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Principle of functioning of smart solution to clean high power lines in cold climate

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Abstract

Dependency of human activities on electricity supply goes from emergency services to comfort aspects. Reliability of electricity distribution systems is a complex problem to tackle, especially when the systems are located at cold climate regions, dealing with ice accretion on the elements of the electrical systems and its consequences become a priority to be included in maintenance maneuvers in order to guaranty the energy distribution. De-icing methods must demonstrate their effectiveness in removing ice accreted on ground wires and conductors under severe environment conditions. Therefore, these methods are restricted by specific mechanical, electrical and thermal constrains related with the power line operation. Mechanical stresses imposed on the lines by stretching and torsion caused by the ice accreted on the system elements, the weight and action of the de-icing mechanism or wind effects on the structure determine the dynamics restrictions must be considered during installation as well as operation of new deicing mechanisms. Measures to insulate the de-icing mechanisms from electrical and electromagnetic perturbations are needed in order to overcome the electrical restrictions. Risk of damage or affected performance of de-icing mechanisms due to thermal shock during releasing of the high current pulse of lightning through the surface of the conductors, towers or other elements also imposes new set of constrains on the de-icing mechanism. Expansion of electrical system on remote location, with severe winter conditions along with the changes introduced by the climate changes, put extra interests on the technology development of mechanisms to prevent or remove ice from long lines with single or bundled conductors. Research has been carried out including large-scale technologies testing to address this problem. Mechanisms based on thermal effects, shock waves, cutting, or others have been already proposed. In this paper a comprehensive discussion of the existing methods and the comparison with a new proposed mechanism is presented. So, a new functioning principle of percussion will be presented, analyzed and discussed leading to new scenarios of technology development.

This method represents a valid alternative that require less energy than the energy is used to melt the ice on the power lines. The implementation of this mechanism is also possible actually a design of the principle of functioning produced with support of external sources.

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A	Cross-sectional area of the object
a	Radiation linearization constant
B	Bulk modules
C	Stiffness
C_p	Specific heat of air
C_w	Specific heat of water
D	Cylinder diameter
D_o	Diameter of the work piece
d	Droplet diameter
d_c	Depth of cut
E	Young`s modulus
E_{cut}	Amount of energy to break/remove the ice for cut
E_{ice}	Amount of energy to break/ remove the ice for percussion
e_s	Saturation water vapor pressure over the accretion surface
e_a	Ambient vapor pressure in the airstream
F	Flux density
F_c	Cutting force
f	Feed of cut
G	Shear modulus
h	Convective heat-transfer coefficient
K	Strength specific cutting resistance of the material- related
L	Length of the work piece
L_e	Latent heat of vaporization
L_f	Latent heat for fusion from solid to liquid
m	mass
P_c	Cutting power
p	Air pressure
p_a	Air density
p_w	Water density
Q	Amount of energy in the form of heat
R_{MR}	Material removal rate

Re	Droplet Reynolds number based on the free stream velocity
r	radius
r	Recovery factor for viscous heating
S	Compliance
T_m	Machining time
t_a	Air temperature
t_d	Temperature of the droplets at impact
t_s	Temperature of the icing surface
V	Volume
v	Velocity
v_c	Cutting speed
w	Mass concentration
$\propto_1$	Collision efficiency
$\propto_2$	Sticking efficiency
$\propto_3$	Accretion efficiency
ε	Strain
λ	Liquid fraction of the accretion
μ	Absolute viscosity of air
v	Wind speed
π	Pi
ρ_{ice}	Density of ice
σ	Stress
ϵ	Ratio of the molecular weights of dry air and water vapor

1 Introduction

Combating ice deposits on overhead transmission lines has been a big challenge in cold climate regions since the installation of the first power lines. With an expanding electric system, it has been a difficult work to prevent or remove ice from long lines with single or bundled conductors. Extensive research has been carried out and large-scale technologies have been developed to address this problem. Based on worldwide power utility experience, two different strategies regarding ice accretion on overhead lines have been adopted. To prevent failure, power utilities try to build overhead lines that are capable of withstanding large icing events (with a low probability of occurrence). This commonly requires strengthened towers and costly lines. Therefore, transmission lines deicing technology is one of the major issues of intelligent power grid construction and development which needs to be resolved.

There have been many studies about combating icing damage on overhead lines, a large number of anti-icing and de-icing methods have been developed. Some of these methods have been well documented in specific reviews since the 1990s.

1.1 Remote sensing of snow and ice

Cryosphere is the surface of the Earth where water can be presence in form of snow, sea ice, freshwater ice, the large ice masses on land and permafrost. The presence of ice and snow on the Earth is significant over a wide range of spatial and temporal scales. The cryosphere represents an important part of the earth climate system.

Falling or deposited ice particles formed mainly by sublimation is defined as snow. There are three types of snow cover such as permanent, seasonal and temporary. Permanent snow cover is retained for many years, while temporary and seasonal snow covers do not survive the summer. The global distribution of snow is shown in Figure 1.

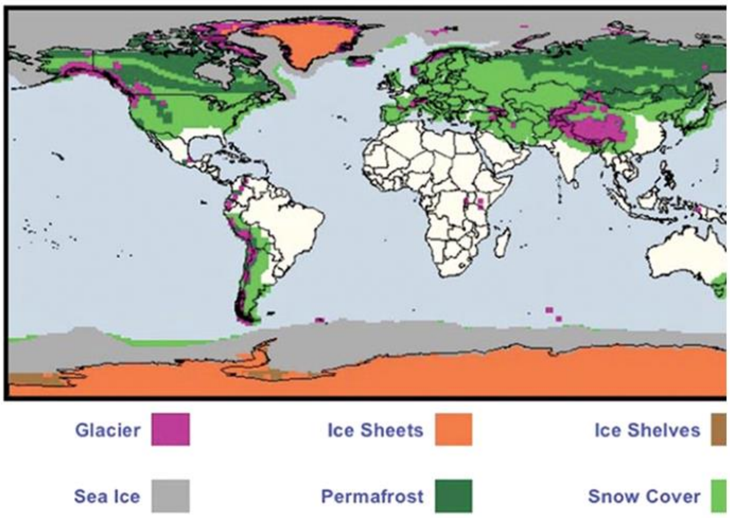

Figure 1 – The global distribution of snow cover [1].

Permanent snow cover eventually forms a glacier, defined as an accumulation of ice and snow that moves under it is own weight. Icebergs are masses of freshwater ice that have calved from a glacier or ice shelf and fallen into the sea or a body of fresh water, or that have been produced as a result of the breaking up of larger icebergs. Icebergs are classified according to both size and shape [2].

Norway and China locations correspond to the area where it is presented of snow cover, glacier and permafrost.

2 Power transmission system

Power transmission can be defined as *the bulk transfer of power by high-voltage links between central generation and load centers. Power distribution, on the other hand, describes the conveyance of this power to consumers by means of lower voltage networks* [3].

The high voltage links are the structures that carry this electrical energy above the ground between source and distribution points, namely towers, lines and insulators.

The main elements of the transmission and distribution system are tower, conductors (cables), isolators and protection devices

2.1 Towers

The towers are one of the types of structures that are used to transmit the electricity, see Figure 2. They support the insulators on which the lines are suspended. Depending on the function of the towers, they can be classified in two main types: towers for straight runs and towers for changes in route. The function of the former is to withstand the weight of the line, whereas the latter withstands the forces when there's a change in the direction of the lines [3]. In both cases, the design of the tower must take into account wind, ice accretion and the rupture of the lines from one side of the tower as additional loads [4].

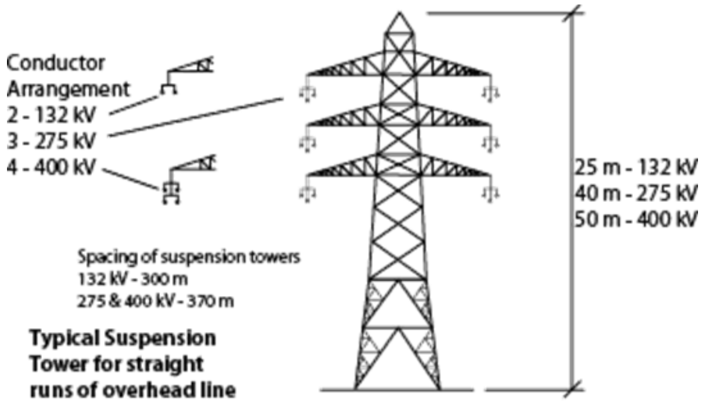

Figure 2 – Typical suspension tower for straight runs of overhead line [4].

The basic geometries of the towers are lattice, pole, H frame, guyed V and guyed Y [5].

2.2 Conductors

The type of conductors nowadays are different from those in the early days of electrical development. They are no longer made of copper, but aluminium. Aluminium conductors are more economical than copper, though they have a lower conductivity. A typical aluminium conductor provides only 60% of the conductivity of a copper conductor [5] [6]. With the same conductivity, an aluminium conductor has 48% of the weight of a copper conductor, whereas the cross section is 160% of the copper conductor [7].

2.3 Insulators

The high voltage lines are suspended by insulators made of porcelain or glass. They can take three forms: pin type, suspension type and strain type. The pin type is used in lines that carry less than 33kV [3]. Though is one of the oldest, it is still in use. The suspension type is made of several discs arranged in a string and is used for lines above 33kV [8]. This type of insulator allows stacking the necessary amount of discs to suffice the necessary voltage, and when a disc gets damaged, it can be replaced. The third type is a variation of the suspension type. It is designed to withstand large tensile loads, since it is used in changes in route. The three types of insulators can be seen in Figure 3.

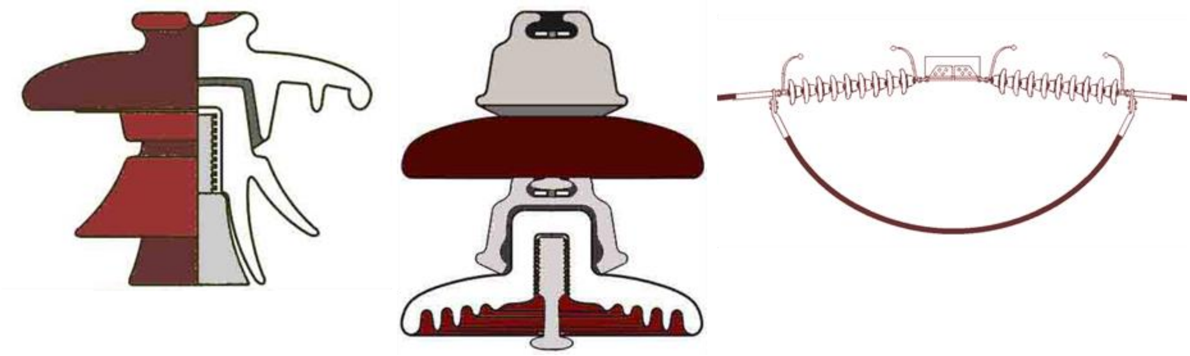

Figure 3 – Types of insulators. Left to right: pin type insulator, suspension disc type and strain type [8].

2.4 Protection devices

Since the towers, conductors and insulators are in the open, they are susceptible to damage by the nature, e.g. winds and lightning's. Thus, wind and lightning protection are an important part of the design of a transmission network.

2.4.1 Wind protection

Wind can be disastrous for high voltage lines. It can cause the lines to hit against each other, and the vibration caused by the wind can damage the conductors and other parts of the structures. To prevent this, a protection device is installed on the lines. The most common protection devices are the Stockbridge damper, the spacer damper and the spiral vibration damper.

The Stockbridge damper (Figure 4) consists of two weights at the end of a stiff cable located under the conductors, close to the tower [9]. Its function is to absorb the vibrational energy created by the wind [5].

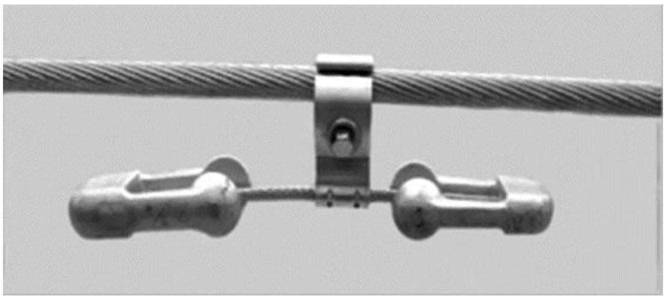

Figure 4 – Stockbridge damper [9].

Spacer dampers (Figure 5) maintain the original geometry and provide a separation between the conductors of a bundle line. There are different spacer models according to the bundle configuration on which they are going to be installed, e.g. three and four conductor's bundle [10] [11].

Figure 5 – Spacer damper for a three conductor's bundle [10].

The spiral vibration damper (Figure 6) is a spiral shaped wire that wraps around the conductors. It has two different inner diameters: the first one grips and holds around the conductor, and the second one provides the damping on the conductor.

Figure 6 – Spiral vibration damper [12].

3 Configuration/Mechanical model of the line.

When there is ice on the line, the distributed or non-distributed load increases on the cable and the adverse impact can be classified into two broad categories: one related to the excessive load on the sides (Figure 7) that can generate broken conductors or fallen towers and the second relates to the fact that ice formations on insulators decrease their electrical strength and can result in flashover across the surface at operating voltage, – this process is called ‘icing flashover’.

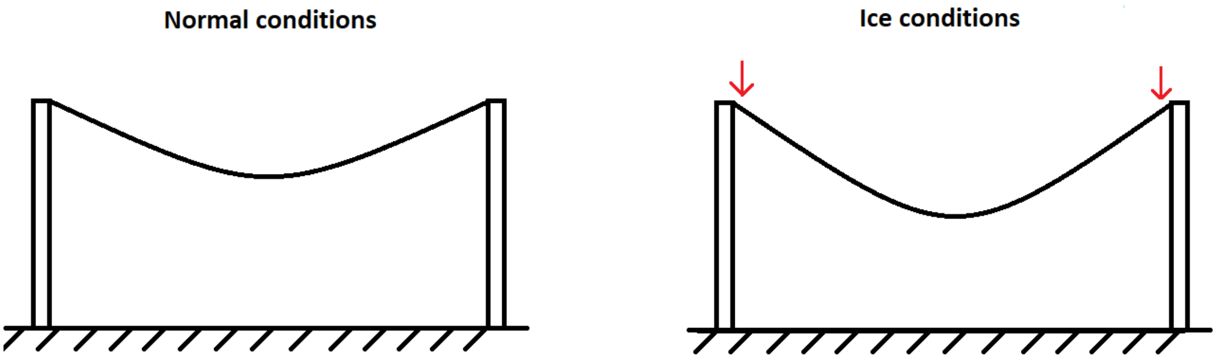

Figure 7 – Mechanical model of the line

4 Models for the growth of rime, glaze, icicles and wet snow on structures

The origin of natural ice that forms on structures may be either cloud droplets, raindrops, snow or water vapor. These particles can be either liquid, solid or a mixture of ice and water. In any case, the maximum rate of icing per unit projection area of the object is determined by the flux density of these particles. The flux density, *F*, is a product of the mass concentration, *w*, and the velocity, *v*, of the particles relative to the object. Consequently, the rate of icing is obtained from:

$$\frac{\mathrm{dM}}{\mathrm{dt}} = \propto_1 \propto_2 \propto_3 wvA \tag{1}$$

Where *A* is the cross-sectional area of the object (relative to the direction of the particle velocity vector *v*). The correction factors $\propto_{1,}\propto_2$ and $\propto_3$ represent different processes that may reduce dM/ dt from its maximum value. The correction factors $\propto_1, \propto_2$ and $\propto_3$ vary between 0 and 1.

In equation (1) $\propto_1$ denotes the collision efficiency, $\propto_2$ the sticking efficiency, and $\propto_3$ the accretion efficiency.

Collision efficiency is the ratio of the flux density of the particles that hit the object to the maximum flux density. Sticking efficiency is the ratio of the flux density of the particles that stick to the object to the flux density of the particles that hit the object. Accretion efficiency is the ratio of the rate of icing to the flux density of the particles that stick to the surface. The main point is to simulate these coefficients because the complexity of the whole phenomenon.

There are several types of ice, but the most common are rime and glaze. Rime ice is the result of dry growth ($\propto_3 = 1$) that is when there is no liquid layer and no run-off. This type of ice is shown in the Figure 8 [13] [14] .

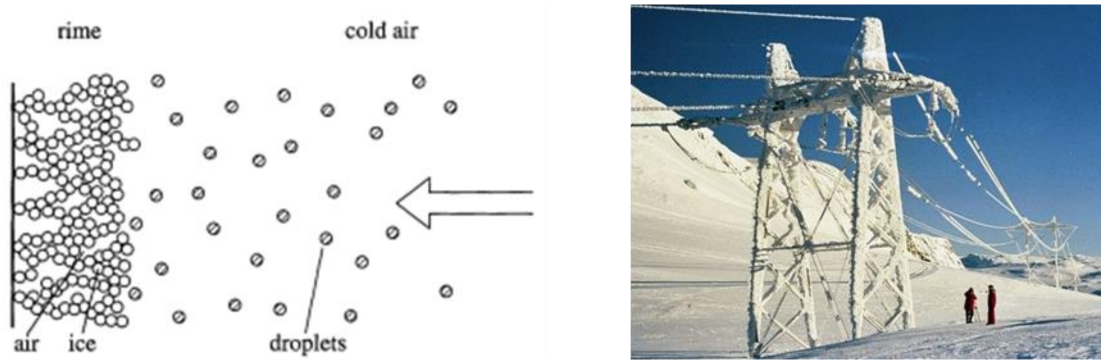

Figure 8 – Rime ice (dry growth) [13] [14].

Glaze ice is the result of wet growth ($\propto_3 < 1$) that is when there is a liquid layer on the surface of the accretion and freezing takes place beneath this layer. This type of ice is shown in the Figure 9 [13].

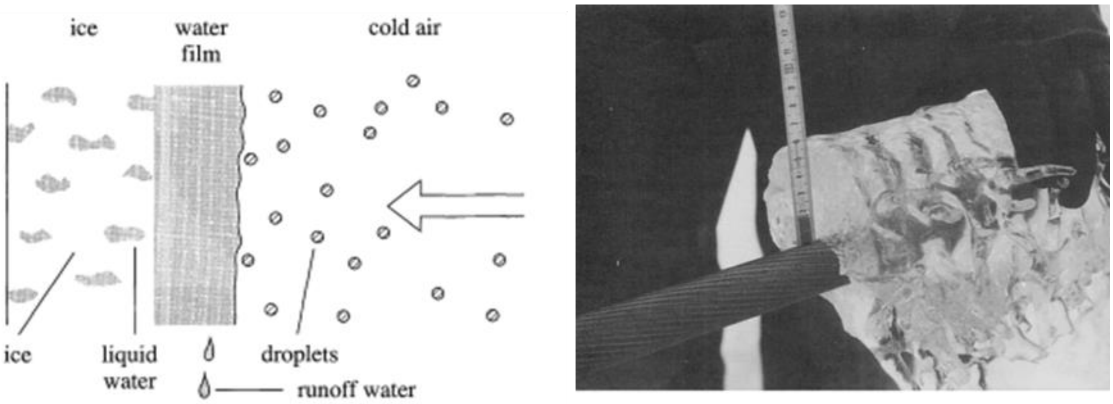

Figure 9 – Glaze ice (wet growth) [13].

4.1 Icing on power lines

On the early stages of the ice formation around the conductor, the shape of the accreted ice starts as a lobe and grows irregularly as the ice is accumulated on the windward side of the conductor. The shape is determined by the direction of the wind and the gravitational force.

A typical shape of ice on an overhead conductor can be seen on Figure 10.

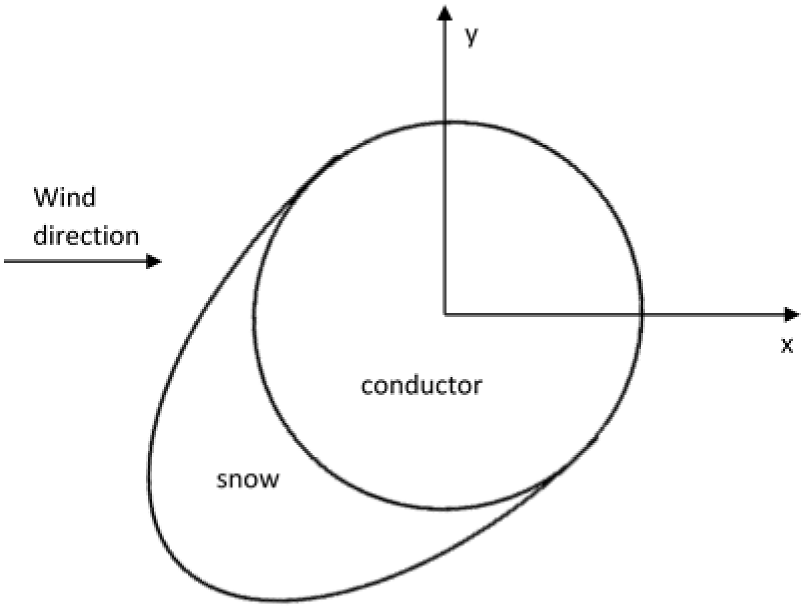

Figure 10 – Schematic diagram of snow accretion on an overhead conductor [15].

4.2 Torque

As ice accumulates on power lines, it forms a teardrop shape. When the wind blows, wires can start to move up and down in an oscillating motion (Torque). In essence, the wires encased in ice act like an aerodynamic airplane wing. This effect is known as “galloping” (Figure 11). Galloping can cause wires to eventually touch, resulting in a fault or subsequent outage. The increased movement can also cause cross-arms to break, bringing lines to the ground.

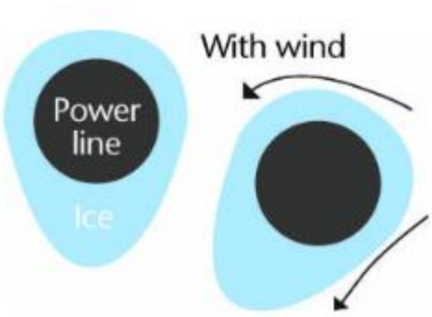

Figure 11 – Rotational force [16].

5 Calculation of ice loads

For the approximate calculation of ice loads thought density of the ice and growth of the ice and a valuable, often the most important parameter is the duration of the icing event. In addition to the parameters that determine the rate of icing as for instance, wind speed, air temperature, temperature of the structure, air liquid water content and droplet diameter in the air. The key element of successful icing modelling is the understanding of the combinations of different parameters where icing takes place. This is not a trivial problem, but, in short, for freezing precipitation, when it is required the wet bulb temperature to be less than 0 °C and for liquid precipitation that transform on formation of rime ice, when it is required the fog or the location of interest is at a higher altitude than the cloud base and for wet-snow situations with heavy snow fall when the wet-bulb temperature is greater than 0 °C.

Simulation of ice accretion for practical purposes requires careful considerations of all these criteria [17]. The classical empirical approach estimates the rate of rime icing applying the condition ($\propto_2 = \propto_3 = 1$) in equation (1) so the icing rate depends only on wind speed.

5.1 Collision efficiency

When a droplet moves with the airstream towards the icing object, its trajectory is determined by the aerodynamic drag and inertia forces. If inertial forces are small, then drag will dominate and the droplets will follow the streamlines of air closely (Figure 12). For large droplets, on the other hand, inertia will dominate and the droplets will tend to hit the object, without being significantly deflected (Figure 12).

The relative magnitude of the inertia and drag on the droplets depends on the droplet size, the velocity of the airstream, and the dimensions of the icing object.

