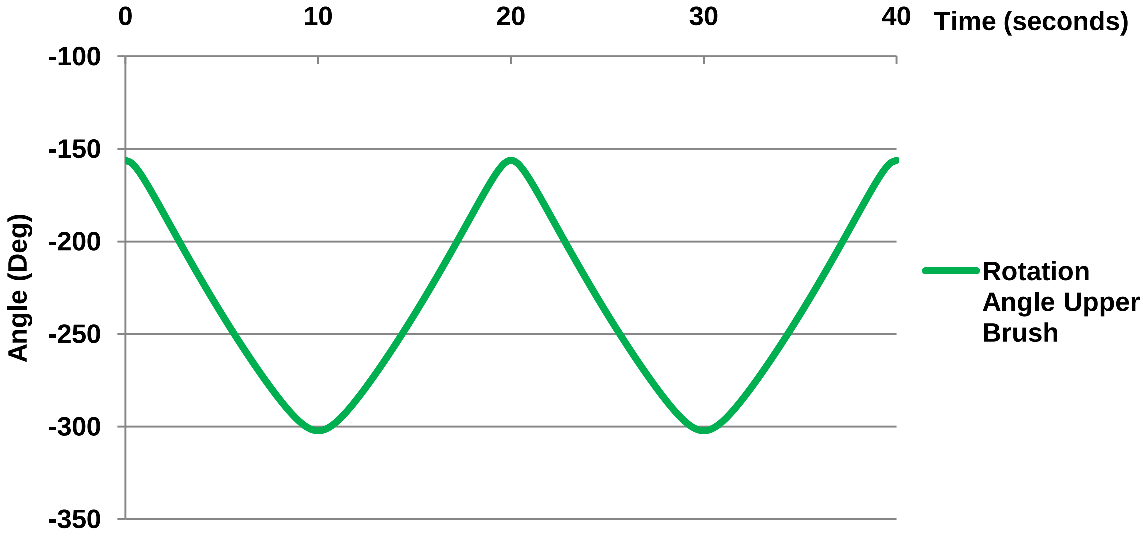
FILE	DIMENSIONS (mm)	UPPER BRUSHROTATION ANGLE (Deg)
Initial	e = 2.50	108.26
	L = 11.87	
Optimization1	e = 2.70	108.26
	L = 11.87	
Optimization2	e = 2.70	99.42
	L = 12.07	
Optimization3	e = 2.30	Locked after 11.33s
	L = 11.87	
Optimization4	e = 2.30	Locked after 11.33s
	L = 12.07	
Optimization5	e = 2.30	121.17
	L = 11.67	
Optimization6	e = 2.10	It does not work around the complete circle
	L = 11.67	

Optimization7	e = 2.10	146.08
	L = 11,47	
Optimization8	e = 2.00	It does not move
	L = 11.37	
Optimization9	e = 1,90	It does not work around the complete circle
	L = 11.47	
Optimization10	e = 1.90	It does not work around the complete circle
	L = 11.27	
Optimization11	e = 1.90	It does not move
	L = 11.07	
ptimization12	e = 2.10	It does not work around the complete circle
	L = 11.67	
	S=60.00	
Optimization13	e = 2.10	It does not work around the complete circle
	L = 11.67	
	S =64.00	
Optimization14	e = 2.30	It does not work around the complete circle
	L <11.67	
	S =61.20	
Optimization15	e = 2.30	It does not work around the complete circle
	L <11.67	
	S >61.20	
Optimization16	e = 2.30	It does not work around the complete circle
	L <11.67	
	S <61.20	

Chart 8.1. Summary of Optimizations

After the simulations done, the dimensions of the *Optimization 7* are chosen because these maximize the angle. For a better design, the angle should be higher than 180º but other parameters of design should be changed, as the diametric eccentricity of the connexion between *PlasticWheel* and *Connection with Wheel* for the *Upper Brush* have higher amplitude in its lineal motion.

In the next graphic, the rotation angle of *Upper Brush* is shown; it is negative due to rotation direction, the maximum value is -156.15º and the minimum is -302.23º, so the rotation angle is **146.08º**.It should be noted that the input angular speed is *π/5 rad/s*.



Graphic 8.1.Rotation angle Upper Brush

8.3. RELATION OF MOVEMENT BETWEEN GEARS

One focus of study, inside the development of the model, is the relation between the angles turned by the gears. This aspect is important because is there where the movement is generated and transmitted, and if it failure, the problem affect to the complete mechanism.

That the gear efficiency is less than 100% is something known by everyone, because no mechanism is perfect, they always have failures due to teeth wear out, sliding, etc. But the transmission by gear is one of the systems of transmission of movement more effectives inside the methods known, as the *Chart 8.2* shows, the efficiency is around 97%.

Characteristic	Friction wheel	Spur gears	Flat belts	Trapezoidal belts	Toothed belts	Chains
Max power [kW]	80	80000	200	350	120	400
Max torque [kNm]	5	7000	3	5	1	40
Max linear speed [m/s]	20	30	100	30	60	10
Efficiency	0.95	0.97	0.97	0.97	0.96	0.95
Power function os speed	y	n	y	y	y	y
Max ratio (1 stage)	6-18	6-10	6-8	6-10	6-10	6-10
Tensioning required	y	n	y	y	n	n
Load on bearing	high	low	high	high	low	low
Build precision	average	high	low	low	low	average
Presence of sliding	y	n	y	y	n	n
Noise	low	average	low	low	low	high
Overload limiter	y	n	y	y	n	n

Chart 8.2. Comparison between different movement transmission methods

For compare this relation in the model aim of study, the values obtained during the simulation have been saved in a excel file to study better its behaviour. This information has been represented in a graphic. The program, at the same time, represented its own graphic with the same information, but it definition and format is not valid to analyze the results because every line is represented in different axis and for the lector and designer is difficult do a comparison and obtain conclusions.

The ideal relation of transmission between the bevel gears of the model is:

$$i = \frac{n_1}{n_2} = \frac{Z_2}{Z_1}$$

Where:

n_1= angular velocity of PlasticGear

n_2= angular velocity of PlasticWheel

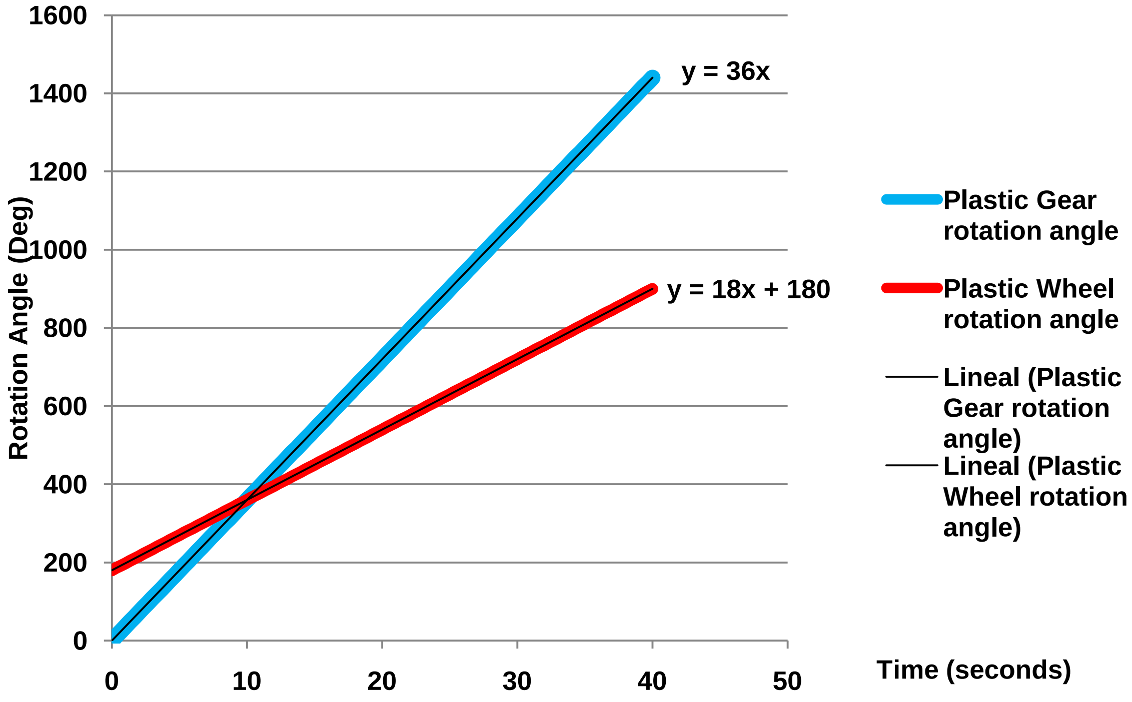
Z_1=number of teeth of PlasticGear

Z_2= number of teeth of PlasticWheel

In this case is:

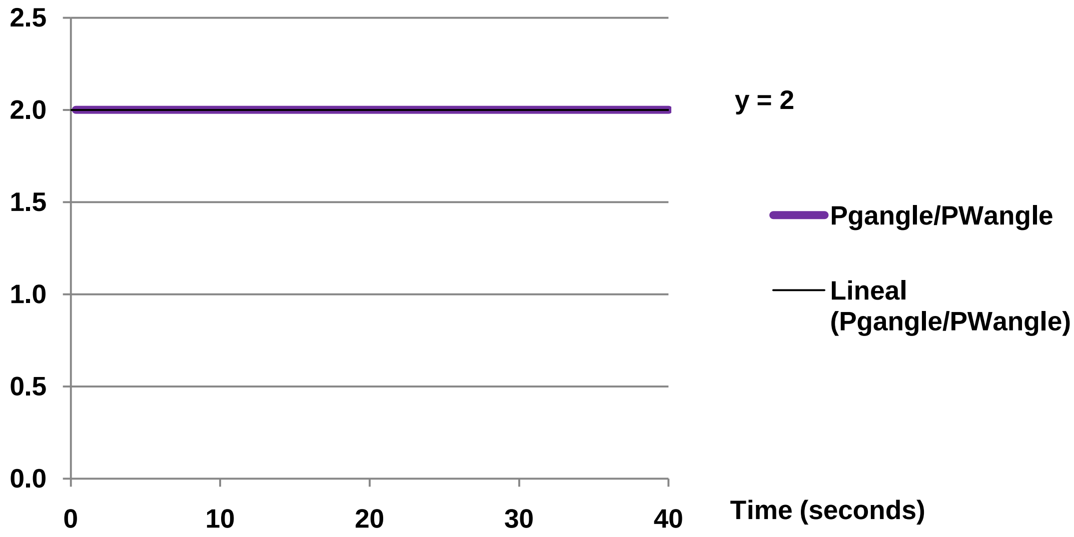
$$i = \frac{n_1}{n_2} = \frac{40}{20} = 2$$

In the next graphic, the results provided by *DMU Kinematic* to the angles turned by both gears are represented. As it can seen, if the equations of the movement are compared, the relation of transmissions between *PlasticGear* and *PlasticWheel* is 2 and the difference in the initial instant is 180º.



Graphic 8.2. Gears Rotation Angle

The *Graphic 8.3* shows more clearly the relation of transmission between the bevel gears. This relation is the ideal calculated in the previous page.



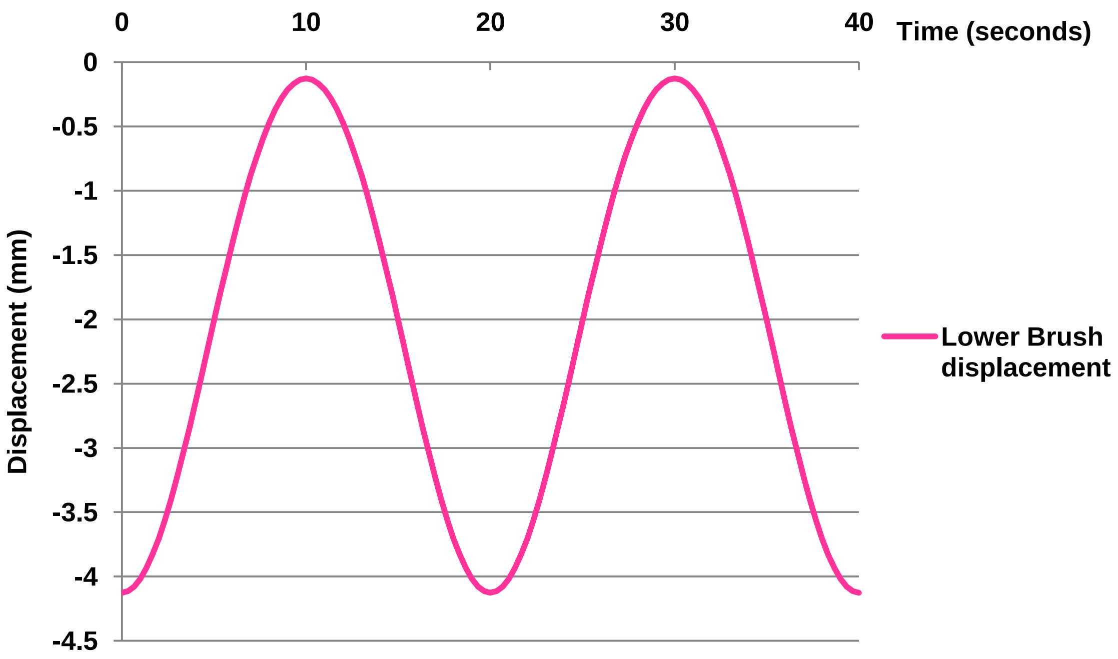
Graphic 8.3. Relation between gears rotation angles

Although the difference is only around 3%, it should be considered for the definitive design because it can change slightly the dimensions of the covers and mobile parts and the initial parameters (input velocity,...)

8.4. OTHER ANALYSIS

Other aspect interesting is check that the *Lower Brush* displacement is 4mm, requirement of design. The results of the sensor located in the *Lower Brush* are supplied to the designer by the *DMU kinematic* module in an excel file and in a graphic that due to its features is included in the *Annexe 12.3*.

If the *Graphic 8.4* is observed, it can conclude that the condition of 4mm of maximal displacement in *Lower Brush* is constant along of the event simulated. This simulation has been realized with an angular *PlasticGear* input speed of π/5 rad/s. Furthermore, this graphics indicated that the output linear velocity is low, and it should be analyzed and probably increased. For calculated *Lower Brush* speed and acceleration a sensor has been defined in the middle of surface of *External Part Lower Brush* and the component of reference is *Cone*.



Graphic 8.4. Lower Brush Displacement

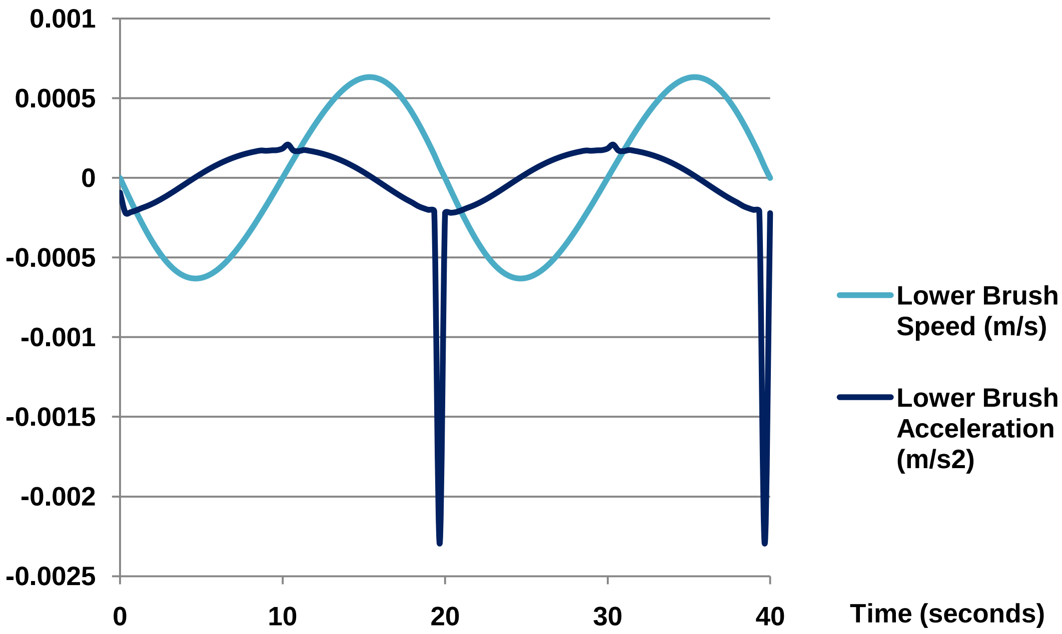
$$LB_{max} - LB_{min} = -4mm$$

Where:

LB_{max}= *maximum position of Lower Brush*

LB_{min}= *minimum position of Lower Brush*

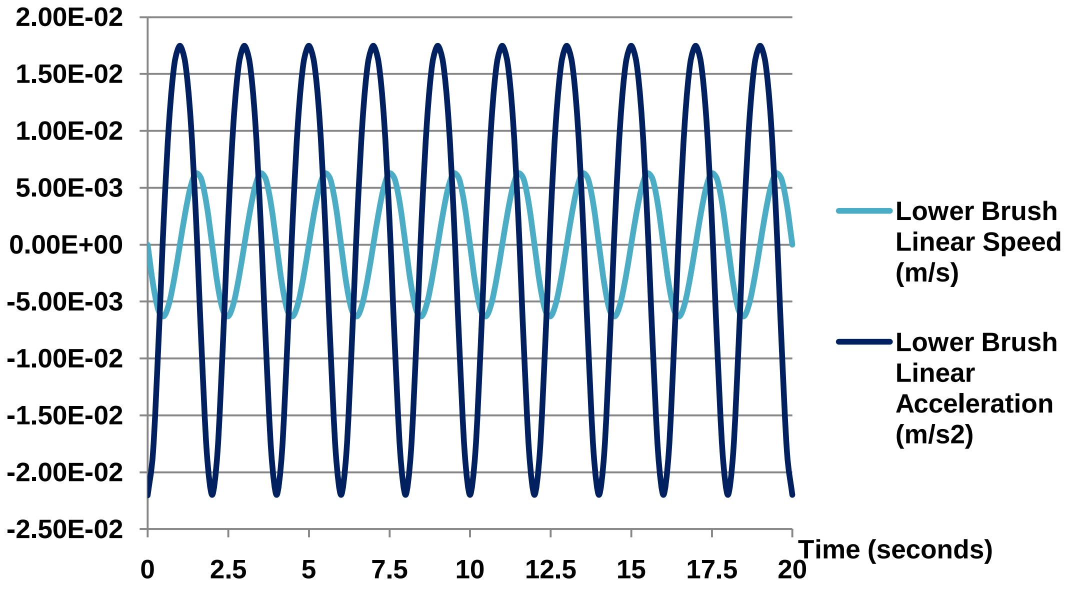
The maximal *Lower Brush* linear speed with the below conditions is $|6.3\cdot10^{-4}|$ m/s and is registered just an instant of time before the *Lower Brush* scroll half of its career. About the linear acceleration, this parameter is maximal just an event of time before that the speed will be zero.



Graphic 8.5. Lower Brush Linear Speed and Acceleration.

With the results shown in the previous graphics, it can conclude that the input angular velocity is low for this application. The sudden drop in speed is due to failures in the program.

The initial angular speed has been increased to 2π rad/s. The *Lower Brush Linear Speed* is increased until around $5 \cdot 10^{-3}$m/s and the acceleration until $1.8 \cdot 10^{-2}$ m/s^2.



Graphic 8.6. Lower Brush Linear Speed and Acceleration 2.

8.5. MODEL SWEEP VOLUME

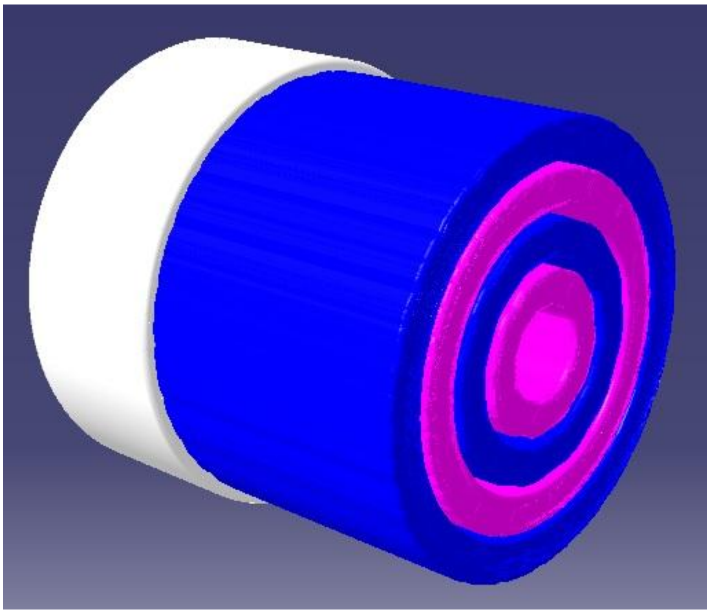
Throughout of this section, the results of the analysis about sweep volume are going to be explained. The sweep volume by the complete mechanism is very similar to real one, so the *Casing* and the *Rear Casing* do not need too space free than the occupied by the elements.

