CONCEPTUAL DESIGN OF THE ACUSTICAL MEASSUREMENT TEST RIG

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1. Abstract

We have to design the mechanical part of a machine that can measure the sound pressure in a hemispherical surface of 2m of diameter.

We'll analyse how with the sound pressure we can get the sound power. The steps that we have to do depend of the system that we are analysing. In our case is always the same kind of system.

To design the model of the real machine in 3D we'll use the program solid works.

The last step and with the same program we are going to simulate the movements that the machine can do to position in the entire surface where we have to be able to measure.

2. Introduction

The problem that we should search solution is how we can measure the sound pressure in the hemispherical surface of two meters of diameter.

We want to measure the sound power. To get the sound power we should measure the sound pressure with a microphone. With the sound pressure and some correlations that will be explained later in this project we'll calculate the sound power.

First of all we'll think how we can get to all coordinates of this surface. We should think how we can position the microphone in all this surface, our positioned error should be less than 1º.

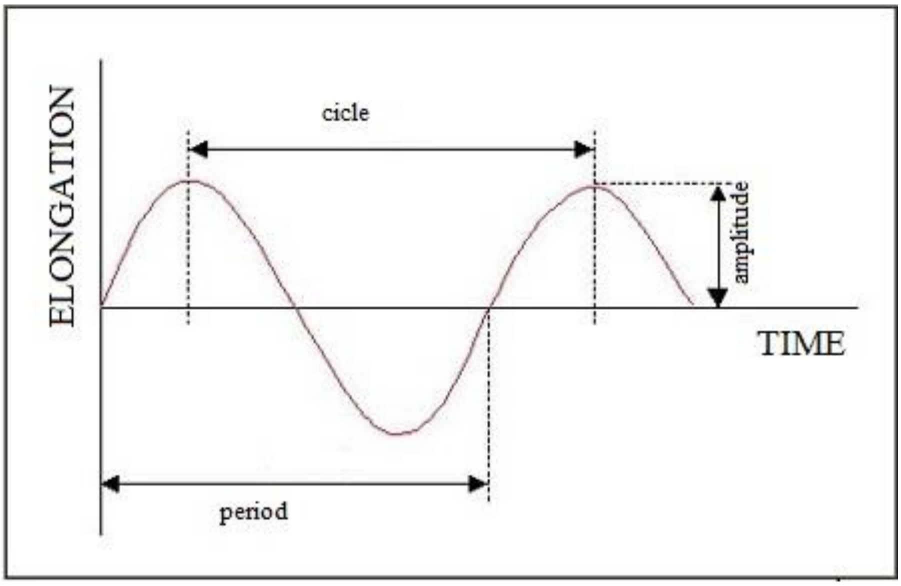
After choose how will be our solution, we have to design the model in designing 3D software. In our case we'll use solid works to do that. For choose the dimensions we have to think about the forces that will be appear in our structure, we have to analyse the static forces thinking about what materials we'll use.

The last step is how we'll get movement to the parts that we need to position the microphone in the correct coordinates. In this step we should choose the motor focusing in the motor torque and the dimensions of our structure.

3. Sound introduction

3.1. Wave parameters

Period (T): it's the time that one complete cycle of the sound wave take. The measure unit is second.



Picture 1: Wave parameters

Frequency (f): it's the number of cycles in one second. So it's the inverse of the period. The measure unit is 1/s.

$$f = \frac{1}{T}$$

Sound velocity (c): it's the velocity that the wave sound spread in an elastic medium, and only depends about the characteristics of this one. The measure unit is m/s.

Below are two examples of tables with propagation velocities of the wave sound in different environments and given conditions:

Table 1: Solids and liquids in normal conditions of P and Tª

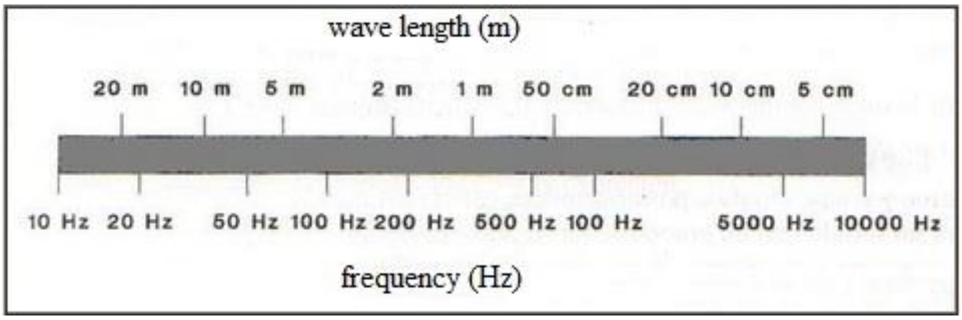
Substance	**Density (Kg/m^3)**	**Speed "*c*" (m/s)**
Aluminum	*2700*	*5104*
Copper	*8900*	*3560*
Steal	*7800*	*5000*
Marble	*2700*	*3810*
Water	*998*	*1473*
Sea water	*1020*	*1460*
Ethyl alcohol	*790*	*1220*
Gasoline	*700*	*1166*

Table 2: Gas in normal conditions of P and Tª

Substance	**Density (Kg/m^3)**	**Speed "*c*" (m/s)**
Hidrogen	*0,09*	*1262*
Water vapour	0,808	*401*
Air	*1,293*	*344*
Oxigen	*1,430*	*317,2*
Chlorine	*3,220*	*206,4*

Wave lenght (λ): it’s the distance between similar points in two successive waves. The wave length is relation with the sound speed, frequency and period, by this expression:

$$\lambda = \frac{c}{f} = c \cdot T$$



Picture 2: wave length and frequency

3.2. Sound qualities

Intensity: it's related with the wave amplitude. We can classify the sound in loud or weak.

Tone: it's related with the frequency. It's a quality that we can tell if the sound is bass or skirl.

Timbre: it's related with the harmonics included in a sound wave. Quality by which we can distinguish two sounds of equal intensity and the same tone that have been issued by different sound sources.

3.3. Sound pressure RMS

When a sound wave propagates in an elastic medium such as air, it creates a pressure variation on the existing ambient pressure. This variation of pressure is extremely useful for characterizing the sound wave and which can easily measure.

Suppose we have a pure tone, a sound that his pressure variations depend on a single frequency, denoted f, whose pressure variation is sinusoidal and is given by the expression:

$$P(t) = P_0 \cdot sen(w \cdot t);\ w \cdot t = 2 \cdot \pi \cdot f$$

The instantaneous value of the pressure p (t) would not be adequate to characterize the wave as it varies continuously with time.

We could consider using the average value given by the expression:

$$P_{average} = \frac{1}{2 \cdot \pi} \int_0^{2\pi} P_0 \cdot sen(\alpha \cdot t) dt = 0$$

The average value not serves to characterize the waveform.