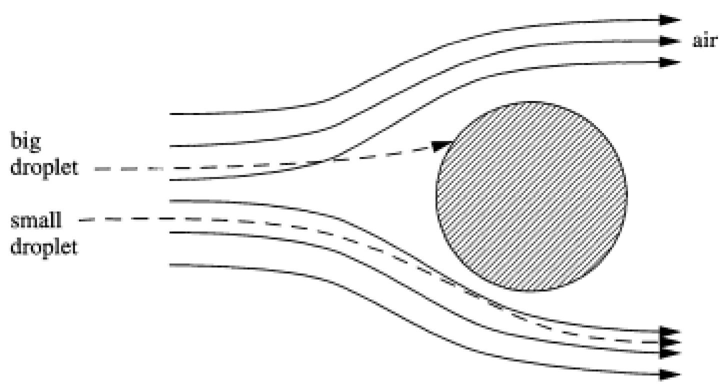

Figure 12 – Air streamlines and droplet trajectories around a cylindrical object [13].

Finstad et al. [18] have developed the following empirical fit to the factor $\propto_1$ numerically calculated data:

$$\propto_1 = A - 0.028 - C(B - 0.0454) \quad (2)$$

Where

$$A = 1.066K^{-0.00616} \exp(-1.103K^{-0.688}) \quad (3)$$

$$B = 3.641K^{-0.498} \exp(-1.497K^{-0.694})$$

$$C = 0.00637(ø-100)^{0.381}$$

$$K = p_w d^2/9\mu D \quad (4)$$

$$ø = Re^2/K \quad (5)$$

$$Re = p_a dv/\mu \quad (6)$$

Here, d is the droplet diameter, D the cylinder diameter, p_w the water density, μ the absolute viscosity of air, p_a the air density and Re the droplet Reynolds number based on the free stream velocity, v.

5.2 Sticking efficiency

When a super cooled, water droplet hits an ice, surface it rapidly freezes and does not bounce (Figure 8). When there is a liquid layer on the surface, the droplet spreads on the surface and again there is no rebounding (Figure 9).

Snow particles, however, bounce very effectively [19] . For completely solid particles, i.e. dry snow, the sticking efficiency,$\propto_2$ is zero.

When there is a liquid layer on the surface of the snow particles, they stick more effectively, so that at small impact speeds and favorable temperature and humidity conditions $\propto_2$ is close to unity for wet snow.

The best first approximation for $\propto_2$ for cylindrical shapes is probably [20].

$$\propto_2 = \frac{1}{v} \quad (7)$$

Where the wind speed, v is in m/s. When $v < 1$ m/s, $\propto_2 = 1$. Humidity and air temperature also affect $\propto_2$, but there are not data to consider them.

5.3 Accretion efficiency

In dry-growth icing (Figure 8), all the impinging water droplets freeze and the accretion efficiency $\propto_3$ = 1.

Solving the accretion efficiency results in the following equation:

$$\propto_3 = \frac{1}{F(1-\lambda)L_f}\left[(h+6a)(t_s-t_a) + \frac{h\epsilon L_e}{C_p p}(e_s-e_a) - \frac{hrv^2}{2C_p} + FC_w(t_s-t_d)\right] \quad (8)$$

Where, λ is the liquid fraction of the accretion (value of λ around 0.3), F is the flux of water to the surface ($F = \propto_1 \propto_2 wv$), h is the convective heat-transfer coefficient, r is the recovery factor for viscous heating (r = 0.79 for cylinder), v is the wind speed, C_p is the specific heat of air, t_s is the temperature of the icing surface (t_s = 0 °C for pure water) , t_a is the air temperature, ϵ is the ratio of the molecular weights of dry air and water vapor (ϵ = 0.622), a is the radiation linearization constant (8.1 x 10^7 K^3), L_e is the latent heat of vaporization, e_s is the saturation water vapor pressure over the accretion surface, e_a is the ambient vapor pressure in the airstream, p is the air pressure, C_w is the specific heat of water, and t_d is the temperature of the droplets at impact. For cloud droplets, $td = ta$ can be assumed because of their small terminal velocity. Here, e_s is a constant (6.17 mbar) and e_a is a function of the temperature and relative humidity of ambient air. The effect of surface roughness on h has been studied in detail theoretically [21] and this theory can be used as part of an icing model.

5.4 Numerical modelling

Resolving the icing rate analytically from, say, equations (2) and (8) is not practical, because equations for the dependence of the specific heats and the saturation water vapor pressure on temperature. All this makes the process of icing a rather complicated one. Notice that all parameters are interconnected in a complex way so, it will produce a highly dependency behavior of any model used or simulation done. Nowadays, rime icing can be simulated numerically by ballistic models [22] [23] [24].

When the estimates of the density of accretions are included, a numerical model can be developed to simulate time-dependent icing of an object. Various physical phenomena can be included in the model as sub-routines and run selectively according to the input data and the state of the simulated process. Calculation progresses in a stepwise manner. A schematic description of an icing model is shown in Figure 13.

5.4.1 Modelling tools

Tools to model or simulate the ice accretion on structures. ANSYS Fluent and FENSAP-ICE are two of them. Following a summary about how these tool work.

ANSYS Fluent

The calculation method of ANSYS Fluent uses a finite element based on Navier-Stokes equations, energy balance, and Sheil equation for the ice accretion.

The solidification/melting model capabilities allow ANSYS Fluent to simulate a wide range of solidification/melting problems, including melting, freezing, crystal growth, and continuous casting.

FENSAP-ICE

The calculation method of FENSAP-ICE Fluent uses a finite element based on Navier-Stokes equations, the droplet impingement with an Eulerian model containing water droplets and finally a control volume analysis of the mass and heat transfer for the ice accretion.

FENSAP-ICE can calculate 3-D geometry of glaze, rime or mixed-type ice shapes and roughness on any surface, for any icing condition. It has a built-in graphical interface to simplify selection of icing conditions. The ice shapes on power lines, stabilizers, control surfaces, air data probes, rotors, wings etc. can be used to evaluate performance degradation. Icing on intake screens can be used to calculate blockage effects.

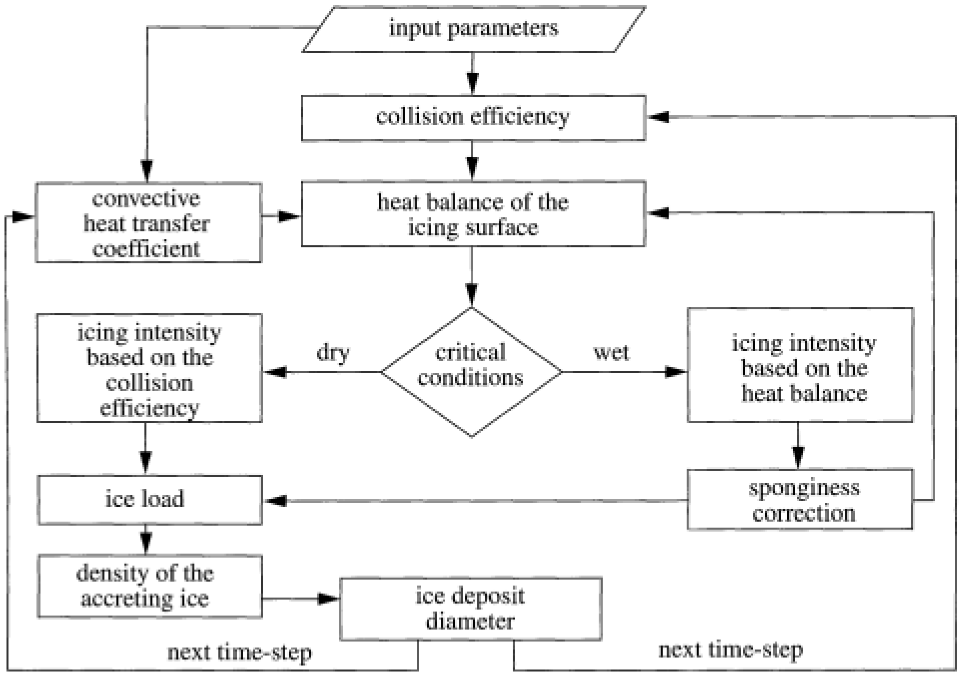

Figure 13 – Block-diagram of a numerical icing model [13].

6 De-icing mechanism principle of functioning

It is important to know the elastic properties of ice, in order to make calculations of the amount of energy in the form of heat to melt the ice, the amount of specific energy to cut the ice and the amount of energy needed to break or remove the ice.

The elastic boundary of ice is close to zero and ordinarily the elastic properties appear together with the plastic. Consequently, it is problematic to determine the exact value of the various *E*, the shear modulus *G* and Poisson's ratio *v*.

When the load acting upon the ice is changed, three different types of deformation appear [25]:

1. Elastically reversible instantaneous deformation
2. Irreversible deformation – creep
3. The slowly reversible deformation of the aftereffect

Hooke's law states that $\varepsilon = S\sigma$ where ε denotes strain, σ stress and S, compliance. Otherwise, $\sigma = C\varepsilon$ where C is stiffness. Both strain and stress are specified by second orders tensors and so C and S are specified by four order tensors.

Hooke's law may then be written:

$$\varepsilon_i = S_{ij}\,\sigma_j(i,j = 1,2\,....6) \tag{9}$$

Or

$$\sigma_i = C_{ij}\,\varepsilon_j(i,j = 1,2\,....6) \tag{10}$$

Where S_{ij} and C_{ij} denotes the components of the matrices:

$$S_{ij} = \begin{pmatrix} S_{11} & S_{12} & S_{13} & 0 & 0 & 0 \\ S_{12} & S_{11} & S_{13} & 0 & 0 & 0 \\ S_{13} & S_{13} & S_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & S_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & S_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & 2(S_{11} - S_{12}) \end{pmatrix}$$

$$C_{ij} = \begin{pmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{11} & C_{13} & 0 & 0 & 0 \\ C_{13} & C_{13} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/2(C_{11} - C_{12}) \end{pmatrix}$$

On this basis the elastic compliance constants may be interpreted as follows:

- S_{11} gives the standard strain perpendicular to the *c*-axis owing to a normal stress acting along X_1
- S_{33} gives the standard strain parallel to the *c*-axis owing to a normal stress acting along the *c*-axis;
- S_{12} gives the standard strain perpendicular to the *c*-axis owing to a normal stress also perpendicular to the *c*-axis and perpendicular to the direction of interest;
- S_{13} gives the standard strain perpendicular to the *c*-axis owing to a normal stress acting along the *c*-axis, as well as the normal strain along the *c*-axis owing to a normal stress along a direction perpendicular to the *c*-axis;
- S_{44} gives the shear strain in a plane parallel to the *c*-axis owing to a shear stress in the same plane.

The most precise values to date have been attained by Gammon et al. [26] shown in Table 1.

Table 1 – Fundamental elastic constants for ice at -16°C [25].

Property and units	Symbol	Value
Elastic stiffness (10^9 N m^{-2})	C_{11}	13.93±0.04
	C_{12}	7.08±0.04
	C_{13}	5.76±0.02
	C_{33}	15.0±0.05
	C_{44}	3.01±0.01
Elastic compliance (10^{-12} m^2 N^{-1})	S_{11}	103±0.05
	S_{12}	-42.9±0.4
	S_{13}	-23.2±0.2
	S_{33}	84.4±0.4
	S_{44}	331.8±0.2
Compressibility (10^{-12} m^2 N^{-1}) 2S11 + S33 + 2(S12 + 2S13)	K	112.4±0.2
Bulk modulus (10^9 N m^{-2})	$B = 1/K$	8.90±0.02
Poisson`s ratio	v	$v = -S_{12}/S_{11} = 0.415$
		$v = -S_{13}/S_{11} = 0.224$
		$v = -S_{13}/S_{33} = 0.274$

As a result, their elastic properties are totally described by only two independent constants [27] [26], chosen from Young`s modulus E, the shear modulus G, Poisson`s ratio v and the bulk modules B. Where:

$$G = E/2(1+v) \tag{11}$$

$$B = E/3(1-2v) \tag{12}$$

The values measured at -16°C are listed in Table 2 and the effect of temperature may be obtained from Equation (5).

$$V(T) = V(T_r)\ [1 \pm a\ (T\text{-}T_r)\ ] \tag{13}$$

Where T_r is the reference temperature at which the constant was measured, a = 1.42 x 10^{-3} K^{-1}, "+" is for compliance and "–" is for stiffness.

Table 2 – Elastic properties for ice at -16°C [25].

Property	**Units**	**Value**
Young`s modules , *E*	N m^{-2}	9.33 x 10^9
Compressibility, *K*	N^{-1} m^2	112.4 x 10^{-12}
Bulk modulus, *B*	N m^{-2}	8.90 x 10^9
Shear modulus, *G*	N m^{-2}	3.59 x 10^9
Poisson`s ratio, *v*	n/a	0.325
Latent heat	KJ/kg	334
Density	kg/m^3	916.8

Both E and G depend only on the angle between the crystal axis ad the *c*-axis of the unit cell. This means that the elastic properties of ice are invariant with respect to rotation about that axis.

The properties that are going to be used next are latent heat and density named in Table 2.

6.1 De-icing mechanism required energy calculations

To make the calculations, a case was taken as reference where symmetrical ice created with help of PVC tubes around the conductor with the following dimensions, the conductor diameter is 12.7 mm, the outside diameter 38.1 mm of ice and the length is 1 m [28] . Show in the Figure 14. The calculations were made for four methods that are shockwave, smelt the ice (Superheat steam), cut and percussion.

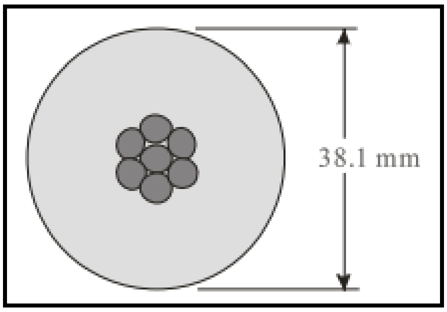

Figure 14 – Ice accretion on the conductor [28].

1. **Shockwave:**

In the case of shockwave an energy of 1.86 J/m or 2 J/kg is represented to break or remove the ice [28] according with the proposed conditions and geometry named above.

2. **Smelt the ice**

In the case of melting of ice, the geometry named above was used to calculate the amount of energy needed to melt the ice that is in the line of power. The following formulas were used in order to do the calculations.

$$V = \pi * r^2 * h \quad (14)$$

$$m = \rho_{ice} * V \quad (15)$$

$$Q = L_f * m \quad (16)$$

Where V is volume, r is the radius, *h* is the length of the cylinder, *m* is the mass, ρ_{ice} is the density of ice, Q amount of energy in the form of heat and L_f is the latent heat for fusion from solid to liquid.

The first step for the calculations was to find the volume of the ice around the conductor, then the ice mass and finally calculate the amount of energy to melt the ice shown below.

$$V_{tot} = V_1 - V_2 = (\pi * 0.1905^2 * 1) - (\pi * 0.0635^2 * 1) = 0.101\ m^3$$

$$m = \rho_{ice} * V = 916.8\ \frac{kg}{m^3} * 0.101 m^3 = 92.6\ kg$$

$$Q = L_f * m = 334 \frac{kJ}{kg} * 92.6 kg = 30.9\ MJ$$

The calculations show that the needs 30.9 MJ to smelt the ice with the proposed conditions and geometry named above.

3. Cut

In the case of cutting, a turning scenario is proposed where the ice with the dimensions named above is cut with a tool in the axial direction. The tool used to cut ice is made of Stainless steel, therefore the following data and assumptions are used:

D_o = 38.1

L = 1000 mm

K = 2700 N/ mm^2

v_c = 1.1 m/s

f = 0.7 mm/rev

d_c = 7.5 mm

T_m = 8.0 min

The following formulas are used in order to fulfill the calculation of amount of specific energy to cut the ice:

$$P_c = F_c * v_c \quad (17)$$

$$F_c = K * f * d_c \quad (18)$$

$$v_c = \frac{\pi * D_o * L}{f * T_m} \quad (19)$$

$$R_{MR} = vfd_c \quad (20)$$

$$E_{cut} = \frac{P_c}{R_{MR}} \quad (21)$$

Where P_c is the cutting power, F_c is the cutting force, v_c is the cutting speed, K is the strength specific cutting resistance of the material- related, f is the feed of cut, d_c is the depth of cut, D_o is the diameter, L is the length of the work piece, T_m is the machining time, R_{MR} is the material removal rate and $E_{cut}$is the amount of energy to break/remove the ice.

The first step for the calculations was to find the cutting speed of the tool, then the cutting force, so the cutting power, later the material removal rate and the end calculate the specific energy to cut the ice shown below.

$$v_c = \frac{\pi * D_o * L}{f * T_m} = \frac{\pi * 38.1 * 1000}{0.25 * 7.5} = 0.38\, m/s$$

$$F_c = K * f * d_c = 2700 * 0.7 * 7.5 = 14175\, N$$

$$P_c = F_c * v_c = 14175\ N * 0.38 \frac{m}{s} = \ 5.39\ kW$$

$$R_{MR} = v_c f d_c = 22799 \frac{mm}{min} * 0.7\ \frac{mm}{rev} * 7.5mm = 119694.75\ mm^3/min$$

$$E_{cut} = \frac{P_c}{R_{MR}} = \frac{323400\ J/min}{119694.75\ mm^3/min} = 2.7\ J/mm^3$$

Multiplying for the volume of the ice to remove, calculated above (14):

$$E_{tot\_cut} = E_{cut} * \ V_{tot} = 2.7 \frac{J}{mm^3} * 1{,}01 * 10^9 = 2{,}727\ MJ$$

The calculations show that the c energy to cut the ice is 2.7 MJ.

4. Percussion/ impact

In the case of percussion the scenario is of impact in axial direction to the ice with the dimension named above with 6 pins. The following formula was used to calculate the amount of energy to break or remove the ice:

$$E_{ice} = \frac{m * v^2}{2} \tag{20}$$

Where E_{ice} is the amount of energy to break/remove the ice, *m* is the mass and *v* is the velocity.

The following assumptions were made to carry out the calculations as the speed of the 6 nails that are going to break the ice and the mass of these.

v = 1, 2 and 3 m/s

m = 1, 2 and 3 kg

Here we calculated the energy to break or break the ice with the different data and assumptions named above.

$$E_{ice1} = \frac{m * v^2}{2} = \frac{1 * 1^2}{2} = 0.5\ J$$

$$E_{ice2} = \frac{m * v^2}{2} = \frac{2 * 2^2}{2} = 4\ J$$

$$E_{ice2} = \frac{m * v^2}{2} = \frac{3 * 3^2}{2} = 13{,}5\ J$$

The energy use to break/remove the ice is dependent of velocity and mass.

The comparison of the methods for the same ice geometry shows that the percussion is a viable alternative based on an energy criterion and therefore it will be considered as such for the design process.

7 Design process

The objective is to evaluate the design of the de-icing equipment to test concept and then try to improve a de-icing equipment or give suggestions about new designs of de-icing devices. To reach the objective the eight stages of the design process by Nigel Cross [29] was used. This method is an overall strategy from concept to detail design, outlining the nature of design thinking and setting it within broader contexts of product development and design process management. The process is composed by the following steps:

1. Identifying opportunities
2. Clarifying objectives
3. Establishing functions
4. Setting requirements
5. Determining characteristics
6. Generating alternatives
7. Evaluating alternatives
8. Improving details

7.1 Restrictions of applicability for de-icing methods/Identifying opportunities

De-icing and anti-icing methods must respect some specific mechanical, electrical and thermal restrictions relative to power line operation.

7.1.1 Mechanical restrictions

All methods used on ground wires and conductor have to withstand mechanical restrictions as mechanical stresses (stretching and torsion) caused by the high-amplitude low-frequency vibration, called galloping, of energized conductors or ground wires, created by wind , ice shedding or electrodynamic stresses induced by high current pulses [30] [31] . Under conductors, ground wires oscillate at a frequency close to the important lower order harmonics (from 0.5 to 3 Hz), but with amplitudes that can range from 1 m to 10 m or more, depending on the length of the section. Also, any device mechanically connected to the conductor, such as ferromagnetic heating rings and vibrating devices, could be subjected to high acceleration forces produced by wind vibrations or galloping oscillations.

Therefore, the mechanical restrictions that are inherent to the installation and the dynamic behavior of conductors and ground wires must be taken into account in the applicability of the new methods of prevention and thawing currently under development. This will also help to diminish the potential of some new concepts based on rigid dielectric coatings [30]. Preferably, the coatings will have to be more flexible, but with the same mechanical coefficient equivalent to that of the conductor or ground wire in which they are installed.

7.1.2 Electrical restrictions

The presence of high electric and magnetic fields, as well as electrical discharges and the impact of lightning should normally be taken into account in the development of de-icing and anti-icing methods. In addition, electromagnetic perturbations, caused by the high-frequency electric fields emitted by some devices, can interfere with military or civil apparatus and must be taken into account in the design.

As concerns lightning, it induces very high impulse currents in connection with high voltages, together with large mechanically induced high temperatures and forces [32] [33]. Depending on the type of attack (direct or indirect), currents can be generated between 30 and 60 kA, and sometimes can reach as high as 200 kA in the worst cases [32]. These high currents are accompanied by voltages higher than 1 MV, which are generally sufficient to induce flashover on or between overhead line equipment. In fact, lightning can breakdown the electrical insulation of dielectric coatings or electrical tracing of such methods as electromagnetic expulsive sheathings and vibrating devices. Therefore, lightning can straight affect active anti-icing or de-icing methods, implying that the equipment's used should be electrically protected from live conductors or ground wires.

7.1.3 Thermal restrictions

One of the major aspects that must be taken into account is the thermal energy released by the high current pulse of lightning. In fact, because of the short duration of the pulse, this is equivalent to high frequency leakage current from hundreds kHz to MHz flowing mainly to the surface of the conductor due to the skin effect. In this condition, most of the thermal Joule energy produced by the strike is dissolute at the surface of the conductor. In some cases, thermal energy is sufficient to melt the surface aluminum conductor fibers [33], and could consequently melt material on the surface of the energized conductors or ground wires. For this cause, any equipment installed on the surface of live conductors or ground wires, can be subjected to this kind of thermal shock, which can cause permanent damage and extremely reduce their life performance and expectancy.

Now, one of the methods to ice prevention or removal is coatings, the thermal limitation of energized conductors must be considered. With these coatings, the convective heat loss values and the total heat capacity of the conductor must be taken into account in the calculation of the maximum permitted temperature [34]. As these coatings are permanently installed on the conductors, particular consideration will be paid to the thermal conductivity of the coating and the different current values suitable for the conductor and its prevention or de-icing coating.

7.1.4 De-icing equipment applicable to overhead power lines.

Seven equipment were found that are used in transmission lines that comply with the restrictions named above. Below are listed:

A. Design of control system for the De-icing robot on transmission line

Liu, Hu et al. [35] designed a new type of control system for de-icing robot on high voltage transmission line. Using the control system, the de-icing robot can get rid of the ice of transmission line effectively. This also can detect the basic information and comprehend the de-icing and line inspection.

De-icing robot (Figure 15) is built with mobile mechanism, control systems and sensing system. The main mechanical structure of this de-icing robot consists on walking mechanism, de-icing mechanism, brake mechanism, telescopic mechanism, etc. This robot has three arms that are equipped with a telescopic mechanism, which can manage arm scaling throughout walking. The middle arm is equipped with a walking mechanism, containing two walking wheels and a brake device.

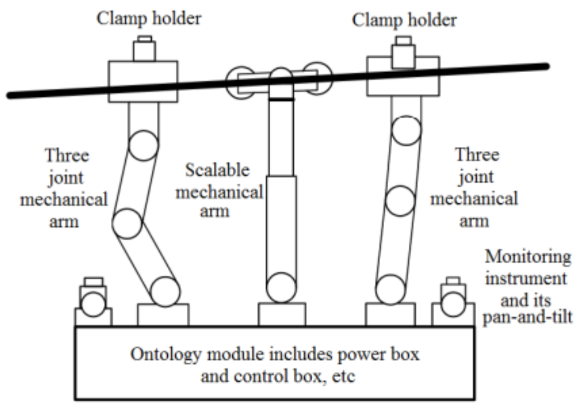

Figure 15 – De-icing robot [35].