The general sweep volume is shown in the *Pictures 8.4* and *8.5:*

Picture 8.4. Mechanism Sweep Volume

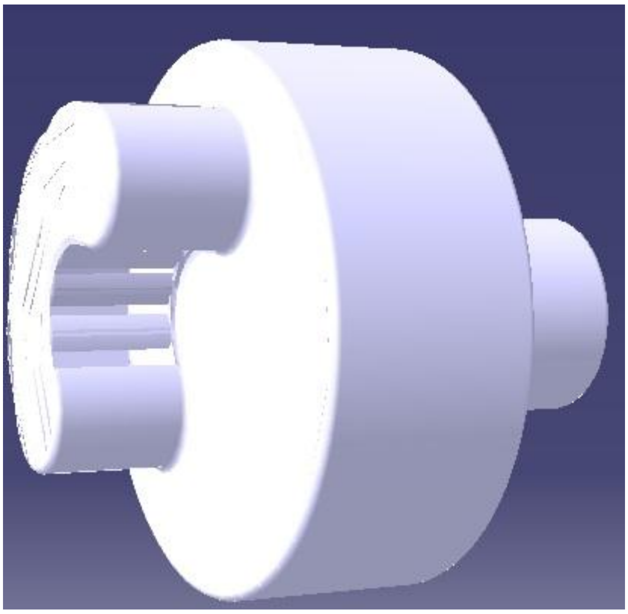
Picture 8.5. Mechanism Sweep Volume 2

The mechanism is going to be studied from the upper part to the lower part. The first mobile part is *Upper Brush* whose sweep volume is the same that it takes up statically.



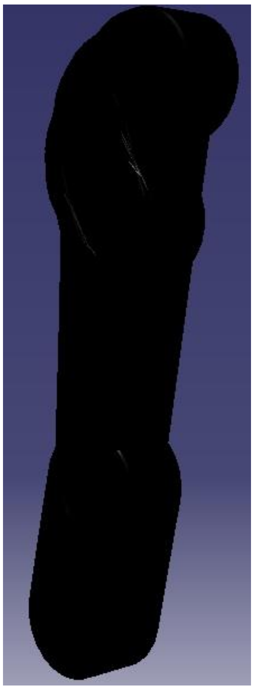
Picture 8.6. Upper Brush Sweep Volume

The second mobile part is *Internal Cylinder Upper Brush* that similarly to *Upper Brush* only needs the space of its silhouette and other semicircle with an eccentricity of 2.1mm and with 1mm of radius, as is show in the following picture.



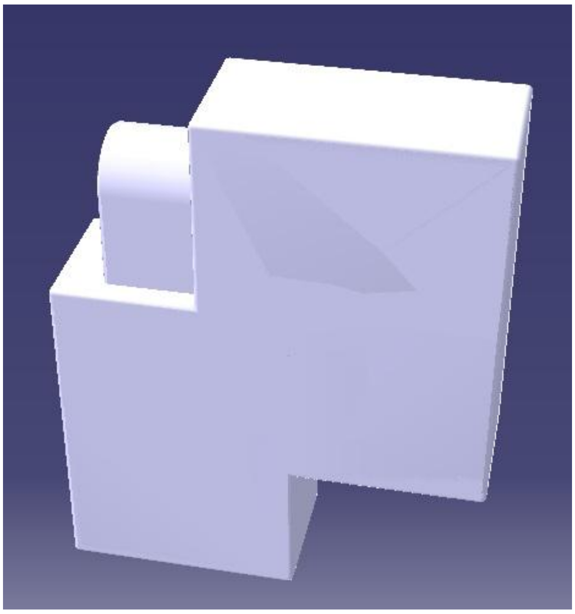
Picture 8.7. Internal Cylinder Upper Brush Sweep Volume

In the case of *Connection Between Brushes*, a semicircle can be seen in the upper part, and the lower part has increased 4mm.



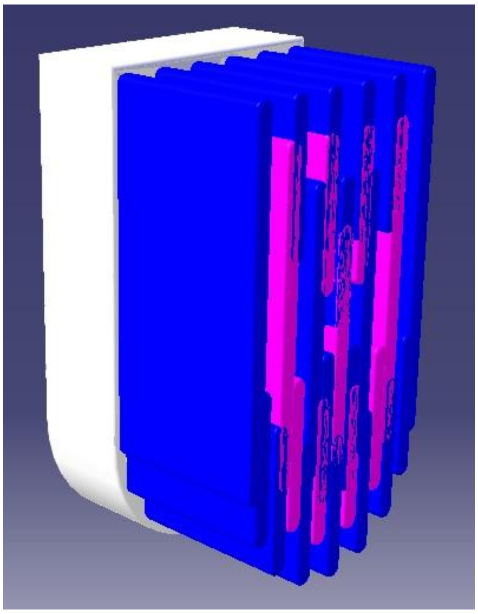
Picture 8.8. Connection Between Brushes Sweep Volume

The sweep volume of the *Connection Lower Brush with Mechanism* has a form similar to the original element, but the dimensions in the Z axis have been increased 4mm in the positive direction.

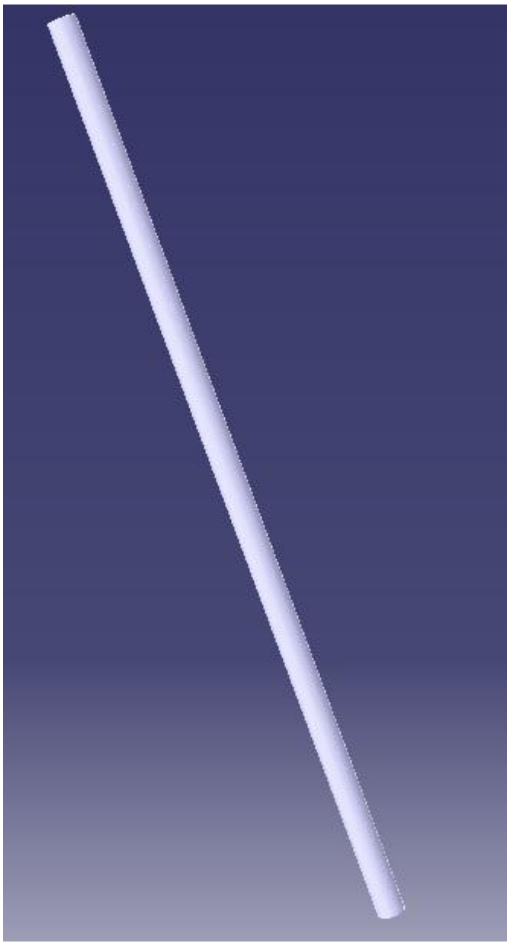


Picture 8.9. Connection Lower Brush with Mechanism Sweep Volume

The sweep volume by mobile part *Lower Brush* is 4mm higher than the space that it takes up statically as *Stick.Pictures 8.10* and *8.11.*

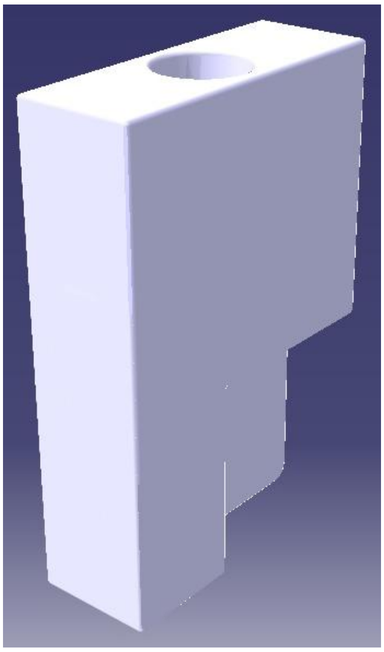


Picture 8.10. Lower Brush Sweep Volume



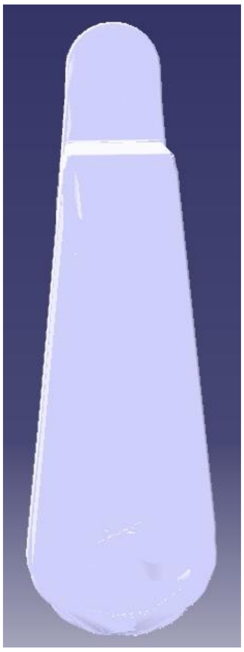
Picture 8.11. Stick Sweep Volume

The sweep volume by *L* has a form similar to the original element, but the dimensions in the Z axis have been increased 4mm in the negative direction.



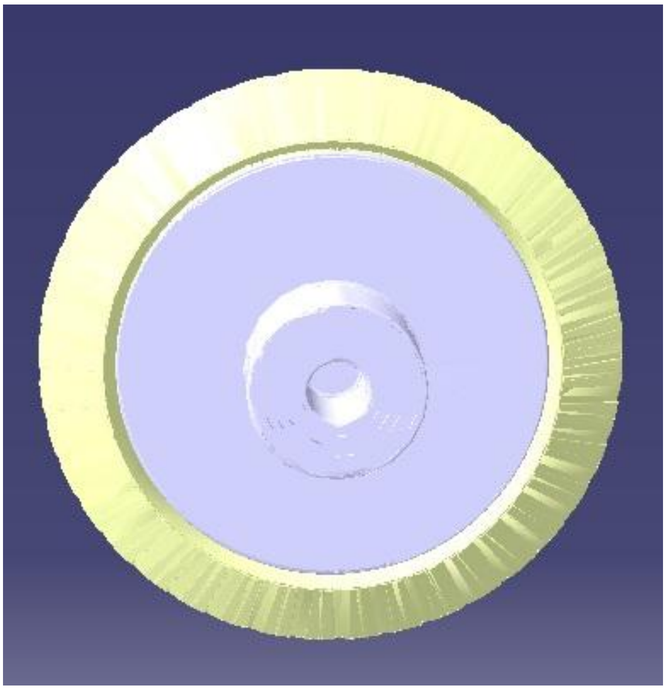
Picture 8.12. L Sweep Volume

The silhouette of the sweep volume by *Connection with Wheel* change slightly, it is different than the original form in the length and in the lower part shape, where show that it has followed a circle.

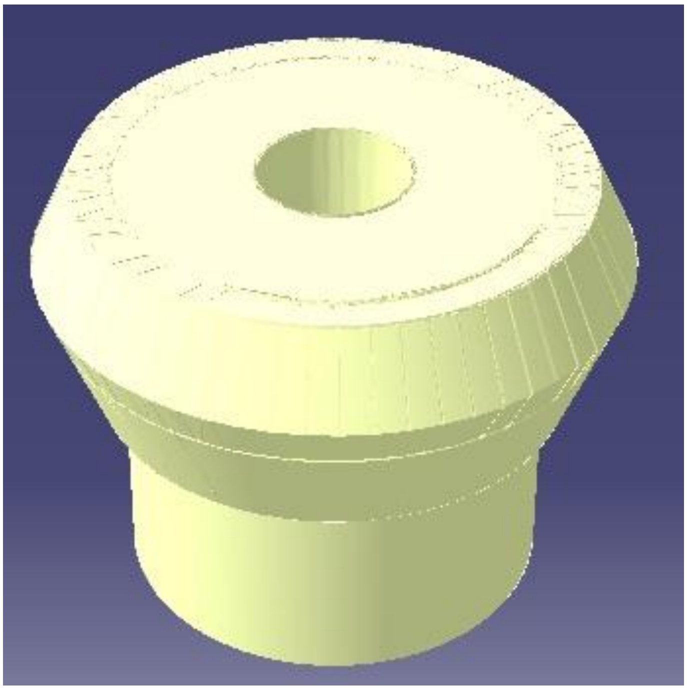


Picture 8.13. Connection with Wheel Sweep Volume

Finally, in the *Pictures 8.13* and *8.14* are represented the sweep volume by the gears, they have the same external form, but the teeth disappeared, seem simple wheels. In the internal surface of the *PlasticWheel* there is a circle of 2mm of thickness due to the complete circle covered by the little cylinder where is inserted the element *Connection with Wheel.*



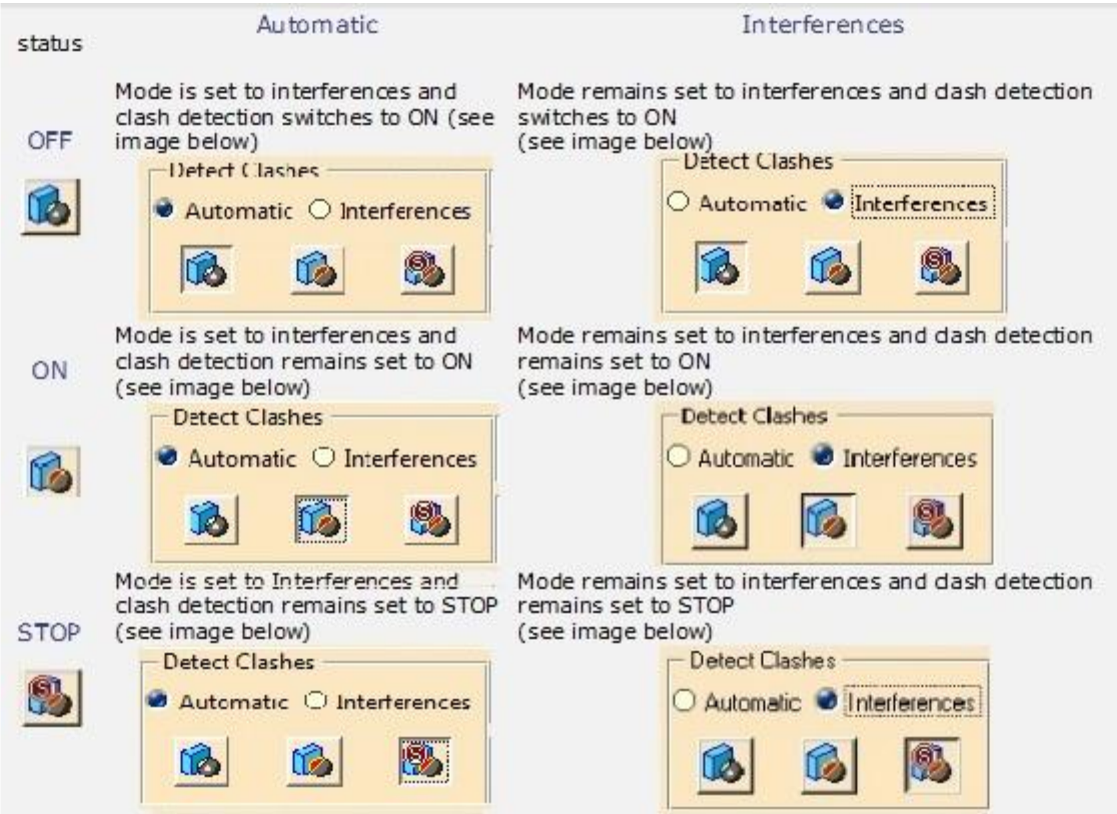
Picture 8.14. Plastic Wheel Sweep Volume



Picture 8.15. Plastic Gear Sweep Volume

8.6. CLASHES

CATIA® allows make different analysis of clashes. On the one hand, the static collisions can be calculated and on the other hand, the clashes during the movement (in the simulation) can be detected in the different ways. In the following picture are registered the differences between the 6 types.

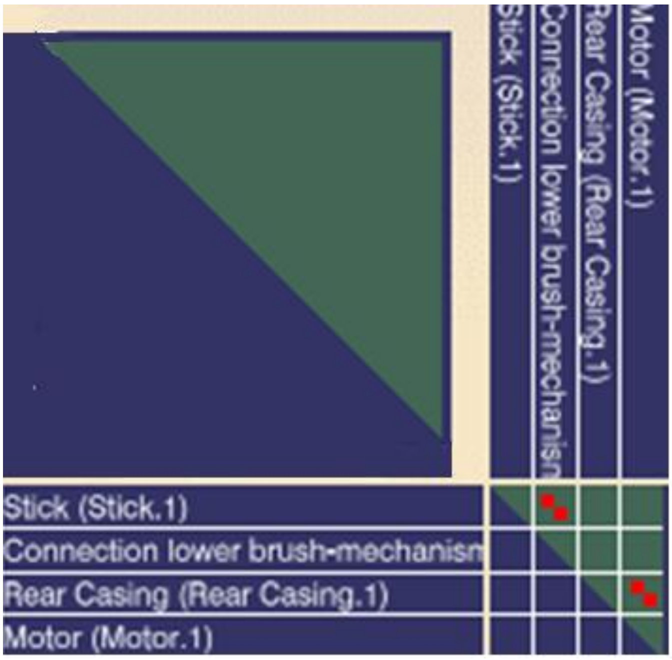


Picture 8.16. Types of Clashes

(Scribd Inc., 2011)

In the case studied the last option is the selected, because is the most clear while the simulation is running. If the software finds a clash, immediately the simulation stops. Initially, the mechanism *Toothbrush* had interferences between the gears due to problems in the teeth positions, but finally it was resolved.

Furthermore, the static collisions have been studied with null results about clashes. The relevant contacts are shown in the next graphic. These contacts are located between *Stick* and *Connection Lower Brush- Mechanism* and between *Motor* and *Rear Casing.*



Graphic 8.7. Relevant contact between Toothbrush elements

9. CONCLUSIONS

As mentioned at the beginning of this report, the objectives of this project are: first, deepen the learning of mechanical design tools and kinematic simulation modules inside the software *CATIA*® due to it is a reference program in the field of mechanical design. As it is a learning project, set out to design an electric toothbrush for the simplicity of its operation method.

Throughout the document, the information required to know the theme studied has been specified: description of the model, mechanism, drafts of the several parts, knowledge about the software, etc.

In view of the results presented in the previous chapter, it can conclude that, after the simulations done in the section *8.2*, the dimensions of the *Optimization 7* (*e=2.1mm, L=11.47mm)* are chosen because these maximize the rotation angle *Upper Brush*.

For a better design, the angle should be higher than 180º but other parameters of design should be changed, as the diametric eccentricity of the connexion between *PlasticWheel* and *Connection with Wheel* for the *Upper Brush* have higher amplitude in its lineal motion.

Furthermore, the motion relation between gears is ideal during the simulation; although the difference is only around 3% with respect to the real relation, it should be considered for the definitive design because it can change slightly the dimensions of the covers and mobile parts and the initial parameters (input velocity,..)

After the *Lower Brush* kinematic analysis it can conclude that the condition of 4mm of maximal displacement in *Lower Brush* is constant along of the event simulated, and the initial angular speed is low to *Toothbrush* normal operation. Then, the *PlasticGear* input speed has been increased until 2π rad/s

If the result of the sweep volume analysis and the clashes are considered, it can conclude that, the sweep volume by the complete mechanism is very similar to real one, so the *Casing* and the *Rear Casing* do not need too space free than the occupied by the elements.

10. FUTURE ANALYISIS

Throughout of this project has been realized the design of the mechanical system of an electric toothbrush and the kinematic analysis. The development of this product will be complete with other kinds of designs and analysis.

On the one hand, the design would be finished with the electric and electronic systems and its respective analysis that in this project were not considered, because the problem studied is mechanical.

On the other hand, additional mechanical studies will be necessary. Inside of these kinds of analysis, the model required: dynamical analysis, test of stress and deformation, check the impermeability of the casing, collision, etc.

Finally, the design of the recharge system is essential before the electric toothbrush manufacture.

