3D Printed MIT Challenge

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Abstract—**This article presents the results of a 2-DOF vibration analysis carried out on the 3D CreatBot DE Plus Printer. Three-dimensional printing has spread worldwide in recent years due to the competitive advantage it gives to the companies using it. The aim of this study is to propose a low and high impact solution to reduce the vibrations. By using Matlab and SolidWorks, the best modification resulted in adding rubber bushings at the bottom of the mechanism and placing a steel counter weight at the base (low impact), individually showing a reduction of initial vibrations by 30% and 60%, respectively. The findings show that changing the geometry of the printer (high impact), by adding steel "walls" produces a reduction of 50% of the vibrations. While low impact solutions are not expensive and easy to implement, high impact solutions are more expensive but could result in better quality of production.**

Index Terms— **Mechanical vibrations, 3D Printer, printing speed, mechanical properties, springs, dampers.**

INTRODUCTION

During recent years, one of the most used additive manufacturing (AM) processes is three-dimensional (3D) printing, which has spread worldwide due to functional rapid prototyping and the amount of material involved is reduced compared to other manufacturing processes. The attractiveness of 3D printing is related to time saving, where the process of prototyping and designing is significantly shortened; no external commission, there is no need to pay other companies to create prototypes and molds; and financial savings, due to the use of molds for multiple series productions.

In this process, the object is printed layer by layer in the Cartesian system, where the material is selected according to the mechanical properties required. However, this process is far from being "perfect", due to the movement of the printer head, and other external aspects, mechanical vibrations occur throughout the process, which have a direct effect on the printing quality and speed. In other words, if there are less mechanical vibrations, the higher the speed and quality of the process.

Most printers in this industry are built with 3 degrees of freedom, and depending on the printer configuration, the degrees are distributed between the printer table and the print head. In our case, we will be analyzing a CreatBot DE Plus Printer, where the print head moves in the X and Y axis, while the table moves in the Z axis.

Functional products require the 3D printer to be fully stable throughout the printing, this is the reason why it needs to operate without excessive vibrations, causing imperfections in the functionality and mechanical properties.

In the hypothetical case where we can change the mechanical properties of the structure of the printer, we would be able to achieve higher printing speeds with an increased rigidness with the use of dampers and springs.

Materials and Methods

Firstly, we a analized a series of previous investigative articles regarding vibrations that are present in 3D printers and how they proposed innovative solutions to reduce their negative effects.

According to Kam (2018), "the orientation of the product has a significant effect on the response of the printer systems in terms of vibrations". In one of his studies, he found out that the test sample of 60° and 30° displayed "better damping capacity" compared to the one in 45° by 45°.

During recent experiments, Pilch (2015) tried to understand the causes of several vibrations his 3D printer was facing, and found out the following:

1. "Increasing print speed to about 160% of base speed [did not] affect the value of vibration of the stand in the direction of axis Z. Increasing print speed over 160% results in a significant increase in the value of the vibration.
2. The plane of incidence and the plane of reflection of the laser beam should be parallel to the layers of the model".

Another experiment proposed by Rong Wang, Jianzhong Shang, Xin Li, Zirong Luo and Wei Wu analized constrained layer dampers (CLD), which are in widespread use for passive vibration damping, in applications including aerospace structures. They found that introducing the damping layer can reduce the stiffness of the sandwich structures. A viscoelastic material filling (VMF) balances the structural and vibrational performance of lattice truss in this work. The 3D Kagome truss with face sheet was manufactured by selective laser sintering technology and uses a viscoelastic filling material of thermosetting polyurethane. An elaborate modal analysis method for Hybrid composite lattice truss sandwich is introduced in this paper. The experiment results showed that the VMF method is effective in reducing the vibration amplitude and it has the potential for band-gap design. The VMF method can provide high stiffness at low mass and considerable vibrational performance at low cost and it can be considered as a general vibration design method in lattice truss manufacture.

These results that we found in the scientific article lead us to believe that another possible solution to reducing the mechanical vibrations in the system is to utilize a viscoelastic material filling and implement them in hollow or loose structural components of the 3D Printer. Although we do not test this hypothesis in this analysis, we do consider it for subsequent investigations and improvements.

The research led us to develop a series of questions that were presented to an expert from MIT who utilizes the 3D-Printer on a daily basis. On this occasion, Anthony Taylor, a Doctoral student, helped us by answering our doubts.

Firstly, the interviewer mentioned that he didn't seem to observe any harmful vibrations. When asked about what he thought were the main factors that affected the system he said "the natural frequencies of the printer components, the change in inertia of the printer head as it is printing, and the speed at which the head moves. The whole frame of the printer moves when the printer head starts or stops moving, however, I believe the printer bed is decoupled from the printer frame." This leads us to believe that we must find what are the natural frequencies of the printer in order to avoid such velocities and reduce the change in inertia of the head.

According to Taylor (2020), "the 3D simplify software has many parameters that can be changed in order to manipulate the printer speed. It typically started with the default values and then modified them to improve the print quality". In addition, he mentioned that there were no hardware changes to improve the printing speed.

The user mentioned that he would print a series of single layer membranes and then measure the thicknesses in the four quadrants of each membrane; if the thicknesses were not close to each other, he would adjust the four spring-loaded feet that level the bed and then reprint until the bed was level. Nonetheless, the bed did not typically deviate from level very often. Also, the slicing software uses a constant speed setting, which we must consider in our analysis.

Finally, Anthony mentioned that it is possible to consider some type of polymer to be placed under the printer in order to absorb vibrations. In addition to such, we could add a printed piece to reduce movement or a kind of structural support.