The control system structure of de-icing robot as shown in Figure 16.

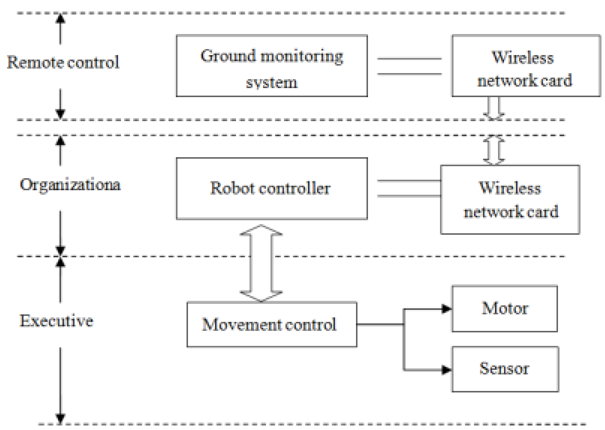

Figure 16 – Representation of the control system structure of de-icing robot [35].

In Figure 16, it can be seen that there are three levels in the control system structure of de-icing robot called remote control, organization and executive levels. The remote control is responsible for the coordination of levels and helping the organization level. The organization is the robot body, is the core of the control system. It is responsible for collecting and processing the sensor information and image. The executive has high accuracy and contains various motor controlled and motion controlled cards [35].

B. LineScout

LineScout (Figure 17) was designed by Hydro-Québec TransÉnergie [36], which is an inspection robot. It is designed to move along single energized conductors, including one of the conductors of a conductor bundle, and is immunized to electromagnetic and radio-frequency interferences (EMI/RFI) from lines of up to 735 kV [36].

Figure 17 – LineScout [37].

The mechanical structure of this robot is able to cross warning spheres (0,76m diameter), double insulator strings, vibration dampers and corona rings (Figure 18). This makes the system very versatile, but crossing dead end structures and jumper cables (Figure 18, e) were not included in the design specifications [36]. LineScout is design based on two "extremity frames" and a "centre frame" which guarantees the movement of the robot along the line. All are autonomous from each other. The "extremity frames" are constituted by a "wheel frame" and an "arm frame". The "wheel frame" includes two rubber "traction wheels" and a camera mounted on a pan-and-tilt unit. The "arm frame", besides two arms and two grippers includes other two cameras on a pan-andtilt unit and most of the possible application modules. The "centre frame" (white circle) hosts the electronics on board and the battery pack. In addition, it links the "extremity frames" and allow them to rotate and slid. LineScout has a top linear speed of 1 m/s, weights 98 kg and has a battery duration of 5 hours.

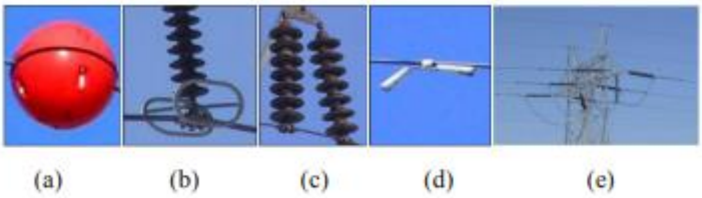

Figure 18 – (a) Warning spheres, (b) Corona rings, (c) Double insulator strings, (d) Vibration dampers, (e) Jumper cable located at an angle tower [37].

C. Expliner

Expliner (Figure 19) was developed by HiBot Corp., in a joint project with Kansai Electric Power Corporation (KEPCO) and Tokyo Institute of Technology in Japan in 2008 [38]. This robot is designed for inspection up to four cables grouped in a bundle, and has been extensively tested in live lines up to 500kV. The mechanical carbon fiber structure of the robot is made by two pulley units, a Tshaped base, a counter-weight and a manipulator with 2 degrees of freedom. Expliner carries four sensing units to inspect up to 4 cables simultaneously. The sensing units incorporates visual camera able to get images of the entire surface of the cables and laser sensors capable to identify changes in the diameter in the order of 0.5mm to detect internal corrosion along the line. Expliner has a top linear speed of 0.33 m/s, weights 80 kg and has a battery duration of 6 hours [38].

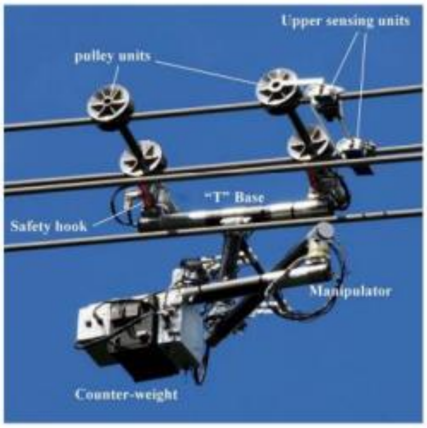

Figure 19 – Expliner [37].

D. T21

In Australia, researchers at the Australian Research Centre for Aerospace Automation (ARCAA), a joint venture between the Commonwealth Scientific and Industrial Research Organization (CSIRO) Information & Communication Technologies (ICT) and the Queensland University of Technology (QUT), designed an autonomous helicopter for power line inspection, which requires minimal operator input [37]. The autonomous helicopter (T21) (Figure 20) [37] [39], powered by micro-turbine, 2.2 m rotor diameter, from 1 to 1.5 hrs. of durability, maximum take-off 30 kg. Their activity in particular has focused to develop obstacle detection and path planning for avoidance using stereo vision and laser scanning to produce a 3D Occupancy Map of the environment [37] [40].

Figure 20 – T21 [37].

E. LineROVer

LineROVer (Figure 21) is a remotely operated (1km max remote distance) robotic device designed by Hydro-Québec TransÉnergie [30] [41], which is an inspection and de-icing robot of ground wires and conductors. LineROVer de-icing tool based on a set of steel blades which allowing for gradually de-icing. LineROVer is able to work on conductors with a diameter between 10 to 37 mm. It can be installed from a helicopter or an insulated boom truck. This can perform on transmission lines of up to 315 kV, but it is only made to operate down to a temperature of -10 °C and has a traction force equal to 670N. LineROVer weights 23 kg and has a battery duration of 45 minutes to several hours (depending on the task).

Figure 21 – LineROVer [30] [41].

F. De-Icer Actuated by Cartridge (DAC)

De-Icer Actuated by Cartridge (DAC) (Figure 22) was designed by Hydro-Québec TransÉnergie [30] [28] , which is a remote controlled mechanical de-icing device. The DAC consists of using a portable cylinder piston system that creates shock waves to de-ice the cable. The device is designed to take advantage of the brittleness of ice at high strain rates to create shock waves that propagate along the span and break the ice. This is generated with a cartridge that explodes. The DAC is a portable, robust, effective, and simple device that can easily be used after a line fault due to clearance violation between ground wires and phase conductors. The de-icing operation is carried out entirely from the ground. The

DAC is equipped with a revolver barrel that stocks 6 blank cartridges that can be remotely fired from the ground. DAC allows an average of 50 to 100 shots (dependent on ambient temperature).

Figure 22 – De-Icer Actuated by Cartridge (DAC) [28].

G. Remotely Operated De-icing All-weather Vehicle (RODAV)

Remotely Operated De-icing All-weather Vehicle (RODAV) (Figure 23) was made by Hydro-Québec TransÉnergie [42] [43], which is a de-icing vehicle. RODAV can perform on transmission line up to 330 kV, wood poles and transformers using superheated steam (200°C). The steam is led through an insulated hose on a 3.8 m (retracted) and 16 m (extended) long non-conductive hydraulic telescope mast mounted on a truck. The unit is operated through a remote control with a range of 300 meter.

Figure 23 – Remotely Operated De-icing All-weather Vehicle (RODAV) [43].

7.2 Desirable de-icing methods

In addition to the need to respond to severe restrictions, methods in development must primarily demonstrate their effectiveness in removing ice accreted on ground wires and conductors.

Because the whole idea is evaluate the functioning principle of the de-icing methods used on power lines, the design process by Nigel Cross [29] the second step is called clarifying objectives where all the characteristics desired for the de-icing elements are defined, classified and applicable.

7.3 Clarifying objectives

After evaluating what is there on the need of market, the following characteristics were identified:

1. **De-icing system classification**

A summary of the most notable de-icing methods developed so far and the differences between them, divided into two groups, conductors de-icing and ground wire de-icing, can be seen respectively in the Table 3 and Table 4.

Table 3 – Conductor de-icing

Name	Mechanism
Load shifting	Use the heating effect of load currents to prevent conductor icing or to remove ice form from conductors.
Reduced-voltage short-circuit	Use short-circuit heating to melt ice on the conductors.
High-voltage short-circuit	Involves circulating short-circuit current at the rated voltage of the transmission lines and the subsequent action of electromagnetic forces that allow conductors to knock against each other to de-ice.
AC/DC current	AC and DC can use to heat line conductors. AC for small lines and DC for large lines.

Table 4 – Ground wire de-icing

Name	Mechanism
Joule effect de-icing	Use Joule effect to remove ice from ground wires.
Remotely Operated Vehicle (LineROVer)	Use the cut function to remove the ice from ground wires.
De-Icer Actuated by cartridge (DAC)	Use shock waves to de-ice the cable.
Remotely Operated De-icing All-weather Vehicle (RODAV)	Use superheated steam to de-ice the cable.

2. Mobile mechanism

A mechanism that allows access to places of difficult access and that can move in turn through the line.

3. Remote control

Equipment of operation used to control functionality of the device with a good range of distance.

4. Inspection

System able to get information of the entire surface of the power lines before and after the treatment.

5. Transmission line

The type of transmission lines that the equipment can perform.

6. Speed

The velocity at which the device operates and moves on the power lines.

7. Weight

The mass of the device meeting the mechanical restrictions.

8. Power supply

It refers to the type of energy source used to operate and move the system.

9. Sensors

The type of systems capable to identify changes of diameter, from ice to no-ice conditions, on the transmission lines.

10. Operation temperature

The device able to perform in extremely cold conditions.

11. Material

The material resistant to ice/freezing, thermal conductivity, water vapor permeability, water, solvents and chemicals.

12. Maintenance requirements

The maintenance requirements do not have to be expensive and very often.

The named characteristics are used to stablish the design objectives and sub objectives of the new proposed de-icing mechanism. Based on the design idea and on the relevance of the showed characteristics, the proposed relationships and interconnections between them can be seen on Figure 24, ordered from a higher to a lower level.

Additionally to the characteristics named above, there are others like:

- Navigation, defined as the process of monitoring and controlling the location of the device.
- Drive system, used for controlling the speed, torque and direction of the device.

These characteristics are important to mention because they help and are a plus to achieve the main objective of designing a simple and smart equipment to remove the ice on the power lines.

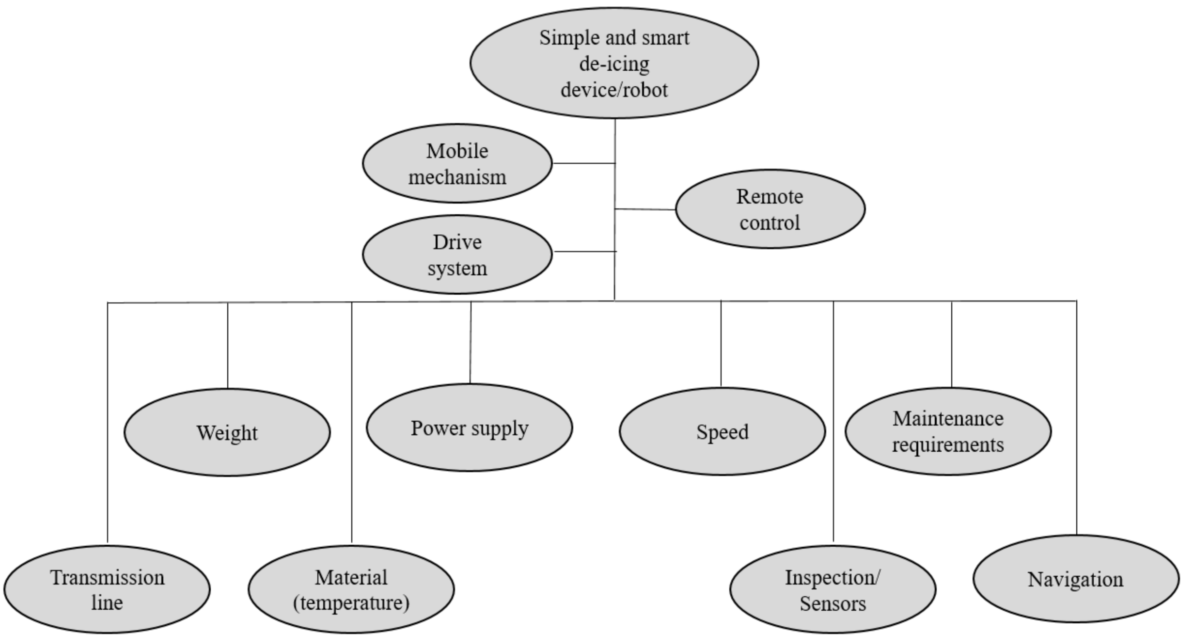

Figure 24 – Design characteristics

7.4 Establishing functions

In this section, the functions required and the system boundary of the new design (Table 5) are stablished in order to achieve the required design.

The table shows the connection between the characteristic of the system, listed in the previous section, and four different categories, referring to the macro-requirements that should be met by the final product. The first category, simple and smart, refers to the main goal that should be achieved by the device: to be simple as functioning and to build and smart in the way to operate. Cleaning indicates that the device should carry out its main function: remove the ice from power lines. The third category, cold climates indicates the specific environment conditions where the device is collocated and the last category, optional, refers to those elective requirements that could be met by the system. This method gives an overview on which parameters have to be considered during the designing of a specific component.

Table 5 – Functions analysis

Aspect considered	Simple and Smart	Cleaning	Cold climate	Optional
Mobile mechanism		x		
Remote Control	x			
De-icing system		x		
Inspection		x		
Material			x	
Transmission line		x		
Power supply			x	
Speed		x		
Weight	x			
Operation temperature			x	
Sensors	x			
Maintenance requirements				x
Navigation	x			
Drive system	x			

7.5 Setting requirements

After establishing the functions of the new design, the obtained requirements have been divided in four classes, shown in Table 6.

Table 6 – Requirements categories

Code	Description
A	These requirements must be met to obtain a stable system.
B	These requirements are given by the examiner and must be met.
C	These requirements should be met.
D	These requirements are optional.

Then, all the initial requirements have been listed in Table 7 with the respective classification.

The objective to performance specifications aim is to make an accurate specification of the performance required of the design solution.

Table 7 – Specifications

Specifications	Class
The device needs a mechanism to move along the conductor	A
The range of remote control needs to be around 1Km	C
The de-icing system must be a percussion system	B
The device needs a simple inspection system	B
Restrictions on material are given	A
The device has to woks on conductors with a diameter between 10 to 37 mm	A
The device has a power supply duration of 1 hour	C
The speed of the device has to be between 0.33 to 1 m/s	B
Restrictions on weight are given 23 kg	B
The device has to perform on conditions -10°C to -20°C	A
The sensors will be determined by the inspection system	B
No maintenance plan or requirements are requested	B
The device needs a simple navigation system	C
The device needs a simple and functional drive system	C
The device must be easy to install on the overhead line	A

7.6 Determining characteristics

Quality function deployment (QFD) is a method for industrial product designers to gain information and insight about which technical parameters are most important in the development or improvement of a product.

For this project, four different QFD analysis have been developed, each one referring to different parts of the de-icing machine: the de-icing system (Table 9), the mobile mechanism (Table 10), the drive system (Table 11) and the remote control (Table 12). All tables are a matrix composed by engineering requirements and customers' requirements and a value, explained in Table 8, is assigned to each cell in order to evaluate the effectiveness between them.

Table 8 – Rates descriptions

Symbol	**Meaning**
+	Weak
++	Good
+++	Excellent

Table 9 – QFD: De-icing system

Customer/designer requirements	**De-icing system**		**Engineering opinion/ requirements**			
			Simple construction	Controllable	Easy maintenance	Strength
		Percussion	++	+++	+	+++
		Cut	++	+++	+	+++
		Superheated steam	++	+	+++	++
		Shockwaves	++	++	++	++

Requirements considered for the de-icing system mechanism are the simplicity of the construction, the de-icing system, the controllability and the strength to remove the ice on the transmission lines.

Table 10 – QFD: Mobile mechanism

Customer/designer requirements	**Mobile mechanism**		**Engineering opinion/ requirements**			
			Simple construction	Controllable	Easy maintenance	Reliability
		Gear set	++	++	+	++
		Slider	+++	++	++	++
		Belting	+++	++	+++	++
		Chain and sprocket	++	++	+	++
		Cam and follower	+++	++	++	++

Requirements considered for the mobile mechanism are the simplicity of the construction, the controllability, maintenance and the reliability.

Table 11 – QFD: Drive system

Customer/designer requirements	Drive system		Engineering opinion/ requirements			
			Efficiency	Controllable	Easy maintenance	Reliability
		Electric	+++	+++	++	+++
		Bar Linkage	++	++	++	++
		Hydraulic	++	++	++	++
		Pneumatic	++	+++	++	+++

Requirements considered for the drive system are the efficiency of the engine, the controllability, the maintenance and the reliability.

Table 12 – QFD: Remote control

Customer/designer requirements	Remote control		Engineering opinion/ requirements			
			Simple installation	Controllable	Range	Reliability
		Tethered	+	++	++	++
		Wireless	+++	++	+++	++
		Automatic	++	++	+	+

Requirements considered for the remote control are the simplicity of installation, the controllability, the range of working operation and the reliability.

7.7 Generating alternatives

The objective of the morphological chart method (Table 13) is to generate the complete range of alternative design solutions for a product, and hence to widen the search for potential new solutions.

The table can be seen as a matrix, composed by several options for each component, that combined can generate several possible solutions.

Table 13 – Morphological chart

Concepts		1	2	3	4	5
Mobile mechanism	1	Gear set	Slider	Belting	Chain and sprocket	Cam and follower
Remote control	2	Tethered	Wireless	Automatic stop		
De-icing system	3	Percussion	Cut	Superheated steam	Shock waves	
Sensors	4	Contact	Optics	Thermal		
Power	5	Battery	Line current	Fuel		
Drive system	6	Electric	Bar linkage	Hydraulic	Pneumatic	
Navigation	7	GPS	GNSS	IRS		
Inspection	8	Visual/Camera	Ultrasonic			

7.8 Evaluating alternatives

The intention of the weighted objectives method (Table 15) is to compare the utility values of alternative design proposals on basis of performance against differentially objectives.

Parameters analyzed in the selection matrix has been divided in three macro area and then each parameter has been evaluated with a rate between 0 and 5 as show in Table 14. Reliability is the first category considered, and it has been divided in two sub categories: working environment and operating characteristics. Working environment refers to those phenomenon, such as cold temperature, strong wind and precipitations that could occur in that specific environment where the device will operate. Instead, operating conditions refers to the technical characteristics, such as working speed and programmability, of the component considered. The second macro area is production. It includes those parameters useful to evaluate the complexity of the production process, analyzing the number of parts needed to produce, their complexity in terms of geometry and the number of standard parts used. The last category evaluated is efficiency. It considers the easiness of operation, installation, assembling, maintenance and transportation of the device.

The result of the analysis is a concept composed by belting transmission system and moved by an electric motor supplied by a battery. The ice-removing system operates via percussion with a contact sensor used to evaluate the thickness of the ice layer and a camera for the inspection after the removal phase. A wireless remote control is used to control and manage the device and a GPS navigation system ensures a correct location and motion of the device on the transmission line.

Table 14 – Rates description

5-points scale	Meaning
0	Inadequate
1	Weak
2	Satisfactory
3	Good
4	Excellent

Table 15 – Weighted objectives

		Reliability (0-5)				Production (0-5)			Efficiency (0-5)					Total
		Working environment		Operating characteristics										
De-icing device	**Concept Number**	Temperature	Device environment	Speed	Programmable	Number of parts	Complexity	Use of standard parts	Easy to operate	Easy to install	Easy to assemble	Easy to maintain	Easy to transport	
Mobile mechanism	Concept 1,1	3	3	4	4	-	-	-	5	5	5	3	-	32
	Concept 1,2	3	3	4	4	-	-	-	5	5	5	3	-	32
	Concept 1,3	4	4	4	4	-	-	-	5	5	5	4	-	35
	Concept 1,4	3	3	4	4	-	-	-	5	5	5	3	-	32
	Concept 1,5	3	3	3	4	-	-	-	5	5	5	4	-	32
Remote control	Concept 2,1	-	-	-	5	-	-	-	1	1	-	2	1	10
	Concept 2,2	-	-	-	5	-	-	-	5	5	-	5	5	25
	Concept 2,3	-	-	-	5	-	-	-	3	5	-	5	5	23
De-icing system	Concept 3,1	5	5	4	5	4	4	4	5	3	4	3	5	51
	Concept 3,2	5	5	4	5	4	4	4	5	3	3	3	5	50
	Concept 3,3	5	5	5	4	3	3	4	5	3	2	3	2	44
	Concept 3,4	5	5	4	5	3	3	4	5	3	3	3	5	50
Sensors	Concept 4,1	5	5	-	5	-	-	-	4	4	4	4	4	35
	Concept 4,2	5	3	-	3	-	-	-	4	4	4	4	4	31
	Concept 4,3	5	4	-	5	-	-	-	4	4	4	4	4	34
Power	Concept 5,1	3	5	-	-	-	-	-	5	5	-	5	4	27
	Concept 5,2	5	5	-	-	-	-	-	5	3	-	3	5	26
	Concept 5,3	5	5	-	-	-	-	-	4	3	-	4	3	24
Drive system	Concept 6,1	5	5	-	5	-	-	5	5	5	5	5	4	44
	Concept 6,2	5	3	-	3	-	-	5	4	3	3	3	3	32
	Concept 6,3	3	4	-	2	-	-	5	3	3	4	3	3	30
	Concept 6,4	5	5	-	3	-	-	5	5	5	5	3	3	39
Navigation	Concept 7,1	-	-	-	5	-	-	-	5	5	-	5	5	25
	Concept 7,2	-	-	-	5	-	-	-	4	5	-	5	5	24
	Concept 7,3	-	-	-	5	-	-	-	3	5	-	5	5	23
Inspection	Concept 8,1	5	4	4	3	-	-	-	5	5	5	4	4	39
	Concept 8,2	5	4	3	4	-	-	-	5	5	5	3	3	37

7.9 Improving details

The main goal of the value engineering method is to increase or maintain the value of the product to its purchaser whilst reducing the cost to its producer.

Different aspect have been considered in order to improve the design after the first implementation. These are listed below.

1. **Utility**

It measure the performance on two aspects. First accuracy in the ice removal process and on inspections reports based on multiple sets of accurate data, and second efficiency, which allows to work in multiple spans.

2. **Reliability**

It is defined as the freedom from breakdown and malfunction or as the performance under varying environmental conditions. It is evaluated by the versatility of the device, which should be equipped with sensors and tools to perform a wide range of de-icing and inspection, by the ruggedness, for ensure the use in hostile environments and at last by the continuity of service, for ensuring the simplicity of installation and operation.

3. **Safety**

It is ensured with a design for a use in hard-to-reach locations, reducing risk and increasing stability and reliability. It can be improved enhanced worker health and safety

4. **Maintenance**
5. **Lifetime**

A long lifetime offers good value in the initial purchase price.

6. **Cost**

Reducing costs through deferring capital spending ensure improvement of the product.