11. BIBLIOGRAPHY

Web sites:

[1]. Repair Sewing Machine. (2011). *Repair Sewing Machine at Home. Step by step.* Retrieved 05 01, 2011, from http://www.repairsewingmachine.com/?hop=0

[2]. Colgate-Palmolive Company. (2011). *Colgate*. Retrieved 04 28, 2011, from http://www.colgateprofesional.com.gt

[3]. Dassault Systemes. (2002-2011). *Dassault Systemes.* Retrieved 04 27, 2011, from http://www.3ds.com

[4]. Fotopedia. (2008-2011). *Fotopedia*. Retrieved 04 29, 2011, from http://www.fotopedia.com

[5]. Gargles. (2011). *ComFy Magazine*. Retrieved 04 28, 2011, from http://gargles.net/

[6]. KINGLY MOTOR. (2011). *KINGLY MOTOR*. Retrieved 05 2011, 07, from http://www.kinglymotor.com/en/

[7]. KMODDL. (2002-2006). *KINEMATIC MODELS FOR DESIGN DIGITAL LIBRARY*. Retrieved 05 29, 2011, from http://kmoddl.library.cornell.edu/collection-toc.php

[8]. Martinez, J. (1999-2011). *Blogger*. Retrieved 05 01, 2011, from http://fundamentodemaquinasudo.blogspot.com/

[9]. Monografias.com S.A. (n.d.). *Monografías.com*. Retrieved 05 01, 2011, from http://www.monografias.com

[10]. phpBB Group. (2000-2007). *Theopia*. Retrieved 04 28, 2011, from http://www.theopia.com

[11]. Plasticbages Industrial S.L. (n.d.). *Plasticbages Industrial S.L.* Retrieved 05 2011, 23, from http://www.plasticbages.com/caracteristicasacetal.html

[12]. Scribd Inc. (2011). *Scribd*. Retrieved 06 01, 2011, from http://es.scribd.com/doc/8230874/Catia-V5-R16DMU-Kinematics#outer_page_169

[13]. Stock Drive Product / Sterling Instrument. (2011). *SDP/SI.* Retrieved 04 25, 2011, from https://sdp-si.com

[14]. Universidad Nacional de Colombia. (2011). *Universidad Nacional de Colombia. Sede de Bogotá*. Retrieved 05 01, 2011, from http://www.virtual.unal.edu.co/cursos/ingenieria/2001734/lecciones/tem05/lec03_1_2.htm

[15]. Wikipedia. (2001-2011). *Wikipedia*. Retrieved 04 28, 2011, from http://en.wikipedia.org

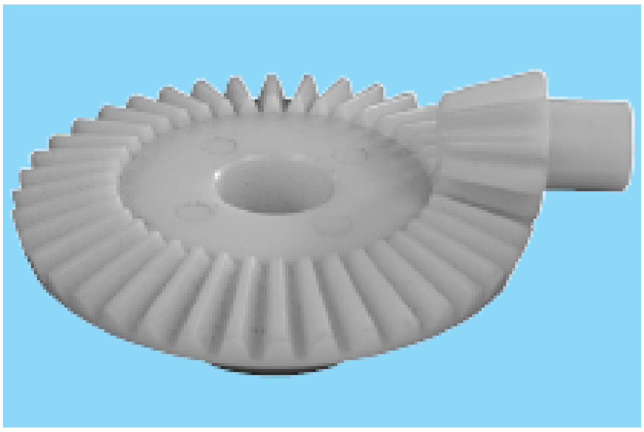
[16]. Xie, D. C. (2004-2011). *MOLECULAR WORKBENCH*. Retrieved 05 01, 2011, from National Science Foundation: http://mw.concord.org/modeler1.3/mirror/mechanics/SliderCrank.html

[17]. ZonaDental.tv. (2001-2011). *ZonaDental.tv*. Retrieved 04 28, 2011, from http://www.zonadental.tv/

12. ANNEXES

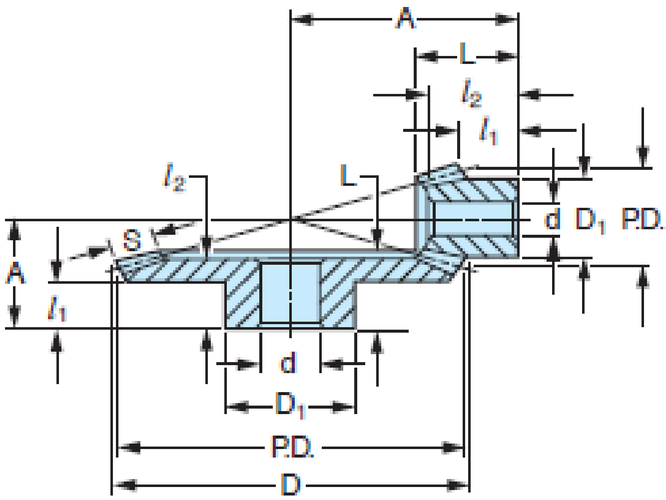
12.1. CHARACTERISTICS OF THE GEARS

The casting bevel gears chosen for the project are made by the company *SDP/SI*© (*Stock Drive Products/ Sterling Instrument*). The pressure angle of the gears is 20º and its material is acetal. The next chart shows the characteristics of the gears used in the model designed. The pair of gear chosen is: *A 1M 3MYH0520*® and *A 1M 3MYH0540*®, as it can be seen in the following chart.



Picture 12.1. Bevel Gears

(Stock Drive Product / Sterling Instrument, 2011)



Picture 12.2. Sketch of dimensions of the Bevel Gears

(Stock Drive Product / Sterling Instrument, 2011)

In the Chart 12.1 it is represented the features of the gear used in the model of an electric toothbrush, aim of study in this project.

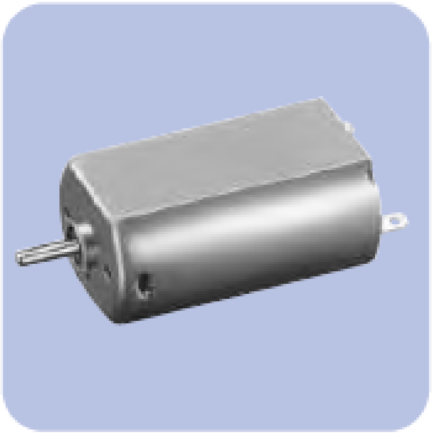
Catalog Number	Module	No. of Teeth	Ratio	P.D.	D	d Bore	S Face Width	L Length	D_1 Hub Dia.	l_1 Hub Proj.	A	l_2
A 1M 3MYZ1516 A 1M 3MYZ1524	1.5	16 24	1:1.5	24 36	26 37	8 10	8	18.8 19.6	20 24	10.8 11.3	30 26.6	17.8 18.2
A 1M 3MYH0520 A 1M 3MYH0540	0.5	20 40		10 20	11.2 20.3	3 4	2.5	8.5 8.3	8 12	4	16 12	8.5 7
A 1M 3MYH0820 A 1M 3MYH0840	0.8	20 40		16 32	17.9 32.5	4 5	3.5	11.5 11.9	12 15	5 6	24 18	11.5 10
A 1M 3MYH1020 A 1M 3MYH1040	1	20 40		20 40	22.4 40.6	5 6	4.5	14.5	15 18	7	30 22	14.5 12
A 1M 3MYZ1015 A 1M 3MYZ1030	1	15 30		15 30	16.8 31.1	5 8	6.6	17 16.2	12.2 18	10.6 9.1	26.4 20.9	17 14.8
A 1M 3MYZ1515 A 1M 3MYZ1530	1.5	15 30	1:2	22.5 45	25.4 46.4	8 10	10.5	22.8 19.5	17 23.4	11.5 9.6	35.8 26.2	22.8 17.5
A 1M 3MYZ2015 A 1M 3MYZ2015A	2	15		30	33.6	10 15	14.6	27	22.5	11.8	44.2	26
A 1M 3MYZ2030A A 1M 3MYZ2030 A 1M 3MYZ2030B		30		60	62.2	10 12 15	14.6	24.2	30.2	11.8	32.6	22.6
A 1M 3MYZ2515	2.5	15		37.5	42	12	17.3	31.2	26.5	13	53.3	29.6
A 1M 3MYZ2530A A 1M 3MYZ2530		30		75	77.3	14 16	17.3	29.5	36.1	15	40.5	27.5
A 1M 3MYZ3015	3	15		45	50.3	14	20.5	36.3	31.2	14.8	63.3	35
A 1M 3MYZ3030 A 1M 3MYZ3030A		30		90	93	18 35	20.5	37	45	19	49.5	34.2
A 1M33MYZ1015A A 1M33MYZ1015	1	15		15	16.6	4 5	9.2	20.4	12.3	11	34.3	—
A 1M33MYZ1045 A 1M33MYZ1045A		45		45	46.1	10 12	9.2	18.2	23.4	9.6	22.7	16.5
A 1M33MYZ1515 A 1M33MYZ1545	1.5	15 45	1:3	22.5 67.5	25.1 68.8	8 12	14	26.8 23	17.2 30.4	12.5 11.5	47.9 29.4	— 21.5
A 1M33MYZ2010 A 1M33MYZ2030	2	10 30		20 60	24 61.7	6 12	12.5	25 22.5	15.5 30.3	12 11.5	43.7 28	— 19.8
A 1M33MYZ2510 A 1M33MYZ2530	2.5	10 30		25 75	29.7 77.2	8 18	15.7	28.8 29	18.8 36.1	13 15.5	52.4 35.7	— 25.2
A 1M 3MYZ1010 A 1M 3MYZ1040	1	10 40		10 40	12 40.8	4 10	8.2	17.7 17	7.8 23.4	9.3 10.8	30.1 20.1	— 15.7
A 1M 3MYZ1510 A 1M 3MYZ1540	1.5	10 40	1:4	15 60	18 61.2	5 12	12.3	23.5 21.7	11.3 30.4	10.9 12.8	41.7 26.2	— 20
A 1M 3MYZ2010	2	10		20	23.8	6	16.3	28.9	14.3	12.8	54	—
A 1M 3MYZ2040A A 1M 3MYZ2040		40		80	81.5	10 18	16.3	27	36	16.6	32.5	24.7
A 1M 3MYZ1012 A 1M 3MYZ1060	1	12 60	1:5	12 60	13.7 60.4	4 10	9.5	20.3 17.4	9.5 20.5	10 11	40.5 21	— 15.5

Chart 12.1.Gear Dimension

(Stock Drive Product / Sterling Instrument, 2011)

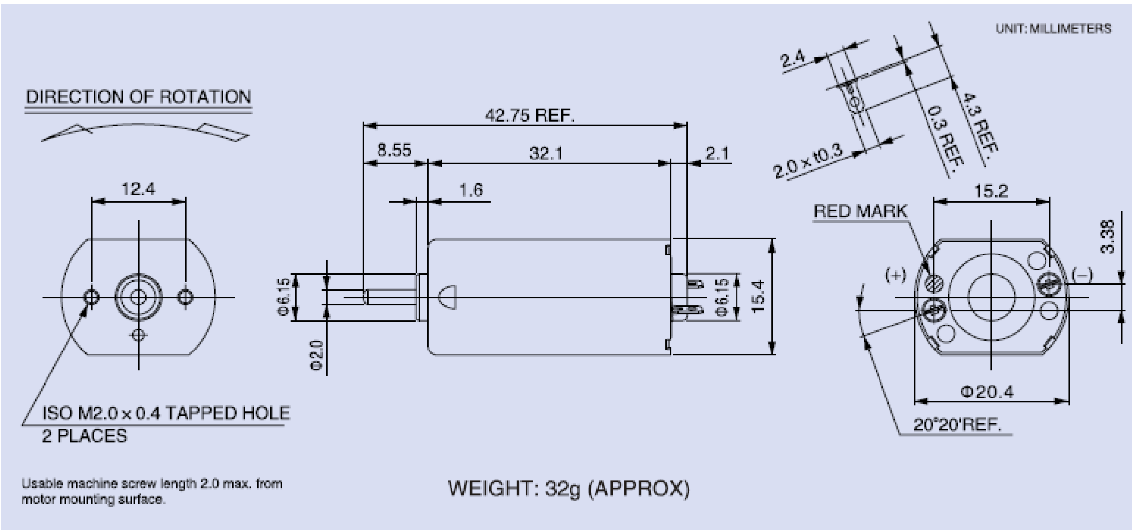
12.2. CHARACTERISTICS OF THE MOTOR

The motor chosen for the project is made by the Chinese company *KINGLY MOTOR*©. The model used is *JFF-180SH-10320*® whose characteristic are shown below. In this chapter it can be seen the motor chosen, the dimensions of the motor for the posterior design with CAD tools, a chart with its characteristics and a relational graphic between the efficiency, current and speed with the torque. This manufacturer sells high variety of low power motors that can be used in electronic experiments, toys, small electrical appliance (for example an electrical toothbrush), etc.



Picture 12.3. Motor JFF-180SH-10320

(KINGLY MOTOR, 2011)



Picture 12.4. Dimensions of the motor JFF-180SH-10320

(KINGLY MOTOR, 2011)

In the *Chart 12.2* it is represented the features of the motor used in the model, aim of study in this project.

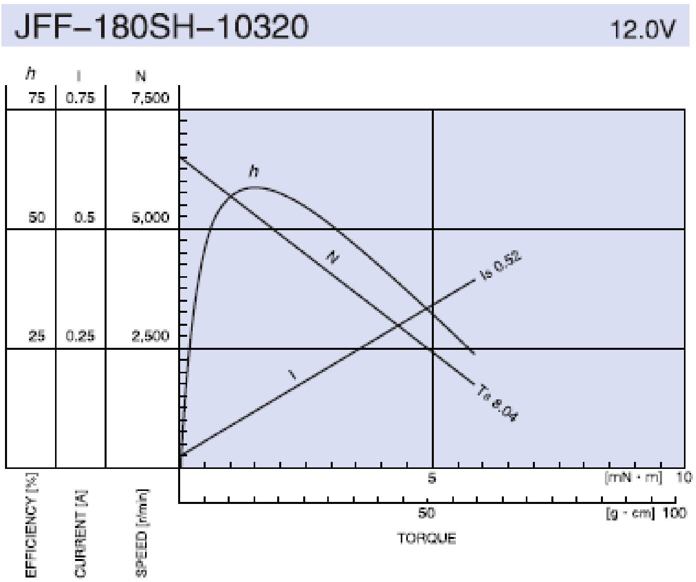
型号 MODEL	电压 VOLTAGE		无负荷 NO LOAD		最大效率点 AT MAXIMUM EFFICIENCY					起动 STALL		
	使用范围 OPERATING RANGE	额定值 NOMINAL	转速 SPEED	电流 CURRENT	转速 SPEED	电流 CURRENT	转矩 TORQUE		功率 OUTPUT	转矩 TORQUE		电流 CURRENT
			r/min	A	r/min	A	mN · m	g · cm	W	mN · m	g · cm	A
JFF-180PH-2852	DC 1~3V	DC 2.4V	8100	0.15	6850	0.82	1.82	18.6	1.30	11.8	120	4.50
JFF-180PH-4022	DC 1.0~1.5V	DC 1.2V	9400	0.40	7830	1.99	1.76	17.9	1.44	10.5	107	9.90
JFF-180SH-10320	DC 6~12V	DC 12V	6500	0.028	5280	0.12	1.51	15.4	0.84	8.04	82	0.52
JFF-180SH-2657	DC 1~3V	DC 2.4V	7700	0.13	6500	0.70	1.56	15.9	1.06	10.0	102	3.80
JFF-180SH-14210	DC 3.7~7.2V	DC 4.5V	3700	0.025	3090	0.13	1.02	10.4	0.33	6.17	63	0.63
JFF-180SH-4026	DC 1.0~1.5V	DC 1.2V	8300	0.30	6990	1.60	1.64	16.7	1.20	10.4	106	8.55

马达性能及转轴长度可按客户的需要设定。
Motors specification and shaft length can be tailor–made according tocustomer's requirements.

Chart 12.2. Characteristics of the motor JFF-180SH-10320

(KINGLY MOTOR, 2011)

The relations between efficiency, speed and current with the torque in the motor *JFF-180SH-10320* are shown in the following graphic.



Graphic 12.1. Graphic Efficiency-Current-Speed vs Torque

(KINGLY MOTOR, 2011)

12.3. SUMMARY OF KINEMATIC SIMULATION VALUES

Below, the kinematic simulation values are shown in the *Chart 12.3*, but only the correspondents to 20seconds of simulation (the middle of the event simulated) because it is the needed time to *PlasticGear* turns 360º with the initial law assigned. The following results are generated automatically by the module *DMU kinematic*.

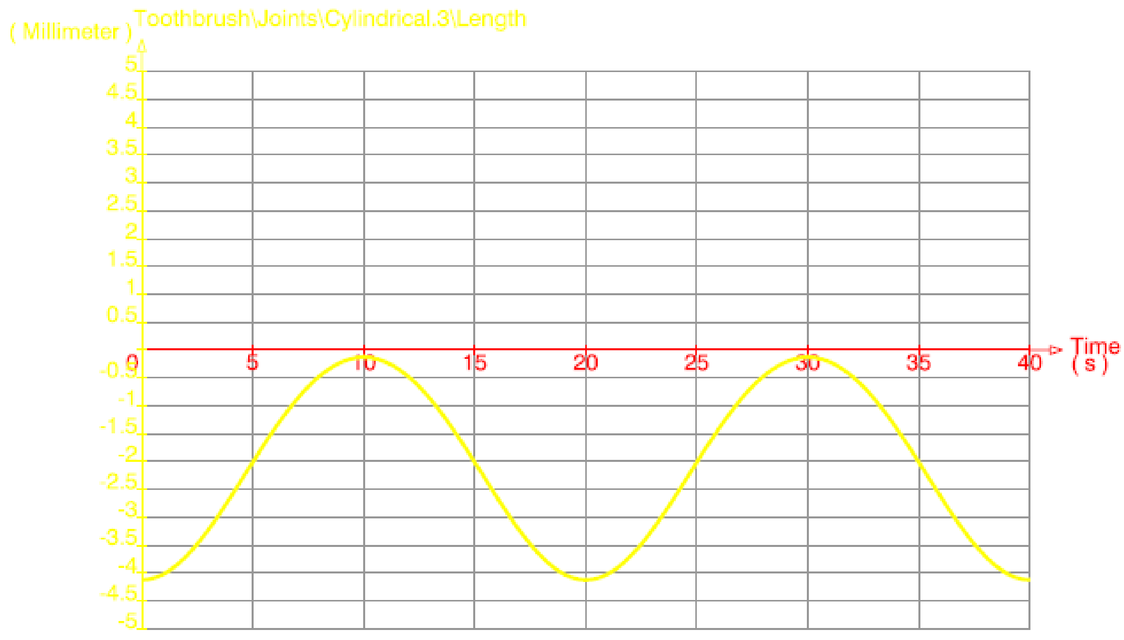
Time	**Displacement *Lower Brush* (mm)**	***Upper Brush* rotation angle (deg)**	***PlasticGear* rotation angle (deg)**	***PlasticWheel* rotation angle (deg)**
0.00	-4.12698	-156.154	0	180
0.33	-4.11477	-157.754	12	186
0.67	-4.07832	-161.768	24	192
1.00	-4.01822	-167.022	36	198
1.33	-3.93518	-172.851	48	204
1.67	-3.83045	-178.948	60	210
2.00	-3.70548	-185.159	72	216
2.33	-3.56201	-191.406	84	222
2.67	-3.40199	-197.636	96	228
3.00	-3.22756	-203.823	108	234
3.33	-3.04116	-209.94	120	240
3.67	-2.84492	-215.988	132	246
4.00	-2.64143	-221.951	144	252
4.33	-2.43321	-227.823	156	258
4.67	-2.22273	-233.6	168	264
5.00	-2.01242	-239.279	180	270
5.33	-1.80462	-244.858	192	276
5.67	-1.60158	-250.336	204	282
6.00	-1.40538	-255.708	216	288
6.33	-1.21799	-260.973	228	294
6.67	-1.04103	-266.129	240	300
7.00	-0.876239	-271.165	252	306
7.33	-0.725283	-276.054	264	312
7.67	-0.589248	-280.783	276	318
8.00	-0.469228	-285.315	288	324
8.33	-0.366158	-289.591	300	330
8.67	-0.281006	-293.515	312	336
9.00	-0.213947	-296.973	324	342
9.33	-0.165747	-299.749	336	348
9.67	-0.136694	-301.584	348	354
10.00	-0.126992	-302.23	360	360
10.33	-0.136706	-301.58	372	366
10.67	-0.165768	-299.744	384	372