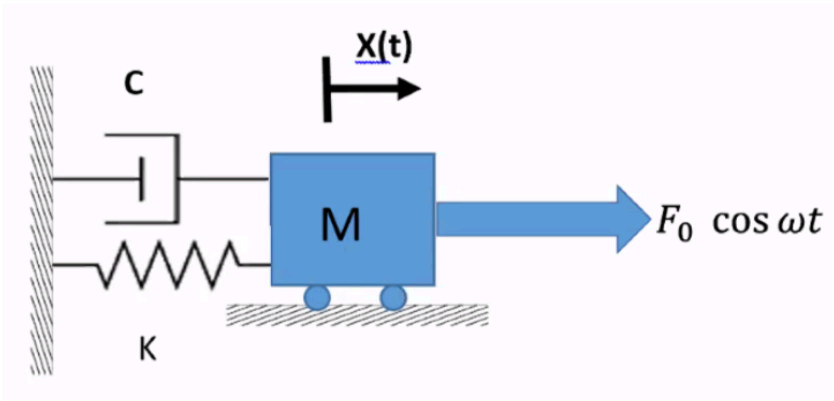
Vibrations must be analyzed in a waveform configuration. These are caused by the printer structure, nozzle type, filling structure type and orientations, and finally, processing speeds. We started our investigative development.

Matlab Analysis

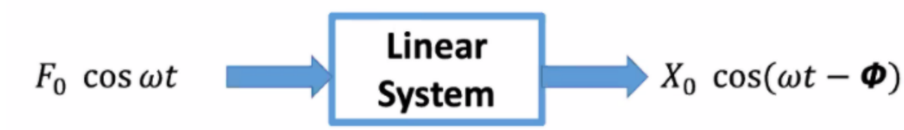
In order to find the bode diagrams, the natural frequency of the system and find out if the vibrations were actually attenuated, we needed to develop a code which could simulate these vibrations. By implementing various configurations of the dampers and materials, we analyzed which would be the optimal case and developed the following report:

Free Body Example

Example of what a system with a harmonic force looks like.



Since it is a linear system, the output will also be of the same frequency.



Balance of Equations

We know the displacement, first and second derivatives. We then input the first second and displacement into the equation. Giving us:

Giving that the steady state is:

$$Xss = Xo * cos(\omega t - \varphi)$$

By substituting we get:

$$m(-X_o\, cos(\omega t - \varphi)) + c\,(-Xo\,\omega^2\, cos(\omega t - \varphi)) + k\,(X_o\,\omega\, sin(\omega t - \varphi)) + k\,(X_o\, cos(\omega t - \varphi))$$
$$(\omega t\,)$$

This equals to:

$$X_o((1 - \frac{\omega^2}{\omega_n^2})\, cos(\omega t - \varphi) - 2\rho\frac{\omega}{\omega_n}\, sin(\omega t - \varphi)) = \frac{F_o}{k} cos\,\omega t$$

In this equation we replace ζ and w_n

Given that ζ and w_n are equal to:

$$\rho = \frac{c}{2m\,\omega_n} \text{ and } \omega_n^{\ 2} = \frac{k}{m}$$

We then get:

$$X_o((1 - \frac{\omega^2}{\omega_n^2})\, cos(\omega t - \varphi) - 2\rho\frac{\omega}{\omega_n}\, sin(\omega t - \varphi)) = \frac{F_o}{k} cos\,\omega t$$

Then, we are able to get the maximum displacement and the angle:

$$X_o = \frac{F_o/k}{\sqrt{(1-\frac{\omega^2}{\omega_n^2}) + (2\rho\frac{\omega}{\omega_n})^{2}}} \text{ and } \varphi = tan^{-1}(\frac{2\rho\frac{\omega}{\omega_n}}{1-\frac{\omega^2}{\omega_n^2}})$$

Transfer function:

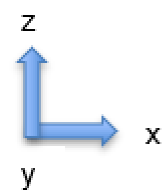
For the transfer function we simply divide the maximum displacement by Fo/k

$$\frac{k\,X_o}{F_o} = \frac{1}{\sqrt{(1-\frac{\omega^2}{\omega_n^2}) + (2\rho\frac{\omega}{\omega_n})^2}}$$

We got these equations and diagrams from the course Mechanical Vibrations (2020,Ramirez)

Accelerations upload

Here we get the average acceleration and average Force. We got the acceleration from the data provided to us by Dr. Izquierdo directly measuring them while the maschine is running. In this case we reviewed the force being exerted on the frame, specifically the X axis, therefore we used the accelerations of the x axis.



We then got

Fx=.0153 N

Fy=.5237 N

Fz=39.9025

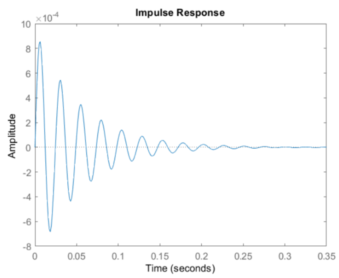
As we can observe we see that the forces in Fy and Fx in the extrusor are not nearly as much as the ones obtained in the frame. We could predict that the frame is being more affected by the vibrations because of the moment that the extrusor causes.

Considering a non-harmonic force 1DOF

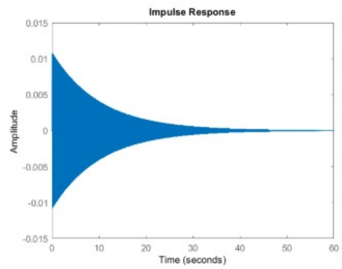
Here we can see the response of the system. We consider a non harmonic force. Here we plan to test the response of the different axes, therefore we will test the frame (z axis), and the extrusor (x and y axis)

For the next sections we have considered a force to be the average acceleration on the plane x* mass for the extrusor in the x axis, the average force on the y axis for the extrusor's y axis response and finally the response of the frame in the z axis. This procedure was done in the section "Getting accelerations"

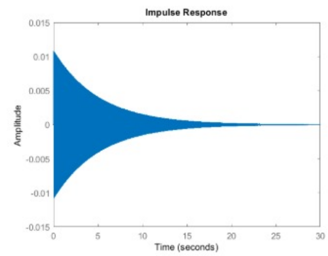
Impulse response for non harmonic systems



This graph shows the impulse response for the frame



Here is the graph for the extruder in the x direction



Here is the graph for the extruder in the x direction

In these graphs we only consider the values of damping, stiffness and mass to graph the impulse response. We can also see the response on a larger scale.