7.10 Material selection

Once the concept of the product has been chosen, it is necessary to proceed to a different stage of the designing process. In this phase, the main goal is to select a material as strong as possible to meet the products performance goals. It is important to highlight that the selection process has been done only for the core of the device: the percussion de-icing system. The four steps of the material selection process are listed below.

1. Functions

The first step of the material selection process is to define the function of the tool, which is to remove ice formation on the transmission lines.

2. Objectives

In the material selection process, it is necessary to establish which variable need to be maximize and which need to be minimize. Weight, brittleness, friction and heat transfer must be minimized to have a light material product with minimum friction and heat losses and low liability to break. On the other hand, hardness has to be maximized.

3. Constraints

Constrains are defined as specific requirements that should be met by the material suitable for the device. The material should have an excellent response under cold and rainy conditions to prevent corrosion phenomenon, and it should resist at friction and shock against ice, to prevent its damage or break.

4. Choice of material

Using the software CES EduPack 2017 [44], it was possible to reach a certain number of possibilities setting those restrictions or limits defined in the previous steps, related to the performance goals established for this de-icing device. Then, minimum working temperature, resistance at fresh and salt water and thermal conduction has been set at first stage.

Figure 25 shows material resulted suitable plotted in a Density-Price chart.

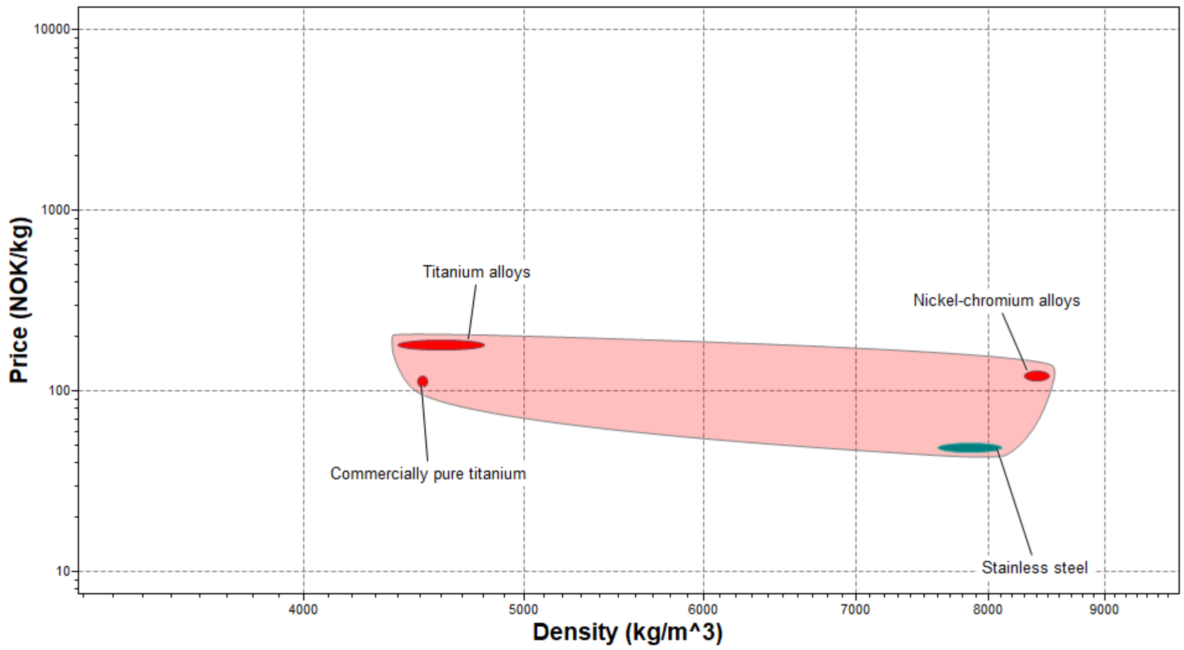

Figure 25 – Material selection chart

Considering the low density, related with a low weight, titanium alloys and commercially pure titanium are the most desirable choice, but, on the other hand, they are expensive and difficult to produce. Nickel-chromium alloy is the worst selected candidate for selection since it has a high density and cost. Despite its high density, stainless steel shows the lowest cost per kilo, an excellent hardness and a great easiness of production.

Considering the objectives listed above, the best choice for the de-icing tool result the stainless steel.

8 Experiment

This is a proposal to made the ice and do the experiments because due for time restrictions it was no possible to do them. Nevertheless, it is important to report that the experiments were planned and designed to test the proposed idea.

This experiment can be conducted in a climatic room inside the Mechanical Laboratory at UiT the Arctic University of Norway, campus Narvik. A could chamber, in which the temperature could be controlled, should be used. Before the experiment it is necessary to put the conductor into a PVC pipe with a diameter and a length to calculate and define. The PVC pipe has to be filled with water and then sealed. After sealed, it should be put into the cold chamber for 48 hours. After freezing, the PVC pipe should be removed and a cylindrical icicle with a specific diameter and density will be shown around the conductor.

It was planned to do two types of experiments once the ice was created as it is named above. One of the experiments was to calculate the amount of force necessary to break the ice by dropping amounts of mass into the ice and thus be able to make the corresponding calculations. The other experiment was to place the proposed percussion method in axial direction to test the tool and make calculations and analysis on it.

9 Final design

It is necessary to generate some initial design and sketches (Figure 26) before any of the final design. This is the most creative part of designing. As the engineer architect, Santiago Calatrava said:

To start with you see the thing in your mind and does not exist on paper and then you start making simple sketches and organizing things and then you start doing layer after layer [45].

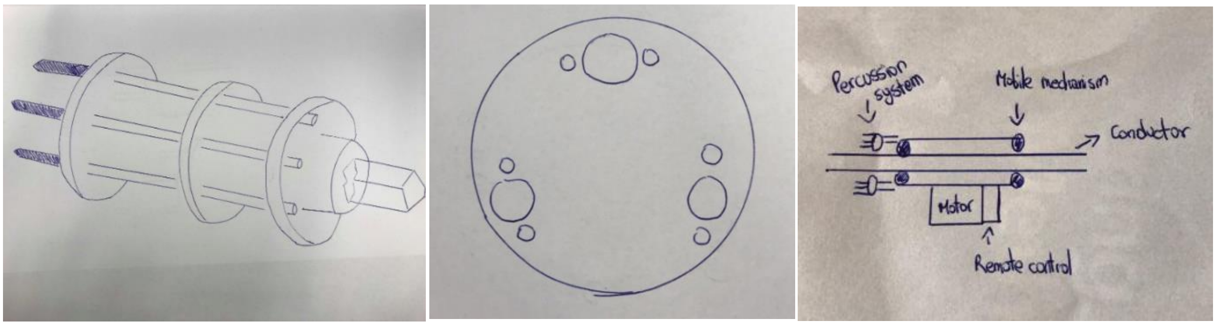

Figure 26 – Sketches

Then, the final sketch and the modelling are made with a desired software. The CAD design is made by using SolidWorks by MsS. Enrique Santos formed student of UiT. It is a whole assembly consisting of small parts connected to each other. The percussion plus rotation mechanism proposed in this work will use an internal motor that will activate six steel pins that will hit the surface of the ice in the axial direction. The energy transmitted by the pins will produce fractures in the front layers that will grow in the ice body. So, the rotation element comes along to induce a momentum on the ice that will break the ice. The final design shown in the Figure 27 and Figure 28.

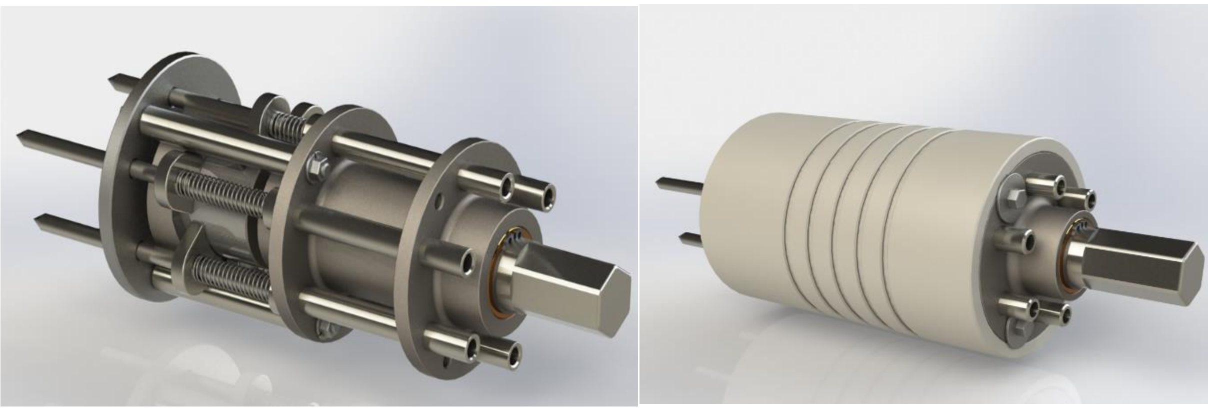

Figure 27 – Percussion de-icing system

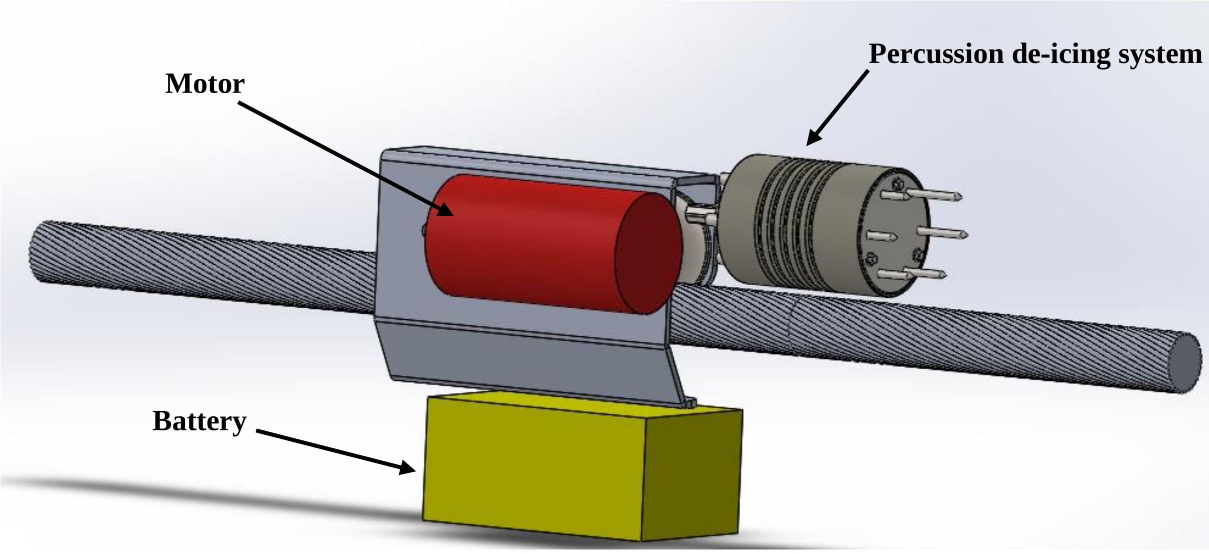

Figure 28 – De-icing device

9.1 Prototype

The prototype referred here only includes the percussion mechanism based on the interaction of six pins but not a full de-icing equipment. At UiT the Arctic University of Norway, campus Narvik only the de-icing system have been produced, where three parts of the prototype are made with the 3D printer. These parts are stem guide, case and spacer. The rest of the parts are made in the CNC machine at the university with the respective G-codes (Appendix 2 for more details). Percussion power is stablished as function of the mechanical properties of ice, show in Table 2, and the velocity imposed as working pace. It is important to highlight that the geometry has a principal role, because the percussion will be applied to the side of the accumulated ice, which corresponds to the angular form, having the internal diameter the same as the external dimeter of the wire and the external diameter as the ice accumulated diameter.

10 Conclusion and future work

A Percussion/rotation de-icing method to maintain the working condition of electricity distribution systems is presented. In principle this method can be adapter to a device as the basic engineering showed in final design section and fulfil the conditions of overcome the three main constrains for any de-icing mechanism. The model was made concentrated in the operating method to remove the ice from the power lines. Power calculation are related with the ice properties and the imposed working velocity. This mechanism take advantage of the fragile condition of the ice in combination with the most vulnerable geometrical constrain of the ice geometry, additionally, imposed impact forces in the axial direction will produce less effect on the towers that the application of the same force in the radial direction.

As future work, it is possible to continue working with de-icing device to make it more detailed and even better adapted for the purpose with thinking of motor, mobile mechanism, drive system, navigation, power supply, weight, inspection system, etc. It is recommended also to include a cost analysis of this project, evaluate risks, strengths and weaknesses of the proposed project and find other possible solutions that could be applied for de-icing of power lines and do the experiments named above.

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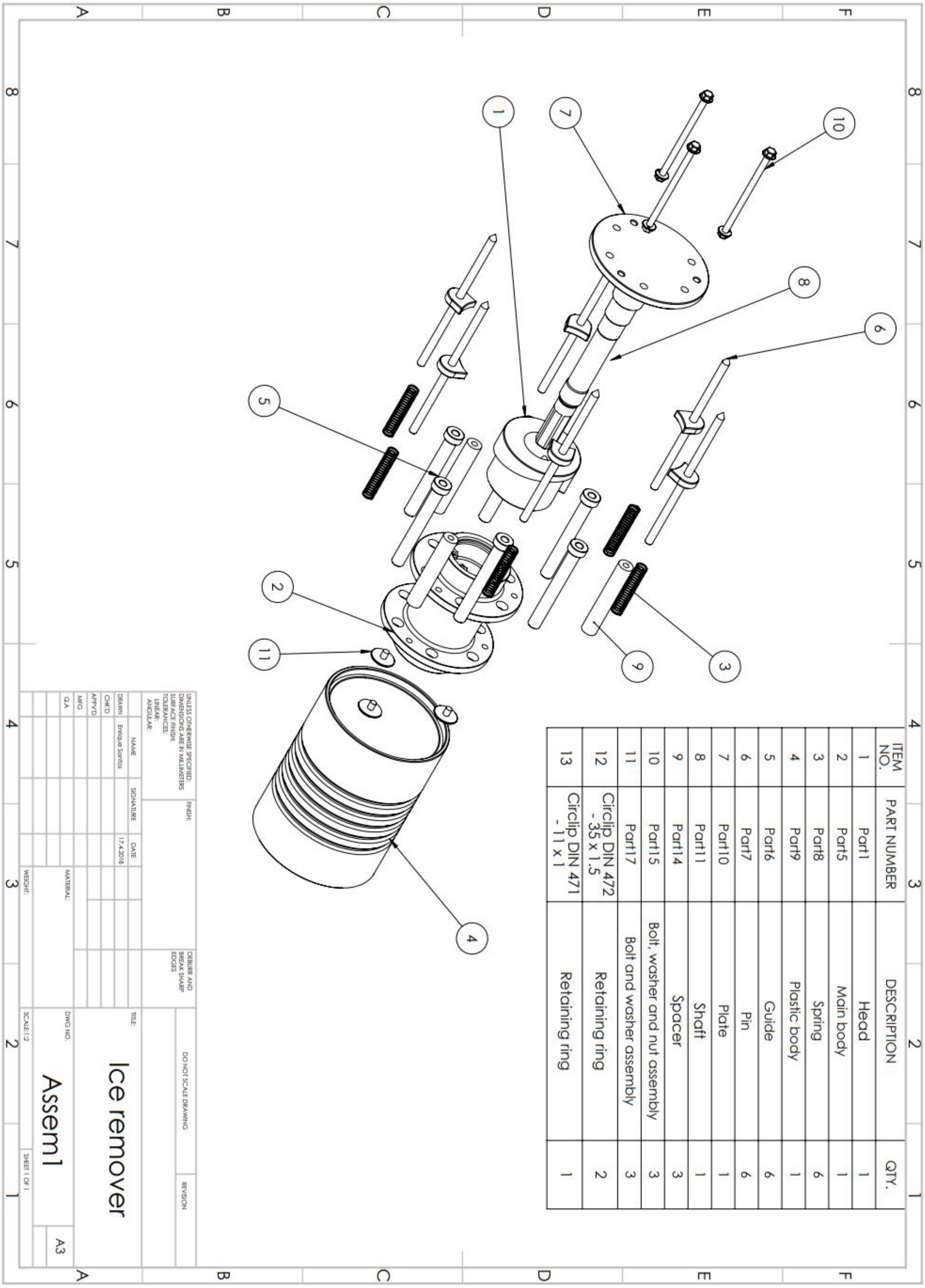
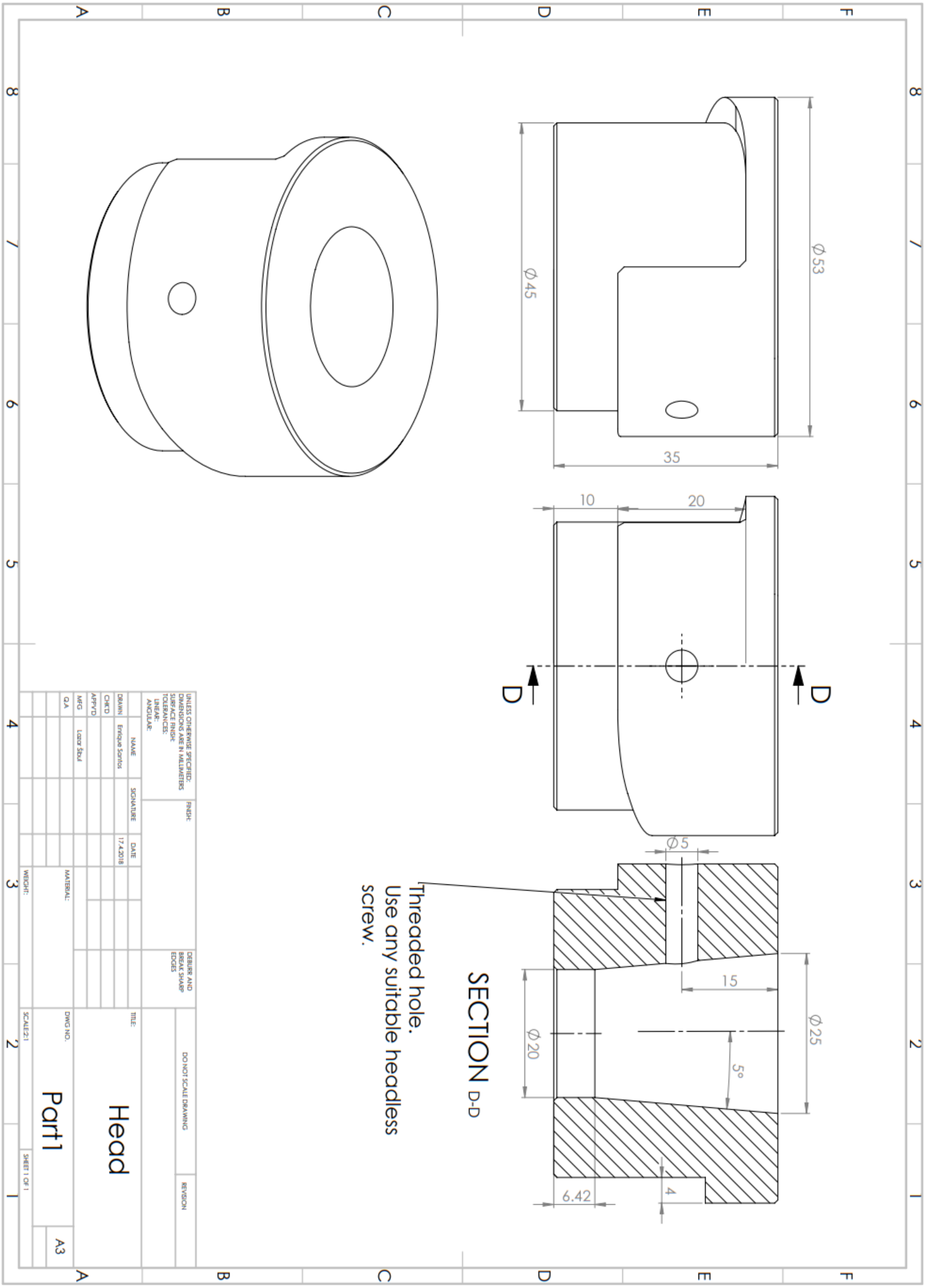
Appendix