11.00	-0.21398	-296.97	396	378
11.33	-0.281105	-293.509	408	384
11.67	-0.366284	-289.585	420	390
12.00	-0.469347	-285.31	432	396
12.33	-0.589384	-280.778	444	402
12.67	-0.725436	-276.049	456	408
13.00	-0.876403	-271.16	468	414
13.33	-1.04122	-266.124	480	420
13.67	-1.21804	-260.973	492	426
14.00	-1.40544	-255.708	504	432
14.33	-1.60164	-250.335	516	438
14.67	-1.8047	-244.858	528	444
15.00	-2.0125	-239.279	540	450
15.33	-2.22281	-233.6	552	456
15.67	-2.43329	-227.823	564	462
16.00	-2.64151	-221.951	576	468
16.33	-2.84514	-215.982	588	474
16.67	-3.04137	-209.934	600	480
17.00	-3.2279	-203.809	612	486
17.33	-3.40232	-197.622	624	492
17.67	-3.56232	-191.39	636	498
18.00	-3.70565	-185.152	648	504
18.33	-3.83055	-178.943	660	510
18.67	-3.93525	-172.846	672	516
19.00	-4.01826	-167.015	684	522
19.33	-4.07841	-161.763	696	528
19.67	-4.11483	-157.766	708	534
20.00	-4.12698	-156.154	720	540

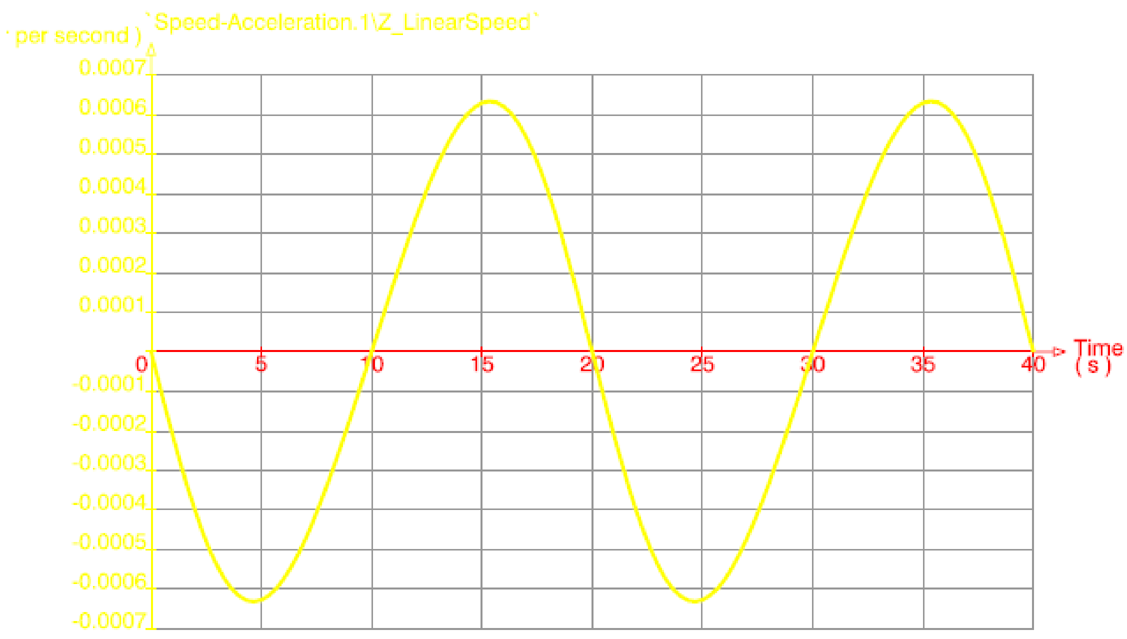
Chart 12.3. Summary of Kinematic Simulation Values

In the following page are included the original graphics drawn by the software. These graphics are not described in the chapter about the results because their features are not adequate to work with the information shown.

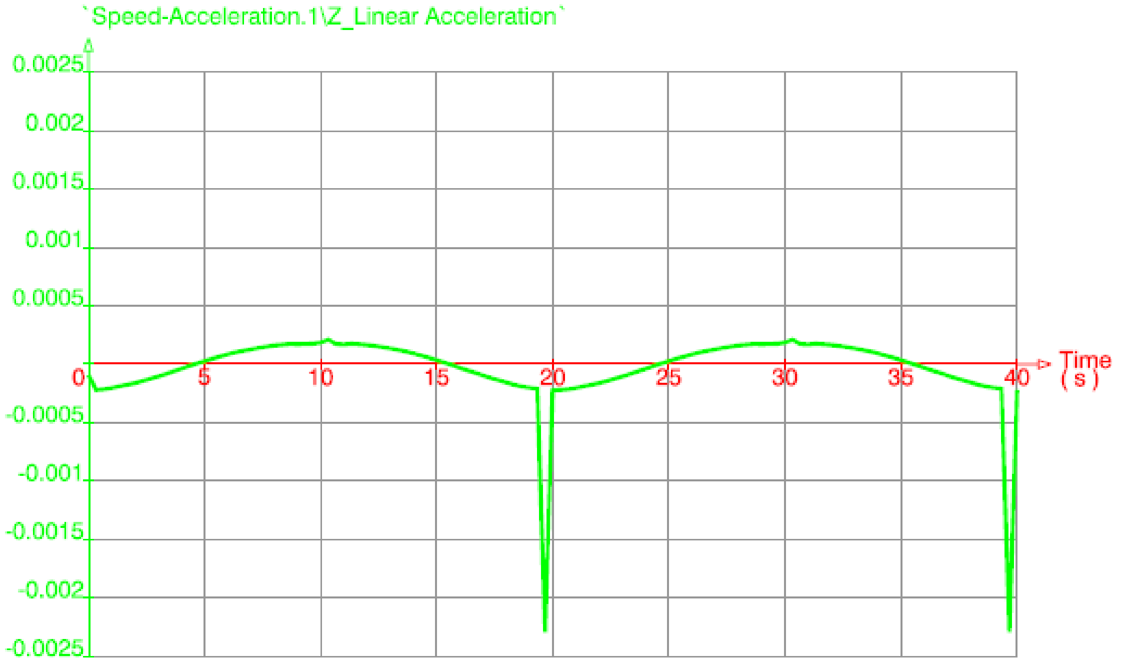
- *Lower Brush* kinematic characteristic with $\omega = \frac{\pi}{5}\frac{rad}{s}$



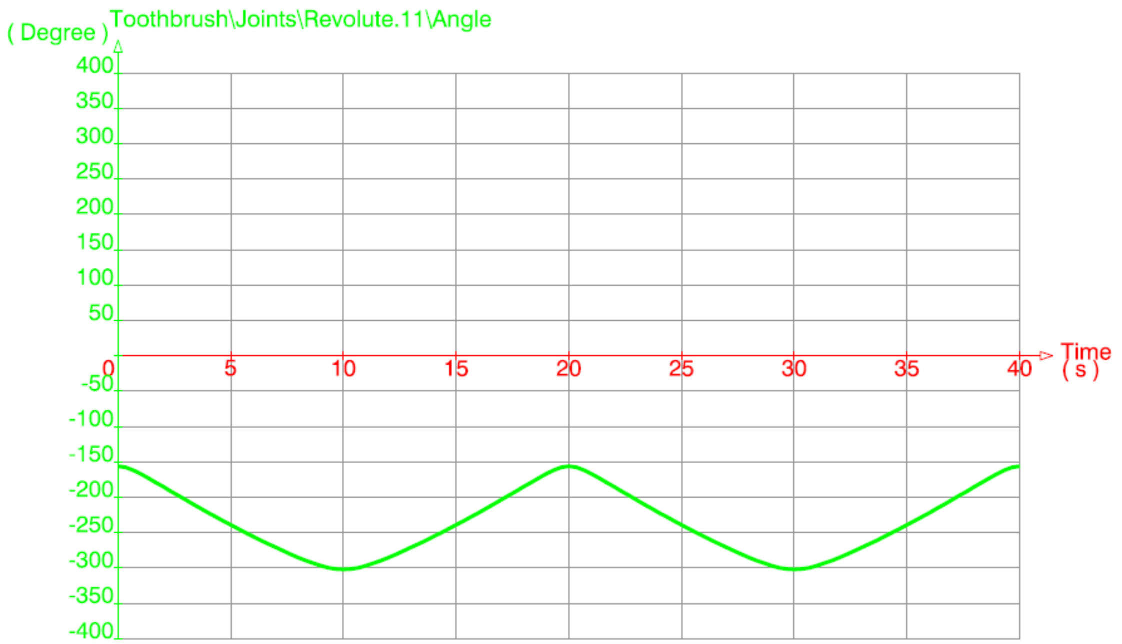
Graphic 12.2. Lower Brush Displacement. Original Graphic



Graphic 12.3. Lower Brush Speed. Original Graphic

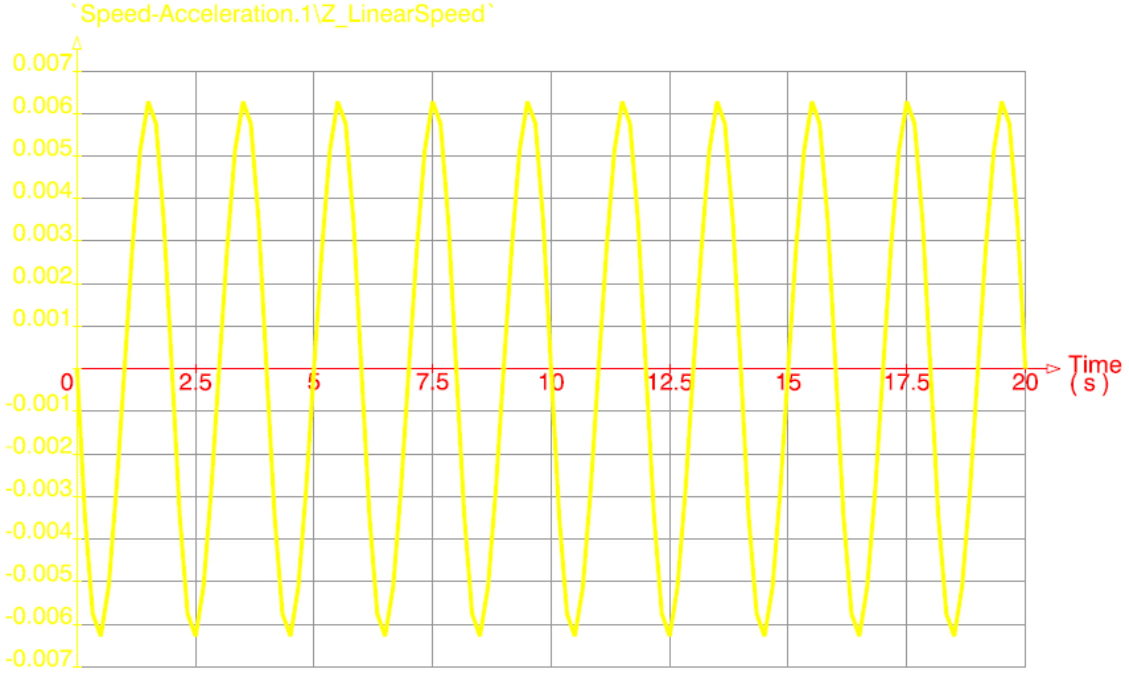


Graphic 12.4. Lower Brush Acceleration. Original Graphic

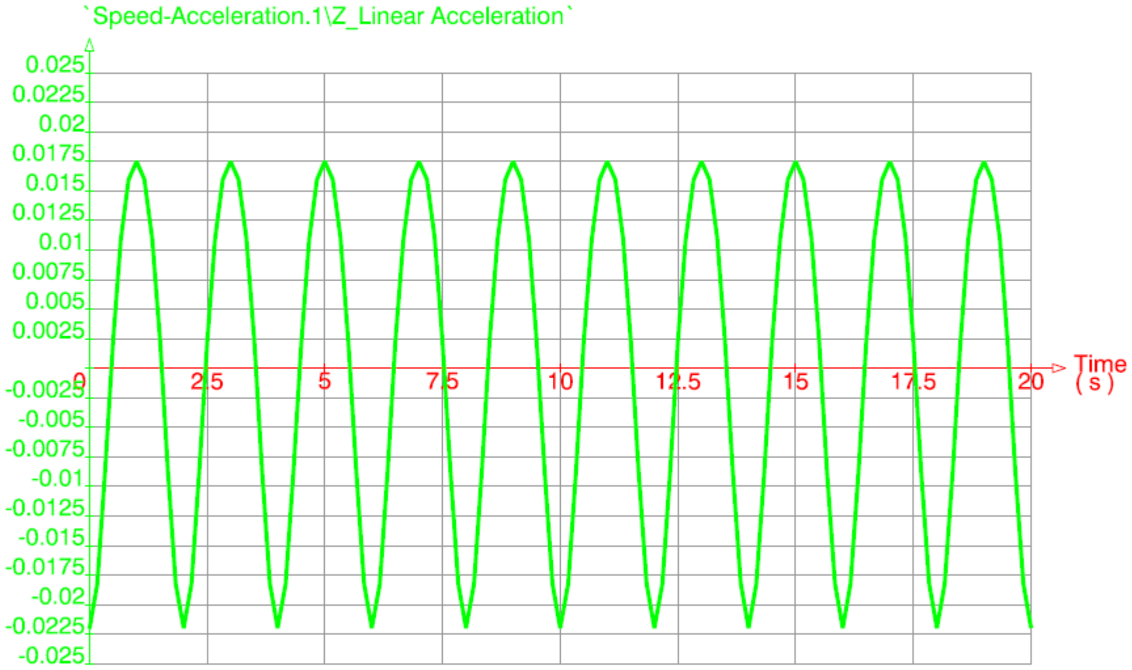


Graphic 12.5. Lower Brush Rotation Angle. Original Graphic

- *Lower Brush* kinematic characteristic with $\omega = \pi \frac{rad}{s}$



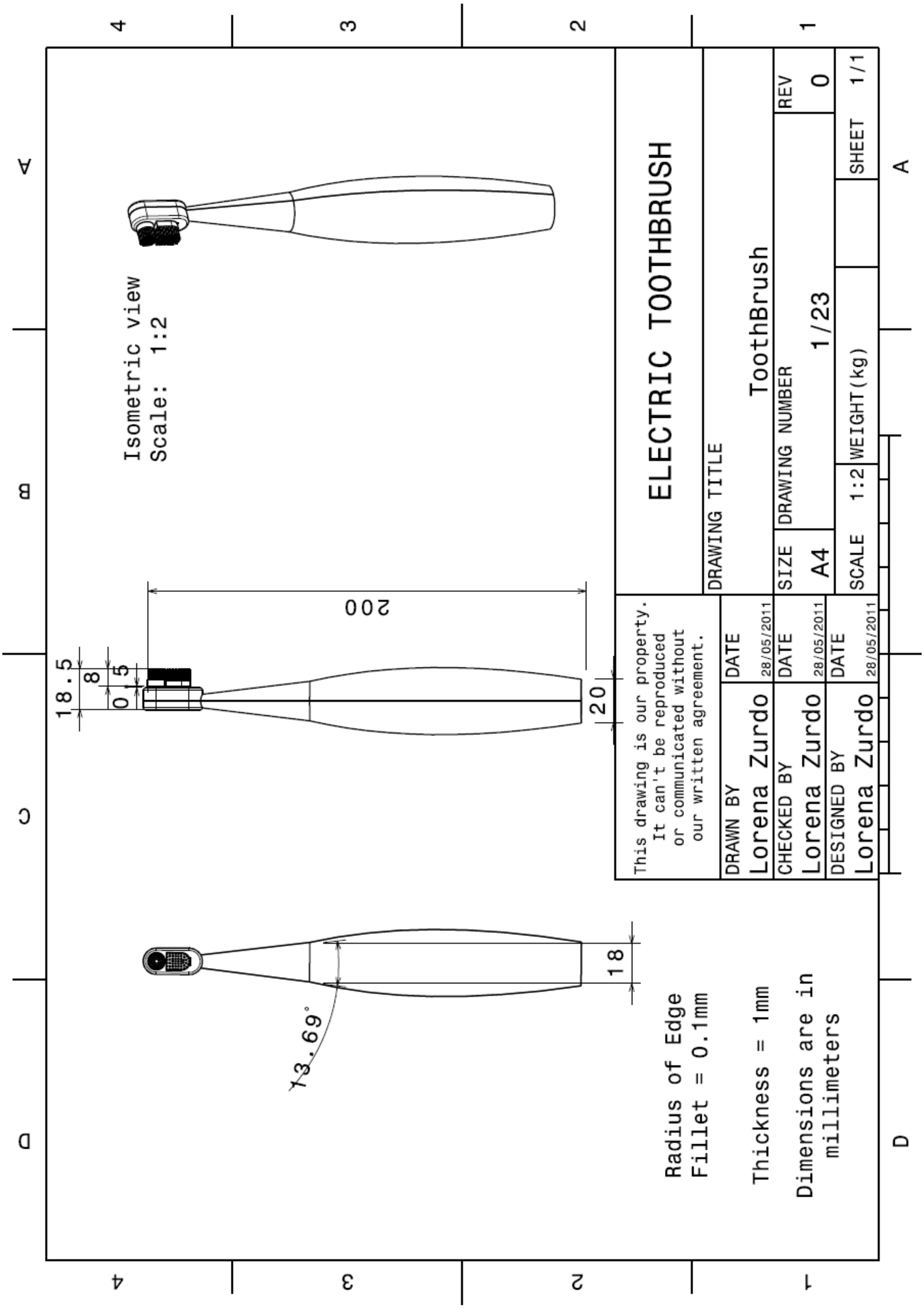
Graphic 12.6. Lower Brush Speed 2. Original Graphic



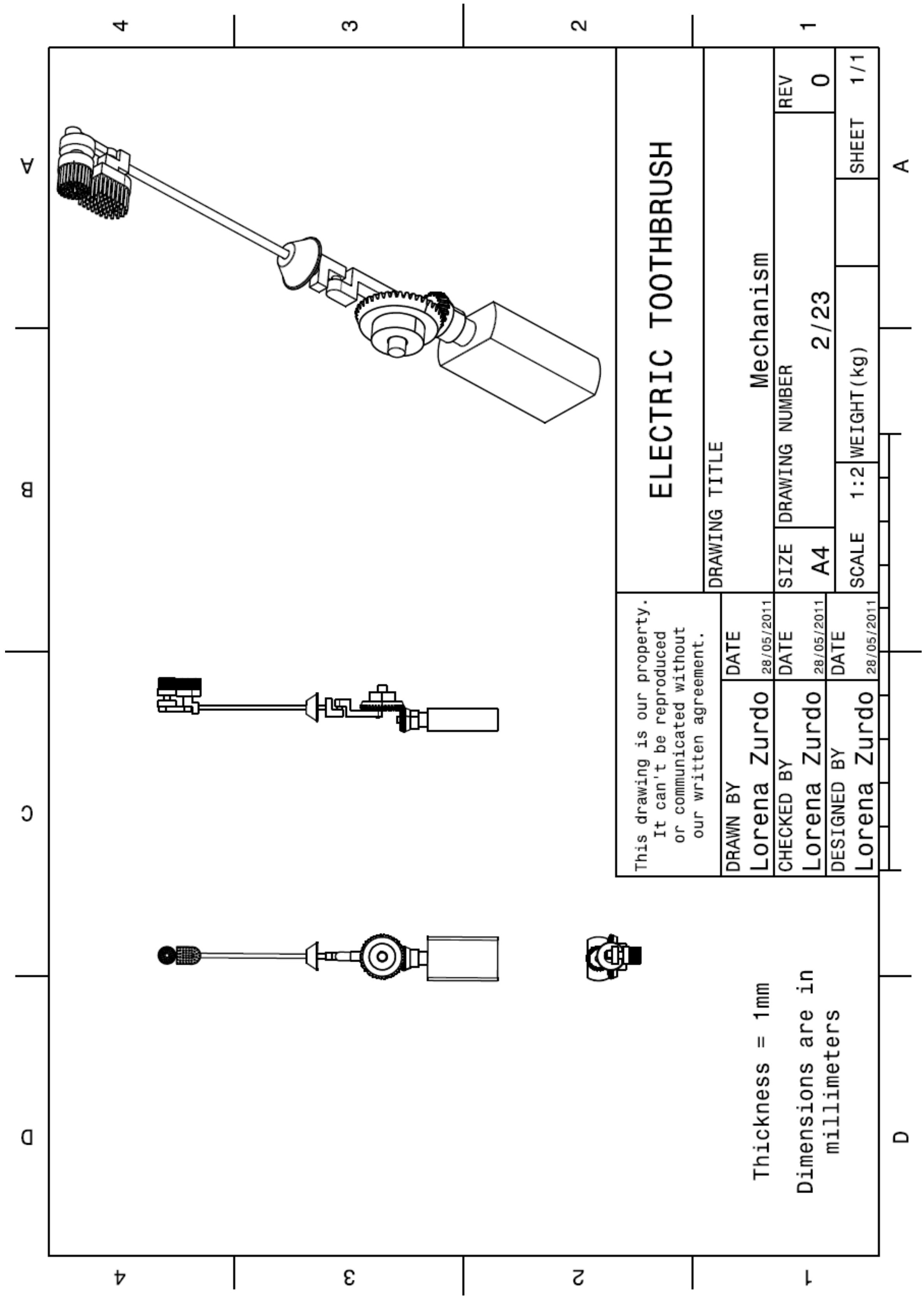
Graphic 12.7. Lower Brush Acceleration 2. Original Graphic