Harmonic force

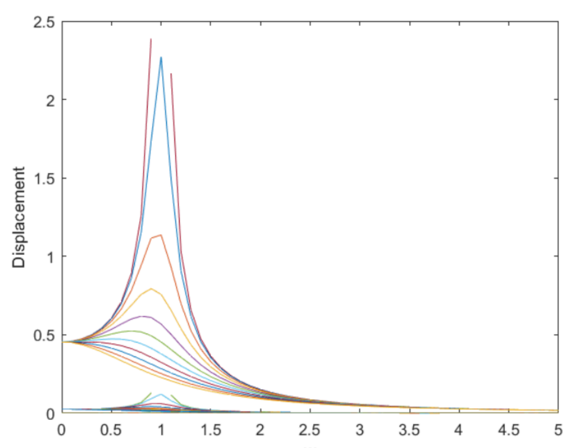
Now that we have considered a non harmonic force we must consider a harmonic force and the response it would have on the system. We know that the actual force may not be harmonic, nevertheless this can be helpful in getting a more appropriate response.

The next graph graphs the response for the system (displacement) and compares the system to different values for zeta (0-1).

Getting X0

We have decided to analyze the harmonic force only on the frame rather than on the extrusor because of design purposes. This is because we can´t change elements inside the machine, specifically elements like the extrusor and the elements it is directly connected to.

The next graph graphs the response for the system (displacement) and compares them to different values for the damping factor, zeta (0-1).



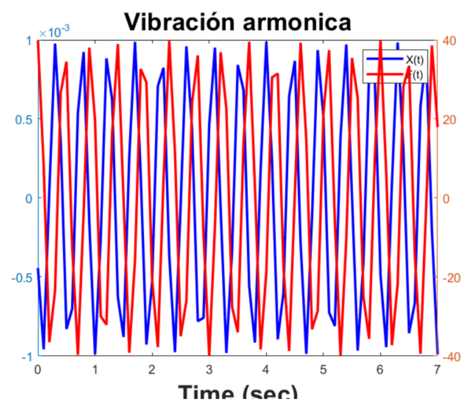
Here we were able to observe that a lower zeta would, as we predicted, give us a higher displacement. Therefore, the higher the number is, the less movement it would show.

Our Zeta given by the tables : https://www.scielo.br/scielo.php?pid=S1678-58782011000300006&script=sci_arttext&tlng=en. This is equal to .75 meaning we have a higher displacement when looking at the frequencies, especially in the natural frequencies. This also accounts for the destructive vibrations we start to see at higher velocities.

Now we obtain the graphs of the harmonic force

By obtaining the graphs of a non harmonic force we could see how the displacement is affected. We have decided to directly compare it to the force that is being exerted. We used a force of about 10 newtons which we got from the average accelerations*mass of the frame (40kg/9.81)

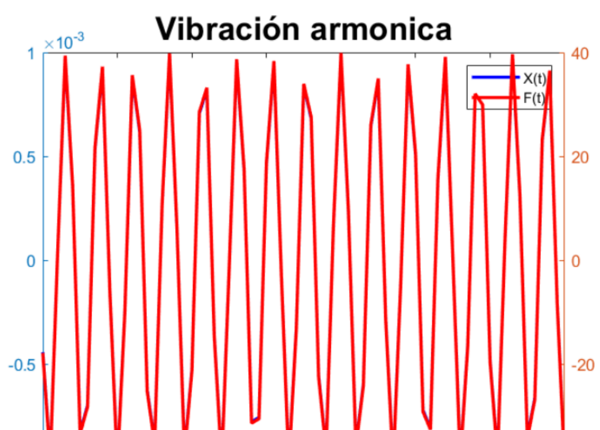
Here we have the opportunity to see the displacement. We therefore calculated with various w, because this can alternate when we accelerate or decelerate.

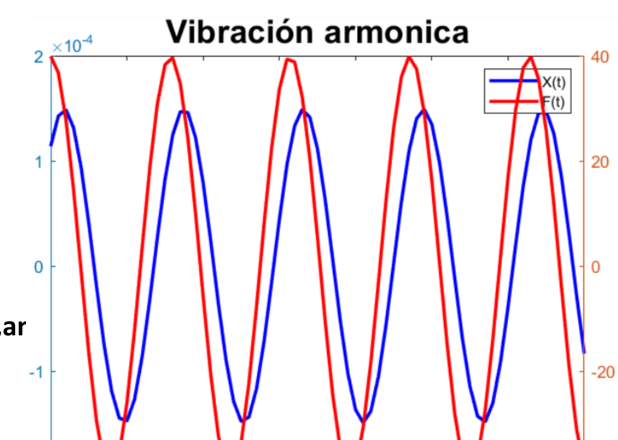


Here is what we get with a low frequency w=20: A displacement of 1.7727*10^-4

Wn=w=49.21 Here the force is exactly behind the X(t). That is because when Wn=w we get X0=F0/k

Displacement 9.89*10^-4





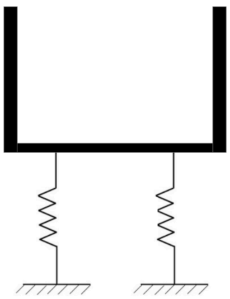
As we can see the closer we get to the natural frequency (w =49.21 rad/s) the more displacement there is.

w=4 rad/seg Max displacement= 1.4935*10^-4

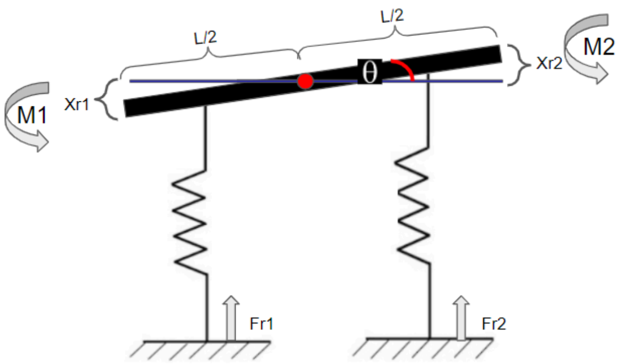
Getting the equations for our system

Simplified model for getting the mass and stiffness matrix

The following picture will represent the system we will be analyzing. We simplified the model so it would be easier for us to obtain the equations.