Appendix 1 – Technical drawings




Ø45
Ø53
35
10
20
D
D
Ø5
SECTION D-D
Threaded hole.
Use any suitable headless screw.
15
Ø25
Ø20
5°
6.42
4
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Enrique Santos
17.4.2018
CHK'D
APPV'D
MFG
Lazar Šbul
Q.A
MATERIAL:
WEIGHT:
TITLE:
Head
DWG NO.
Part1
A3
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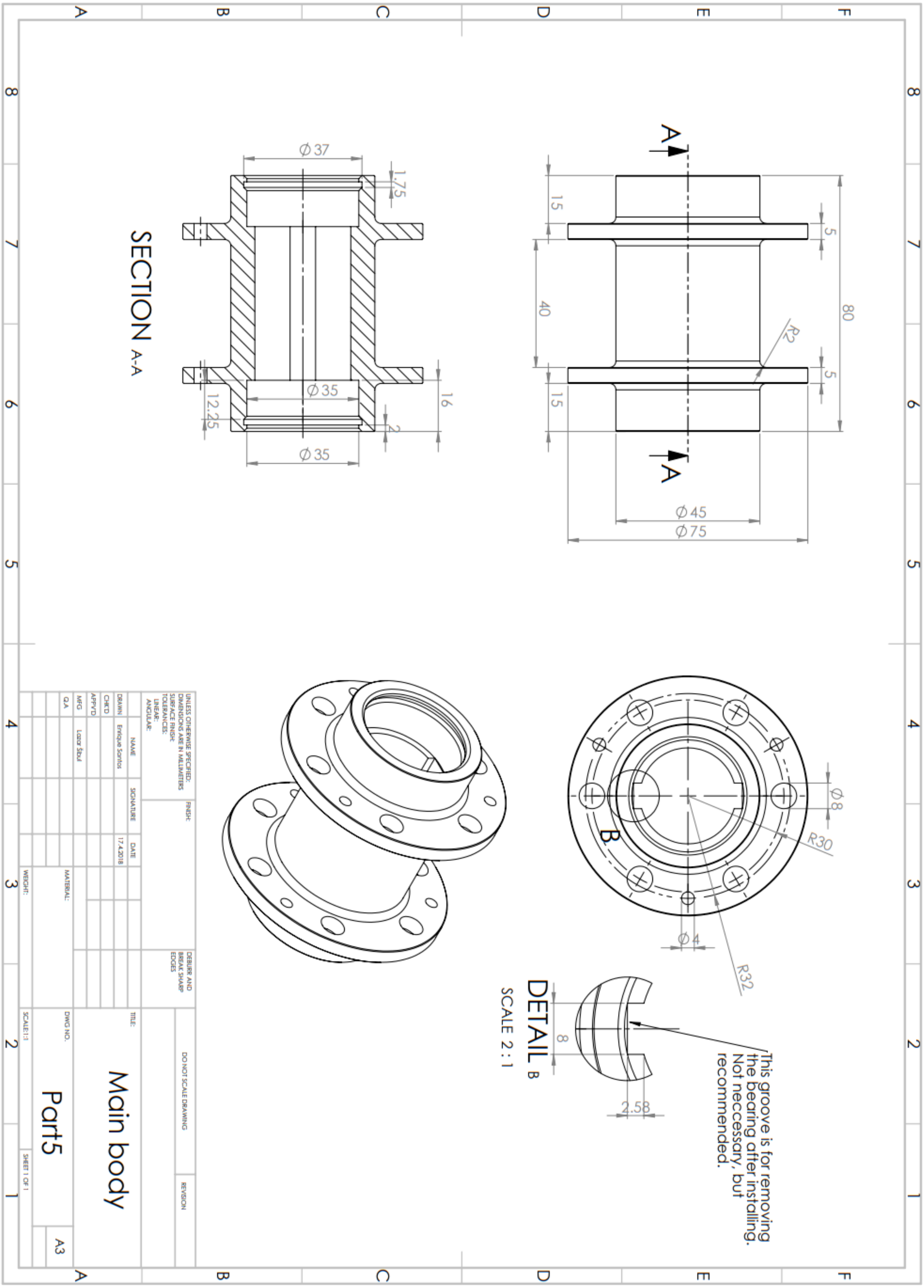
SHEET 1 OF 1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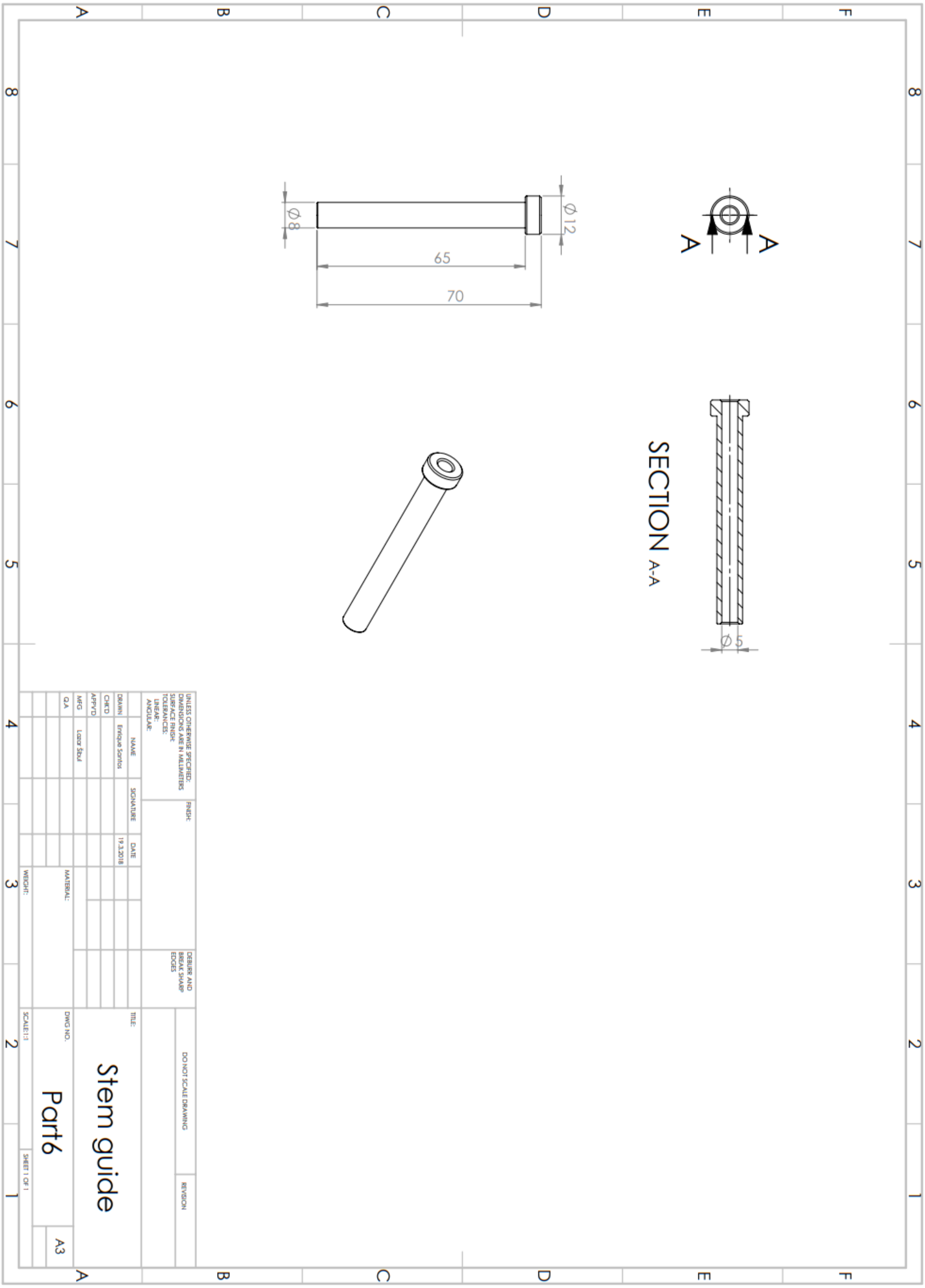
Ø37
1.75
Ø35
12.25
16
2
Ø35
A
15
40
15
5
5
80
R2
Ø45
Ø75
Ø8
R30
Ø4
R32
B
DETAIL B
SCALE 2 : 1
8
2.58
This groove is for removing the bearing after installing. Not neccessary, but recommended.
DO NOT SCALE DRAWING
REVISION
TITLE:
Main body
DWG NO.
Part5
A3
SCALE:1:1
SHEET 1 OF 1
WEIGHT:
MATERIAL:
DRAWN
Enrique Santos
17.4.2018



Ø8
Ø12
65
70
A
A
SECTION A-A
Ø5
UNLESS OTHERWISE SPECIFIED:
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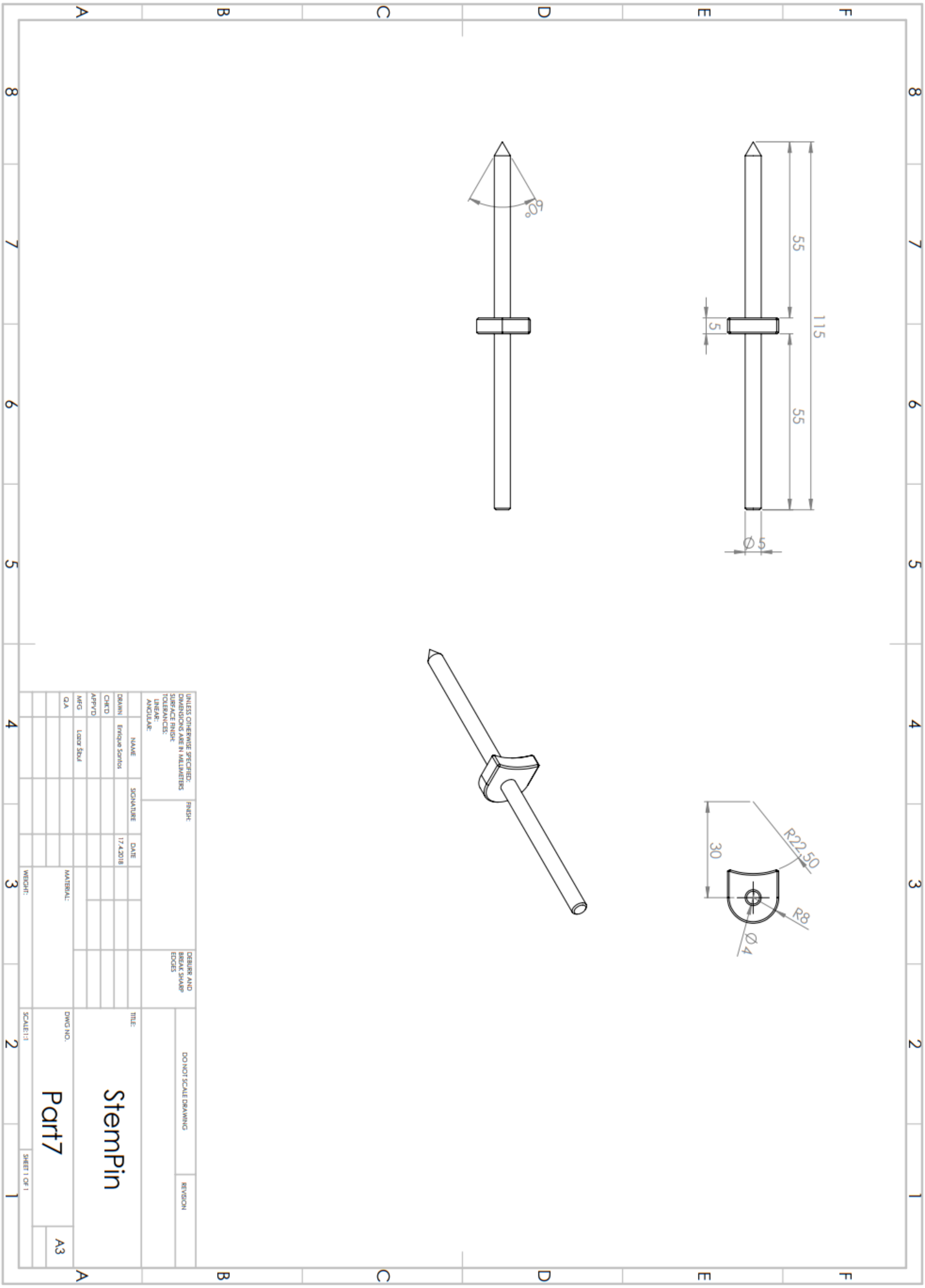
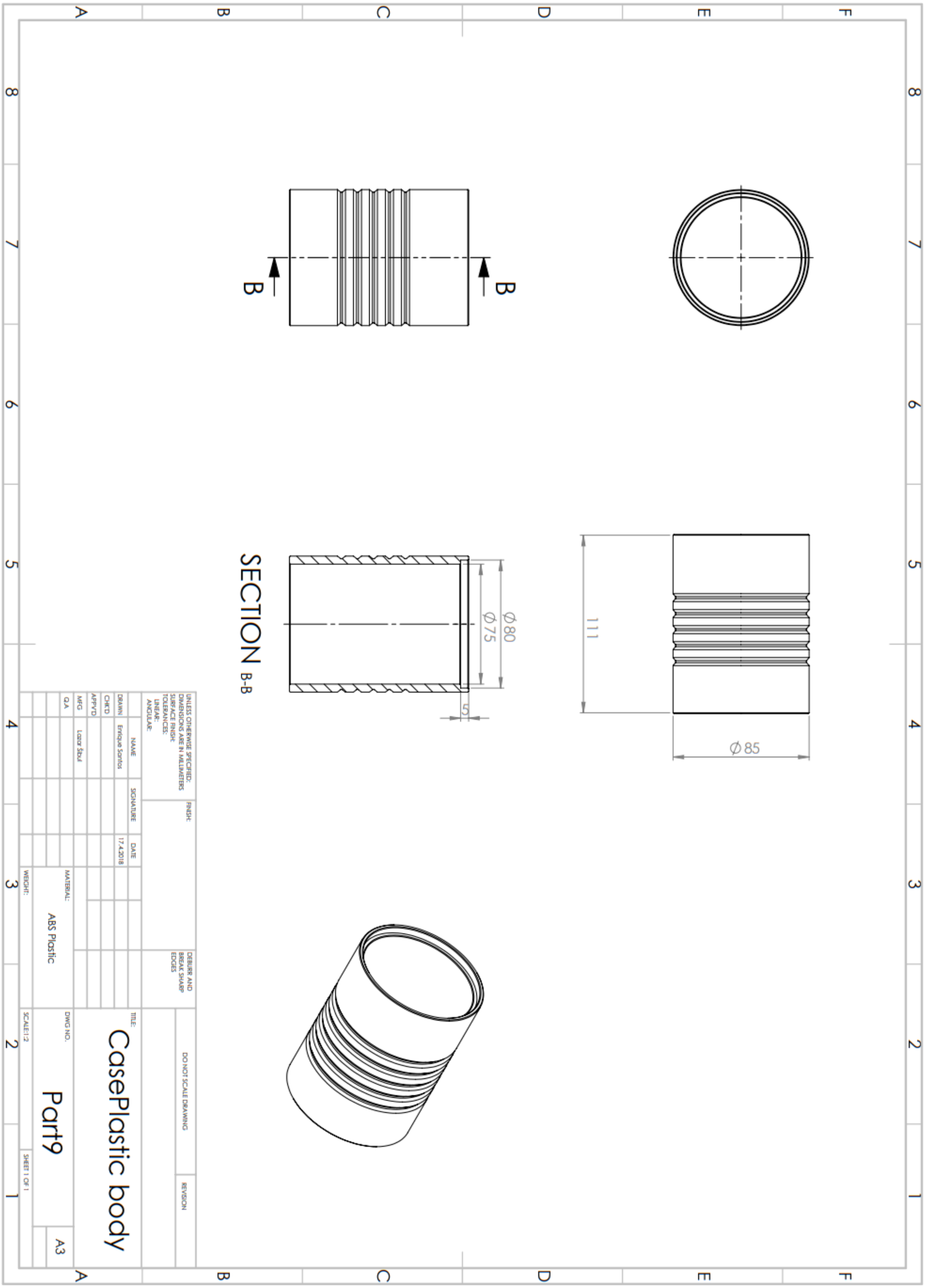
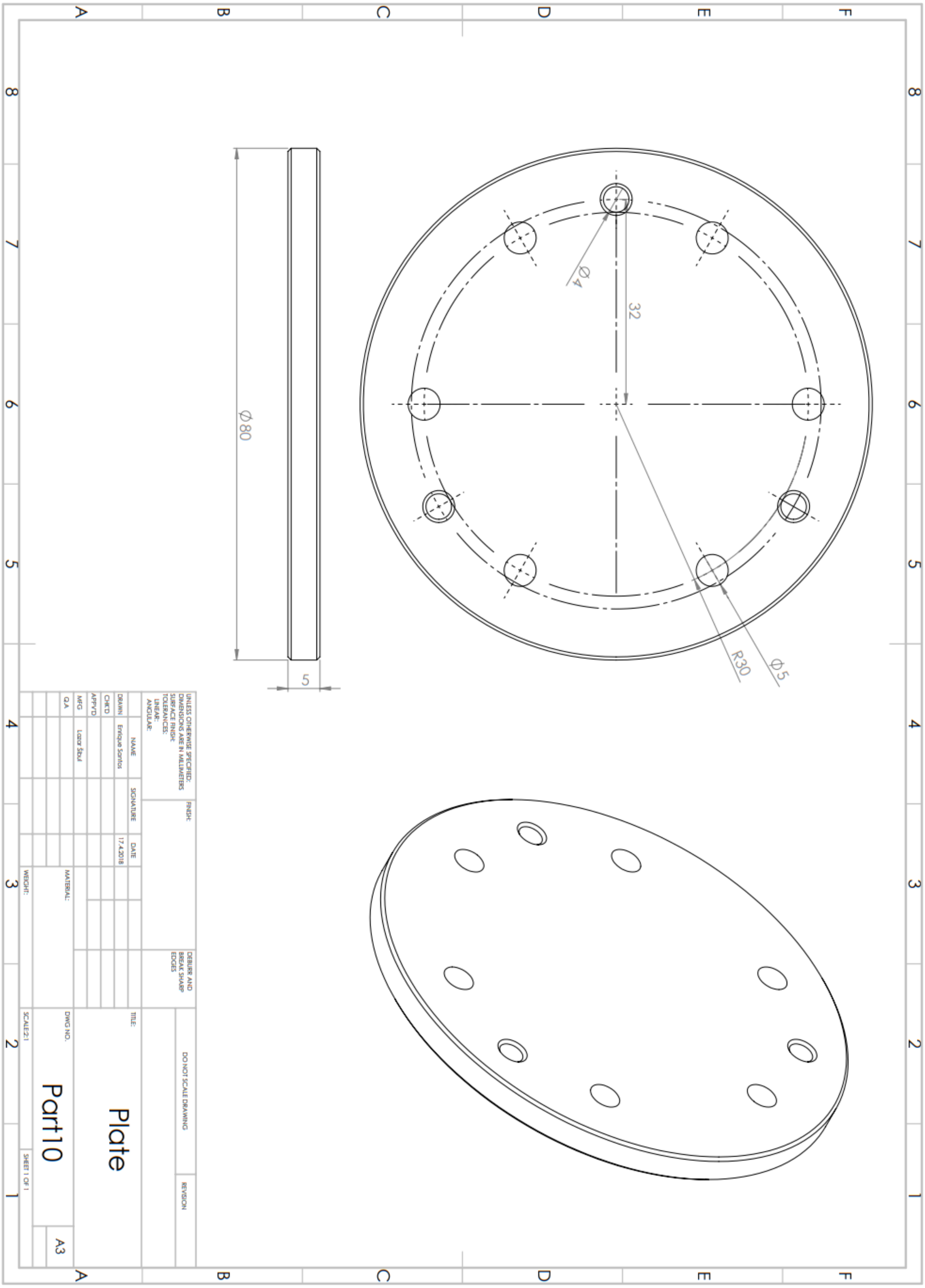
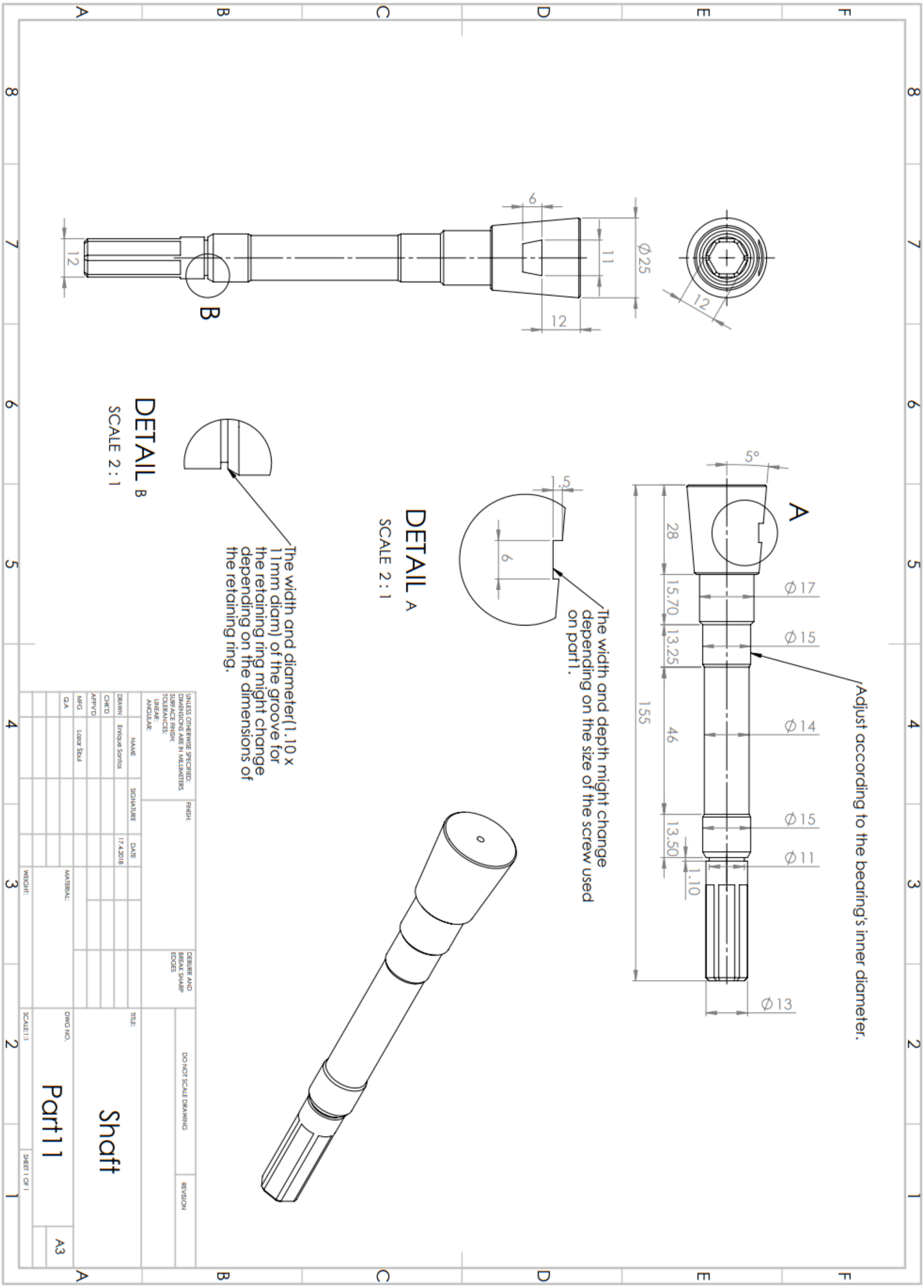
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Enrique Santos
19.3.2018
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
Stem guide
DWG NO.
Part6
A3
SCALE:1:1
SHEET 1 OF 1

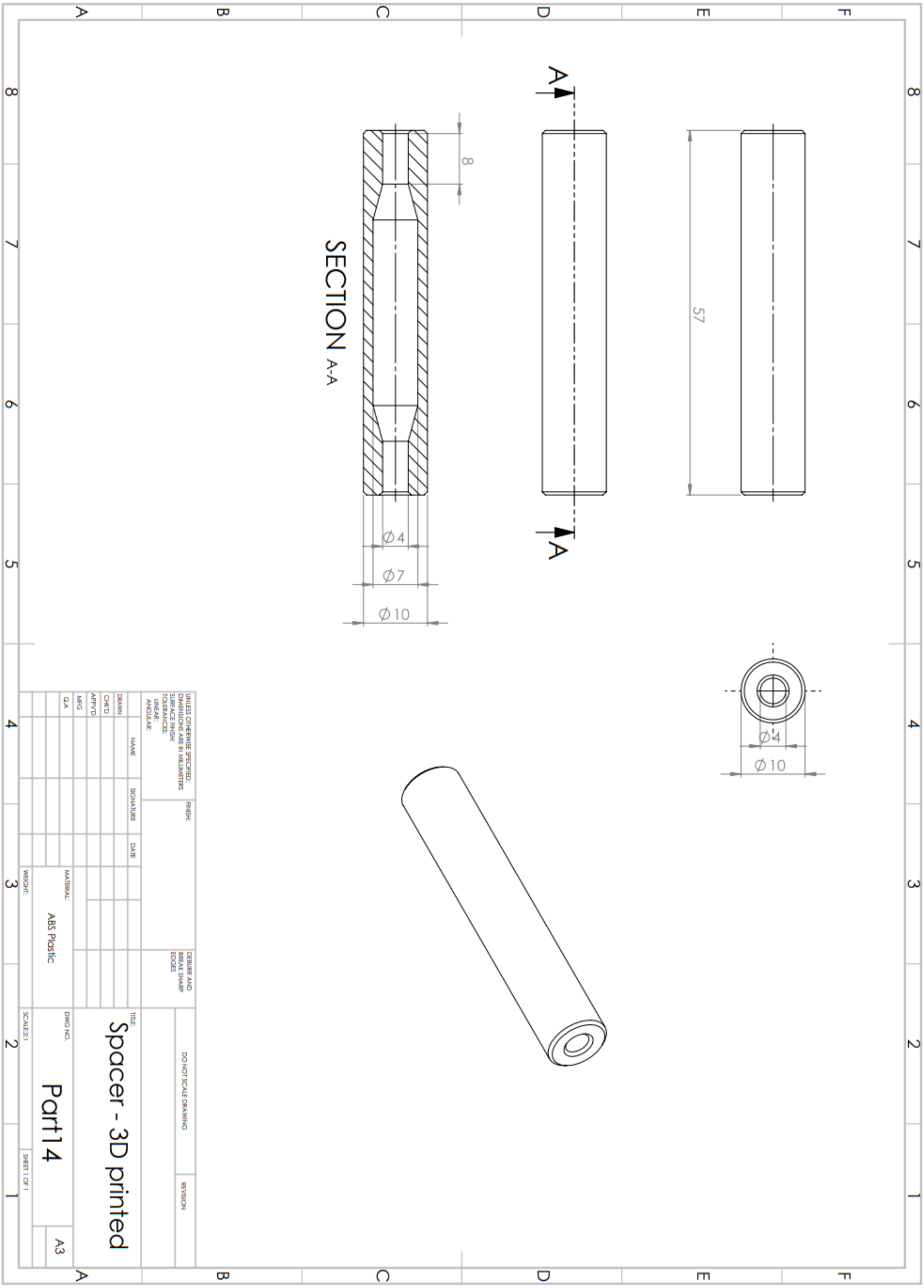

60°
55
5
115
55
Ø 5
30
R22.50
R8
Ø 4
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
Enrique Santos
17.4.2018
MATERIAL:
WEIGHT:
TITLE:
StemPin
DWG NO.
Part7
A3
SHEET 1 OF 1