12.4. DRAFTS OF TOOTHBRUSH

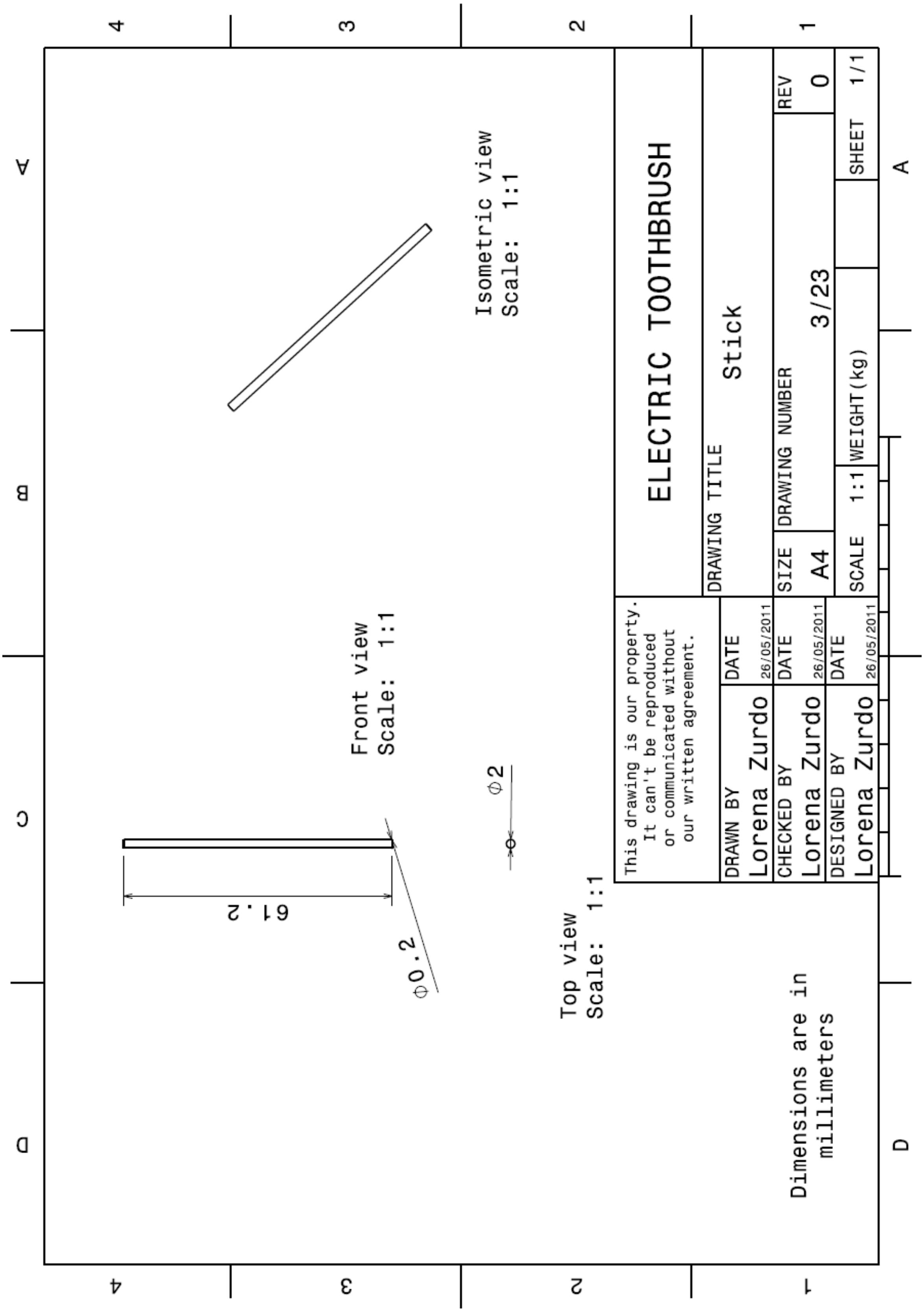
In the following pages are included the drafts of the model designed for make the studies required for the development of this project. The drafts of the model, mechanism, subassemblies and the individual part are included. It has been used the module *Drafting* of the software *CATIA® V5 R19* to draw them as it has explained in previous chapters.