We are considering a moment that will be an effect to the movements in the x and y axis of the extruder. We will be showing a free body diagram that includes: forces, displacements, angle, moments and some extra things we have considered for this analysis.



Here we have all the parameters we need for our equations.

*We have also considered moments to be the same so M1=M2

*Another consideration we took to facilitate our equations is $sin(\theta) = \theta$

*Moments negative clockwise and assumed constant

$$\sum Fy = k\left(x - \frac{L}{2}\theta\right) + k\left(x + \frac{L}{2}\theta\right) = m\frac{d^2x}{dt^2}$$

$$\sum Fy = m\frac{d^2x}{dt^2} - 2kx = 0$$

$$\sum Mg = 2M_1 - F_{r1}\left(\frac{L}{2}\right) + F_{r2}\frac{L}{2} = I\frac{d^2\theta}{dt^2}$$

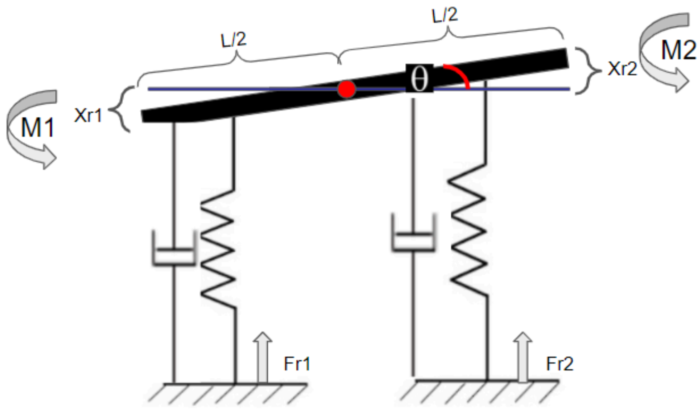
$$\sum Mg = 2M_1 + k\,L^2\frac{\theta}{2} = I\frac{d^2\theta}{dt^2}$$

Here we can observe that the natural frequencies are the following:

wn=629.04 rad/seg

wn=363.18 rad/seg

Now we are ready to obtain the bode diagram, the natural frequencies and the state matrix.



$$\sum F_y = k\,(x - \tfrac{L}{2}\theta) + k\,(x + \tfrac{L}{2}\theta) + c\,(dx - d\theta) + c\,(dx + d\theta) = m\frac{d^2x}{dt^2}$$

$$\sum F_y = m\frac{d^2x}{dx^2} - 2x\,dx - 2kx = 0$$

$$\sum M_g = 2M_1 - F_{r1}(\tfrac{L}{2}) + F_{r2}(\tfrac{L}{2}) - F_{c1}(\tfrac{L}{2}) + F_{c2}(\tfrac{L}{2}) = I\frac{d^2\theta}{dt^2}$$

For the following calculations, we assumed the stiffness and damping values for the rubber dampers using these specific values:

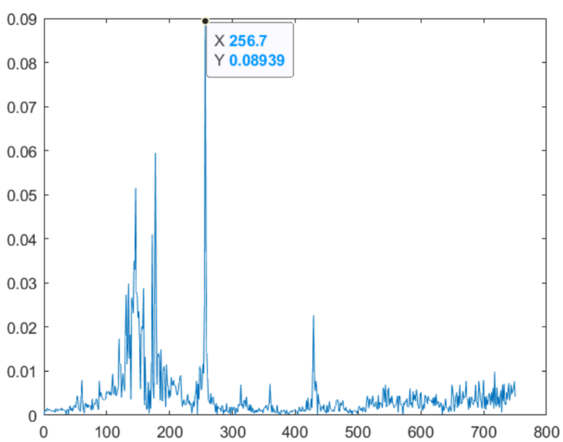
Table 1. Materials properties estimated by curve fitting of the Voigt model.

Rubber hardness	Without preload		Preload – 10% of strain			
	Stiffness K_v $[N/m]$	Damping C_v $[Ns/m]$	Stiffness K_v		Damping C_v	
			Absolute Value $[N/m]$	Variation	Absolute Value [Ns/m]	Variation
Soft – 25 shore	149,986.61	114.59	163,948.13	9.31%	124.91	9.00%
Medium – 33 shore	244,605.26	144.48	268,906.82	9.93%	150.13	3.91%
Hard – 48 shore	980,356.04	107.37	1,104,445.91	12.66%	102.72	-4.33%

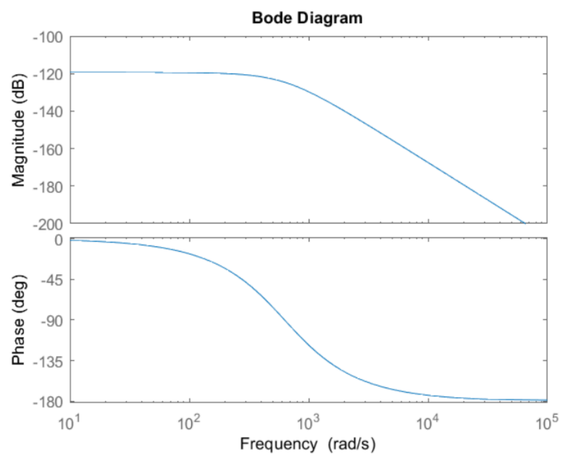
Table 2. Physical parameters of the tested vibratory systems.

Rubber hardness	Without preload			Preload – 10% of strain		
	Natural Frequency [Hz]	Damping factor ξ	Half power bandwidth [Hz]	Natural Frequency [Hz]	Damping factor ξ	Half power bandwidth [Hz]
Soft – 25 shore	39.50	0.074	5.846	40.75	0.077	6.276
Medium – 33 shore	47.39	0.075	7.109	49.21	0.075	7.382
Hard – 48 shore	79.47	0.027	4.291	81.99	0.027	4.427

In the following graphs, we can observe the vibrations utilizing a 33 shore Medium Rubber hardness assuming that it has 10% strain.