B
B
SECTION B-B
Ø80
Ø75
5
111
Ø85
DRAWN
NAME
SIGNATURE
DATE
Enrique Santos
17.4.2018
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
TITLE:
CasePlastic body
MATERIAL:
ABS Plastic
DWG NO.
Part9
A3
WEIGHT:
SCALE:1:2
SHEET 1 OF 1



Ø4
32
Ø80
5
R30
Ø5
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
Enrique Santos
17.4.2018
CHK'D
APPV'D
MFG
Lazar Šibul
Q.A
MATERIAL:
WEIGHT:
TITLE:
Plate
DWG NO.
Part10
A3
SCALE:2:1
SHEET 1 OF 1


Adjust according to the bearing's inner diameter.
The width and depth might change depending on the size of the screw used on part1.
The width and diameter(1.10 x 11mm diam) of the groove for the retaining ring might change depending on the dimensions of the retaining ring.
DETAIL A
SCALE 2 : 1
DETAIL B
SCALE 2 : 1
A
B
155
28
15.70
13.25
46
13.50
1.10
Ø17
Ø15
Ø14
Ø15
Ø11
Ø13
Ø25
5°
1.5
6
12
11
DO NOT SCALE DRAWING
REVISION
TITLE:
Shaft
DWG NO.
Part11
A3
SCALE:1:1
SHEET 1 OF 1
17.4.2018



SECTION A-A
A
A
8
57
Ø4
Ø7
Ø10
Ø4
Ø10
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
DRAWN
CHK'D
APPV'D
MFG
Q.A
NAME
SIGNATURE
DATE
MATERIAL:
ABS Plastic
WEIGHT:
TITLE:
Spacer - 3D printed
DWG NO.
Part14
A3
SCALE:2:1
SHEET 1 OF 1