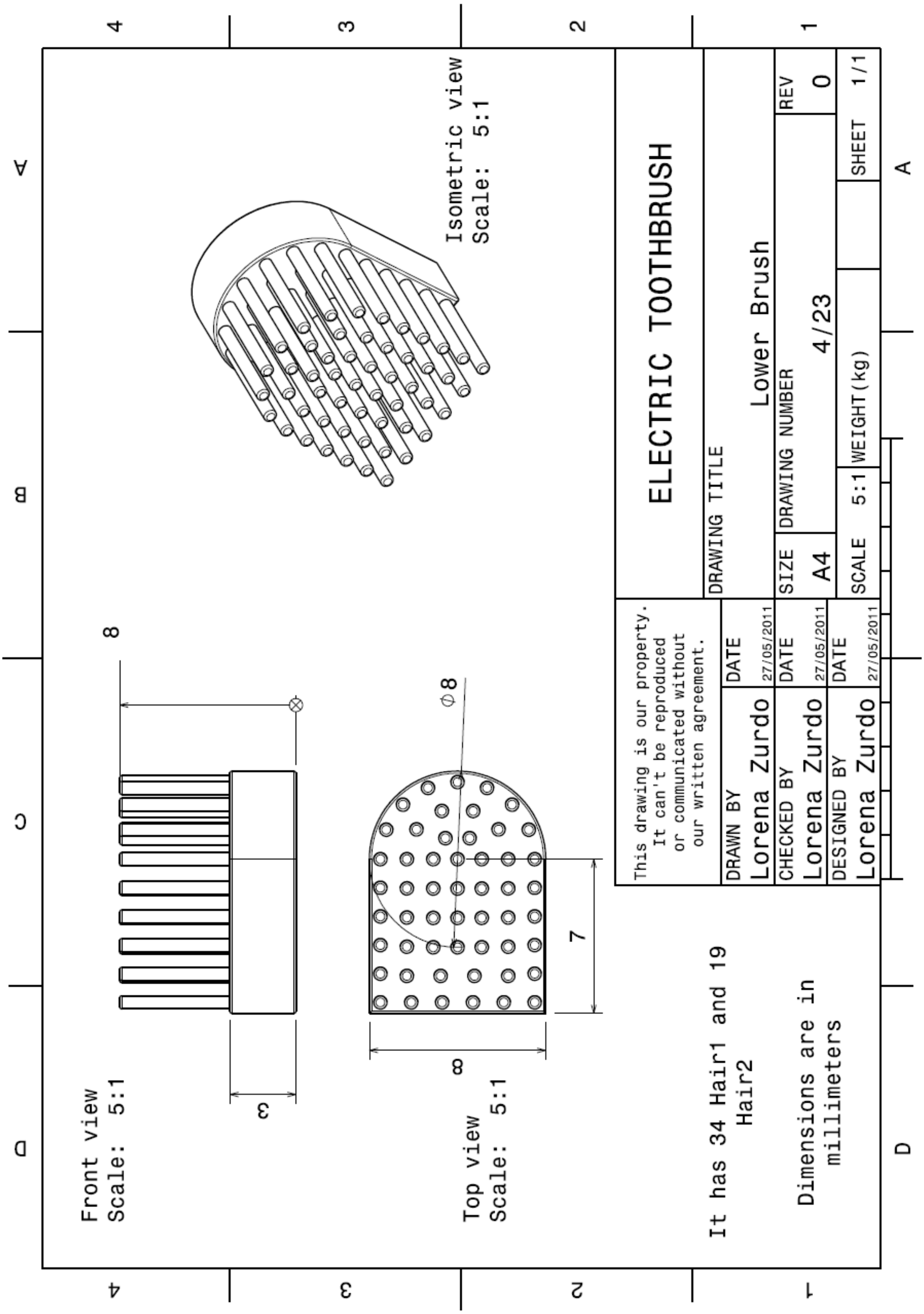
Picture 12.5. ToothBrush Draft



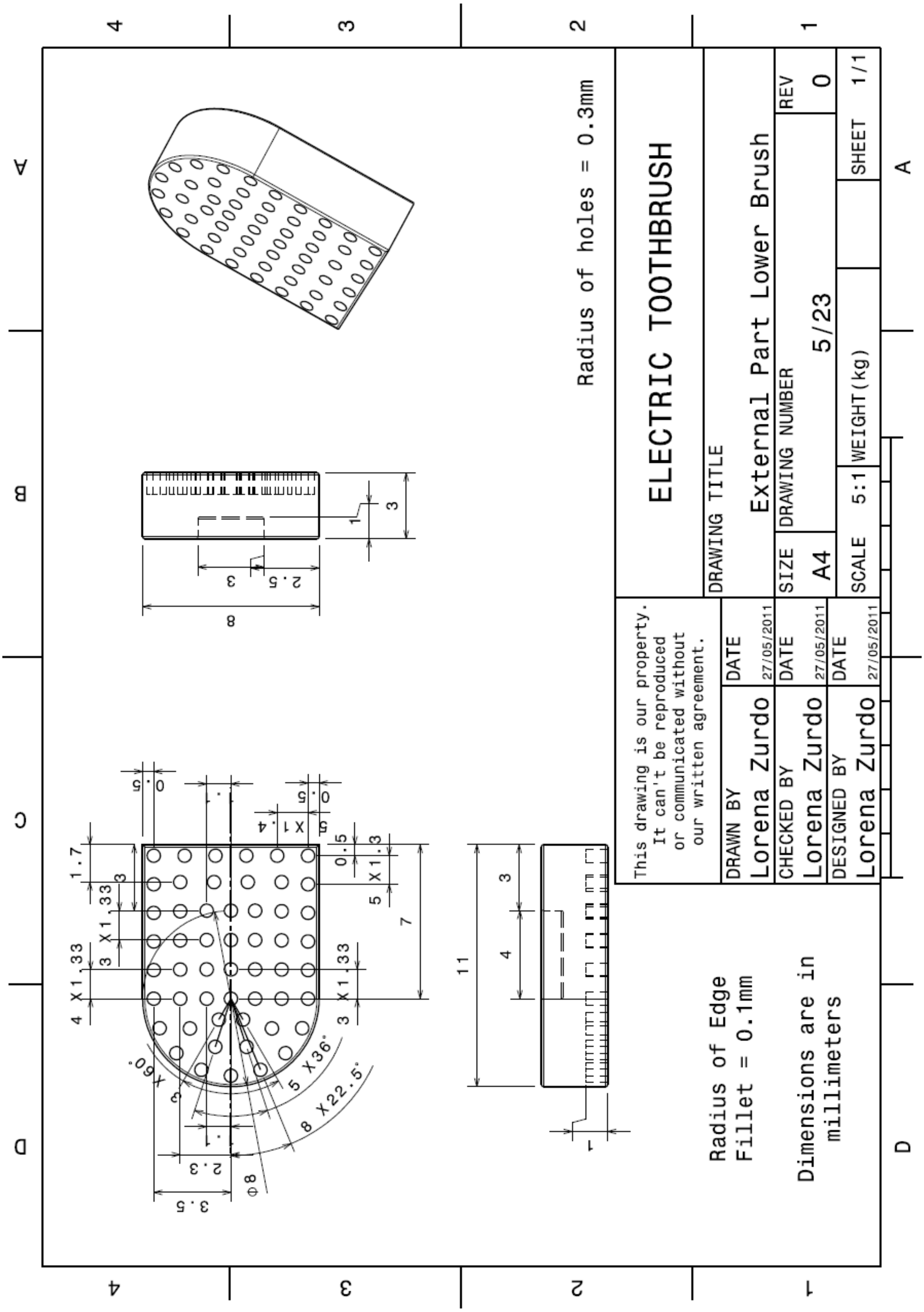
Picture 12.6. Mechanism Draft



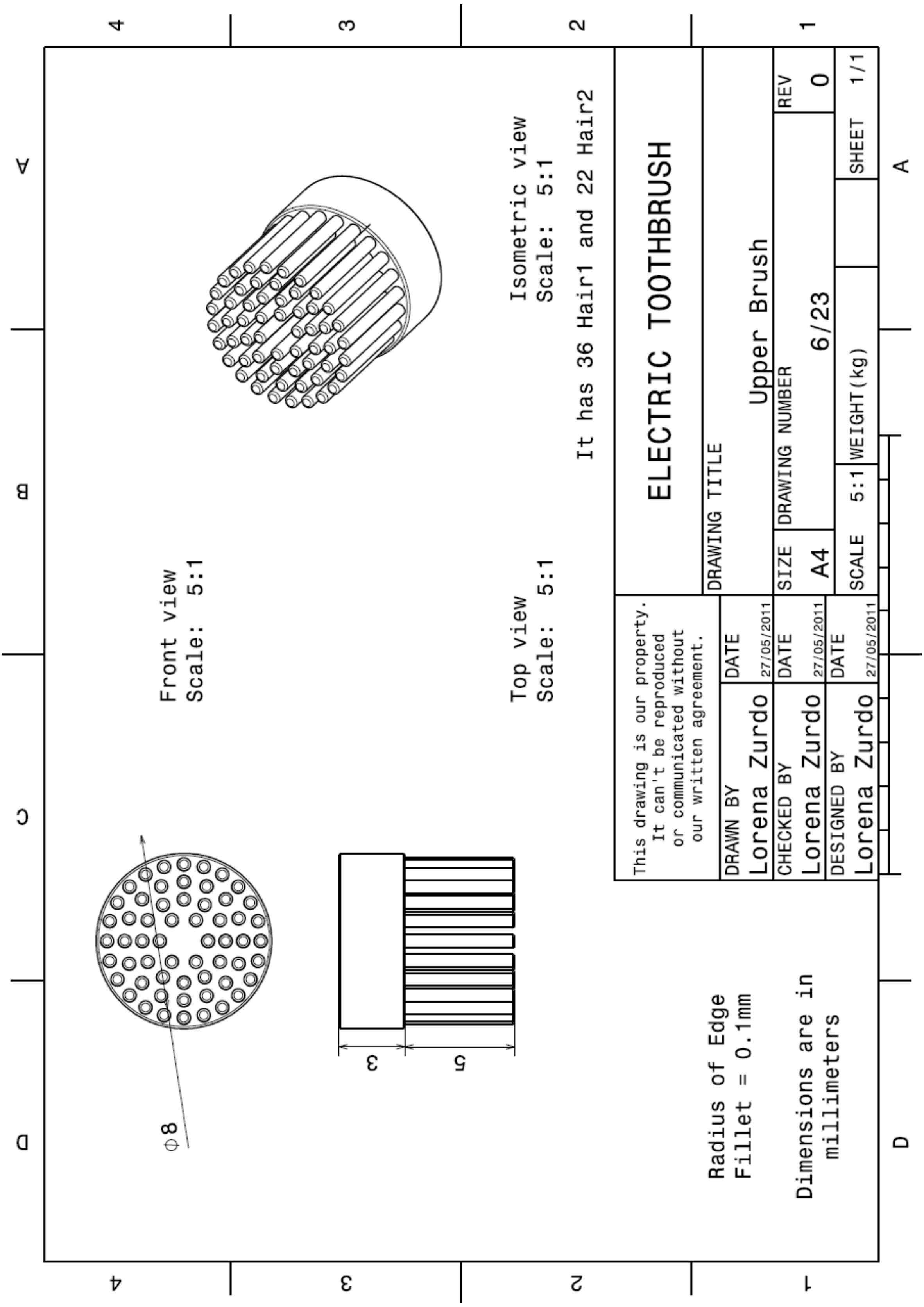
Picture 12.7. Stick Draft



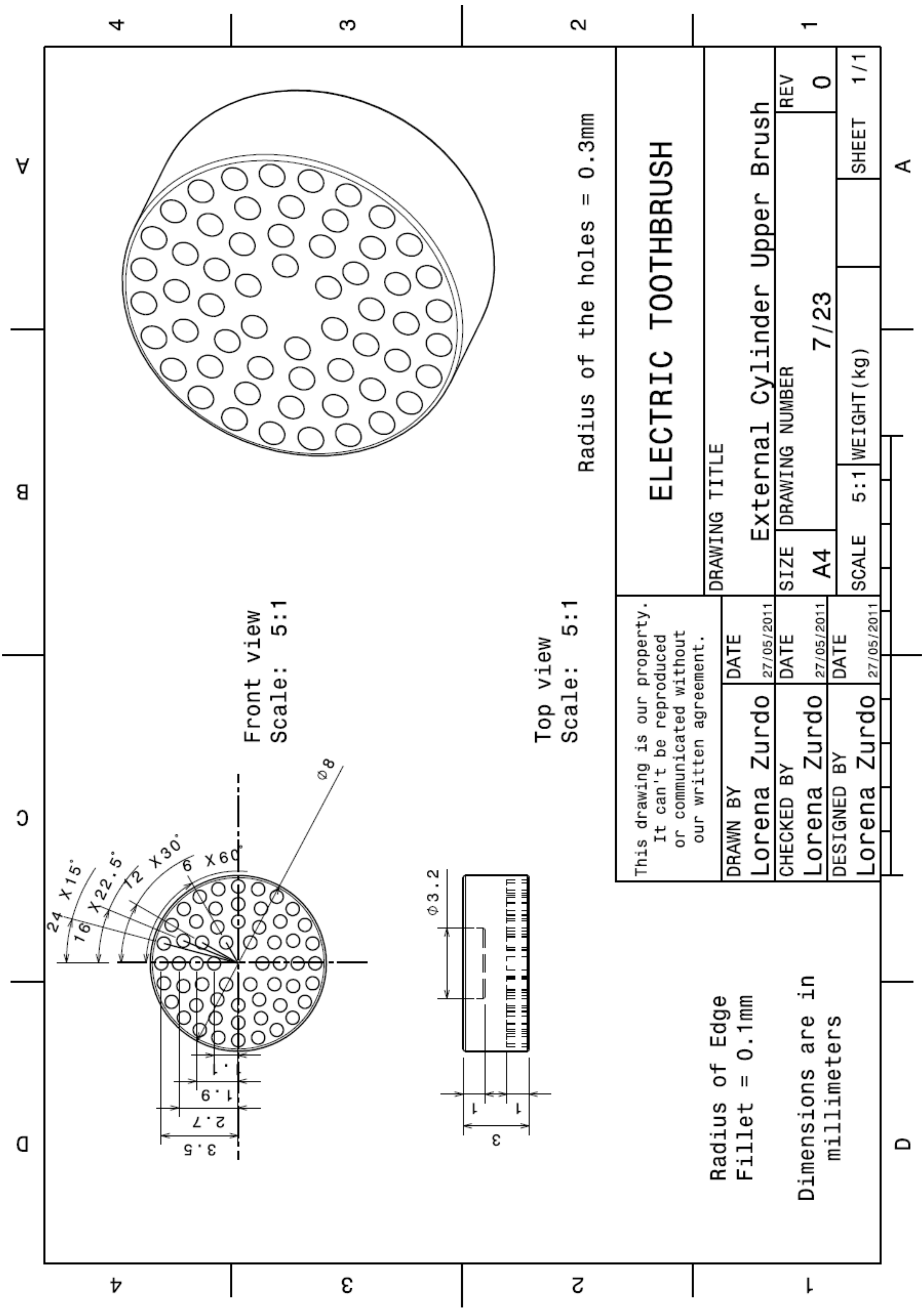
Picture 12.8. Lower Brush Draft



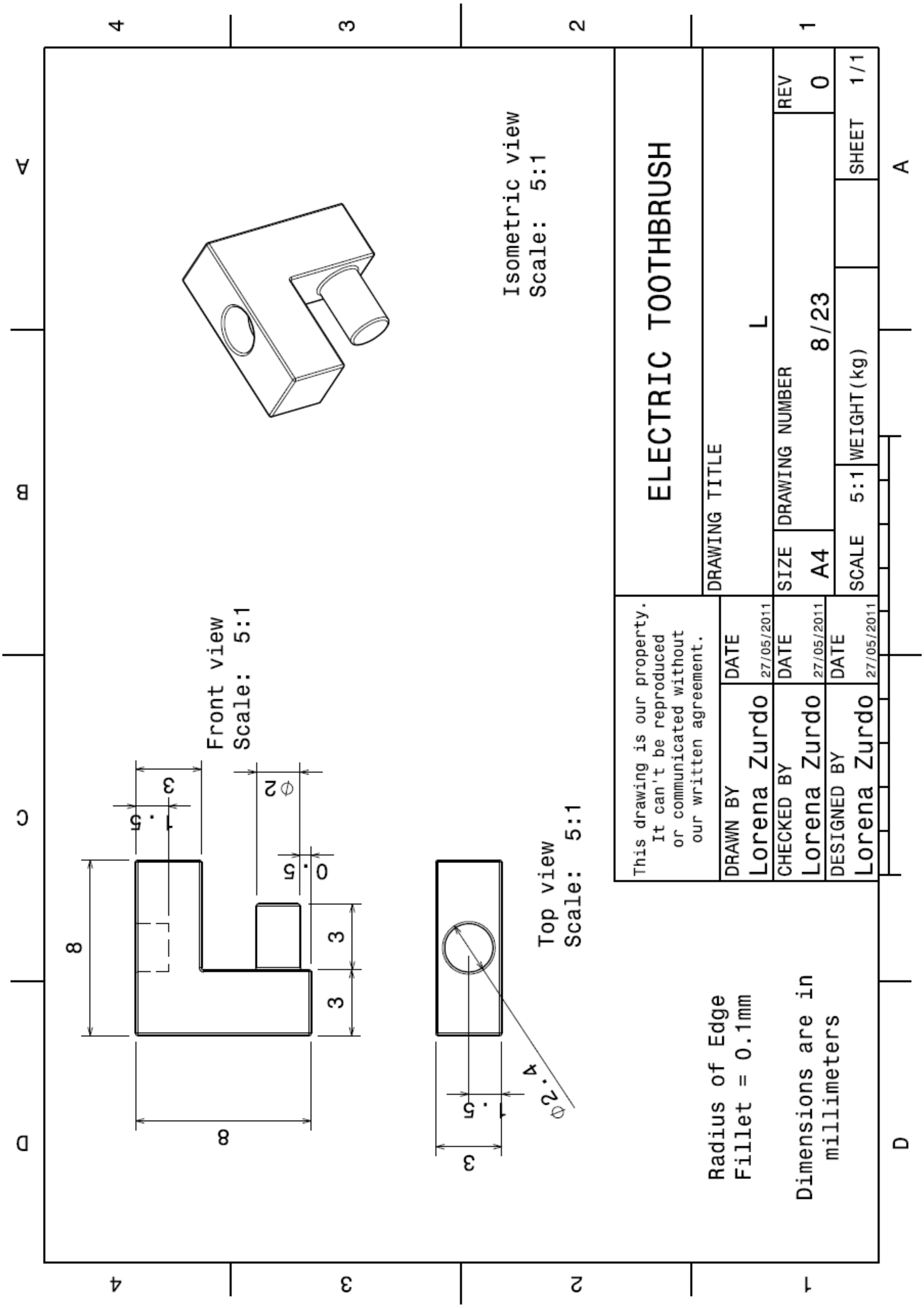
Picture 12.9. External Part Lower Brush Draft



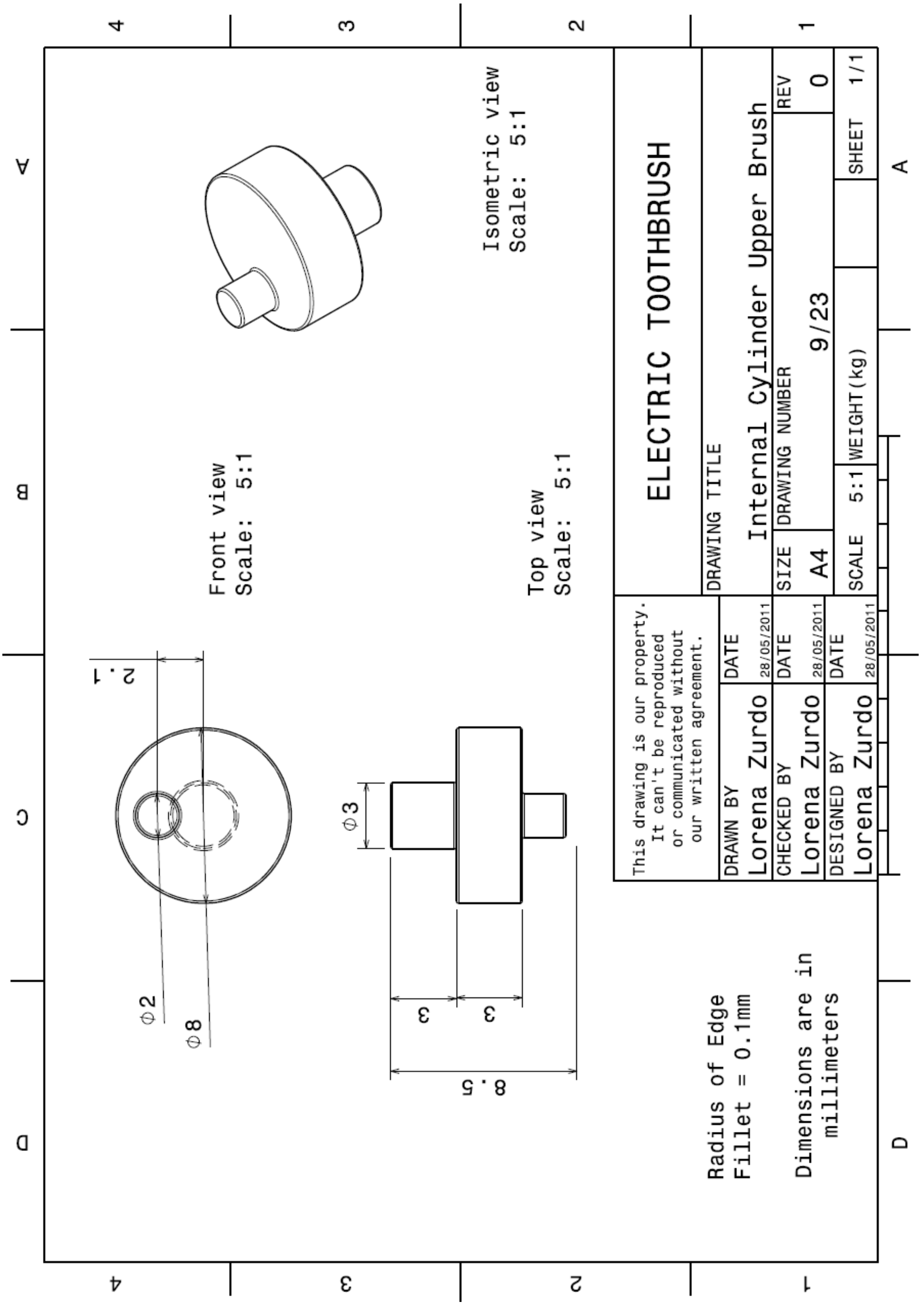
Picture 12.10. Upper Brush Draft



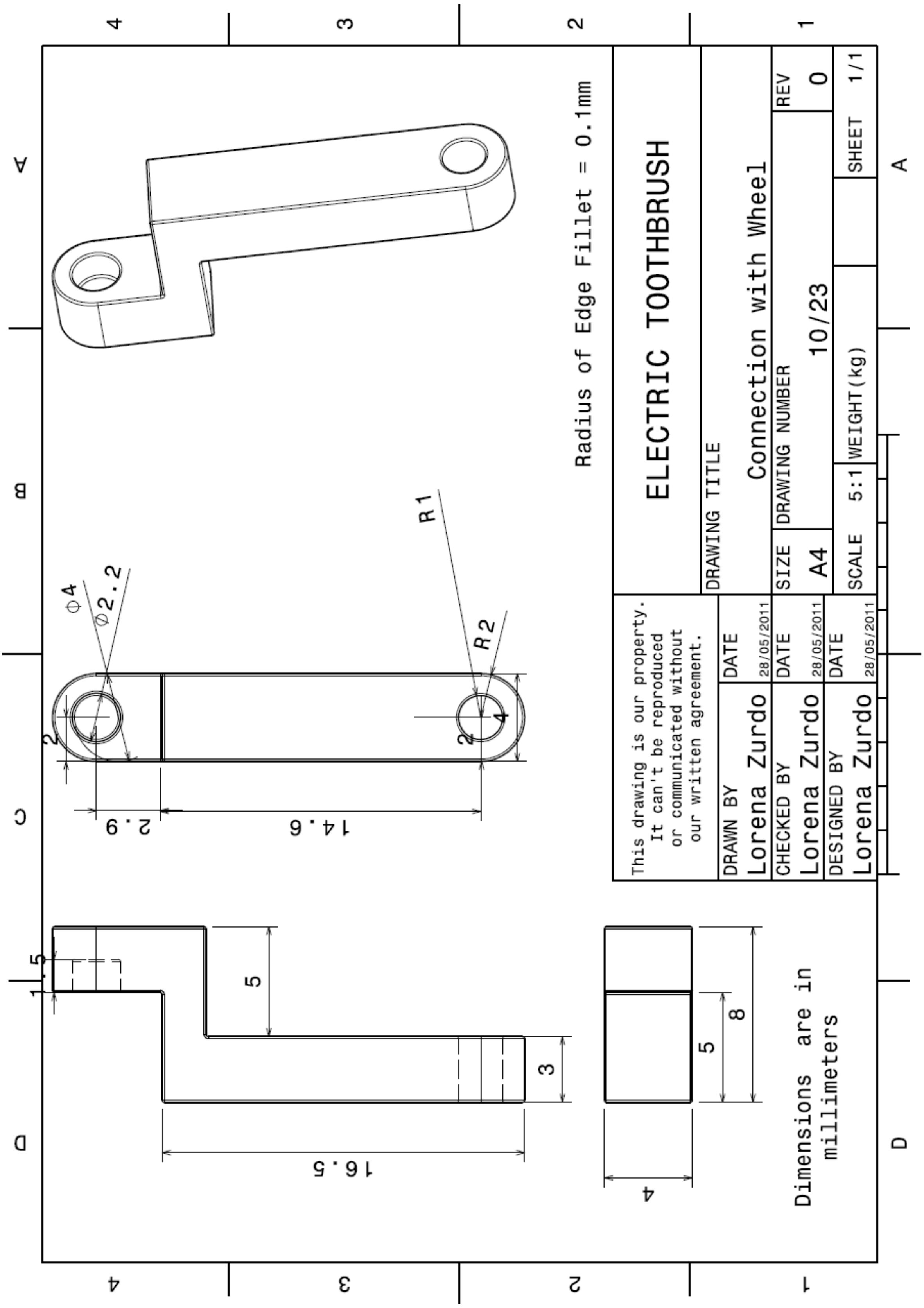
Picture 12.11. External Cylinder Upper Brush Draft



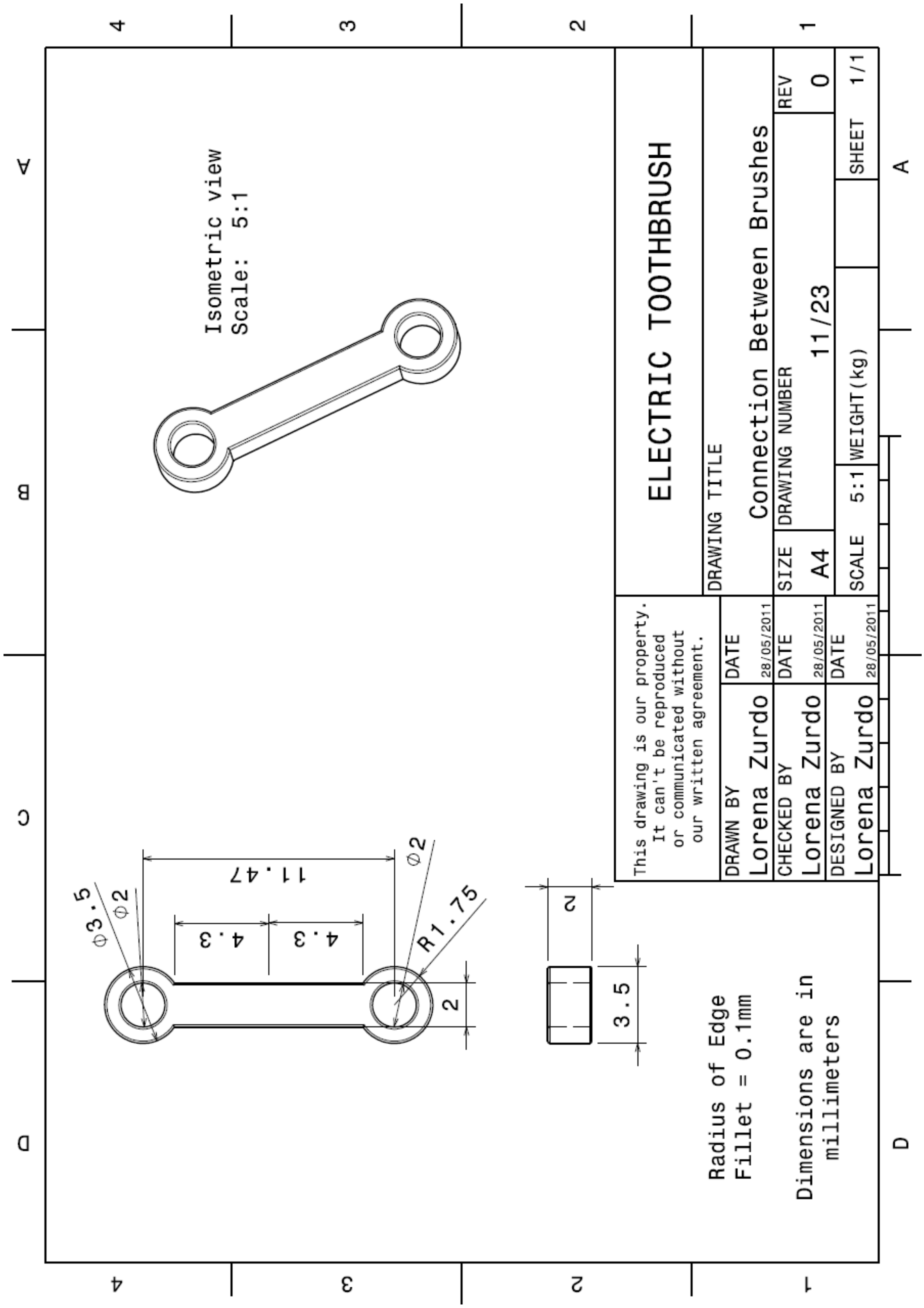
Picture 12.12. L Draft



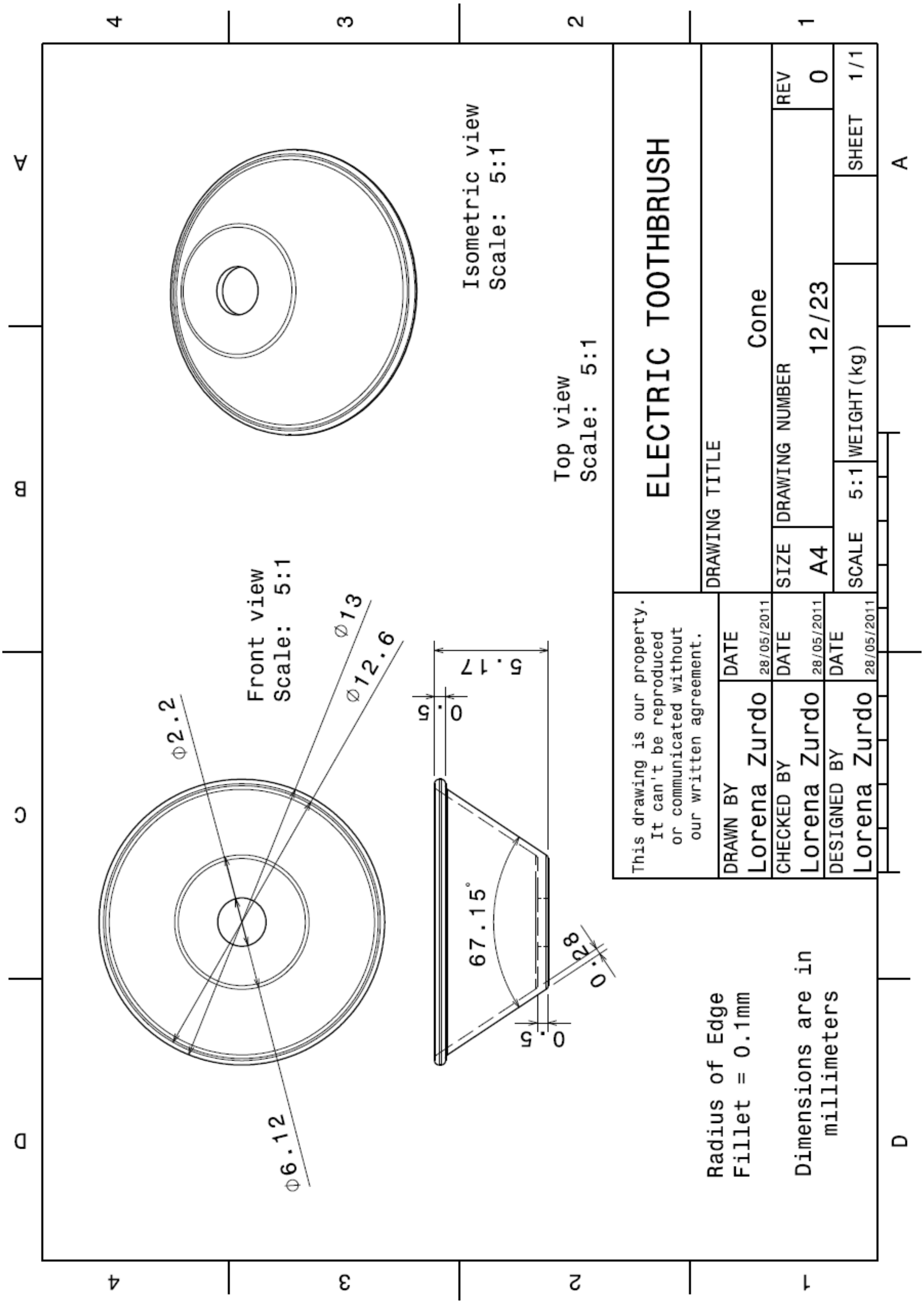
Picture 12.13. Internal Cylinder Upper Brush Draft