Using fourier transformations we graph an acceleration vs frequency function.



Here is the bode diagram deducted from the fourier transformation for the medium rubber.

Observing the data

We have the data from the lab that tells us the acceleration of the machine, Here we would see the data but transformed into frequencies, therefore we would be able to see if we are operating at the natural frequency and at which acceleration we might visualize deteriorating results.

Here we can see that at the frequency of 256.7 we have the highest acceleration. Now we have to pass the frequency we got here from Hz to rad/seg for us to compare it to the frequency we got in the bode diagram (where we would visualize deteriorating results)

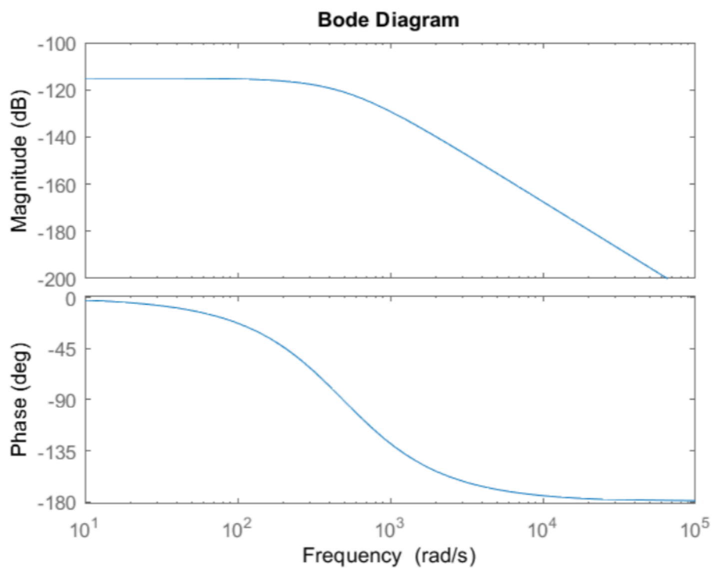
Frequency 256.7 to frequency= 1612.89 rad/s
Frequency of bode 629 to hz=100.1
Now we divide 256.7/100.1
ratio= 256.7/100.1 = 2.5644

We can see from this number that our system is not functioning at the natural frequency since the ratio is not an integer number.

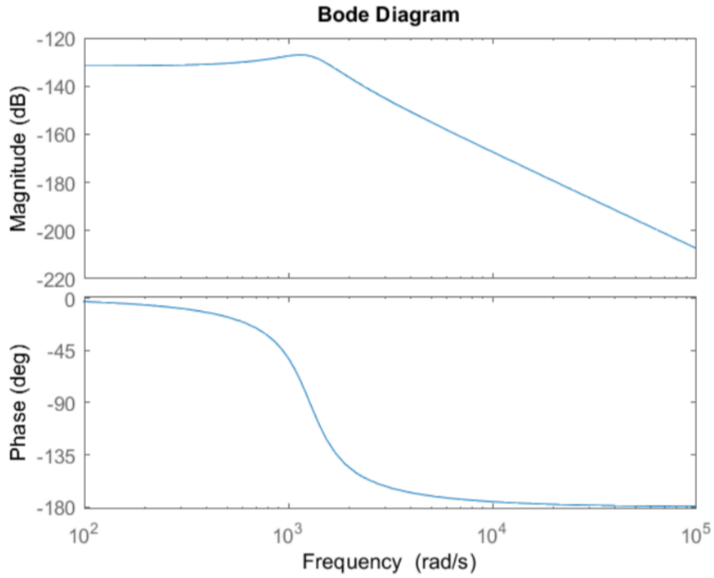
Propositions

Here we will try slight changes, whether it is in material of the frame or of the rubber stands, so we can propose some solutions. The first attempts are going to be based on the change of rubber. We therefore change its properties and seek better results. We will be getting the properties from the table mentioned in Harmonic Force.

Soft-25 shore

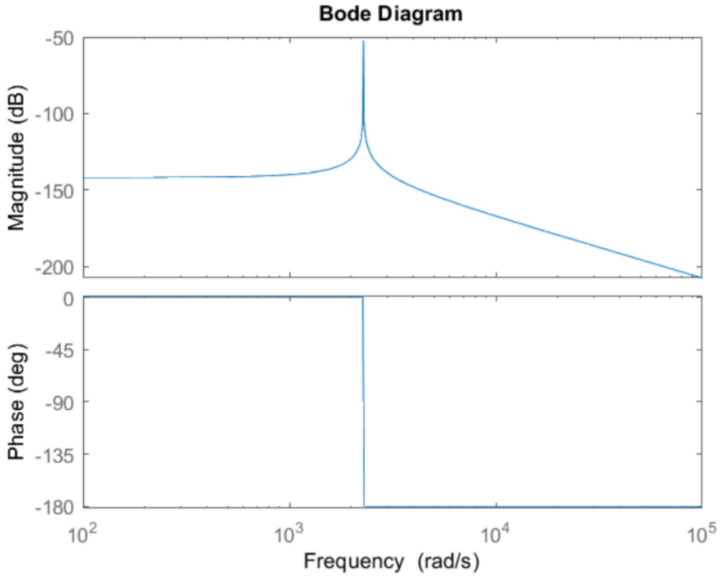


Now we explore results with the following: Hard-48 Shore



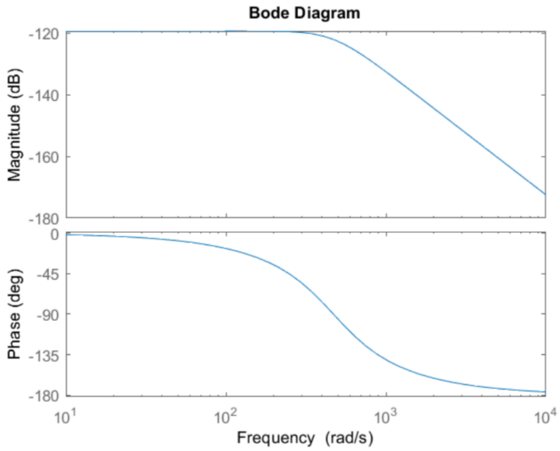
This is the graph we believe approaches the actual situation the most