The valid parameter is the effective value (RMS: root mean square), defined as:

$$P_{rms} = \sqrt{\frac{1}{T}\int_0^T p^2(t)dt}$$

For a pure tone (sine wave) the RMS value is equal to:

$$P_{rms} = \sqrt{\frac{1}{T}\int_0^{2\pi} (P_0 \cdot sen(\alpha \cdot t))^2 dt} = \frac{P_0}{\sqrt{2}}$$

Moreover, it can be shown that the energy of the sound wave is proportional to the square of the pressure value. For this reason it’s an easily measurable magnitude, we will use from now on, the pressure sound effective value as the basic parameter that quantifies the sound wave.

3.4. Sound intensity

It’s convenient to clarify the distinction between real or physical intensity of sound loudness of the sound produced by this particular agent.

Physically, the intensity is defined as the amount of energy that passes through the surface unit per second positioned perpendicular to the direction of propagation of the sound wave.

$$I = \frac{Energy}{Time \times Area} \text{ [W/m}^2\text{]}$$

If the focus issues in an isotropic medium (equally in all directions), we know the power at all points of the surface of a sphere of radius r, if we know the intensity of the emitting source:

$$Power = I \cdot 4 \cdot \pi \cdot r^2$$

A sound wave can be characterized by:

- The displacement which produces particles of the medium.
- The particle speed (u)
- The wave pressure (p)

Depending on the velocity and pressure, the intensity can be expressed as:

$I = u \times p \times \cos(j)$ (Being j the phase angle between u and p)

$$u = \frac{p}{\rho \cdot c}$$

Where: ρ = density of the medium (kg/m^3)
c = sound speed in the medium (m/s)

$$I = \frac{p^2}{\rho \cdot c} \cdot \cos(j)$$

If j=90º, cos (j) = 0 therefore I = 0

This formula shows us that a perpendicular direction with the propagation direction, the intensity is null.

3.4.1. Acoustic intensity level

Symbol: L_I
Unit: decibel (dB) ($I_{ref} = I_0 = 10^{-12}$ w/m^2)

It's defined with this expression:

$$L_I = 10 \cdot \log\left(\frac{I}{I_0}\right)$$

3.5.Sound power

It's defined like the energy issued in a time unit by determinate sound source.

Taking the definition of sound intensity:

$$I_{mean} = \frac{Energy}{Time \times Area} = \frac{Power}{Area} = \frac{W}{S}$$

For a sphere: $S = 4\pi R^2$

$$I_{mean} = \frac{W}{4\pi R^2} \Rightarrow W = I_{mean} \cdot 4\pi R^2$$

$$I_{mean} = \frac{p^2}{10 \cdot \rho \cdot c}$$

$$W = \frac{p^2}{10 \cdot \rho \cdot c} \cdot 4\pi R^2$$

Table 3: examples of pressure and power sound

	Power	**Pressure level (dB)**
Plane reactor	10 kilowatios	160
Pneumatic Hammer	1 watio	120
Car at 72 Km/h	0,1 watio	110
Piano	20 miliwatios	103
Normal conversation	20 µwatios	73
Electric clock	0,02 µwatios	43
Whisper	0,00 µwatios	30

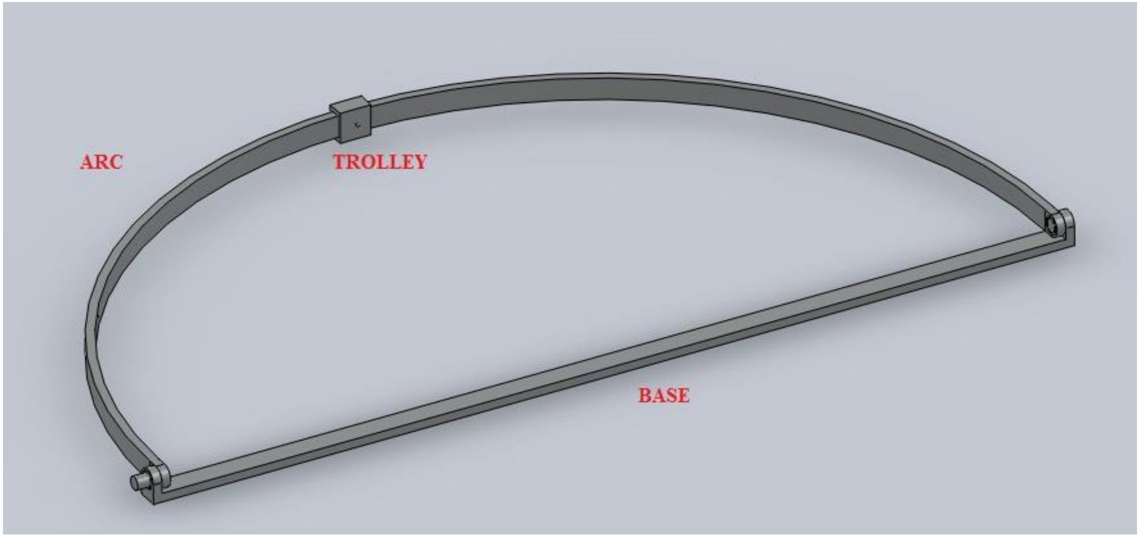
Reference sound power: $W_0 = 10^{-12}$ W

Sound power level:

$$L_w = 10 \cdot \log\left(\frac{W}{W_0}\right) = 10 \cdot \log(W) - 10 \cdot \log(W_0) = 10 \cdot \log(W) + 120$$

4. Description of the machine

The solution that we had thought for the problem that had been presented at the beginning of this project is based mainly in three parts: Base, arc and trolley. Then we need some additional pieces for the contacts between the different pieces like bearings, gear, etc.



Picture 3: Solution model

We think in this solution because only with move two components of our machine we can get the position where we want to measure the sound pressure. There are more solutions to solve the problem but we choose this one because in the ideas appear the one with less material, easier to build and in both case the cheapest one.

Other option was a crane and a rope with the microphone, but mainly the accuracy to be in the good position where we want to measure the sound pressure isn't so reliable.