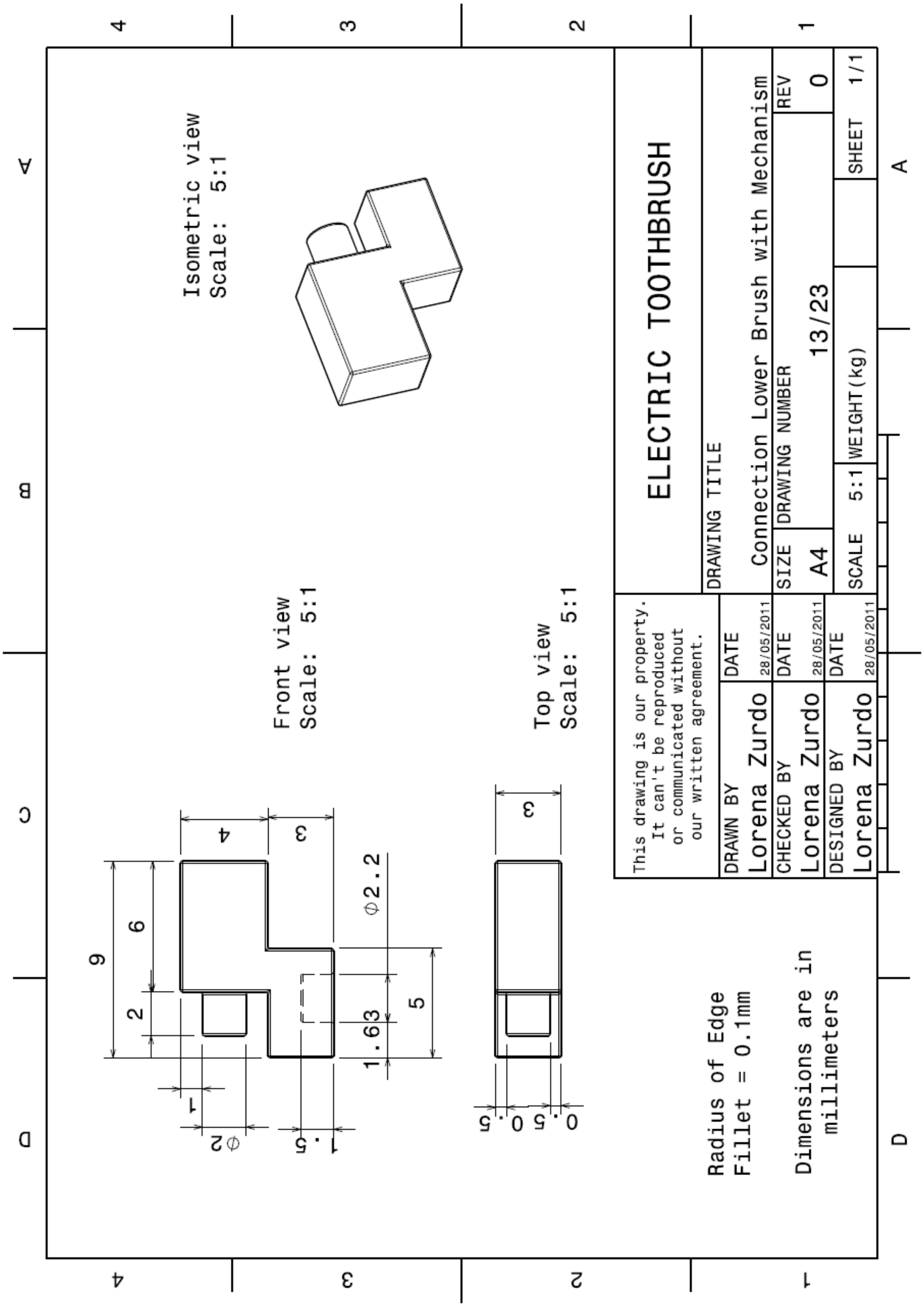
Picture 12.14. Connection with Wheel Draft



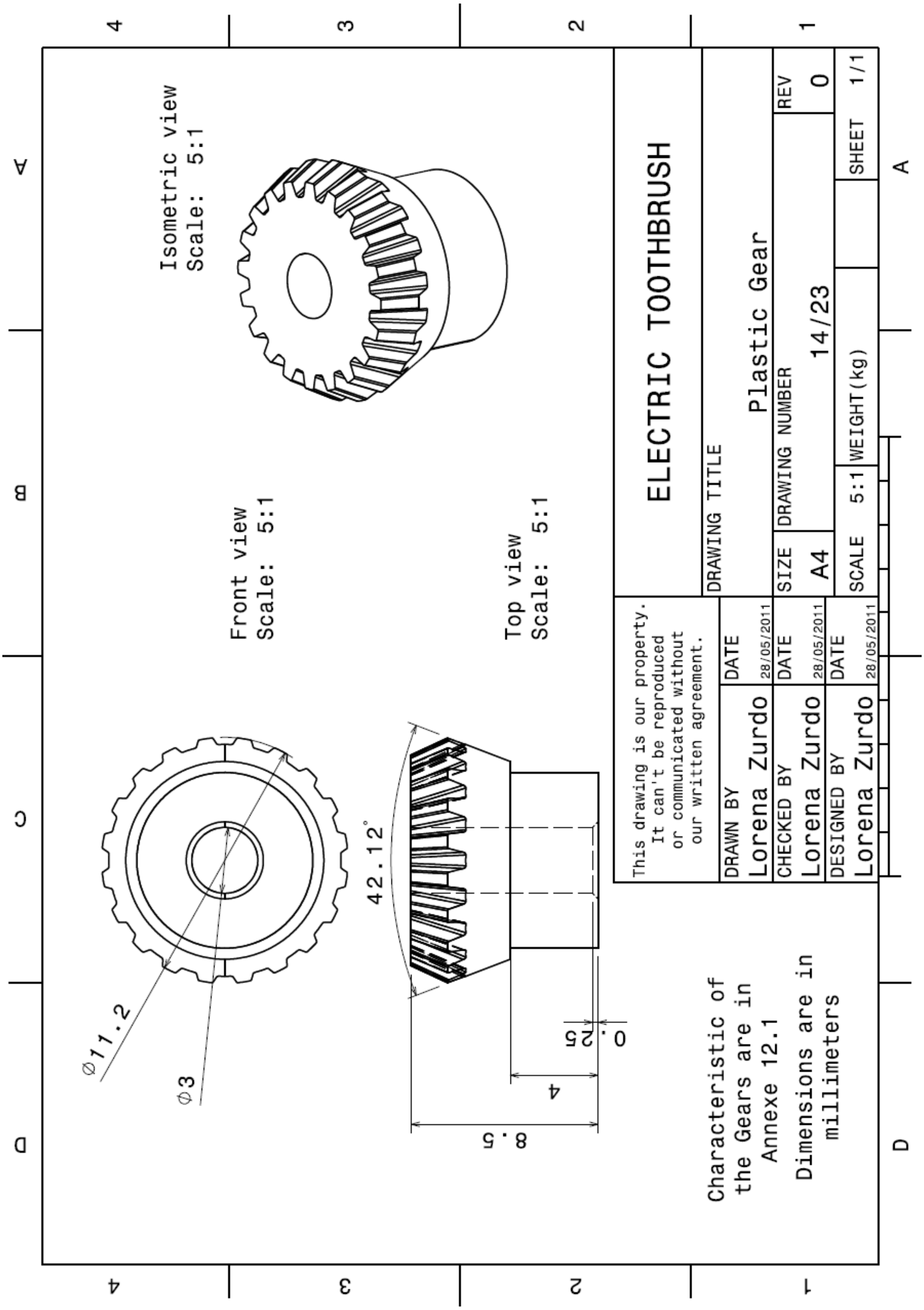
Picture 12.15. Connection Between Brushes Draft



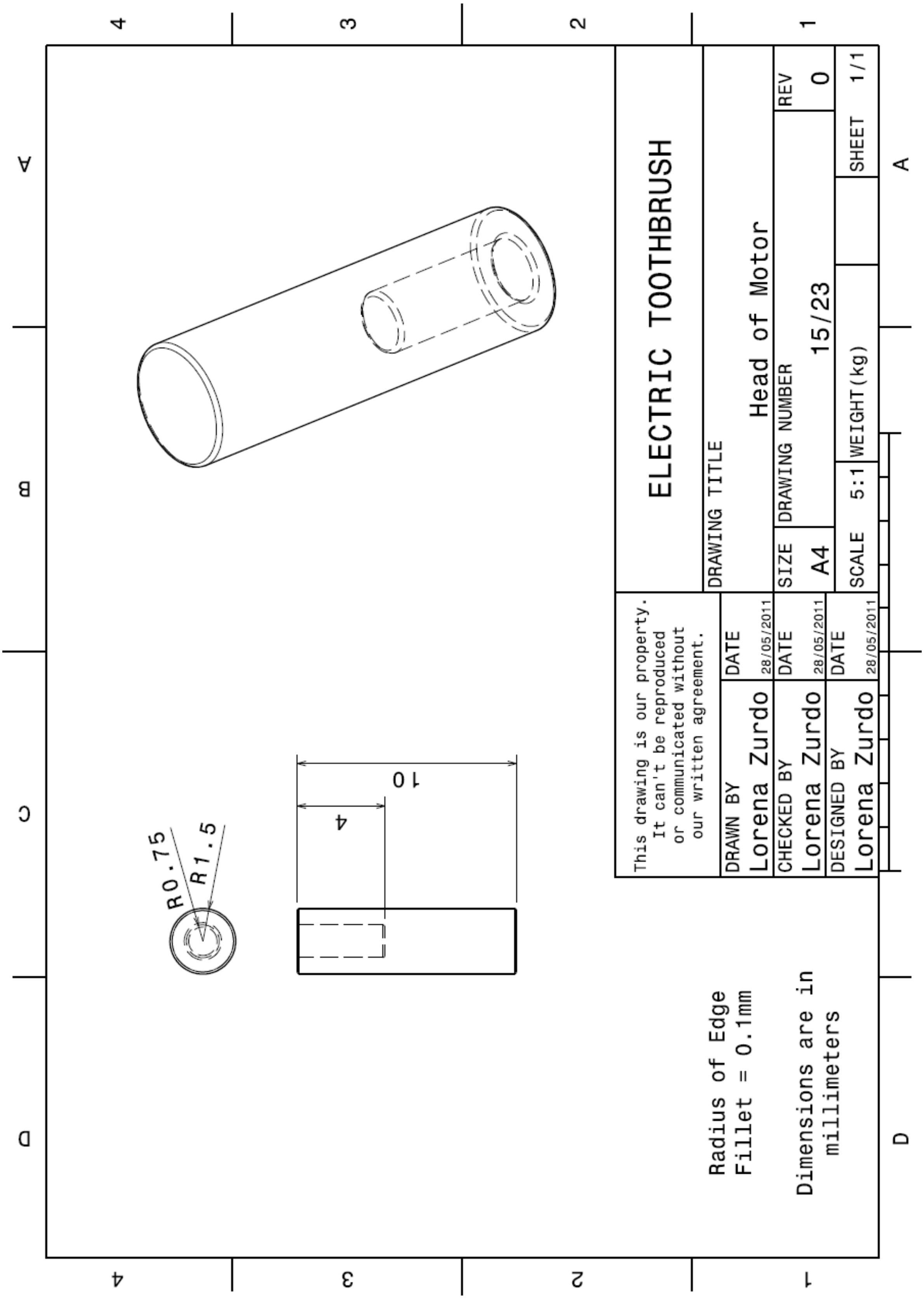
Picture 12.16. Cone Draft



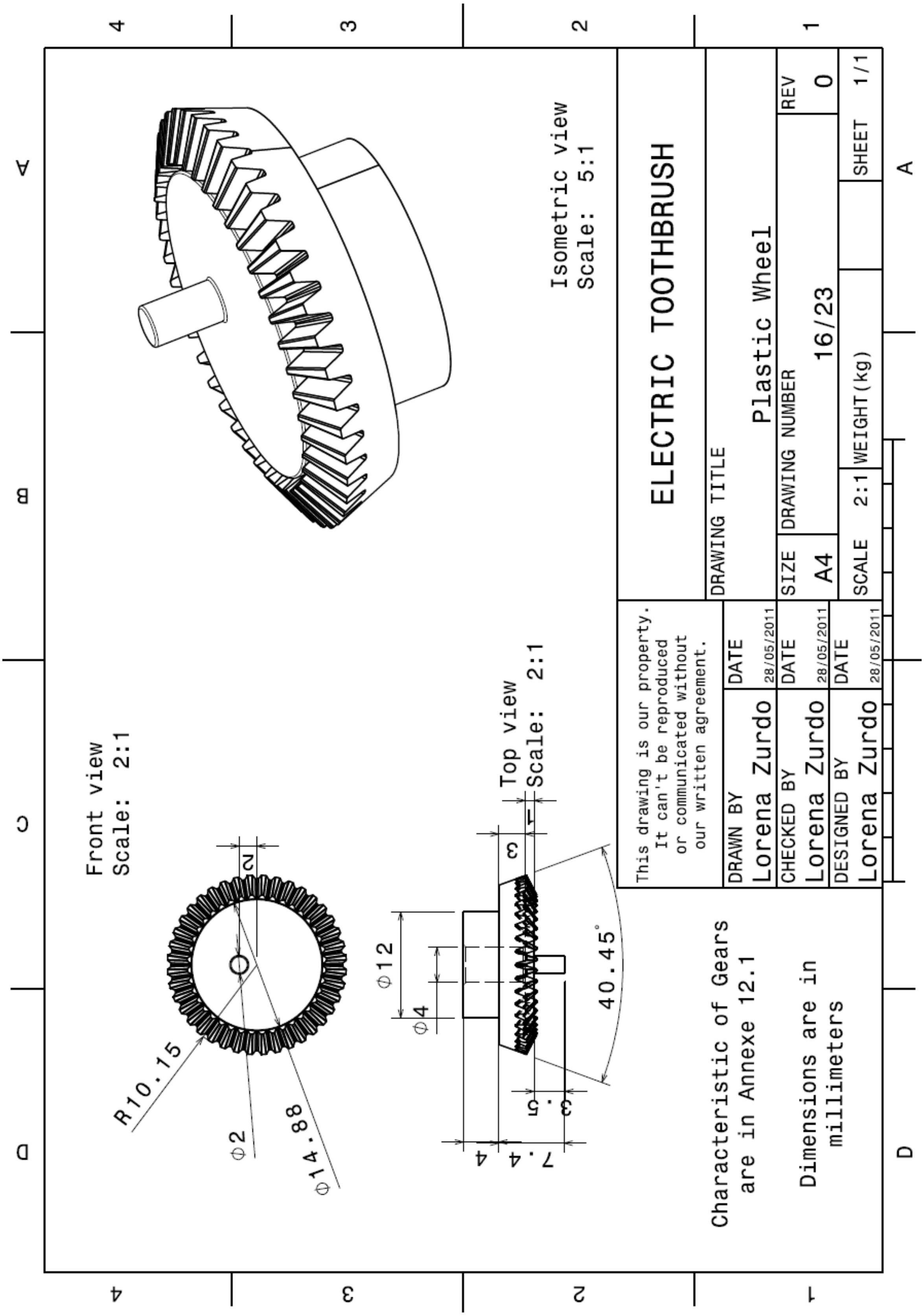
Picture 12.17. Connection Lower Brush with Mechanism Draft