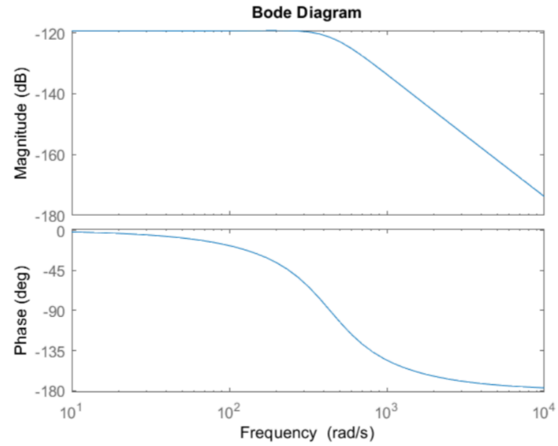
Steel



We can see that, in the steel graph, the point of the natural frequency is significantly pronounced, thus not being very optimal for use.

Aluminum **Titanium level 4**





With aluminum, the bode diagram is less pronounced.

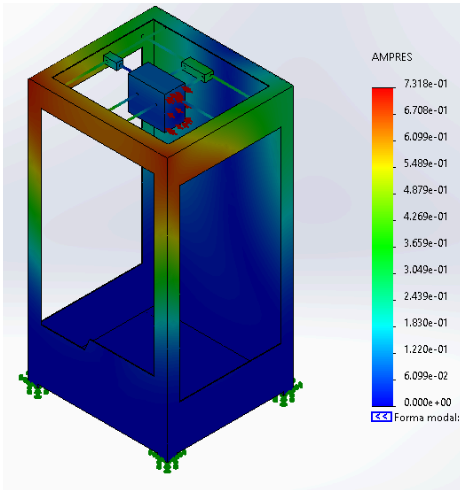
The titanium bode diagram is very similar to aluminum, where the inflection point is less pronounced than with steel.

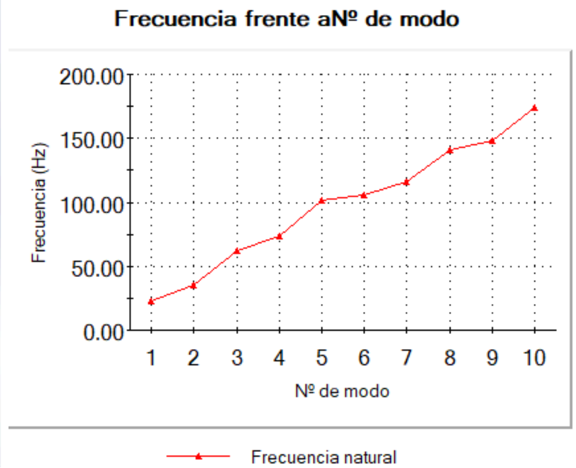
Here we see a correlation between the mechanical properties of the printer and the vibrational gain.

SolidWorks Simulation

In order to be able to propose a solution for reducing the vibrations in the mechanism, we had to create a very precise simulation, which in our case was produced in SolidWorks. Dimensions were given by Dr. Izquierdo, which ended up being helpful to give a series of possible solutions, either **low impact**, being not expensive and easy to implement; or **high impact**, which are related to the structure itself (modifying the material or the geometry) and require costly and complex changes.

Here we can appreciate the simulation of the 3D printer in vibration without any type of modification. The simulation showed that the maximum amplitude of the frequency ended up being 7.318 x 10^{-1}. This frequency increased as the number of nodes increased as well.



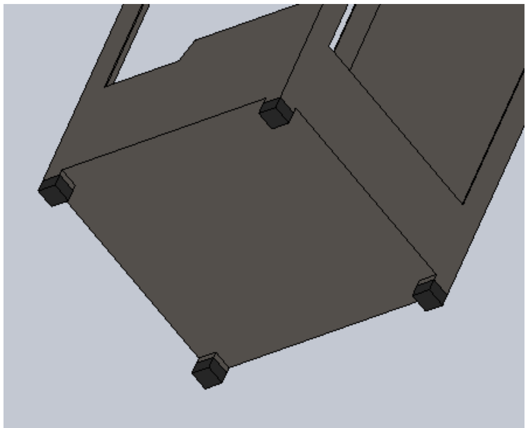


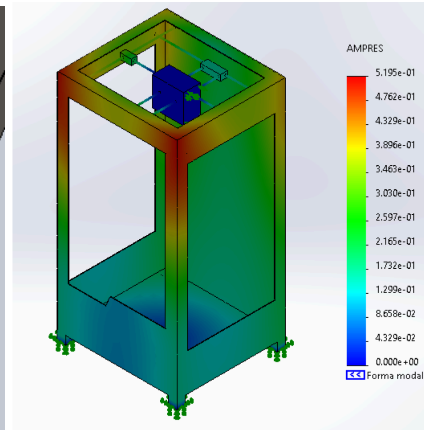
In the following table we can visualize the frequencies of the vibrations that were simulated in the system. All of the proposals were tested with the same forces and frequencies in order to be able to compare the amplitudes of the displacement in the frame.