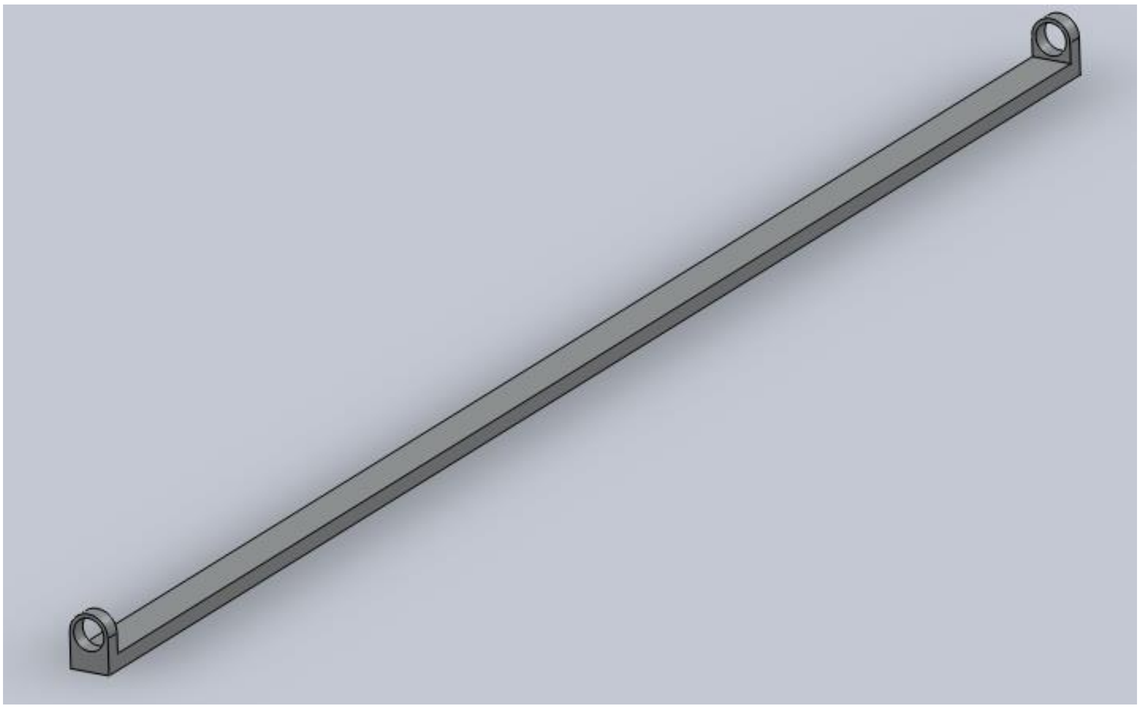
Other one was a hydraulic lift from the ground, but in this idea appear two main problems the first one hydraulic machine is expensive and they need a lot of maintenance. The second problem is how to get to the position over the vacuum cleaner.

When we think about our idea haven't this problems that we find in the others ideas. In this way we start to design this idea. We can get to all the coordinates with only two movements, mainly only have three components and the joining elements for had soft movements and less friction. This machine is easy to automate with only two degrees of freedom.

The base will be the connection with the ground to fix the machine, and it's the element that supports the arc and the actions of the motor. The connection between the base and the arc will be with bearings. We will use cylindrical-bearings for this connection. The chosen material to build the base has been aluminium alloy 1060 of the library of solid work. This material has the next properties:

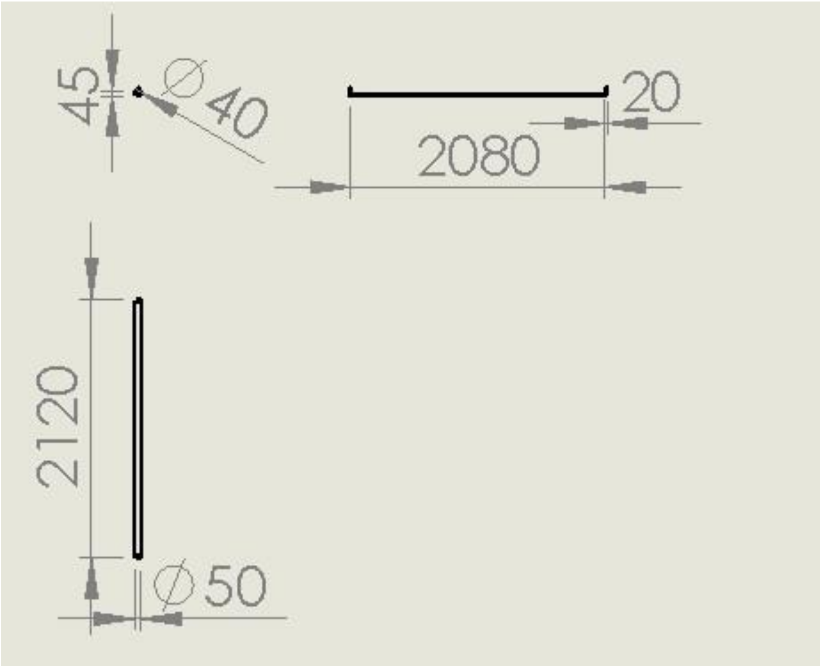
Table 4: properties of aluminium alloy 1060

PROPERTY	VALUE	UNITS
Elastic module	6,9E+10	N/m^2
Poisson coefficient	0,33	N/D
Shear module	2,7E+10	N/m^2
Density	2700	Kg/m^3
Traction limit	68935600	N/m^2
Elastic limit	27574200	N/m^2
Thermal expansion coefficient	2,4E-5	1/K
Thermal conductivity	200	W/m·K
Specific heat	900	J/Kg·K



Picture 4: Base design

To design the base we choose the next dimensions that we can watch in the picture.



Picture 5: Base measures

Table 5: Physical properties of the base

PROPERTY	VALUE	UNITS
Mass	3,582	Kg
Volume	0,001327	m^3
Surface area	0,51966858	m^2

The arc will be the support of the trolley. The arc will have an oscillating movement to get to the first coordinate of the position that we will want to get. This movement have the amplitude of 180º and the velocity of the movement will be controlled by the engine that will be descripted later. The chosen material to build the arc has been aluminium alloy 1060 of the library of solid work. This material has the next properties:

Table 6: Properties of aluminium alloy 1060

PROPERTY	VALUE	UNITS
Elastic module	6,9E+10	N/m^2
Poisson coefficient	0,33	N/D
Shear module	2,7E+10	N/m^2
Density	2700	Kg/m^3
Traction limit	68935600	N/m^2
Elastic limit	27574200	N/m^2
Thermal expansion coefficient	2,4E-5	1/K
Thermal conductivity	200	W/m·K
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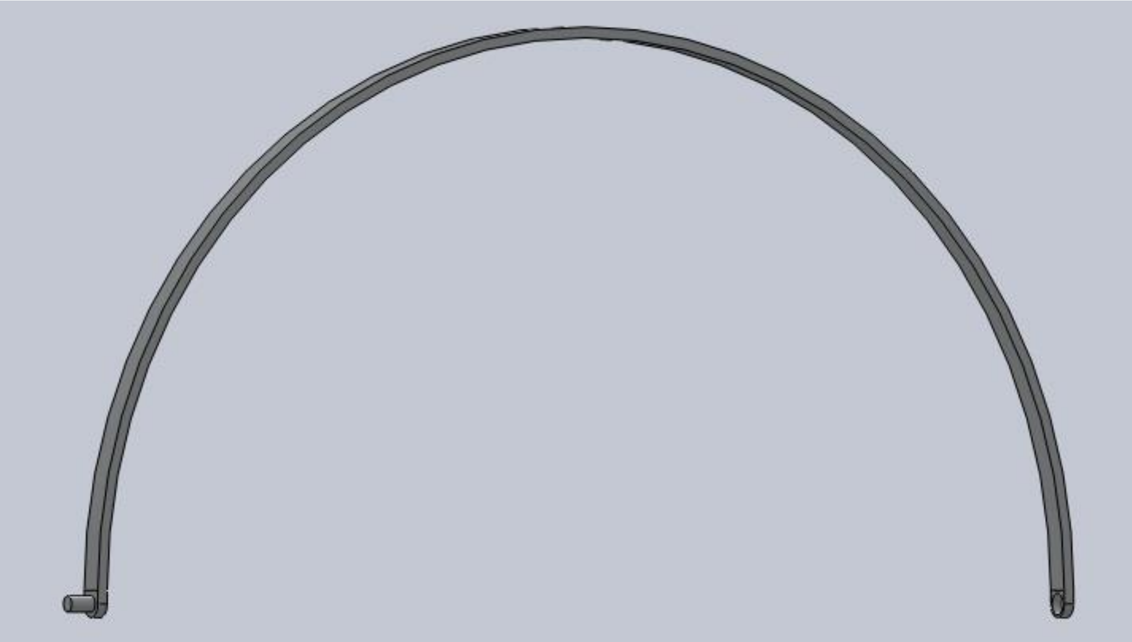
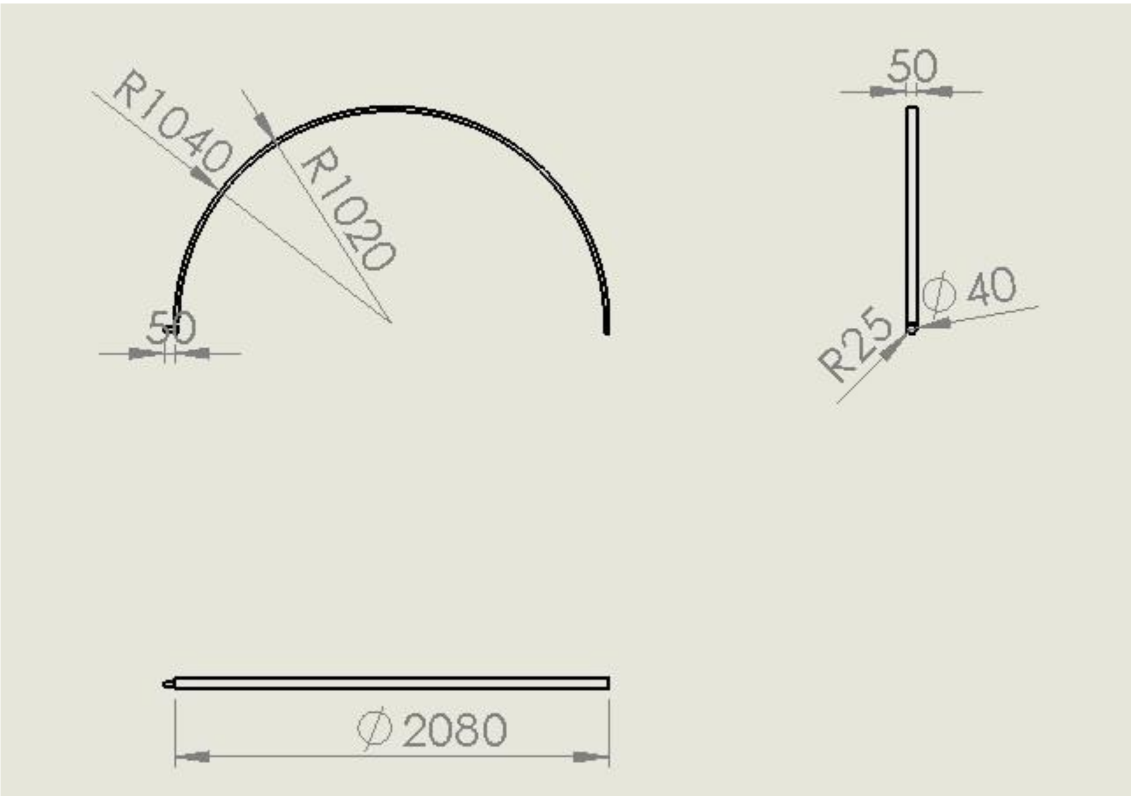


Picture 6: Arc design

To design the arc we choose the next dimensions that we can watch in the picture.

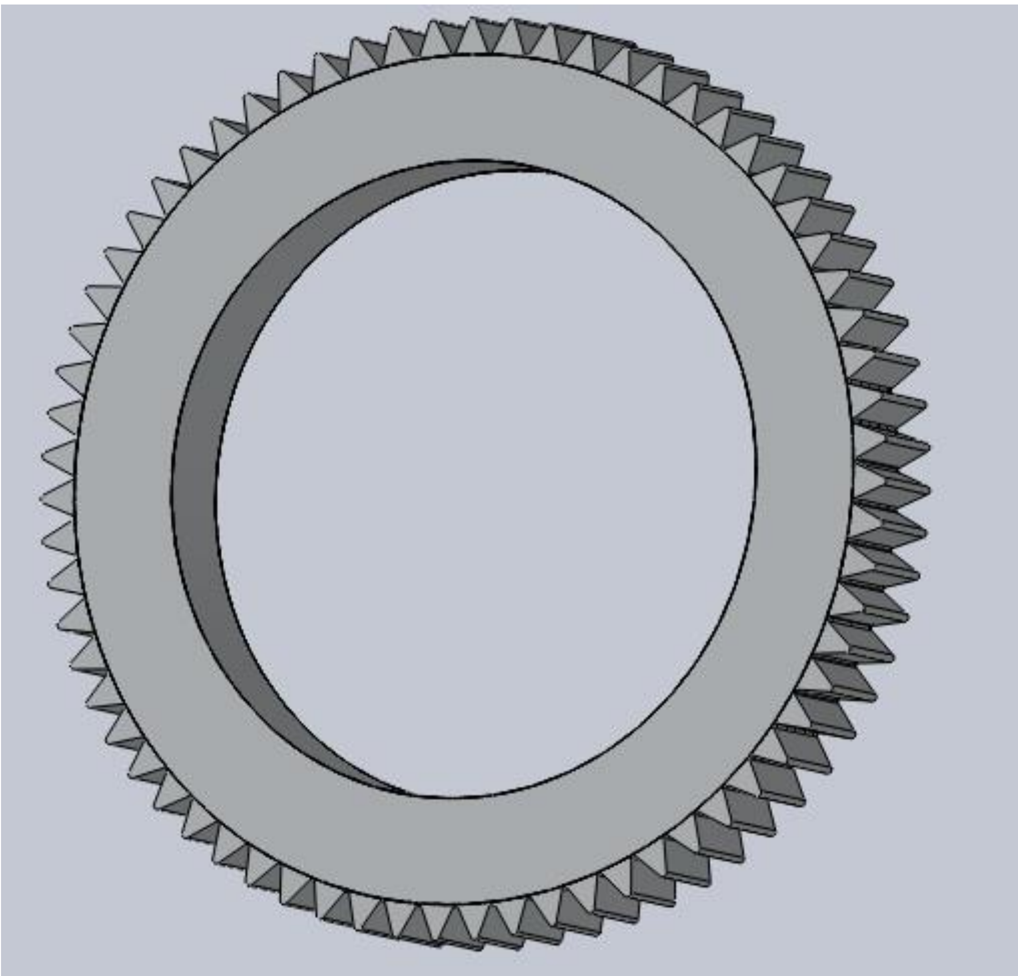


Picture 7: Arc measures

Table 7: Physical properties of the arc

property	Value	Units
Mass	5,51066	Kg
Volume	0,00204	m^3
Surface area	0,7961	m^2

The connection between the arc and the engine will be by a gear. We choose a gear because this method gives us more precision at the time to position the arc than a belt. We'll only need teeth in the half of the gear, because the movement that we are going to transmit is an oscillating movement with 180º of amplitude. The gear had been designed with 67 teeth.