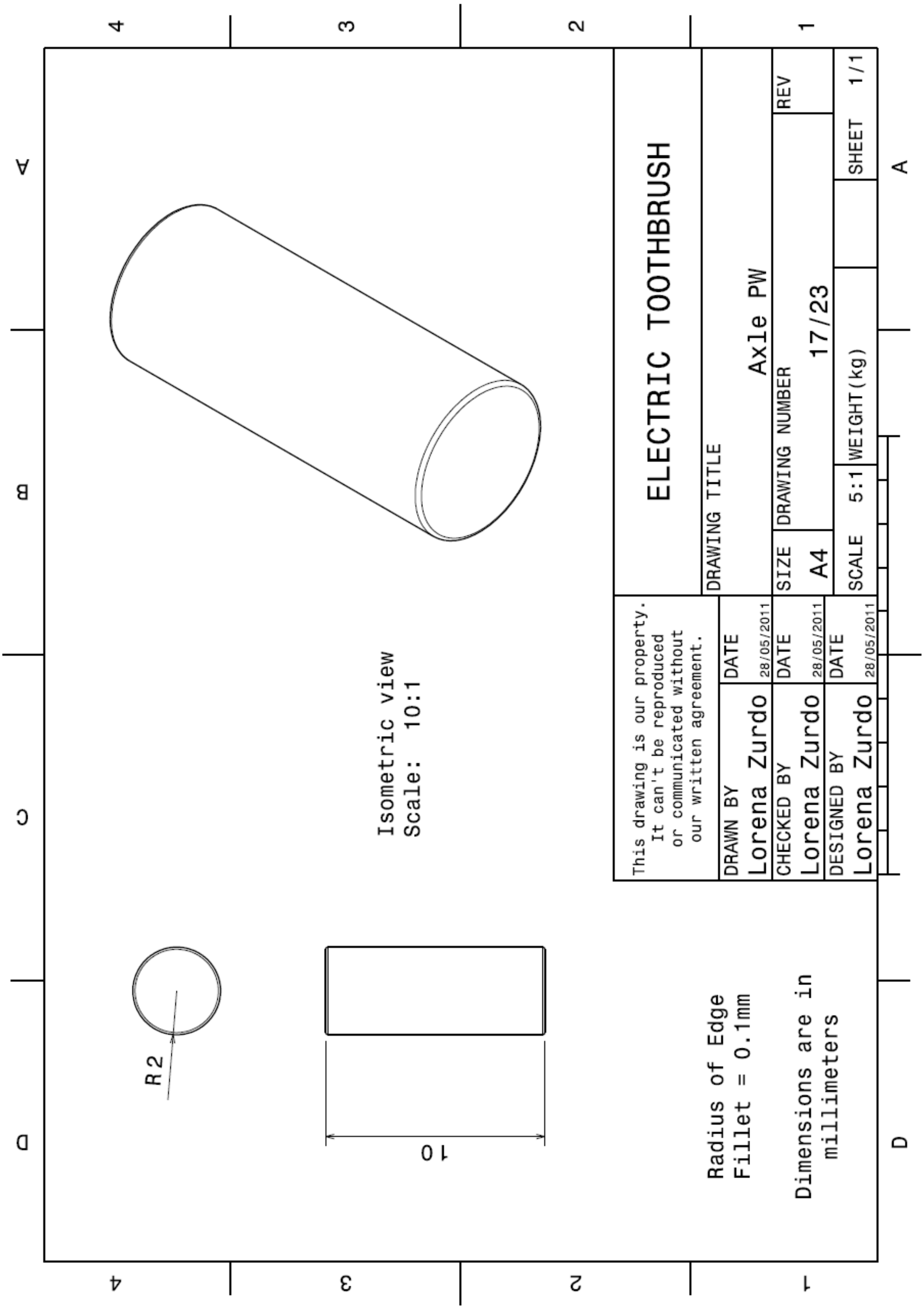
Picture 12.18. Plastic Gear Draft



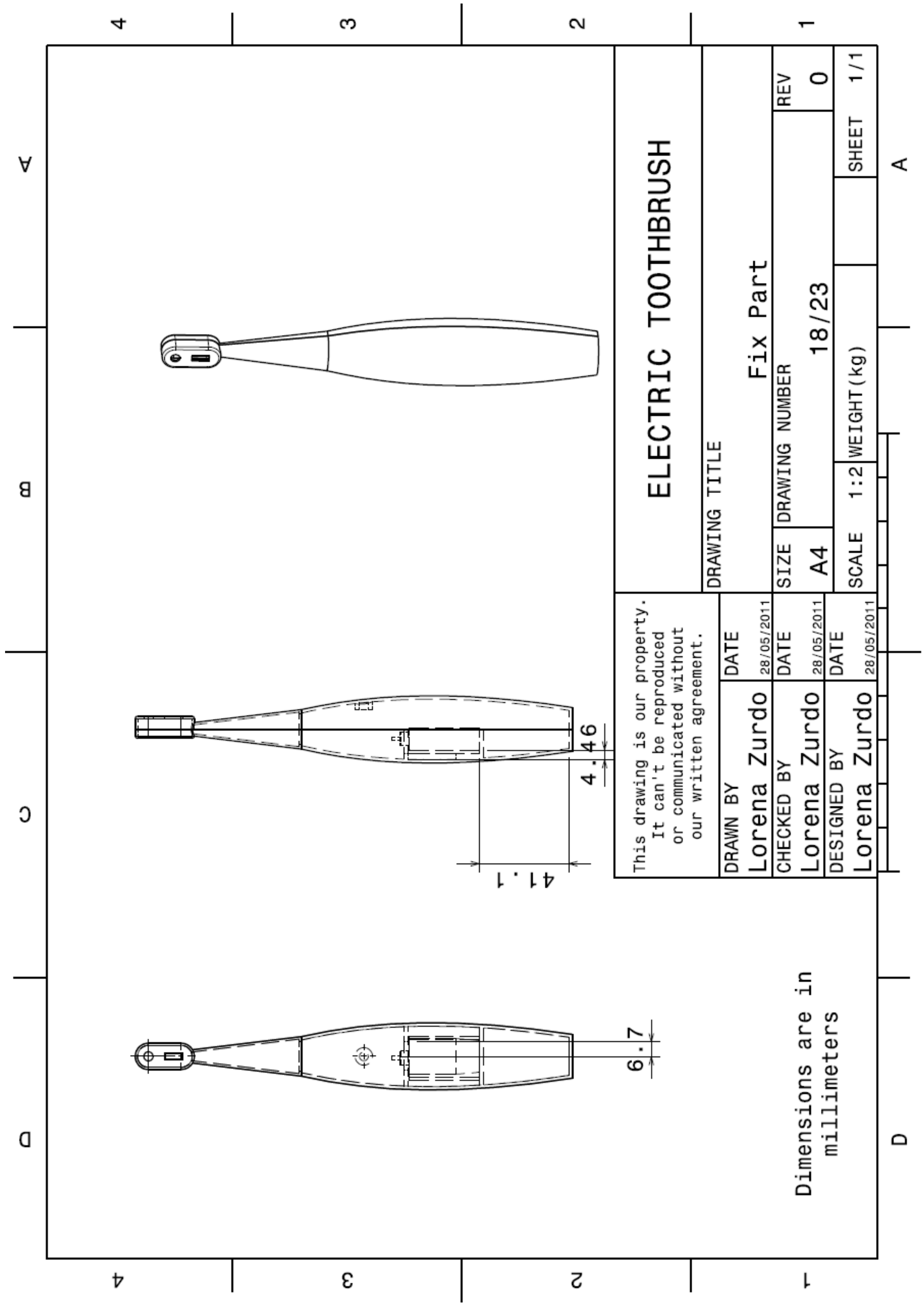
Picture 12.19. Head of Motor Draft



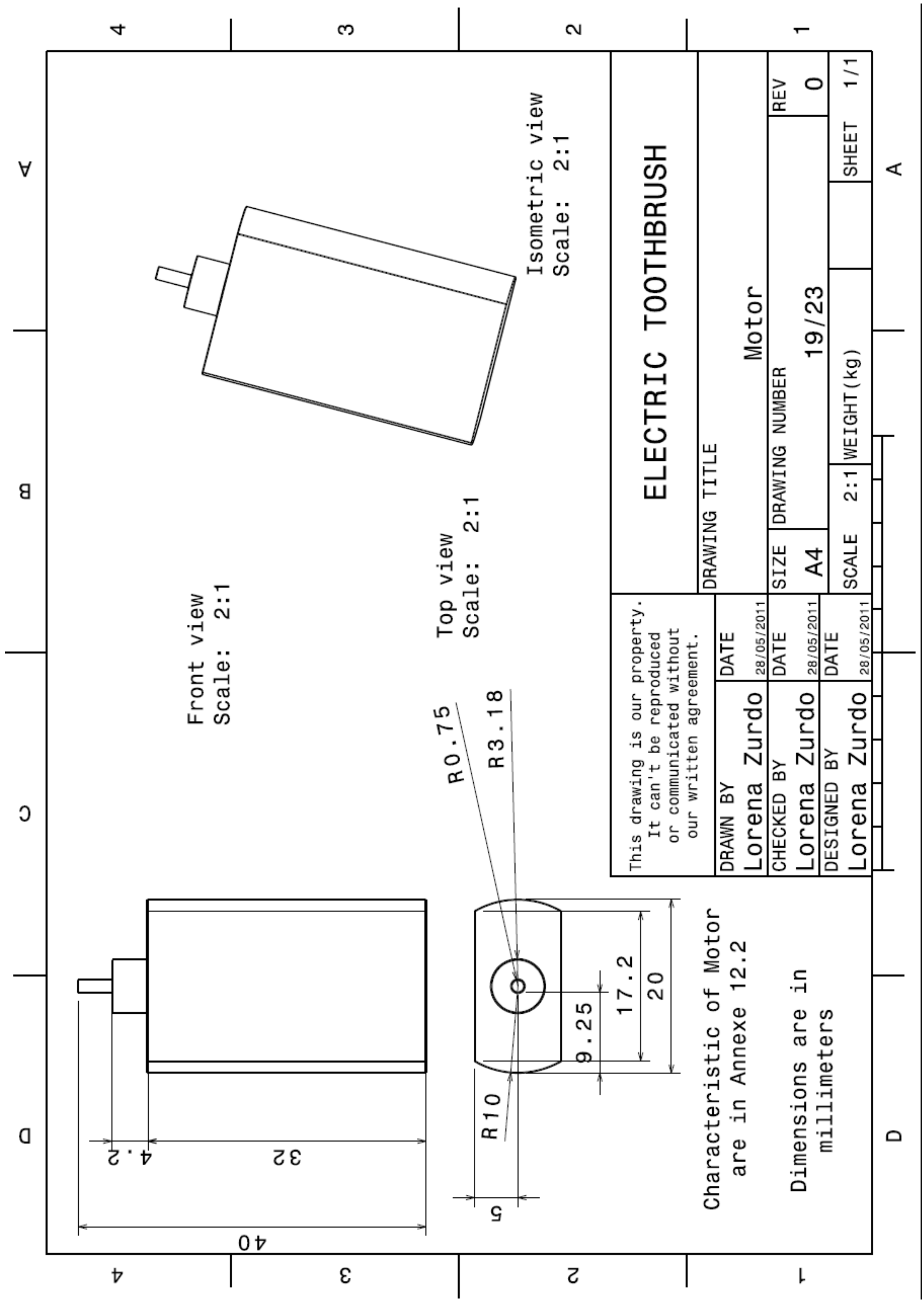
Picture 12.20. Plastic Wheel Draft



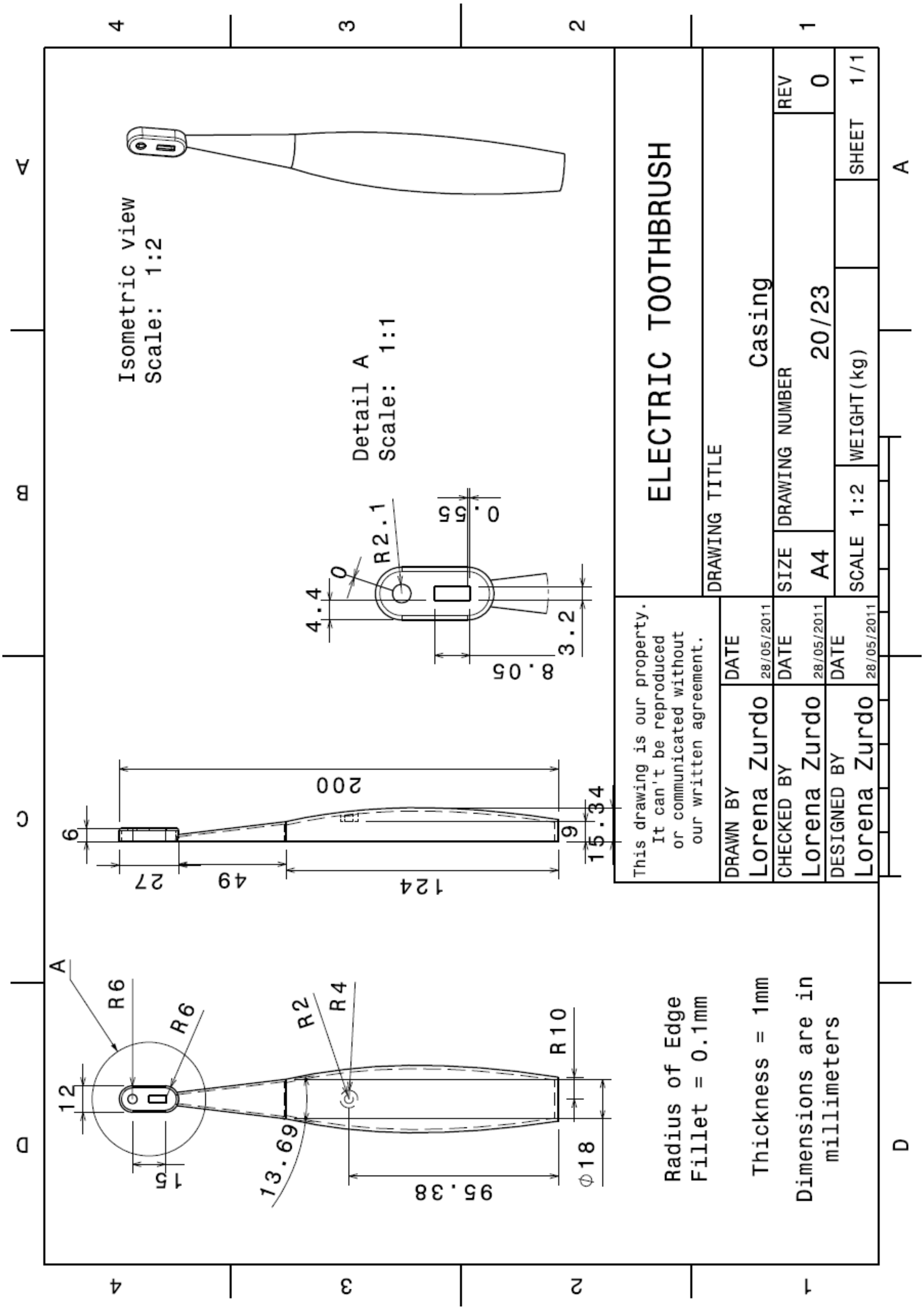
Picture 12.21. Axle PW Draft



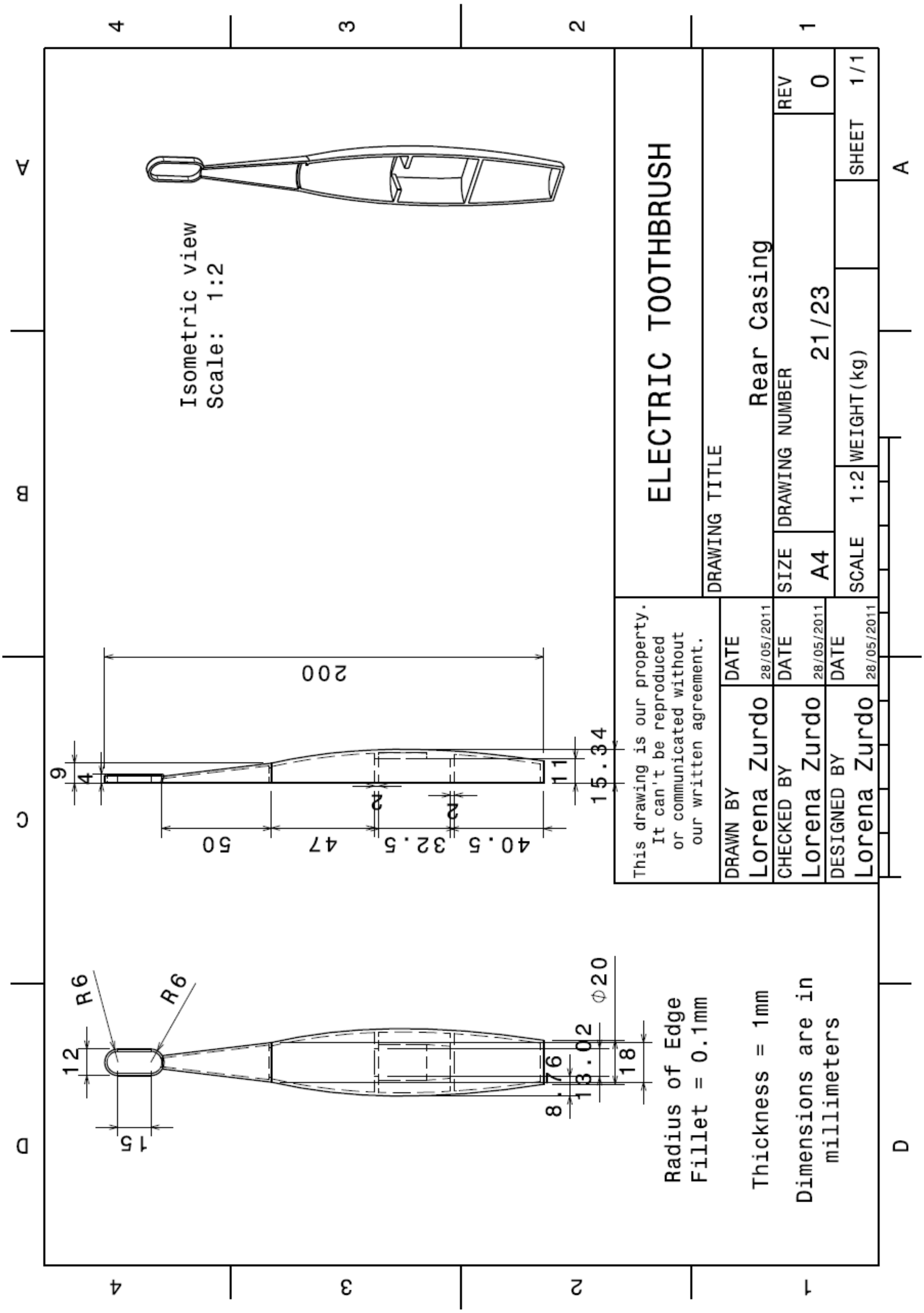
Picture 12.22. Fix Part Draft



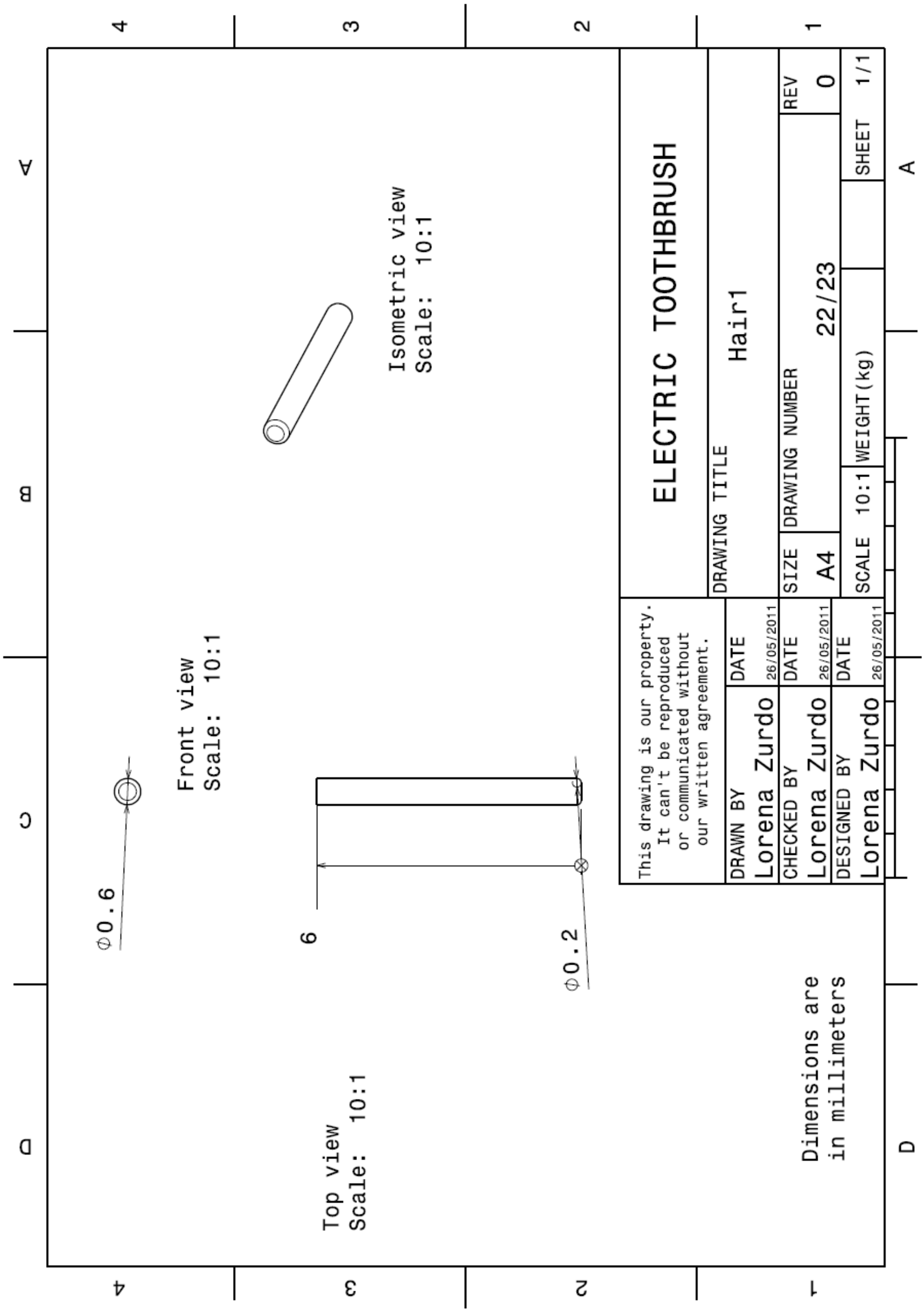
Picture 12.23. Motor Draft



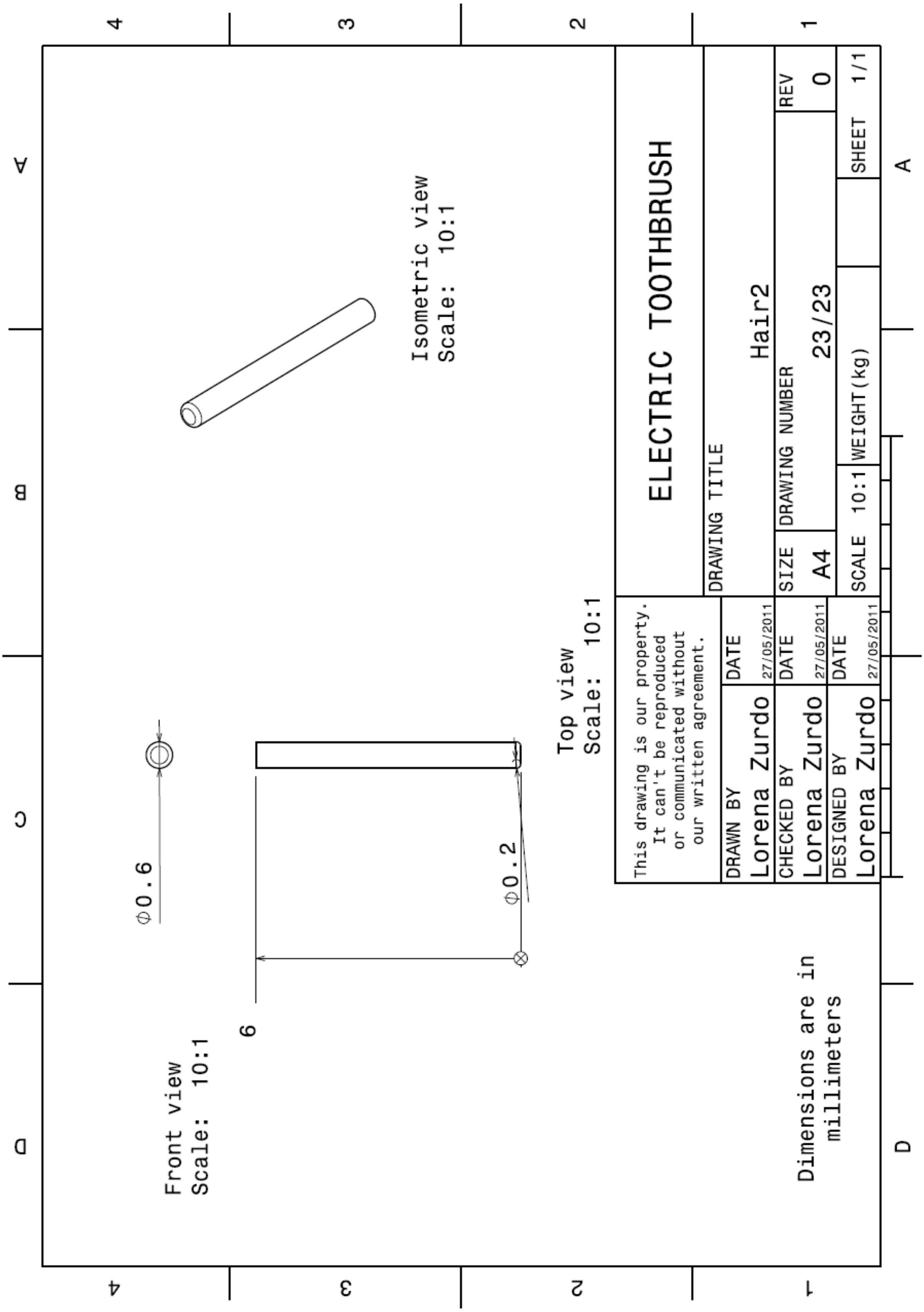
Picture 12.24. Rear Casing Draft



Picture 12.25. Rear Casing Draft



Picture 12.26. Hair1 Draft



Picture 12.27. Hair2 Draft