Nº de modo	Frecuencia(Rad/seg)	Frecuencia(Hertz)	Período(Segundos)
1	142.02	22.604	0.044241
2	219.47	34.93	0.028628
3	390.48	62.147	0.016091
4	463.72	73.803	0.013549
5	638.09	101.56	0.0098468
6	661.67	105.31	0.009496
7	732.07	116.51	0.0085827
8	886.47	141.09	0.0070879
9	929.95	148.01	0.0067565
10	1,096.5	174.52	0.00573

For low impact solutions we came up with two different alternatives:

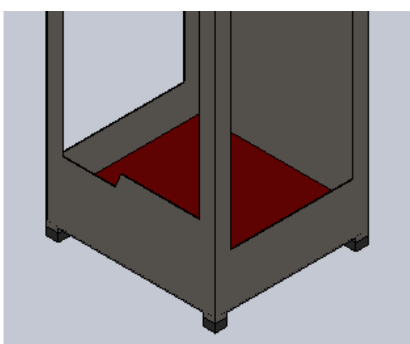
1. Adding bushings at the legs of the frame; these are going to work as an elastic/damping component to reduce vibration. In our case, we chose rubber as our material, which ended up reducing the original amplitude of vibration by 30%.

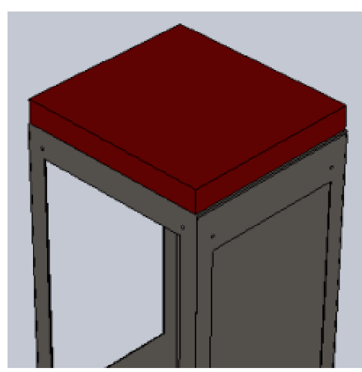


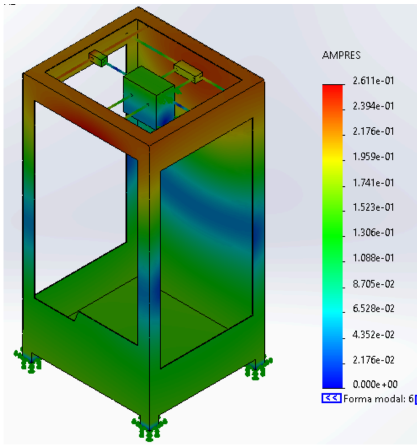


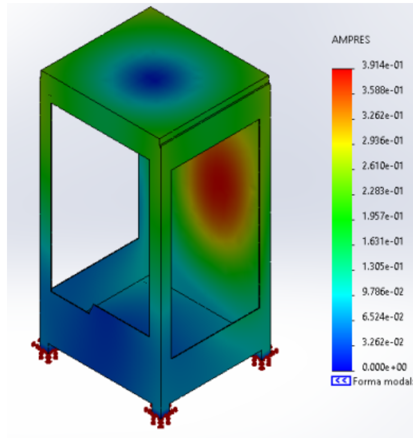
Nº de modo	Frecuencia(Rad/seg)	Frecuencia(Hertz)	Período(Segundos)
1	135.81	21.615	0.046265
2	183.17	29.152	0.034303
3	316.73	50.409	0.019838
4	391.96	62.382	0.01603
5	416.08	66.222	0.015101
6	581.04	92.475	0.010814
7	638.13	101.56	0.0098462
8	800.1	127.34	0.007853
9	808.95	128.75	0.0077671
10	847.29	134.85	0.0074156

2. Add a counter weight either on top or at the bottom of the structure, this increased weight would reduce vibrations due to the need of a higher force to move the mechanisms. Both counter weights (top and bottom) were made of the same material of the structure: steel. The simulation of both options showed that adding the weight at the base gave better results, reducing vibrations by 64%.









The following is the table of frequencies for the lower counterweight.

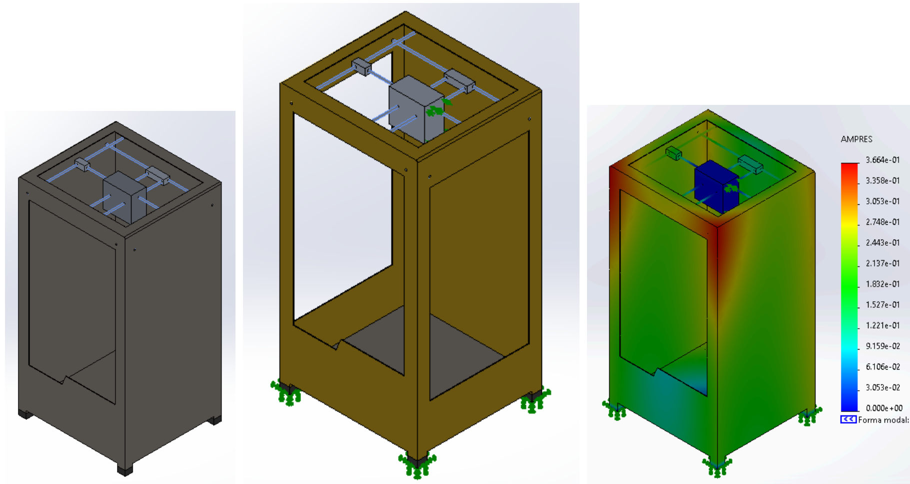
Nº de modo	Frecuencia(Rad/seg)	Frecuencia(Hertz)	Período(Segundos)
1	135.87	21.624	0.046244
2	182.78	29.09	0.034376
3	304.2	48.414	0.020655
4	355.14	56.522	0.017692
5	387.1	61.609	0.016231
6	482.81	76.841	0.013014
7	494.01	78.624	0.012719
8	563.17	89.631	0.011157
9	638.28	101.59	0.0098439
10	750.44	119.44	0.0083727

The following is the table of frequencies for the upper counterweight.

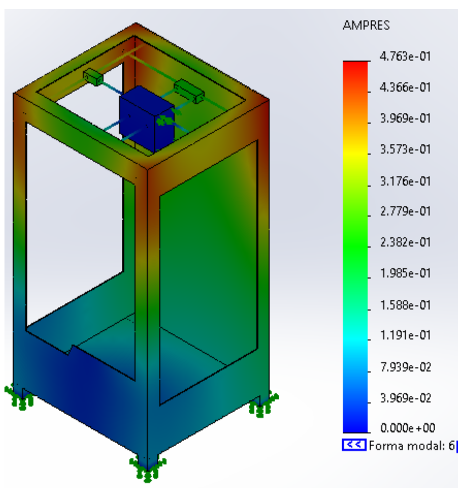
Nº de modo	Frecuencia(Rad/seg)	Frecuencia(Hertz)	Período(Segundos)
1	117.58	18.714	0.053437
2	133.19	21.197	0.047175
3	178.65	28.433	0.035171
4	211.66	33.687	0.029685
5	350.11	55.721	0.017946
6	353.08	56.195	0.017795
7	372.99	59.363	0.016846
8	514.05	81.813	0.012223
9	624.93	99.46	0.010054
10	695.32	110.66	0.0090365

Furthermore, the possible high impact solutions were the following:

1. Partially change the geometry of the 3D Printer, this is because vibrations are propagated in different ways through different geometries. Especifically, we proposed adding “walls” to the printer also made of steel, which ended up reducing vibrations by 50%.