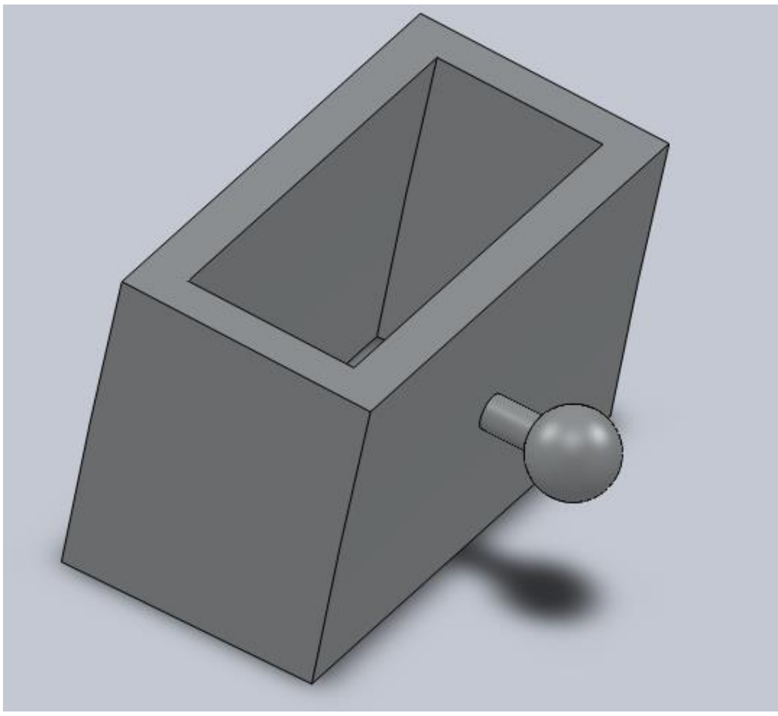


Picture 8: Gear (connection between motor and arc)

The trolley will move over the arc to get the position of the second coordinate where we want to measure the sound pressure. The movement over the arc have the amplitude of 180º and the velocity will be controlled with a step motor. The transmission of the movement from the step motor to the trolley over the arc will be with gears. Inside the trolley will be a gear that will take the movement from the step motor and transmit it to move the trolley over the arc’s surface that will be a surface of a gear. This connection will give us a really good accuracy to get the exact position where we want to get the measure. The chosen material to build the trolley has been aluminium alloy 1060 of the library of solid work. This material has the next properties:

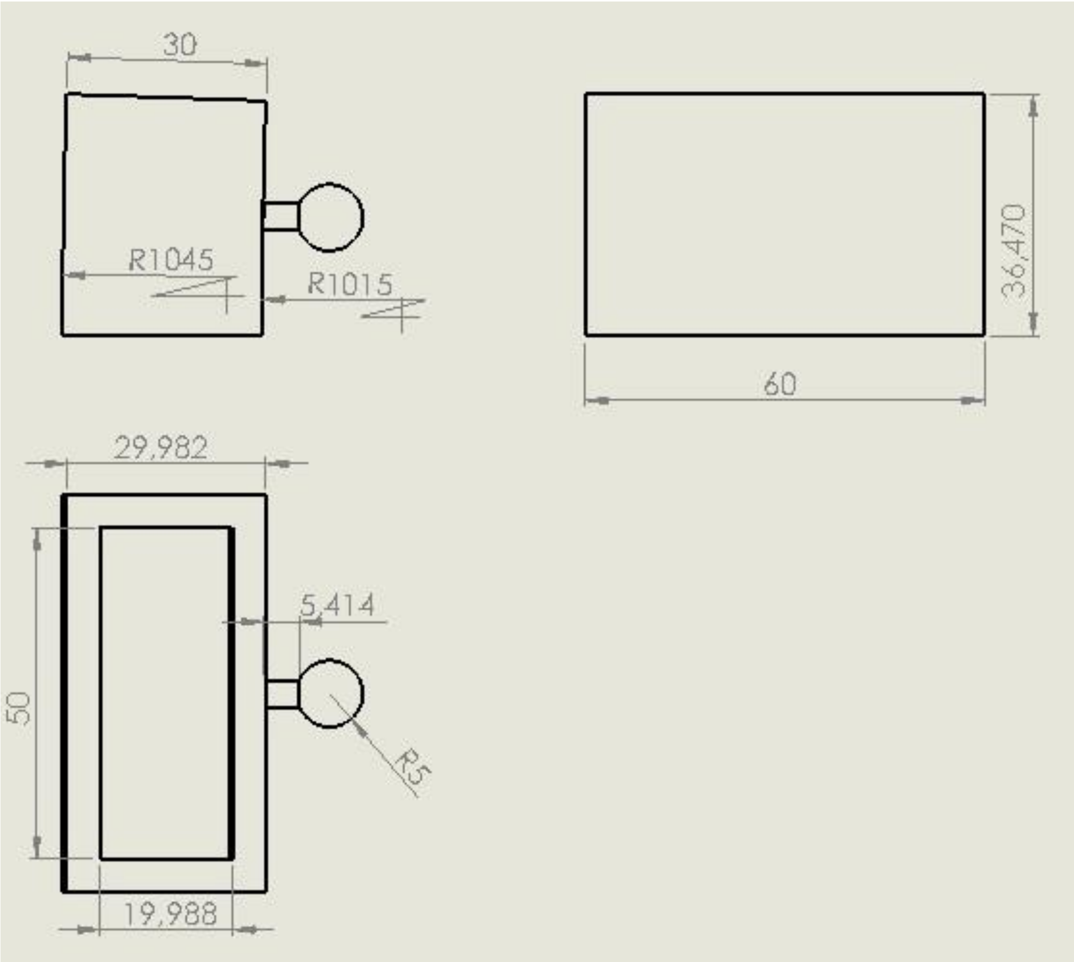
Table 8: Properties of aluminium alloy 1060

PROPERTY	VALUE	UNITS
Elastic module	6,9E+10	N/m^2
Poisson coefficient	0,33	N/D
Shear module	2,7E+10	N/m^2
Density	2700	Kg/m^3
Traction limit	68935600	N/m^2
Elastic limit	27574200	N/m^2
Thermal expansion coefficient	2,4E-5	1/K
Thermal conductivity	200	W/m·K
Specific heat	900	J/Kg·K



Picture 9: Trolley Design

To design the trolley we choose the next dimensions that we can watch in the picture.