Appendix 2 – G-codes

Part 1 – Head

```
PART 1 - Head
; $PATH=/_N_WKS_DIR/_N__WPD
;
**************************************************
; Machine Tool   : DMU 40 eVo - Siemens 840D SL
; Part Name      : Part 1
; Sequence       : New Toolkit.10
; Programmed By:
; Date           : 05/31/18
; Time           : 13:07:03
; Cycle time     : 9.327
;
**************************************************
;
;   T0 = 10.0 mm Multi-Flute End Mill D10.0
;
G17 G710 G40 G90 G64
CYCLE800 ()
TRAFOOF
;
;
;
**************************************************
N0 T="10.0 mm Multi-Flute End Mill» D01
;
**************************************************
M6
G0 G153 Z-0.11 D0
D01
T="6.0 mm Multi-Flute End Mill»; NEXT TOOL
;
G54; Top
CYCLE800(5,"DMG",0,57,0,0,0,0,0,0,0,0,0,1)
CYCLE800 ()
MSG ("Rough MIlling")
S2485 M3
G0 X0 Y0
Z45
G17
X24.11 Y-18.1513
Z5.0001
Z-9
G1 G94 Z-10 F200
G3 X22.5113 Y-17.0941 CR=2.4972 F270
X21.9642 Y-17.0569 CR=1.295
X21.5662 Y-17.3019 CR=0.75
G2 X17.7698 Y-21.1828 CR=28.1129
X-25.7977 Y-9.9472 CR=27.655
X9.1021 Y26.1081 CR=27.6522
G1 X10.4881 Y25.5838
G3 X10.9544 Y25.5627 CR=0.75
G1 X11.1013 Y25.6208
G3 X11.9559 Y26.5926 CR=2.5
G0 Z5.0001
X1.1731 Y-32.571
Z-14
G1 Z-15 F200
G3 X-0.2863 Y-31.5071 CR=2.4957 F270
G2 X-2.7167 Y-30.222 CR=5.1357
G1 X-3.1353 Y-29.8218
G3 X-6.0758 Y-27.8622 CR=20.5082
X-9.8584 Y-25.8404 CR=106.9495
X-10.1279 Y-25.7209 CR=2.5
G1 X-10.3709 Y-25.63
G2 X-26.0081 Y9.3707 CR=27.6492
X8.3588 Y26.3557 CR=27.6492
G1 X9.7575 Y25.8713
G3 X10.4996 Y26.018 CR=0.75
G1 X10.9613 Y26.4261
G3 X11.7923 Y28.0404 CR=2.5
G0 Z5.0001
X-2.0319 Y-31.867
Z-14
G1 Z-15 F200
G3 X-2.7167 Y-30.222 CR=2.5 F270
G2 X-4.1812 Y-27.7428 CR=5.2179
G3 X-4.7455 Y-27.2399 CR=0.75
G2 X-9.0032 Y-26.142 CR=27.7742
G1 X-10.1279 Y-25.7209
G3 X-11.416 Y-25.5963 CR=2.5
G0 Z5.0001
X-25.7447 Y-19.9554
Z-19
G1 Z-20 F200
G3 X-25.6329 Y-18.4267 CR=2.5 F270
G1 X-25.7252 Y-18.1294
G2 X-26.0654 Y-15.5794 CR=4.9473
G3 X-25.9323 Y-13.8132 CR=11.4459
G1 X-25.9926 Y-12.6172
G3 X-26.691 Y-7.2452 CR=73.4266
X-26.7532 Y-6.9506 CR=2.5
G1 X-26.8413 Y-6.6303
G2 X8.353 Y26.3573 CR=27.6524
G1 X9.7563 Y25.8717
G3 X10.4985 Y26.0188 CR=0.75
G1 X10.9785 Y26.4435
G3 X11.8084 Y28.0581 CR=2.5
G0 Z5.0001
X-26.9899 Y-17.1006
Z-19
G1 Z-20 F200
G3 X-26.0654 Y-15.5794 CR=2.5 F270
G2 X-24.9124 Y-12.8963 CR=5.3253
G3 X-24.8387 Y-12.1476 CR=0.75
G2 X-26.4528 Y-8.0428 CR=27.7774
G1 X-26.7532 Y-6.9506
G3 X-27.4077 Y-5.8342 CR=2.5
G0 Z5.0001
X-31.3231 Y9.1164
Z-24
G1 Z-25 F200
G3 X-29.7532 Y10.2319 CR=2.4972 F270
G1 X-29.7481 Y10.2392
G2 X-27.9867 Y11.9194 CR=5.0749
G1 X-27.4541 Y12.1984
X-26.4473 Y12.8811
G3 X-21.8965 Y17.0148 CR=49.1063
G1 X-21.5281 Y17.3704
G3 X-21.3078 Y17.613 CR=2.5
G2 X-19.2427 Y19.853 CR=26.2388
X9.7524 Y25.873 CR=27.6728
G3 X10.4937 Y26.0187 CR=0.75
G1 X10.9748 Y26.4424
G3 X11.8041 Y28.0139 CR=2.5
G0 Z5.0001
X-29.7809 Y11.7556
Z-24
G1 Z-25 F200
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G2 X-25.7073 Y12.5926 CR=5.2163
G1 X-25.065
G3 X-24.4031 Y12.9897 CR=0.75
G2 X-21.3078 Y17.613 CR=27.6773
G3 X-20.7919 Y18.7998 CR=2.5
G0 Z5.0001
X-17.4776 Y27.5714
Z-27.8
G1 Z-28.8 F200
G3 X-15.8831 Y27.313 CR=2.5 F270
G1 X-15.6159 Y27.3737
G2 X-12.8361 Y27.5059 CR=5.1295
G1 X-12.2695 Y27.3676
G3 X-8.7172 Y27.1478 CR=21.0072
X-4.4104 Y27.2995 CR=109.4708
X-4.1269 Y27.3299 CR=2.5
G2 X-0.9433 Y27.6288 CR=26.092
X9.0042 Y26.1425 CR=27.7602
G3 X9.7409 Y26.3102 CR=0.75
G1 X10.2066 Y26.7456
G3 X10.9909 Y28.3654 CR=2.5
G0 Z5.0001
X-14.2649 Y28.5901
Z-27.8
G1 Z-28.8 F200
G3 X-12.8361 Y27.5059 CR=2.5 F270
G2 X-10.3032 Y26.0906 CR=5.2122
G3 X-9.5621 Y25.939 CR=0.75
G1 X-8.041 Y26.4545
G2 X-4.1269 Y27.3299 CR=26.7932
G3 X-2.9483 Y27.8643 CR=2.5
G0 Z5.0001
X8.5969 Y27.2794
Z-8.8
G1 Z-9.8 F200
G3 X9.8437 Y25.8431 CR=2.5 F270
G1 X11.6105 Y25.0907
G2 X21.8163 Y-16.9852 CR=27.6523
G3 X21.2816 Y-18.1637 CR=2.5
G0 Z5.0001
Z45
S2487
X0 Y0
X24.1877 Y-18.0074
Z5.0001
Z-9
G1 Z-10 F200
G3 X22.6067 Y-16.958 CR=2.4972 F300
G1 X22.0936 Y-16.8671
G3 X21.4946 Y-17.1453 CR=0.75
G2 X18.0639 Y-20.7316 CR=28.6305
X8.8513 Y-26.0336 CR=27.5764
X-12.5235 Y-24.479 CR=27.5038
X-27.4745 Y1.1459 CR=27.5086
X10.5149 Y25.4105 CR=27.5053
G3 X10.9893 Y25.3899 CR=0.75
G1 X11.1382 Y25.4504
G3 X11.9799 Y26.4334 CR=2.5
G0 Z5.0001
X19.1482 Y-26.1984
Z-11
G1 Z-12 F200
G3 X17.4717 Y-26.222 CR=2.5 F300
G1 X16.6312 Y-26.6009
G2 X12.8046 Y-26.4548 CR=5.0443
G1 X11.8922 Y-26.1318
X10.9696 Y-25.8937
X10.495 Y-25.8064
G3 X9.2607 Y-25.8906 CR=2.5
G2 X-10.0952 Y-25.5775 CR=27.5239
X-27.1949 Y4.0691 CR=27.5056
X9.7901 Y25.6984 CR=27.5055
G3 X10.5419 Y25.8509 CR=0.75
G1 X10.9641 Y26.234
G3 X11.7755 Y27.8769 CR=2.5
G0 Z5.0001
X13.9923 Y-27.8134
Z-11
G1 Z-12 F200
G3 X12.8046 Y-26.4548 CR=2.5 F300
G2 X11.3864 Y-25.4908 CR=5.167
G3 X10.6292 Y-25.3624 CR=0.75
G1 X9.2916 Y-25.8804
G3 X8.2091 Y-26.5896 CR=2.5
G0 Z5.0001
X8.2415 Y-31.3946
Z-13
G1 Z-14 F200
G3 X6.305 Y-30.8244 CR=2.5 F300
G2 X2.1415 Y-29.2974 CR=5.0102
G1 X1.4123 Y-28.6593
X0.6404 Y-28.1014
X0.2513 Y-27.8587
G3 X-1.0284 Y-27.4806 CR=2.5
G2 X-6.105 Y-26.8136 CR=30.7143
X-27.3713 Y2.6366 CR=27.5107
X9.7941 Y25.6969 CR=27.5055
G3 X10.5464 Y25.8497 CR=0.75
G1 X11.0087 Y26.2699
G3 X11.8125 Y27.8488 CR=2.5
G0 Z5.0001
X2.7393 Y-31.0086
Z-13
G1 Z-14 F200
G3 X2.1415 Y-29.2974 CR=2.5 F300
G2 X1.1901 Y-27.8894 CR=5.1655
G3 X0.5319 Y-27.4902 CR=0.75
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G1 X-1.0284 Y-27.4806
G3 X-2.2983 Y-27.7297 CR=2.5
G0 Z5.0001
X-4.009 Y-32.1983
Z-15
G1 Z-16 F200
G3 X-5.228 Y-31.08 CR=2.5 F300
G1 X-6.1099 Y-30.7723
G2 X-8.5236 Y-28.6084 CR=5.0025
G1 X-8.7764 Y-28.0889
X-9.2094 Y-27.2216
X-9.7189 Y-26.4202
X-10.038 Y-25.9848
G3 X-11.0617 Y-25.1682 CR=2.5
G2 X-24.3469 Y-12.7752 CR=27.4511
X-27.4977 Y-0.2475 CR=27.5183
X9.7919 Y25.6977 CR=27.5054
G3 X10.5444 Y25.8507 CR=0.75
G1 X11.0092 Y26.2734
G3 X11.8148 Y27.8739 CR=2.5
G0 Z5.0001
X-8.8308 Y-29.8935
Z-15
G1 Z-16 F200
G3 X-8.7764 Y-28.0889 CR=2.5 F300
G2 X-9.1674 Y-26.3646 CR=5.2164
G3 X-9.6495 Y-25.7463 CR=0.75
G1 X-10.1217 Y-25.5693
X-11.0415 Y-25.1769
G3 X-12.3226 Y-24.9943 CR=2.5
G0 Z5.0001
X-14.5182 Y-29.0397
Z-17
G1 Z-18 F200
G3 X-15.4443 Y-27.4623 CR=2.5 F300
G1 X-15.7012 Y-27.2855
X-16.4832 Y-26.8162
G2 X-18.5085 Y-22.803 CR=5.0176
G1 X-18.5993 Y-21.8357
X-18.7836 Y-20.9015
X-18.9066 Y-20.4456
G3 X-19.5603 Y-19.3212 CR=2.5
G1 X-19.6749 Y-19.2077
G2 X-23.6805 Y-13.9727 CR=27.3128
X-27.4977 Y-0.2475 CR=27.5253
X9.7908 Y25.6982 CR=27.5054
G3 X10.542 Y25.8501 CR=0.75
G1 X11.0512 Y26.3112
G3 X11.8594 Y27.9022 CR=2.5
G0 Z5.0001
X-19.2516 Y-24.46
Z-17
G1 Z-18 F200
G3 X-18.5085 Y-22.803 CR=2.5 F300
G2 X-18.2381 Y-21.1344 CR=5.2334
G3 X-18.4485 Y-20.3902 CR=0.75
G1 X-19.0735 Y-19.8037
X-19.5603 Y-19.3212
G3 X-20.6839 Y-18.6791 CR=2.5
G0 Z5.0001
X-24.1184 Y-21.7311
Z-19
G1 Z-20 F200
G3 X-24.4507 Y-19.8617 CR=2.5 F300
G1 X-24.6125 Y-19.6356
X-25.0266 Y-19.12
G2 X-25.8018 Y-17.4406 CR=5.4258
X-25.5212 Y-14.156 CR=5.0819
G1 X-25.2745 Y-13.213
X-25.1201 Y-12.2677
X-25.096 Y-12.029
G3 X-25.2955 Y-10.7707 CR=2.5
G2 X-27.3713 Y2.6367 CR=27.4314
X9.7907 Y25.6982 CR=27.5055
G3 X10.5439 Y25.8519 CR=0.75
G1 X11.0051 Y26.2724
G3 X11.8086 Y27.8751 CR=2.5
G0 Z5.0001
X-26.8802 Y-15.3299
Z-19
G1 Z-20 F200
G3 X-25.5212 Y-14.156 CR=2.5 F300
G2 X-24.7544 Y-12.943 CR=6.5855
G3 X-24.6681 Y-12.1442 CR=0.75
G1 X-24.88 Y-11.714
X-25.2955 Y-10.7707
G3 X-26.1059 Y-9.7617 CR=2.5
G0 Z5.0001
X-30.6031 Y-10.8148
Z-21
G1 Z-22 F200
G3 X-30.1962 Y-9.0299 CR=2.5 F300
G1 X-30.4091 Y-8.063
G2 X-29.0381 Y-3.8539 CR=5.0436
G1 X-28.4478 Y-3.0778
X-27.943 Y-2.2639
X-27.7568 Y-1.9051
G3 X-27.4761 Y-0.7148 CR=2.5
G2 X-27.3537 Y2.8163 CR=24.5338
X-16.9905 Y21.6196 CR=27.5229
X9.7881 Y25.699 CR=27.5229
G3 X10.5471 Y25.858 CR=0.75
G1 X10.9484 Y26.2317
G3 X11.7362 Y27.8538 CR=2.5
G0 Z5.0001
X-30.7154 Y-4.5161
Z-21
G1 Z-22 F200
G3 X-29.0381 Y-3.8539 CR=2.5 F300
G2 X-27.7996 Y-2.9385 CR=4.5063
G3 X-27.4051 Y-2.2216 CR=0.75
G1 X-27.4717 Y-1.0009
G3 X-27.826 Y0.2438 CR=2.5
G0 Z5.0001
X-32.4134 Y1.6124
Z-23
G1 Z-24 F200
G3 X-31.3207 Y3.2295 CR=2.5 F300
G2 X-30.9935 Y4.4514 CR=6.9222
X-28.2989 Y7.1705 CR=5.2274
G1 X-27.4706 Y7.6888
X-26.7046 Y8.2697
X-26.5297 Y8.422
G3 X-25.8 Y9.5148 CR=2.5
G2 X-18.1134 Y20.6886 CR=27.5753
X9.7888 Y25.6988 CR=27.5228
G3 X10.5413 Y25.8517 CR=0.75
G1 X11.0063 Y26.2745
G3 X11.812 Y27.8753 CR=2.5
G0 Z5.0001
X-30.116 Y7.2084
Z-23
G1 Z-24 F200
G3 X-28.2989 Y7.1705 CR=2.5 F300
G2 X-26.8819 Y7.5302 CR=5.5546
G3 X-26.296 Y8.0318 CR=0.75
G1 X-25.8 Y9.5148
G3 X-25.7212 Y10.8065 CR=2.5
G0 Z5.0001
X-29.497 Y13.5495
Z-25
G1 Z-26 F200
G3 X-27.9697 Y14.5033 CR=2.5 F300
G2 X-27.4361 Y15.2633 CR=7.6414
X-23.96 Y17.0718 CR=5.0454
G1 X-23.0005 Y17.2182
X-22.0744 Y17.4482
X-21.5941 Y17.6065
G3 X-20.4958 Y18.3343 CR=2.5
G2 X9.7961 Y25.696 CR=27.5224
G3 X10.5718 Y25.8711 CR=0.75
G1 X10.7976 Y26.0949
G3 X11.5359 Y27.7694 CR=2.5
G0 Z5.0001
X-25.6623 Y17.6864
Z-25
G1 Z-26 F200
G3 X-23.96 Y17.0718 CR=2.5 F300
G2 X-22.2087 Y16.9088 CR=5.1704
G3 X-21.4828 Y17.1606 CR=0.75
G1 X-20.4958 Y18.3343
G3 X-19.8813 Y19.4732 CR=2.5
G0 Z5.0001
X-22.3299 Y23.557
Z-27
G1 Z-28 F200
G3 X-20.5913 Y23.8417 CR=2.5 F300
G2 X-19.762 Y24.3614 CR=7.068
X-15.9452 Y24.6866 CR=5.0441
G1 X-14.9993 Y24.4772
X-14.0535 Y24.3531
X-13.5734 Y24.3254
G3 X-12.3036 Y24.589 CR=2.5
G2 X-4.5933 Y27.1106 CR=27.5111
X9.5504 Y25.788 CR=27.5992
G3 X10.3205 Y25.9669 CR=0.75
G1 X10.5517 Y26.1972
X10.7352 Y26.352
X10.9226 Y26.5022
G3 X11.8338 Y28.0951 CR=2.5
G0 Z5.0001
X-17.2926 Y25.8929
Z-27
G1 Z-28 F200
G3 X-15.9452 Y24.6866 CR=2.5 F300
G2 X-14.417 Y23.9025 CR=5.1691
G3 X-13.6285 Y23.8797 CR=0.75
G1 X-12.7951 Y24.3411
X-12.3036 Y24.589
G3 X-11.3383 Y25.4509 CR=2.5
G0 Z5.0001
X-18.4394 Y26.7039
Z-27.8
G1 Z-28.8 F200
G3 X-16.4726 Y26.833 CR=2.5 F300
G2 X-11.7156 Y26.9418 CR=5.0351
G1 X-10.8125 Y26.5757
X-9.8953 Y26.3006
X-9.4347 Y26.2001
G3 X-8.1357 Y26.2631 CR=2.5
G1 X-8.0061 Y26.3048
G2 X9.0411 Y25.971 CR=27.5541
G3 X9.7888 Y26.1451 CR=0.75
G1 X10.2445 Y26.5836
G2 X11.7589 Y27.475 CR=5.0291
G1 X12.3215 Y27.6476
X12.9004 Y27.7534
G2 X15.7608 Y27.2608 CR=5.0295
G1 X16.841 Y26.6109
G3 X18.9137 Y26.3791 CR=2.5
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X-12.8484 Y28.3515
Z-27.8
G1 Z-28.8 F200
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G3 X-9.5875 Y25.7719 CR=0.75
G1 X-8.7956 Y26.0505
X-8.1357 Y26.2631
G3 X-7.0485 Y26.9651 CR=2.5
G0 Z5.0001
X8.5193 Y27.1531
Z-8.8
G1 Z-9.8 F200
G3 X9.7732 Y25.7078 CR=2.5 F300
G1 X11.479 Y24.9839
G2 X21.7644 Y-16.8079 CR=27.497
G3 X21.2339 Y-17.9883 CR=2.5
G0 Z5.0001
X-2.6822 Y2.8916
Z-1
G1 Z-2 F200
G3 X-4.8691 Y0.837 CR=2.5 F300
G1 X-4.9006 Y0.6565
X-4.9449 Y0.6649
G3 X-4.9828 Y-0.3955 CR=4.3265
G1 X-4.8593 Y-1.1689
X-4.6553 Y-1.817
X-4.3653 Y-2.4315
X-3.9946 Y-3.001
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X-3.5501 Y-3.5149
X-3.04 Y-3.9638
X-2.4737 Y-4.3393
X-1.8617 Y-4.6346
X-1.2154 Y-4.8441
X-0.5466 Y-4.964
X0.1323 Y-4.9921
X0.8088 Y-4.9279
X1.4702 Y-4.7725
X2.1045 Y-4.5288
X2.6999 Y-4.2013
X3.2453 Y-3.7961
X3.7308 Y-3.3207
X4.1473 Y-2.7838
X4.4871 Y-2.1954
X4.7439 Y-1.5663
X4.9131 Y-0.9083
X4.9914 Y-0.2333
X4.9775 Y0.446
X4.8715 Y1.1172
X4.6747 Y1.7697
X4.3885 Y2.3914
X4.02 Y2.9681
X3.5762 Y3.4892
X3.0654 Y3.9447
X2.4972 Y4.3262
X1.8821 Y4.6265
X1.2319 Y4.84
X0.5585 Y4.9627
X-0.1253 Y4.9923
X-0.8067 Y4.9282
X-1.473 Y4.7716
X-2.1116 Y4.5255
X-2.7106 Y4.1944
X-3.2589 Y3.7847
X-3.746 Y3.3039
X-4.1628 Y2.7611
X-4.5017 Y2.1664
X-4.7561 Y1.531
X-4.9214 Y0.8668
X-4.9926 Y0.2548
X-4.9943 Y0.2206
G3 X-4.663 Y-1.0304 CR=2.5
G0 Z5.0001
X-2.6822 Y2.8916
Z-3
G1 Z-4 F200
G3 X-4.8691 Y0.837 CR=2.5 F300
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X-4.9449 Y0.6649
G3 X-4.9828 Y-0.3955 CR=4.3265
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X-4.6553 Y-1.817
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X-2.4737 Y-4.3393
X-1.8617 Y-4.6346
X-1.2154 Y-4.8441
X-0.5466 Y-4.964
X0.1323 Y-4.9921
X0.8088 Y-4.9279
X1.4702 Y-4.7725
X2.1045 Y-4.5288
X2.6999 Y-4.2013
X3.2453 Y-3.7961
X3.7308 Y-3.3207
X4.1473 Y-2.7838
X4.4871 Y-2.1954
X4.7439 Y-1.5663
X4.9131 Y-0.9083
X4.9914 Y-0.2333
X4.9775 Y0.446
X4.8715 Y1.1172
X4.6747 Y1.7697
X4.3885 Y2.3914
X4.02 Y2.9681
X3.5762 Y3.4892
X3.0654 Y3.9447
X2.4972 Y4.3262
X1.8821 Y4.6265
X1.2319 Y4.84
X0.5585 Y4.9627
X-0.1253 Y4.9923
X-0.8067 Y4.9282
X-1.473 Y4.7716
X-2.1116 Y4.5255
X-2.7106 Y4.1944
X-3.2589 Y3.7847
X-3.746 Y3.3039
X-4.1628 Y2.7611
X-4.5017 Y2.1664
X-4.7561 Y1.531
X-4.9214 Y0.8668
X-4.9926 Y0.2548
X-4.9943 Y0.2206
G3 X-4.663 Y-1.0304 CR=2.5
G0 Z5.0001
X-2.6822 Y2.8916
Z-5
G1 Z-6 F200
G3 X-4.8691 Y0.837 CR=2.5 F300
G1 X-4.9006 Y0.6565
X-4.9449 Y0.6649
G3 X-4.9828 Y-0.3955 CR=4.3265
G1 X-4.8593 Y-1.1689
X-4.6553 Y-1.817
X-4.3653 Y-2.4315
X-3.9946 Y-3.001
X-3.5501 Y-3.5149
X-3.04 Y-3.9638
X-2.4737 Y-4.3393
X-1.8617 Y-4.6346
X-1.2154 Y-4.8441
X-0.5466 Y-4.964
X0.1323 Y-4.9921
X0.8088 Y-4.9279
X1.4702 Y-4.7725
X2.1045 Y-4.5288
X2.6999 Y-4.2013
X3.2453 Y-3.7961
X3.7308 Y-3.3207
X4.1473 Y-2.7838
X4.4871 Y-2.1954
X4.7439 Y-1.5663
X4.9131 Y-0.9083
X4.9914 Y-0.2333
X4.9775 Y0.446
X4.8715 Y1.1172
X4.6747 Y1.7697
X4.3885 Y2.3914
X4.02 Y2.9681
X3.5762 Y3.4892
X3.0654 Y3.9447
X2.4972 Y4.3262
X1.8821 Y4.6265
X1.2319 Y4.84
X0.5585 Y4.9627
X-0.1253 Y4.9923
X-0.8067 Y4.9282
X-1.473 Y4.7716
X-2.1116 Y4.5255
X-2.7106 Y4.1944
X-3.2589 Y3.7847
X-3.746 Y3.3039
X-4.1628 Y2.7611
X-4.5017 Y2.1664
X-4.7561 Y1.531
X-4.9214 Y0.8668
X-4.9926 Y0.2548
X-4.9943 Y0.2206
G3 X-4.663 Y-1.0304 CR=2.5
G0 Z5.0001
X-2.6822 Y2.8916
Z-7
G1 Z-8 F200
G3 X-4.8691 Y0.837 CR=2.5 F300
G1 X-4.9006 Y0.6565
X-4.9449 Y0.6649
G3 X-4.9828 Y-0.3955 CR=4.3265
G1 X-4.8593 Y-1.1689
X-4.6553 Y-1.817
X-4.3653 Y-2.4315
X-3.9946 Y-3.001
X-3.5501 Y-3.5149
X-3.04 Y-3.9638
X-2.4737 Y-4.3393
X-1.8617 Y-4.6346
X-1.2154 Y-4.8441
X-0.5466 Y-4.964
X0.1323 Y-4.9921
X0.8088 Y-4.9279
X1.4702 Y-4.7725
X2.1045 Y-4.5288
X2.6999 Y-4.2013
X3.2453 Y-3.7961
X3.7308 Y-3.3207
X4.1473 Y-2.7838
X4.4871 Y-2.1954
X4.7439 Y-1.5663
X4.9131 Y-0.9083
X4.9914 Y-0.2333
X4.9775 Y0.446
X4.8715 Y1.1172
X4.6747 Y1.7697
X4.3885 Y2.3914
X4.02 Y2.9681
X3.5762 Y3.4892
X3.0654 Y3.9447
X2.4972 Y4.3262
X1.8821 Y4.6265
X1.2319 Y4.84
X0.5585 Y4.9627
X-0.1253 Y4.9923
X-0.8067 Y4.9282
X-1.473 Y4.7716
X-2.1116 Y4.5255
X-2.7106 Y4.1944
X-3.2589 Y3.7847
X-3.746 Y3.3039
X-4.1628 Y2.7611
X-4.5017 Y2.1664
X-4.7561 Y1.531
X-4.9214 Y0.8668
X-4.9926 Y0.2548
X-4.9943 Y0.2206
G3 X-4.663 Y-1.0304 CR=2.5
G0 Z5.0001
X2.6154 Y-2.9395
Z-9
G1 Z-10 F200
G3 X4.7283 Y-1.4024 CR=2.5 F300
G1 X4.737 Y-1.3812
X4.7885 Y-1.3991
X4.9016 Y-0.9752
X4.9915 Y-0.2332
X4.9775 Y0.4461
X4.8716 Y1.1173
X4.6747 Y1.7697
X4.3885 Y2.3914
X4.02 Y2.9682
X3.5762 Y3.4893
X3.0654 Y3.9448
X2.4971 Y4.3263
X1.8821 Y4.6266
X1.2318 Y4.8401
X0.5585 Y4.9628
X-0.1253 Y4.9923
X-0.8068 Y4.9282
X-1.473 Y4.7716
X-2.1117 Y4.5255
X-2.7107 Y4.1944
X-3.2589 Y3.7847
X-3.746 Y3.3039
X-4.1629 Y2.761
X-4.5017 Y2.1663
X-4.7562 Y1.531
X-4.9214 Y0.8668
G3 X-4.8593 Y-1.169 CR=4.9563
```

```
G1 X-4.6553 Y-1.8171
X-4.3653 Y-2.4316
X-3.9946 Y-3.0011
X-3.55 Y-3.515
X-3.0399 Y-3.9638
X-2.4737 Y-4.3394
X-1.8617 Y-4.6346
X-1.2153 Y-4.8441
X-0.5465 Y-4.964
X0.1324 Y-4.9921
X0.8089 Y-4.9279
X1.4703 Y-4.7725
X2.1046 Y-4.5288
X2.7 Y-4.2013
X3.2454 Y-3.7961
X3.7309 Y-3.3207
X4.1473 Y-2.7838
X4.4871 Y-2.1953
X4.744 Y-1.5663
X4.9016 Y-0.9752
X4.9081 Y-0.9418
G3 X4.7617 Y0.344 CR=2.5
G0 Z5.0001
X2.3358 Y-3.1702
Z-11
G1 Z-12 F200
G3 X4.6523 Y-1.6419 CR=2.5 F300
G1 X4.6701 Y-1.5997
X4.7255 Y-1.6199
X4.7271 Y-1.6204
X4.7344 Y-1.5989
X4.9131 Y-0.9082
X4.9915 Y-0.2332
X4.9775 Y0.4461
X4.8716 Y1.1173
X4.6747 Y1.7698
X4.3885 Y2.3915
X4.02 Y2.9682
X3.5762 Y3.4893
X3.0653 Y3.9448
X2.4971 Y4.3263
X1.8821 Y4.6266
X1.2318 Y4.8401
X0.5584 Y4.9628
X-0.1254 Y4.9923
X-0.8068 Y4.9282
X-1.4731 Y4.7716
X-2.1117 Y4.5255
X-2.7107 Y4.1944
X-3.259 Y3.7847
X-3.7461 Y3.3039
X-4.1629 Y2.761
X-4.5017 Y2.1663
X-4.7562 Y1.5309
X-4.9214 Y0.8668
G3 X-4.8593 Y-1.169 CR=4.9563
G1 X-4.6553 Y-1.8171
X-4.3653 Y-2.4316
X-3.9946 Y-3.0011
X-3.55 Y-3.515
X-3.0399 Y-3.9638
X-2.4736 Y-4.3394
X-1.8617 Y-4.6346
X-1.2153 Y-4.8441
X-0.5465 Y-4.9641
X0.1324 Y-4.9921
X0.8089 Y-4.9279
X1.4703 Y-4.7725
X2.1046 Y-4.5288
X2.7 Y-4.2013
X3.2454 Y-3.7961
X3.7309 Y-3.3206
X4.1473 Y-2.7838
X4.4871 Y-2.1953
X4.7234 Y-1.6311
X4.7344 Y-1.5989
G3 X4.7638 Y-0.3052 CR=2.5
G0 Z5.0001
X2.3358 Y-3.1702
Z-13
G1 Z-14 F200
G3 X4.6523 Y-1.6419 CR=2.5 F300
G1 X4.6701 Y-1.5997
X4.7255 Y-1.6199
X4.7271 Y-1.6204
X4.7344 Y-1.5989
X4.9131 Y-0.9082
X4.9915 Y-0.2332
X4.9775 Y0.4461
X4.8716 Y1.1173
X4.6747 Y1.7698
X4.3885 Y2.3915
X4.02 Y2.9682
X3.5762 Y3.4893
X3.0653 Y3.9448
X2.4971 Y4.3263
X1.8821 Y4.6266
X1.2318 Y4.8401
X0.5584 Y4.9628
X-0.1254 Y4.9923
X-0.8068 Y4.9282
X-1.4731 Y4.7716
X-2.1117 Y4.5255
X-2.7107 Y4.1944
X-3.259 Y3.7847
X-3.7461 Y3.3039
X-4.1629 Y2.761
X-4.5017 Y2.1663
X-4.7562 Y1.5309
X-4.9214 Y0.8668
G3 X-4.8593 Y-1.169 CR=4.9563
G1 X-4.6553 Y-1.8171
X-4.3653 Y-2.4316
X-3.9946 Y-3.0011
X-3.55 Y-3.515
X-3.0399 Y-3.9638
X-2.4736 Y-4.3394
X-1.8617 Y-4.6346
X-1.2153 Y-4.8441
X-0.5465 Y-4.9641
X0.1324 Y-4.9921
X0.8089 Y-4.9279
X1.4703 Y-4.7725
X2.1046 Y-4.5288
X2.7 Y-4.2013
X3.2454 Y-3.7961
X3.7309 Y-3.3206
X4.1473 Y-2.7838
X4.4871 Y-2.1953
X4.7234 Y-1.6311
X4.7344 Y-1.5989
G3 X4.7638 Y-0.3052 CR=2.5
G0 Z5.0001
X2.3358 Y-3.1702
Z-15
G1 Z-16 F200
G3 X4.6523 Y-1.6419 CR=2.5 F300
G1 X4.6701 Y-1.5997
X4.7255 Y-1.6199
X4.7271 Y-1.6204
X4.7344 Y-1.5989
X4.9131 Y-0.9082
X4.9915 Y-0.2332
X4.9775 Y0.4461
X4.8716 Y1.1173
X4.6747 Y1.7698
X4.3885 Y2.3915
X4.02 Y2.9682
X3.5762 Y3.4893
X3.0653 Y3.9448
X2.4971 Y4.3263
X1.8821 Y4.6266
X1.2318 Y4.8401
X0.5584 Y4.9628
X-0.1254 Y4.9923
X-0.8068 Y4.9282
X-1.4731 Y4.7716
X-2.1117 Y4.5255
X-2.7107 Y4.1944
X-3.259 Y3.7847
X-3.7461 Y3.3039
X-4.1629 Y2.761
X-4.5017 Y2.1663
X-4.7562 Y1.5309
X-4.9214 Y0.8668
G3 X-4.8593 Y-1.169 CR=4.9563
G1 X-4.6553 Y-1.8171
X-4.3653 Y-2.4316
X-3.9946 Y-3.0011
X-3.55 Y-3.515
X-3.0399 Y-3.9638
X-2.4736 Y-4.3394
X-1.8617 Y-4.6346
X-1.2153 Y-4.8441
X-0.5465 Y-4.9641
X0.1324 Y-4.9921
X0.8089 Y-4.9279
X1.4703 Y-4.7725
X2.1046 Y-4.5288
X2.7 Y-4.2013
X3.2454 Y-3.7961
X3.7309 Y-3.3206
X4.1473 Y-2.7838
X4.4871 Y-2.1953
X4.7234 Y-1.6311
X4.7344 Y-1.5989
G3 X4.7638 Y-0.3052 CR=2.5
G0 Z5.0001
X2.3358 Y-3.1702
Z-17
G1 Z-18 F200
G3 X4.6523 Y-1.6419 CR=2.5 F300
G1 X4.6701 Y-1.5997
X4.7255 Y-1.6199
X4.7271 Y-1.6204
X4.7344 Y-1.5989
X4.9131 Y-0.9082
X4.9915 Y-0.2332
X4.9775 Y0.4461
X4.8716 Y1.1173
X4.6747 Y1.7698
X4.3885 Y2.3915
X4.02 Y2.9682
X3.5762 Y3.4893
X3.0653 Y3.9448
X2.4971 Y4.3263
X1.8821 Y4.6266
X1.2318 Y4.8401
X0.5584 Y4.9628
X-0.1254 Y4.9923
X-0.8068 Y4.9282
X-1.4731 Y4.7716
X-2.1117 Y4.5255
X-2.7107 Y4.1944
X-3.259 Y3.7847
X-3.7461 Y3.3039
X-4.1629 Y2.761
X-4.5017 Y2.1663
X-4.7562 Y1.5309
X-4.9214 Y0.8668
G3 X-4.8593 Y-1.169 CR=4.9563
G1 X-4.6553 Y-1.8171
X-4.3653 Y-2.4316
X-3.9946 Y-3.0011
X-3.55 Y-3.515
X-3.0399 Y-3.9638
X-2.4736 Y-4.3394
X-1.8617 Y-4.6346
X-1.2153 Y-4.8441
X-0.5465 Y-4.9641
X0.1324 Y-4.9921
X0.8089 Y-4.9279
X1.4703 Y-4.7725
X2.1046 Y-4.5288
X2.7 Y-4.2013
X3.2454 Y-3.7961
X3.7309 Y-3.3206
X4.1473 Y-2.7838
X4.4871 Y-2.1953
X4.7234 Y-1.6311
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X4.7344 Y-1.5989
G3 X4.7638 Y-0.3052 CR=2.5
G0 Z5.0001
X2.3358 Y-3.1702
Z-19
G1 Z-20 F200
G3 X4.6523 Y-1.6419 CR=2.5 F300
G1 X4.6701 Y-1.5997
X4.7255 Y-1.6199
X4.7271 Y-1.6204
X4.7344 Y-1.5989
X4.9131 Y-0.9082
X4.9915 Y-0.2332
X4.9775 Y0.4461
X4.8716 Y1.1173
X4.6747 Y1.7698
X4.3885 Y2.3915
X4.02 Y2.9682
X3.5762 Y3.4893
X3.0653 Y3.9448
X2.4971 Y4.3263
X1.8821 Y4.6266
X1.2318 Y4.8401
X0.5584 Y4.9628
X-0.1254 Y4.9923
X-0.8068 Y4.9282
X-1.4731 Y4.7716
X-2.1117 Y4.5255
X-2.7107 Y4.1944
X-3.259 Y3.7847
X-3.7461 Y3.3039
X-4.1629 Y2.761
X-4.5017 Y2.1663
X-4.7562 Y1.5309
X-4.9214 Y0.8668
G3 X-4.8593 Y-1.169 CR=4.9563
G1 X-4.6553 Y-1.8171
X-4.3653 Y-2.4316
X-3.9946 Y-3.0011
X-3.55 Y-3.515
X-3.0399 Y-3.9638
X-2.4736 Y-4.3394
X-1.8617 Y-4.6346
X-1.2153 Y-4.8441
X-0.5465 Y-4.9641
X0.1324 Y-4.9921
X0.8089 Y-4.9279
X1.4703 Y-4.7725
X2.1046 Y-4.5288
X2.7 Y-4.2013
X3.2454 Y-3.7961
X3.7309 Y-3.3206
X4.1473 Y-2.7838
X4.4871 Y-2.1953
X4.7234 Y-1.6311
X4.7344 Y-1.5989
G3 X4.7638 Y-0.3052 CR=2.5
G0 Z5.0001
X2.3358 Y-3.1702
Z-21
G1 Z-22 F200
G3 X4.6523 Y-1.6419 CR=2.5 F300
G1 X4.6701 Y-1.5997
X4.7255 Y-1.6199
X4.7271 Y-1.6204
X4.7344 Y-1.5989
X4.9131 Y-0.9082
X4.9915 Y-0.2332
X4.9775 Y0.4461
X4.8716 Y1.1173
X4.6747 Y1.7698
X4.3885 Y2.3915
X4.02 Y2.9682
X3.5762 Y3.4893
X3.0653 Y3.9448
X2.4971 Y4.3263
X1.8821 Y4.6266
X1.2318 Y4.8401
X0.5584 Y4.9628
X-0.1254 Y4.9923
X-0.8068 Y4.9282
X-1.4731 Y4.7716
X-2.1117 Y4.5255
X-2.7107 Y4.1944
X-3.259 Y3.7847
X-3.7461 Y3.3039
X-4.1629 Y2.761
X-4.5017 Y2.1663
X-4.7562 Y1.5309
X-4.9214 Y0.8668
G3 X-4.8593 Y-1.169 CR=4.9563
G1 X-4.6553 Y-1.8171
X-4.3653 Y-2.4316
X-3.9946 Y-3.0011
X-3.55 Y-3.515
X-3.0399 Y-3.9638
X-2.4736 Y-4.3394
X-1.8617 Y-4.6346
X-1.2153 Y-4.8441
X-0.5465 Y-4.9641
X0.1324 Y-4.9921
X0.8089 Y-4.9279
X1.4703 Y-4.7725
X2.1046 Y-4.5288
X2.7 Y-4.2013
X3.2454 Y-3.7961
X3.7309 Y-3.3206
X4.1473 Y-2.7838
X4.4871 Y-2.1953
X4.7234 Y-1.6311
X4.7344 Y-1.5989
G3 X4.7638 Y-0.3052 CR=2.5
G0 Z5.0001
X2.3358 Y-3.1702
Z-23
G1 Z-24 F200
G3 X4.6523 Y-1.6419 CR=2.5 F300
G1 X4.6701 Y-1.5997
X4.7255 Y-1.6199
X4.7271 Y-1.6204
X4.7344 Y-1.5989
X4.9131 Y-0.9082
X4.9915 Y-0.2332
X4.9775 Y0.4461
X4.8716 Y1.1173
X4.6747 Y1.7698
X4.3885 Y2.3915
X4.02 Y2.9682
X3.5762 Y3.4893
X3.0653 Y3.9448
X2.4971 Y4.3263
X1.8821 Y4.6266
X1.2318 Y4.8401
X0.5584 Y4.9628
X-0.1254 Y4.9923
X-0.8068 Y4.9282
X-1.4731 Y4.7716
X-2.1117 Y4.5255
X-2.7107 Y4.1944
X-3.259 Y3.7847
X-3.7461 Y3.3039
X-4.1629 Y2.761
X-4.5017 Y2.1663
X-4.7562 Y1.5309
X-4.9214 Y0.8668
G3 X-4.8593 Y-1.169 CR=4.9563
G1 X-4.6553 Y-1.8171
X-4.3653 Y-2.4316
X-3.9946 Y-3.0011
X-3.55 Y-3.515
X-3.0399 Y-3.9638
X-2.4736 Y-4.3394
X-1.8617 Y-4.6346
X-1.2153 Y-4.8441
X-0.5465 Y-4.9641
X0.1324 Y-4.9921
X0.8089 Y-4.9279
X1.4703 Y-4.7725
X2.1046 Y-4.5288
X2.7 Y-4.2013
X3.2454 Y-3.7961
X3.7309 Y-3.3206
X4.1473 Y-2.7838
X4.4871 Y-2.1953
X4.7234 Y-1.6311
X4.7344 Y-1.5989
G3 X4.7638 Y-0.3052 CR=2.5
G0 Z5.0001
X2.3358 Y-3.1702
Z-25
G1 Z-26 F200
G3 X4.6523 Y-1.6419 CR=2.5 F300
G1 X4.6701 Y-1.5997
X4.7255 Y-1.6199
X4.7271 Y-1.6204
X4.7344 Y-1.5989
X4.9131 Y-0.9082
X4.9915 Y-0.2332
X4.9775 Y0.4461
X4.8716 Y1.1173
X4.6747 Y1.7698
X4.3885 Y2.3915
X4.02 Y2.9682
X3.5762 Y3.4893
X3.0653 Y3.9448
X2.4971 Y4.3263
X1.8821 Y4.6266
X1.2318 Y4.8401
X0.5584 Y4.9628
X-0.1254 Y4.9923
X-0.8068 Y4.9282
X-1.4731 Y4.7716
X-2.1117 Y4.5255
X-2.7107 Y4.1944
X-3.259 Y3.7847
X-3.7461 Y3.3039
X-4.1629 Y2.761
X-4.5017 Y2.1663
X-4.7562 Y1.5309
X-4.9214 Y0.8668
G3 X-4.8593 Y-1.169 CR=4.9563
G1 X-4.6553 Y-1.8171
X-4.3653 Y-2.4316
X-3.9946 Y-3.0011
X-3.55 Y-3.515
X-3.0399 Y-3.9638
X-2.4736 Y-4.3394
X-1.8617 Y-4.6346
X-1.2153 Y-4.8441
X-0.5465 Y-4.9641
X0.1324 Y-4.9921
X0.8089 Y-4.9279
X1.4703 Y-4.7725
X2.1046 Y-4.5288
X2.7 Y-4.2013
X3.2454 Y-3.7961
X3.7309 Y-3.3206
X4.1473 Y-2.7838
X4.4871 Y-2.1953
X4.7234 Y-1.6311
X4.7344 Y-1.5989
G3 X4.7638 Y-0.3052 CR=2.5
G0 Z5.0001
X2.3358 Y-3.1702
Z-27
G1 Z-28 F200
G3 X4.6523 Y-1.6419 CR=2.5 F300
G1 X4.6701 Y-1.5997
X4.7255 Y-1.6199
X4.7271 Y-1.6204
X4.7344 Y-1.5989
X4.9131 Y-0.9082
X4.9915 Y-0.2332
X4.9775 Y0.4461
X4.8716 Y1.1173
X4.6747 Y1.7698
X4.3885 Y2.3915
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X3.5762 Y3.4893
X3.0653 Y3.9448
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X-0.8068 Y4.9282
X-1.4731 Y4.7716
X-2.1117 Y4.5255
X-2.7107 Y4.1944
X-3.259 Y3.7847
X-3.7461 Y3.3039
X-4.1629 Y2.761
X-4.5017 Y2.1663
X-4.7562 Y1.5309
X-4.9214 Y0.8668
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X-4.3653 Y-2.4316
X-3.9946 Y-3.0011
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X-3.0399 Y-3.9638
X-2.4736 Y-4.3394
X-1.8617 Y-4.6346
X-1.2153 Y-4.8441
X-0.5465 Y-4.9641
X0.1324 Y-4.9921
X0.8089 Y-4.9279
X1.4703 Y-4.7725
X2.1046 Y-4.5288
X2.7 Y-4.2013
X3.2454 Y-3.7961
X3.7309 Y-3.3206
X4.1473 Y-2.7838
X4.4871 Y-2.1953
X4.7234 Y-1.6311
X4.7344 Y-1.5989
G3 X4.7638 Y-0.3052 CR=2.5
G0 Z5.0001
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Z-27.8

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X-3.9946 Y-3.0011
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X-2.8864 Y-7.3264 Z1.6217 A3=-0.266909 B3=-0.654899 C3=0.707012

X-2.6467 Y-7.4209 Z1.6217 A3=-0.245326 B3=-0.663325 C3=0.706976

X-2.8697 Y-8.0239 Z2.2644 A3=-0.245326 B3=-0.663325 C3=0.706976

X-3.0928 Y-8.6269 Z2.9071 A3=-0.245326 B3=-0.663325 C3=0.706976

X-3.3158 Y-9.2299 Z3.5498 A3=-0.245326 B3=-0.663325 C3=0.706976

X-3.5388 Y-9.833 Z4.1925 A3=-0.245326 B3=-0.663325 C3=0.706976

X-3.7618 Y-10.436 Z4.8352 A3=-0.245326 B3=-0.663325 C3=0.706976

X-3.9849 Y-11.039 Z5.4779 A3=-0.245326 B3=-0.663325 C3=0.706976

X-4.2079 Y-11.642 Z6.1206 A3=-0.245326 B3=-0.663325 C3=0.706976

X-4.4309 Y-12.245 Z6.7634 A3=-0.245326 B3=-0.663325 C3=0.706976

X-4.6539 Y-12.8481 Z7.4061 A3=-0.245326 B3=-0.663325 C3=0.706976

X-4.8769 Y-13.4511 Z8.0488 A3=-0.245326 B3=-0.663325 C3=0.706976

X-5.1 Y-14.0541 Z8.6915 A3=-0.245326 B3=-0.663325 C3=0.706976

G0 X-7.5532 Y-20.6874 Z15.7612 A3=-0.245326 B3=-0.663325 C3=0.706976

X-7.5532 Y-20.6874 Z150 A3=-0.245326 B3=-0.663325 C3=0.706976

X-10.6371 Y-9.1755 Z140.2763 A3=-0.399246 B3=-0.526481 C3=0.750613

X-8.5858 Y0.3745 Z130.2979 A3=-0.495017 B3=-0.358485 C3=0.791484

X-3.2818 Y6.4394 Z120.2071 A3=-0.528445 B3=-0.181593 C3=0.829319

X3.1527 Y8.5207 Z110.1431 A3=-0.503411 B3=-0.01748 C3=0.86387