Picture 10: Trolley measures

The physical properties of the trolley with this dimensions and the material that we have choose are:

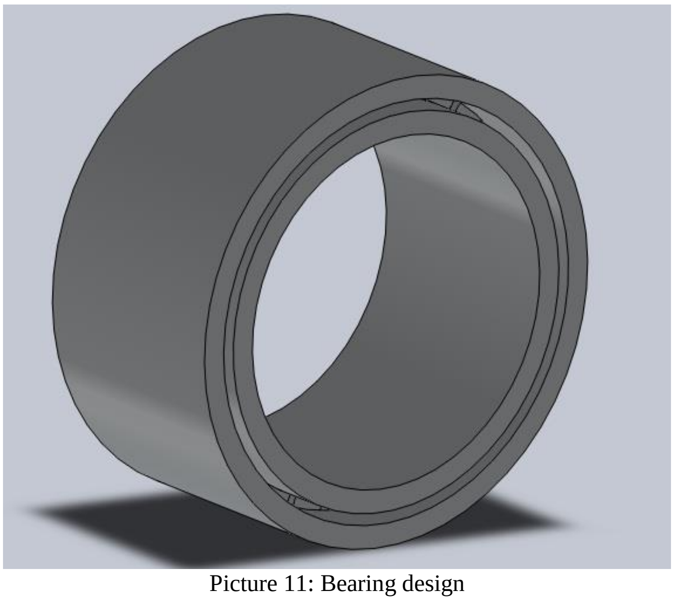
Table 9: Physical properties of the trolley

PROPERTY	VALUE	UNITS
Mass	0,07925	Kg
Volume	2,9352E-5	m^3
Surface area	0,13486	m^2

The bearing that is the connection between the base and the arc to permit the oscillation movement of the arc, have to be chosen. First of all we need to analyse what are the forces that this bearing has to bear. In our case this force can be reduced it to the gravity force that is acting in the arc and in the trolley. Mainly the force will be beared by the engine and helped by the two bearings. The type of bearing that have been chosen is a cylindrical bearing. The chosen material to build the bearing has been aluminium alloy 1060 of the library of solid work. This material has the next properties:

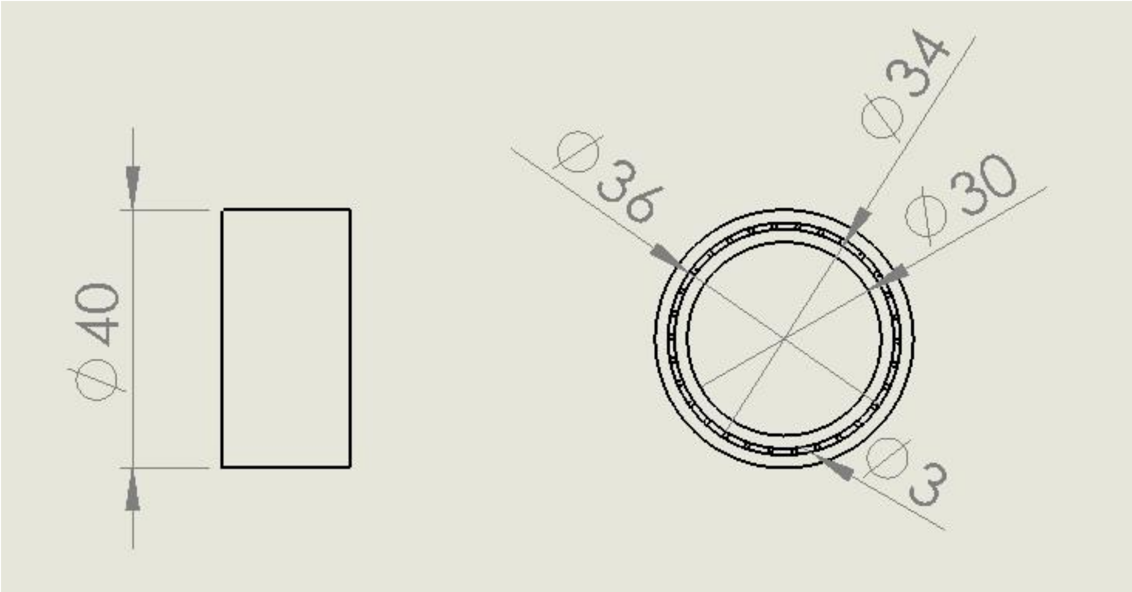
Table 10: Properties of aluminium alloy 1060

PROPERTY	VALUE	UNITS
Elastic module	6,9E+10	N/m^2
Poisson coefficient	0,33	N/D
Shear module	2,7E+10	N/m^2
Density	2700	Kg/m^3
Traction limit	68935600	N/m^2
Elastic limit	27574200	N/m^2
Thermal expansion coefficient	2,4E-5	1/K
Thermal conductivity	200	W/m·K
Specific heat	900	J/Kg·K



Picture 11: Bearing design

To design the bearing we choose the next dimensions that we can watch in the picture.



Picture 12: Bearing measures

The physical properties of the bearing with this dimensions and the material that we have choose are:

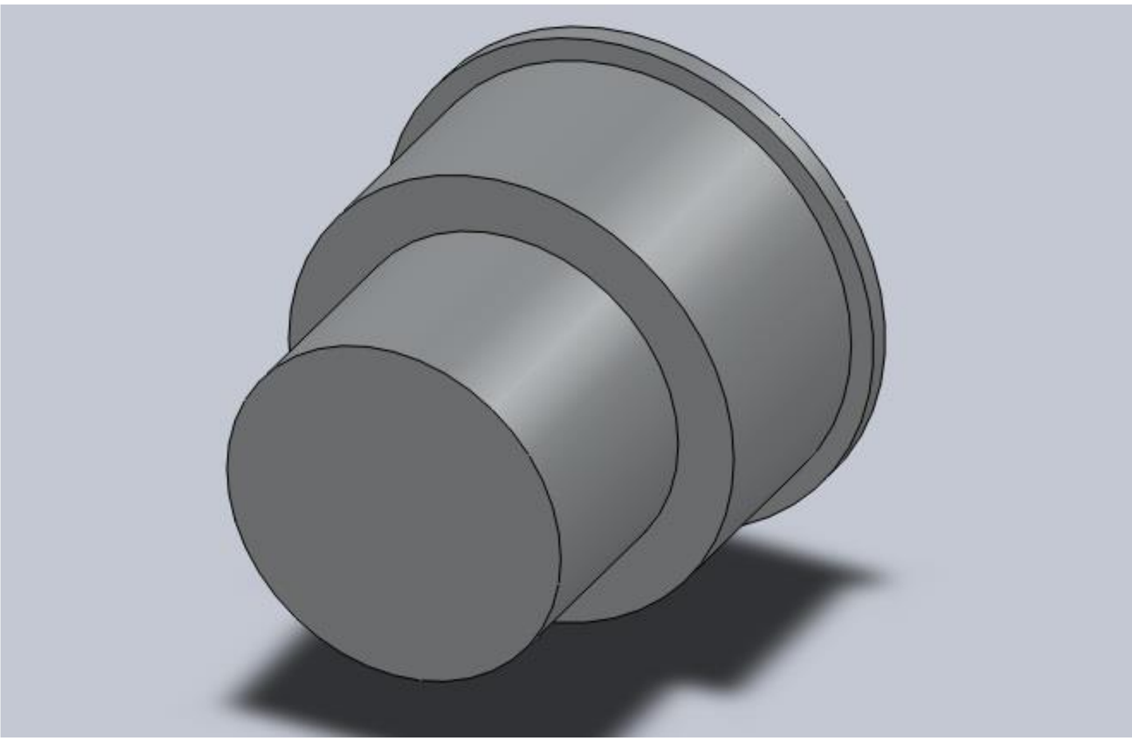
Table 11: Physical properties of the bearing