```
X8.8009 Y7.0706 Z100.2398 A3=-0.431014 B3=0.11559 C3=0.894911
X12.3008 Y3.2536 Z90.625 A3=-0.327749 B3=0.20508 C3=0.922238
X13.0493 Y-1.397 Z81.4184 A3=-0.212974 B3=0.245657 C3=0.945671
X11.2366 Y-5.3569 Z72.7308 A3=-0.106027 B3=0.239629 C3=0.965058
X7.7218 Y-7.4479 Z64.6624 A3=-0.023403 B3=0.196276 C3=0.980269
X3.786 Y-7.0777 Z57.3022 A3=0.023608 B3=0.130199 C3=0.991207
X0.8183 Y-4.3451 Z50.7269 A3=0.030482 B3=0.058905 C3=0.997798
S10000
X0 Y0 Z45 A3=0 B3=0 C3=1
TRAFOOF     ;  TRAORI off
CYCLE832 (0, 0, 1);  Deselect CYCLE832
;
; Workplane for hole.Workplane for hole
CYCLE800 ()
G54
CYCLE800(0,"DMG",0,39,26.5,0,-20,0,0,90,0,0,0,1)
;
G0 X0
Z2
G17
G1 Z-0.1 F100
G0 Z60
; Top. Top
CYCLE800 ()
CYCLE800(0,"DMG",0,57,0,0,0,0,0,0,0,0,1)
CYCLE800 ()
G54
;
G64
TRAFOOF
ROT
TRANS
CYCLE800 ()
T0
M6
M30
```

Part 5 – Main Body

```
PART 5 – Main Body |
%
O0001
(PART5 OP2 BEARING HOUSING)
(EDISON)
N10 G92 S2500
N30 G96 T0303 S180 M3
(ROUGH TURNING)
N50 G0 Z70.014
N60 G95 X84.726
N70 X82.726
N80 G1 Z42.45 F0.1 M8
N90 X84.726
N100 G0 X94.726
N110 Z70.014
N120 X80.726
N130 G1 Z42.45
N140 X82.726
N150 G0 X92.726
N160 Z70.014
N170 X78.726
N180 G1 Z42.45
N190 X80.726
N200 G0 X90.726
N210 Z70.014
N220 X76.726
N230 G1 Z42.45
N240 X78.726
N250 G0 X88.726
N260 Z70.014
N270 X74.726
N280 G1 Z50.085
N290 X74.789 Z50.065
N300 G3 X75.031 Z49.966 R0.8
N310 G1 X75.531 Z49.716
N320 G3 X76.0 Z49.15 R0.8
N330 G1 Z42.45
N340 X76.726
N350 G0 X86.726
N360 Z70.014
N370 X72.726
N380 G1 Z50.2
N390 X73.9
N400 G3 X74.726 Z50.085 R0.8
N410 G0 X84.726
N420 Z70.014
N430 X70.726
N440 G1 Z50.2
N450 X72.726
N460 G0 Z70.014
N470 X68.726
N480 G1 Z50.2
N490 X70.726
N500 G0 Z70.014
N510 X66.726
N520 G1 Z50.2
N530 X68.726
N540 G0 Z70.014
N550 X64.726
N560 G1 Z50.2
N570 X66.726
N580 G0 Z70.014
N590 X62.726
N600 G1 Z50.2
N610 X64.726
N620 G0 Z70.014
N630 X60.726
N640 G1 Z50.2
N650 X62.726
N660 G0 Z70.014
N670 X58.726
N680 G1 Z50.2
N690 X60.726
N700 G0 Z70.014
N710 X56.726
N720 G1 Z50.2
N730 X58.726
N740 G0 Z70.014
N750 X54.726
N760 G1 Z50.2
N770 X56.726
N780 G0 X66.726
N790 Z70.014
N800 X52.726
N810 G1 Z50.2
N820 X54.726
N830 G0 X64.726
N840 Z70.014
N850 X50.726
N860 G1 Z50.2
N870 X52.726
N880 G0 X62.726
N890 Z70.014
N900 G1 X48.726
N910 Z50.2
N920 X50.726
N930 G0 X60.726
N940 Z70.014
N950 G1 X46.726
N960 Z50.541
N970 G2 X48.4 Z50.2 R1.2
N980 G1 X48.726
N990 G0 X58.726
N1000 Z70.014
N1010 G1 X44.726
N1020 Z65.118
N1030 X45.531 Z64.716
N1040 G3 X46.0 Z64.15 R0.8
N1050 G1 Z51.4
N1060 G2 X46.726 Z50.541 R1.2
N1070 G0 X56.726
N1080 Z70.014
N1090 G1 X42.726
N1100 Z66.118
N1110 X44.726 Z65.118
N1120 G0 X54.726
N1130 Z70.014
N1140 G1 X42.203
N1150 Z66.38
N1160 X42.726 Z66.118
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N1170 G0 X84.726
N1180 Z70.014
N1190 Z67.439
N1200 X48.233
N1210 G1 Z66.939
N1220 X23.4
N1230 Z67.439
N1240 G0 Z72.439
N1250 X48.233
N1260 G1 Z66.439
N1270 X23.4
N1280 Z66.939
N1290 G0 Z71.939
N1300 X48.233
N1310 G1 Z65.939
N1320 X23.4
N1330 Z66.439
N1340 G0 Z71.439
N1350 X48.233
N1360 G1 Z65.439
N1370 X23.4
N1380 Z65.939
N1390 G0 Z70.939
N1400 X48.233
N1410 G1 Z65.0
N1420 X23.4
N1430 Z65.439
N1440 G0 Z72.439
N1450 X48.233
N1460 Z67.439
N1470 M400
N1480 Z72.544
N1490 X42.617
N1500 G2 X39.688 Z69.008 R5.0 F0.08
N1510 X42.617 Z65.473 R5.0
N1520 G1 X44.531 Z64.516
N1530 G3 X45.0 Z63.95 R0.8
N1540 G1 Z51.2
N1550 G2 X47.4 Z50.0 R1.2
N1560 G1 X72.9
N1570 G3 X74.031 Z49.766 R0.8
N1580 G1 X74.531 Z49.516
N1590 G3 X75.0 Z48.95 R0.8
N1600 G1 Z43.45
N1610 M9 M5
N1620 G28 U0.
N1630 G28 W0.
N1640 G96 T0606 S180 M3
(A16 .4 TNR BORING BAR 20 MM
MIN BORE)
N1660 G95 Z70.0
N1670 X25.0
N1680 X25.056
N1690 Z68.565
N1700 X26.056
N1710 G1 Z20 F0.1 M8
N1720 X25.056
N1730 G0 Z68.565
N1740 X27.056
N1750 G1 Z20
N1760 X26.056
N1770 G0 Z68.565
N1780 X28.056
N1790 G1 Z20
N1800 X27.056
N1810 G0 Z68.565
N1820 X29.056
N1830 G1 Z20
N1840 X28.056
N1850 G0 X26.056
N1860 Z68.565
N1870 X30.056
N1880 G1 Z49.46
N1890 G2 X29.6 Z49.1 R0.4
N1900 G1 Z20
N1910 X29.056
N1920 G0 X27.056
N1930 Z68.565
N1940 X31.056
N1950 G1 Z49.5
N1960 X30.4
N1970 G2 X30.094 Z49.47 R0.4
N1980 G1 X30.056 Z49.46
N1990 G0 X28.056
N2000 Z68.565
N2010 X32.056
N2020 G1 Z49.5
N2030 X31.056
N2040 G0 Z68.565
N2050 X33.056
N2060 G1 Z49.5
N2070 X32.056
N2080 G0 Z68.565
N2090 X34.056
N2100 G1 Z49.5
N2110 X33.056
N2120 G0 X31.056
N2130 Z68.565
N2140 X35.056
N2150 G1 Z64.494
N2160 X34.834 Z64.383
N2170 G2 X34.6 Z64.1 R0.4
N2180 G1 Z49.5
N2190 X34.056
N2200 G0 X32.056
N2210 Z68.565
N2220 X36.056
N2230 G1 Z64.994
N2240 X35.056 Z64.494
N2250 G0 X33.056
N2260 Z68.565
N2270 X36.534
N2280 G1 Z65.233
N2290 X36.056 Z64.994
N2300 G0 X25.056
N2310 Z68.565
N2320 M401
N2330 Z72.661
N2340 X38.649
N2350 G3 X41.577 Z69.125 R5.0 F0.08
N2360 X38.649 Z65.59 R5.0
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N2370 G1 X35.234 Z63.883
N2380 G2 X35.0 Z63.6 R0.4
N2390 G1 Z49.0
N2400 X30.8
N2410 G2 X30.0 Z48.6 R0.4
N2420 G1 Z23.64
N2430 G3 X20.0 Z18.64 R5.0
N2440 G0 Z80.0
N2450 M9 M5
N2460 G28 U0.
N2470 G28 W0.
N2480 M30
%
```

Part 10 – Plate

```
PART 10 - Plate
* UPPER TURRET
%
O0001 (MX UPPER TURRET)
PART10
N10 G92 S2500
N20 G00 X110.0 Z170.0
N30 G96 T0404 S415 M3 (PCLNL-2525-M12 WITH CNMG-120408)
N40 (ROUGH TURNING)
N50 G0 X115.376
N60 G95 Z1.759
N70 X109.866
N80 G1 X105.866 F0.3 M8
N90 Z-9.3
N100 X111.376
N110 G0 Z-8.5
N120 Z1.759
N130 X104.356
N140 G1 X100.356
N150 Z-9.3
N160 X105.866
N170 G0 Z-8.5
N180 Z1.759
N190 X98.847
N200 G1 X94.847
N210 Z-9.3
N220 X100.356
N230 G0 Z-8.5
N240 Z1.759
N250 X93.337
N260 G1 X89.337
N270 Z-9.3
N280 X94.847
N290 G0 Z-8.5
N300 Z1.759
N310 G1 X83.827
N320 Z-9.3
N330 X89.337
N340 G0 Z-8.5
N350 X99.337
N360 Z1.759
N370 G1 X78.317
N380 Z0.673
N390 X80.731 Z-0.534
N400 G3 X81.2 Z-1.1 R0.8
N410 G1 Z-9.3
N420 X83.827
N430 G0 Z-8.5
N440 X115.376
N450 Z1.759
N460 (FINISH TURNING)
N470 Z7.544
N480 X77.117
N490 G2 X74.188 Z4.008 R5.0 F0.15 S350
N500 X77.117 Z0.473 R5.0
N510 G1 X79.531 Z-0.734
N520 G3 X80.0 Z-1.3 R0.8
N530 G1 Z-7.8
N540 X120.0
N550 M9 M5
N560 G28 U0.
N570 G28 W0.
N580 M400
N1(4.0 MM DIA JOBBER DRILL)
N590 G28 U0 W0
N600 G94 G80 G40
N610 T06[LENGTHOFFSET]
N620 (LOW GEAR)
N630 G54M35
N640 G17
N650 G97 S1000 M203
N660 G0 Z5.2 C0.0 G97 M203
N670 G0 X110.0 M8
N680
N690 X64.0 C-90.0 F100.0
N700 Z2.5
N710 G1 Z-8.202
N720 G0 Z5.2
N730 C-210.0
N740 Z2.5
N750 G1 Z-8.202
N760 G0 Z5.2
N770 C-330.0
N780 Z2.5
N790 G1 Z-8.202
N800 G0 Z5.0
N810 G49
N820M69
N830 G28 U0. M205
N840 G28 V0. W0.
N850 M401
N860 G97 T0808 M203 (5.0 MM DIA JOBBER DRILL)
N2(5.0 MM DIA JOBBER DRILL)
N870 G28 U0 W0
N880 G94 G80 G40
N890 T08 [LENGTHOFFSET]
N900 (LOW GEAR)
N910 G54M35
N920 G17
N930
N940 G0 Z5.2 C-360.0 G97 M203
N950 G0 X110.0 M8
N960
N970 X60.0 C-420.0 F100.0
N980 Z2.5
N990 G1 Z-8.502
N1000 G0 Z5.2
N1010 C-480.0
N1020 Z2.5
N1030 G1 Z-8.502
N1040 G0 Z5.2
N1050 C-540.0
N1060 Z2.5
N1070 G1 Z-8.502
N1080 G0 Z5.2
N1090 C-600.0
N1100 Z2.5
N1110 G1 Z-8.502
N1120 G0 Z5.2
N1130 C-660.0
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N1140 Z2.5
N1150 G1 Z-8.502
N1160 G0 Z5.2
N1170 C-720.0
N1180 Z2.5
N1190 G1 Z-8.502
N1200 G0 Z5.0
N1210 G49
N1220M69
N1230 G28 U0. M205
N1240 G28 V0. W0.
N1250 M402
N1260 (PART OFF OPERATION)
N1270 Z-5.0
N1280 G95 X82.0
N1290 G1 X80.4 F0.12 S800 M3
N1300 X41.2
N1310 X78.8
N1320 X40.4
N1330 X77.2
N1340 X39.6
N1350 X75.6
N1360 X38.8
N1370 X74.0
N1380 X38.0
N1390 X72.4
N1400 X37.2
N1410 X70.8
N1420 X36.4
N1430 X69.2
N1440 X35.6
N1450 X67.6
N1460 X34.8
N1470 X66.0
N1480 X34.0
N1490 X64.4
N1500 X33.2
N1510 X62.8
N1520 X32.4
N1530 X61.2
N1540 X31.6
N1550 X59.6
N1560 X30.8
N1570 X58.0
N1580 X30.0
N1590 X56.4
N1600 X29.2
N1610 X54.8
N1620 X28.4
N1630 X53.2
N1640 X27.6
N1650 X51.6
N1660 X26.8
N1670 X50.0
N1680 X26.0
N1690 X48.4
N1700 X25.2
N1710 X46.8
N1720 X24.4
N1730 X45.2
N1740 X23.6
N1750 X43.6
N1760 X22.8
N1770 X42.0
N1780 X22.0
N1790 X40.4
N1800 X21.2
N1810 X20.0
N1820 M9 M5
N1830 G28 U0.
N1840 G28 W0.
N1850 M403
N1860 M30
%
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Part 11 – Shaft

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PART 11 - Shaft
* UPPER TURRET
%
O0001 (MX UPPER TURRET)
PART11
N10 G92 S2500
N20 G00 X310.0 Z200.0
N30 G96 T0404 S415 M3 (PCLNL-2525-M12 WITH CNMG-120408)
N40 G0 Z5.713
N50 G95 X48.597
N60 X43.129
N70 G1 Z-158.059 F0.3 M8
N80 X48.597
N90 G0 Z5.713
N100 X37.66
N110 G1 Z-158.059
N120 X43.129
N130 G0 Z5.713
N140 X32.191
N150 G1 Z-158.059
N160 X37.66
N170 G0 Z5.713
N180 X26.723
N190 G1 Z-158.059
N200 X32.191
N210 G0 X42.191
N220 Z5.713
N230 X21.254
N240 G1 Z-127.78
N250 G3 X21.382 Z-128.028 R0.8
N260 G1 X26.636 Z-158.059
N270 X26.723
N280 G0 X36.723
N290 Z5.713
N300 X15.786
N310 G1 Z-40.306
N320 X15.986 Z-40.479
N330 G3 X16.2 Z-40.879 R0.8
N340 G1 Z-111.569
N350 X17.731 Z-112.334
N360 G3 X18.2 Z-112.9 R0.8
N370 G1 Z-126.8
N380 X18.601
N390 G3 X19.629 Z-126.987 R0.8
N400 G1 X20.816 Z-127.485
N410 G3 X21.254 Z-127.78 R0.8
N420 G0 X31.254
N430 Z5.713
N440 X10.317
N450 G1 Z0.673
N460 X13.731 Z-1.034
N470 G3 X14.2 Z-1.6 R0.8
N480 G1 Z-38.932
N490 X15.786 Z-40.306
N500 G0 X48.597
N510 Z5.713
N520 (FINISH TURNING)
N530 Z7.544
N540 X9.117
N550 G2 X6.188 Z4.008 R5.0 F0.15 S350
N560 X9.117 Z0.473 R5.0
N570 G1 X12.531 Z-1.234
N580 G3 X13.0 Z-1.8 R0.8
N590 G1 Z-39.132
N600 X14.786 Z-40.679
N610 G3 X15.0 Z-41.079 R0.8
N620 G1 Z-111.769
N630 X16.531 Z-112.534
N640 G3 X17.0 Z-113.1 R0.8
N650 G1 Z-127.0
N660 X17.401
N670 G3 X18.429 Z-127.187 R0.8
N680 G1 X19.616 Z-127.685
N690 G3 X20.182 Z-128.228 R0.8
N700 G1 X25.349 Z-157.761
N710 X65.197 Z-156.018
N720 M9 M5
N730 G28 U0.
N740 G28 W0.
N750 M400
N760 G96 T0101 S200 M3 (12MM BUTTON TOOL)
N770 (GROVE ROUGH)
N780 G0 Z-59.338
N790 G95 X25.0
N800 G1 X15.0 F0.2 M8
N810 X14.4 Z-59.858
N820 Z-102.242
N830 X14.792 Z-102.582
N840 X15.0
N850 G0 Z-101.702
N860 X27.36
N870 Z-59.338
N880 X25.0
N890 M9 M5
N900 G28 U0.
N910 G28 W0.
N920 M401
N930 G96 T1212 S500 M3 (1MM EXT GROOVE B 45)
N940 X14.56 Z0.0
N950 G95 Z-38.447
N960 G1 X12.8 F0.2 M8
N970 X11.0
N980 Z-38.547
N990 X11.2
N1000 X12.96
N1010 G0 X14.56
N1020 G1 X12.8
N1030 X11.0
N1040 Z-38.447
N1050 X12.76
N1060 G0 X14.56
N1070 M9 M5
N1080 G28 U0.
N1090 G28 W0.
N1100 M402
N1110 G96 T0202 S200 M3 (3MMPARTOFFREACH52)
N1120 (PART OFF OPERATION)
N1130
N1140 Z-155.0
```

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N1150 G95 X25.0
N1160 G1 X23.4 F0.1 M8
N1170 G0 X25.0
N1180 X25.4
N1190 G1 X21.8
N1200 G0 X25.0
N1210 X23.8
N1220 G1 X20.2
N1230 G0 X25.0
N1240 X22.2
N1250 G1 X18.6
N1260 G0 X25.0
N1270 X20.6
N1280 G1 X17.0
N1290 G0 X25.0
N1300 X19.0
N1310 G1 X15.4
N1320 G0 X25.0
N1330 X17.4
N1340 G1 X13.8
N1350 G0 X25.0
N1360 X15.8
N1370 G1 X12.2
N1380 G0 X25.0
N1390 X14.2
N1400 G1 X10.6
N1410 G0 X25.0
N1420 X12.6
N1430 G1 X9.0
N1440 G0 X25.0
N1450 X11.0
N1460 G1 X7.4
N1470 G0 X25.0
N1480 X9.4
N1490 G1 X5.8
N1500 G0 X25.0
N1510 X7.8
N1520 G1 X4.2
N1530 G0 X25.0
N1540 X6.2
N1550 G1 X2.6
N1560 G0 X25.0
N1570 X4.6
N1580 G1 X1.0
N1590 G0 X25.0
N1600 X3.0
N1610 G1 X-0.6
N1620 G0 X25.0
N1630 X1.4
N1640 G1 X-2.2
N1650 G0 X25.0
N1660 X-0.2
N1670 G1 X-3.8
N1680 G0 X25.0
N1690 X-1.8
N1700 G1 X-2.0
N1710 M9 M5
N1720 G28 U0.
N1730 G28 W0.
N1740 M403
N1750 M30
%
```

Appendix 3 – Excursion report




On 04.02.2018, there was an academic technical visit to Chongqing .This academic visit is a part of the join collaborative project Study of atmospheric icing on structures in high north between The Arctic University of Norway and Chongqing University. The project is funded by the Norwegian Center for International Cooperation in Education (SIU).

The purpose of the excursion was to gain an insight into how anti-icing and de-icing system take place in practice and the ice accretion. The excursion was completed a little on the project. By doing so we could quiet relevant questions that had appeared along the way while we had it necessary theoretical background to understand the processes that took place.

We departed from Narvik at 08:48. The journey took about 15 hours, and as agreed we met at the airport in Chongqing. Here we were welcomed by the professor Hu Qin, then the next day we went to the research station localized in Xuefeng Mountain. First, we got an introduction about the equipment and the experiments that can be done in the station and how they are related to our study and thesis.

After this we made a schedule of the experiments in the station: Related to the thesis topic as ice accretion on the conductors over the time in a realistic scenario and evaluate the working principle of the solution for anti-icing and de-icing on the conductors. Based on the weather predictions we started the experiments, but unfortunately the climatic conditions for the experiments were not given. We did an experiment of flash over insulator with only ice and with ice and pollution which relates to our study. Finally, we visited the laboratory of the University of Chongqing and we received information about the equipment and the experiments that are carried out there.

We were very well received and the visit was very educational. Excursions also gave a great deal motivation to continue the further work on the task. In addition, the visit provided a lot of important information regarding anti-icing and de-icing systems. We came back to Norway on 24.02.2018. Twenty one days were allocated for the excursion.