PROPERTY	VALUE	UNITS
Mass	0,02343	Kg
Volume	8,679E-6	m^3
Surface area	0,13328	m^2
Dynamic charge capacity	66	kN
Static charge capacity	180	kN
Fatigue limit	22,8	KN
Reference velocity	4300	rpm
Limit velocity	5000	rpm

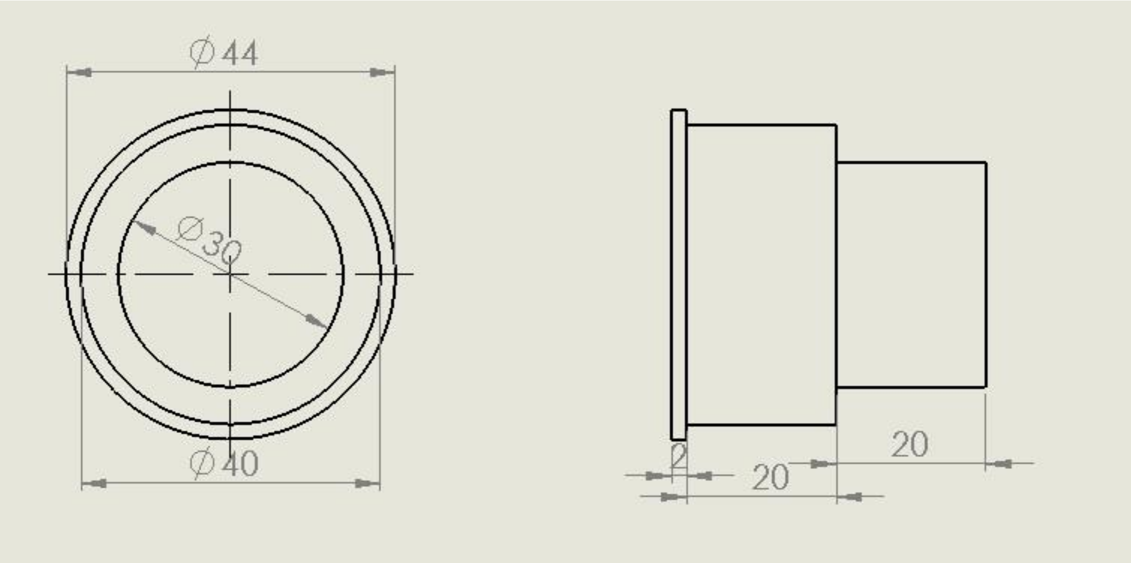
The tap is the element to make possible the way to build the machine, the last connection between the arc and the base. The connection between the arc and the tap will be with a bearing, because the arc has to be able to oscillate 180º. The chosen material to build the tap has been aluminium alloy 1060 of the library of solid work. This material has the next properties:

Table 12: Properties of aluminium alloy 1060

PROPERTY	VALUE	UNITS
Elastic module	6,9E+10	N/m^2
Poisson coefficient	0,33	N/D
Shear module	2,7E+10	N/m^2
Density	2700	Kg/m^3
Traction limit	68935600	N/m^2
Elastic limit	27574200	N/m^2
Thermal expansion coefficient	2,4E-5	1/K
Thermal conductivity	200	W/m·K
Specific heat	900	J/Kg·K



Picture 13: Tap design



Picture 14: Tap measure

The physical properties of the tap with this dimensions and the material that we have choose are:

Table 13: Physical properties of the tap

PROPERTY	VALUE	UNITS
Mass	0,114	Kg
Volume	4,231E-5	m^3
Surface area	0,007715	m^2

The solution that we have designed has the next physical properties:

Table 14: Physical properties of the machine

PROPERTY	VALUE	UNITS
Mass	9,58705	Kg
Volume	0,00355	m^3
Surface area	1,43896	m^2

5. Step Motor

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.

5.1. Stepper Motor Advantages and Disadvantages

Advantages

1. The rotation angle of the motor is proportional to the input pulse.

2. The motor has full torque at standstill (if the windings are energized)

3. Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 – 5% of a step and this error is non-cumulative from one step to the next.

4. Excellent response to starting/stopping/reversing.

5. Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.

6. The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.

7. It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.

8. A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

1. Resonances can occur if not properly controlled.

2. Not easy to operate at extremely high speeds.

5.2. Open Loop Operation

One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. Your position is known simply by keeping track of the input step pulses.

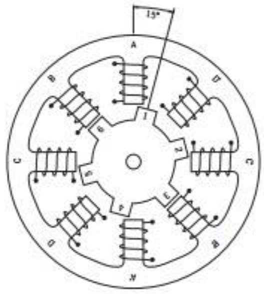
5.3. Stepper Motor Types

There are three basic stepper motor types. They are:

- Variable-reluctance
- Permanent-magnet
- Hybrid

5.3.1. Variable-reluctance (VR)

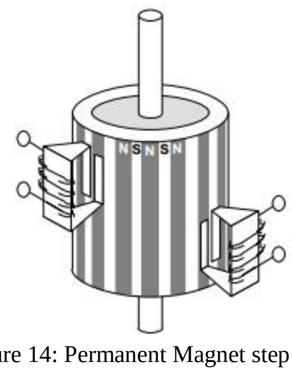
This type of stepper motor has been around for a long time. It is probably the easiest to understand from a structural point of view. Picture 13 shows a cross section of a typical V.R. stepper motor. This type of motor consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles.



Picture 13: Variable-reluctance step motor

5.3.2. Permanent Magnet (PM)

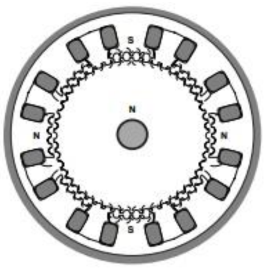
Often referred to as a “tin can” or “can stock” motor the permanent magnet step motor is low cost and low resolution type motor with typical step angles of 7.5° to 15°. (48 – 24 steps/revolution) PM motors as the name implies have permanent magnets added to the motor structure. The rotor no longer has teeth as with the VR motor. Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide and increased magnetic flux intensity and because of this the PM motor exhibits improved torque characteristics when compared with the VR type. Picture 14.



Picture 14: Permanent Magnet step motor

5.3.3. Hybrid (HB)

The hybrid stepper motor is more expensive than the PM stepper motor but provides better performance with respect to step resolution, torque and speed. Typical step angles for the HB stepper motor range from 3.6° to 0.9° (100 – 400 steps per revolution). The hybrid stepper motor combines the best features of both the PM and VR type stepper motors (Picture 15). The rotor is multi-toothed like the VR motor and contains an axially magnetized concentric magnet around its shaft. The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the air gap. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the VR and PM types. The two most commonly used types of stepper motors are the permanent magnet and the hybrid types. If a designer is not sure which type will best fit his applications requirements he should first evaluate the PM type as it is normally several times less expensive. If not then the hybrid motor may be the right choice.



Picture 15: Hybrid step motor

5.4. Size and Power

In addition to being classified by their step angle stepper motors are also classified according to frame sizes which correspond to the diameter of the body of the motor. For instance a size 11 stepper motor has a body diameter of approximately 1.1 inches. Likewise a size 23 stepper motor has a body diameter of 2.3 inches (58 mm), etc. The body length may however, vary from motor to motor within the same frame size classification. As a general rule the available torque output from a motor of a particular frame size will increase with increased body length. Power levels for IC-driven stepper motors typically range from below a watt for very small motors up to 10 – 20 watts for larger motors. The maximum power dissipation level or thermal limits of the motor are seldom clearly stated in the motor manufacturer data. To determine this we must apply the relationship Pº =V × ºI. For example, a size 23 step motor may be rated at 6V and 1A per phase. Therefore, with two phases energized the motor has a rated power dissipation of 12 watts. It is normal practice to rate a stepper motor at the power dissipation level where the motor case rises 65°C above the ambient in still air. Therefore, if the motor can be mounted to a heat sink it is often possible to increase the allowable power dissipation level. This is important as the motor is designed to be and should be used at its maximum power dissipation, to be efficient from a size/output power/cost point of view.

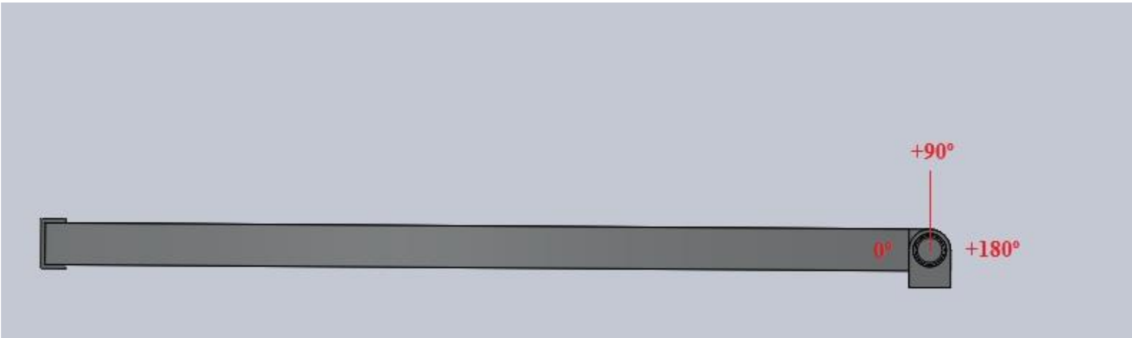
5.5. When to Use a Stepper Motor

A stepper motor can be a good choice whenever controlled movement is required. They can be used to advantage in applications where you need to control rotation angle, speed, position and synchronism. Because of the inherent advantages listed previously, stepper motors have found their place in many different applications. Some of these include printers, plotters, high-end office equipment, hard disk drives, medical equipment, fax machines, automotive and many more.

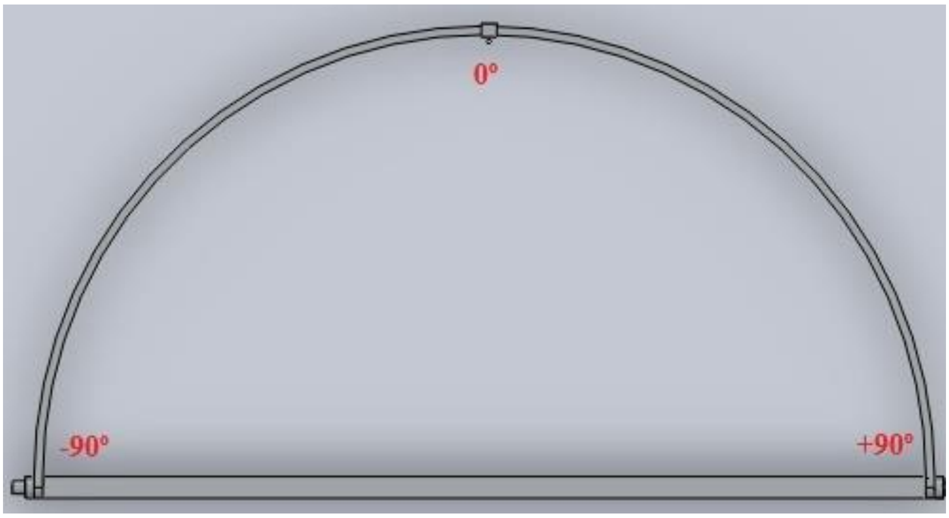
6. How the machine measure

First of all, we are going to analyse the movements and the time that will be requiring measuring the sound pressure.

To move the microphone to the different position where we'll want to measure, we need to now the two parameters of the position the degrees of the arc (0º to 180º) and the degrees of the trolley (-90º to +90º). The coordinate system to position the trolley is the next one that it's show in the two next pictures.



Picture 16: arc coordinate system



Picture 17: trolley coordinate system

We'll always arrange all the coordinates, where we want to measure, from lowest to highest focusing in the first coordinate that will be the arc coordinate. And after it, we'll focus on the second coordinate and do the same arrange inside the groups with the same first coordinate. In this way, we'll move the arc to the next coordinate where we need to measure the sound pressure, and then we'll pass through the coordinates that we have to cover across the arc with the trolley movement.

7. Conclusions

The machine has been designing to measure the sound pressure in a semi spherical area with 2 meters of diameter. In this way we can get to all the points of this area with a high accuracy. The other options that we have thought at the beginning had some problems with this accuracy.

This accuracy is giving by the hybrid step motors that we use to move the arc and the trolley. This motor helps us later to automatize the machine with computer software. We only need to write the coordinates where we want to measure and the software will send the information of the movement to the step motor to get it.

The weight and the dimensions of the machine make it portable. The problem of being portable is that we have to be extremely careful if we disassemble the machine to transport it. In this way we should be really careful to assemble all the pieces again but even more in the bearings and the gear.

With all this characteristics we solve the problem that we had at the beginning.

8. Bibliography

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