2. Completely changing the material used for the printer. Originally, the structure is made of steel, but we proposed brass, due to its high density and ductility. This change in material was only capable of reducing the magnitude of the vibrations by 35%.



Conclusion

After doing the simulations in matlab with the different variants, we were able to conclude that the medium 33-shore was the better option, this is visually shown in the BODE diagram, where the soft shore was closer to zero, and the medium shore was further from this value. However the final with the Hard-48 Shore diagram was the most realistic, having the most noticeable peak of the three options.Therefore we recommend the medium shore that has the least gain in it's BODE diagram. One the reasons why the peak may not be very visible in the rest of the diagrams could be the rubbers' specific values. Additionally, altering the overall weight of the structure does not mitigate the vibrations effects; therefore, we recommend maintaining the original weight of the printer.

As shown in the SolidWorks simulation, adding the bushing with the counter-weight alternative is the way to go regarding a low impact solution. This addition is capable of reducing up to 64% of the original amplitude of vibration at the same frequency. This solution is highly accessible to be implemented right now. We also found out during the simulation that adding bushings and/or adding an absorbent mat at the bottom of the mechanism were the best alternatives. On the other hand, as for a high impact solution, the geometry alternative is the best option available, due to the reduction of 50% of the initial amplitude of vibration. This solution can easily be implemented by the company.

Acknowledgements

The class Mechanical Vibrations imparted by Profesor Dr. Ricardo Ramírez was the prime factor that helped us develop this project. There were three skills learned that completely changed the way we, as a tema, approached the project: critical thinking, teamwork, and innovation. Some of the concepts learned through the class were: vibratory systems, potential and kinetic energy, degrees of freedom, types of vibrations (free and forced, undamped and damped, linear and nonlinear).

The importance of understanding what, where, how, and why mechanical vibrations occur is critical for an engineer due to the presence of these in almost or every single mechanism. The knowledge of this phenomena would help us design new products, lower the possible damage a machine could have, and improve the efficiency of mechanisms.

Having the opportunity of contacting Dr. Javier Izquierdo throughout the project was algo a key factor for the success of our project. Being able to have our research questions answered helped us understand deeper the mechanism and what the real problem was.

This job could not have been realized if it wasn't for Santiago Puma, who was *always willing to offer us insightful and valuable information.*

We would like to thank the Massachusetts Institute of Technology and the "Instituto Tecnológico de Estudios Superiores de Monterrey" for providing us the resources and platform to perform our investigation and advance in our understanding of fundamental topics concerning real-life situations.

It is necessary to mention that after doing this project we will never see a complex mechanism the same way. We know that every single component was well thought before implementing it, analyzing its designs and movement.

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Appendix

The manufacture company of the printer stated several specifications that are essential for the analysis, which are the following:

1. CreatBot announced that their printer is the first one to publish “350°C ultra-high temperature nozzle to mass market”, which is patented and exclusively used. Their blue metal cooling sink is capable of cooling the heartbreak.
2. The printer is capable of printing at 200 millimeters per second with a precision of approximately 0.05 millimeters. This speed is the maximum printing speed, while 45 millimeters per second is considered being the optimal.

3. The printer is customizable for single, double or triple heads, as well as the nozzle height being adjustable.

4. The build maximum volume of the DE Plus model is 400 * 300 * 520 millimeters.

5. The printer's platform is made of borosilicate glass, which has a high thermal efficiency. As a user, you are able to turn off the hot bed automatically after a certain amount of layers.

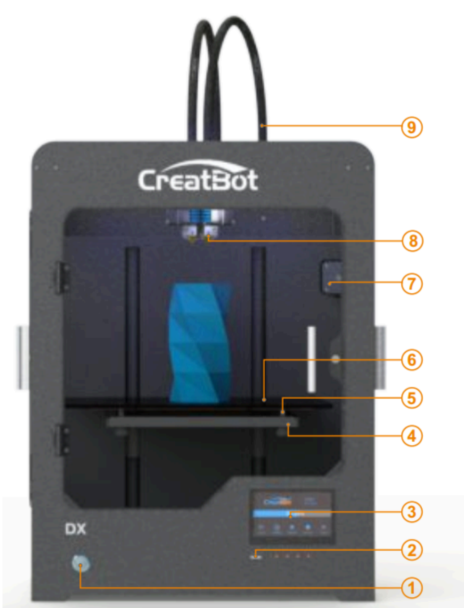
6. A 4.3" touch screen is equipped which makes the printer easier to operate.

7. For the simple feeding frame, "the stepper is separated with the hotends, so that the hotent is [lighter], smaller and will [have] less inertia of movement, also greater space utilization" (CreatBot, 2020).

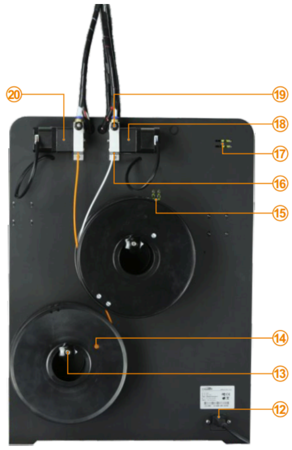
3\. For the filament feeder, "geared motor can reduce speed intelligently and it supports super torque so that it can feed filament in high precision without slipping and delay when withdrawing the filament" (CreatBot, 2020).

Attachments

Printer (Front and back)

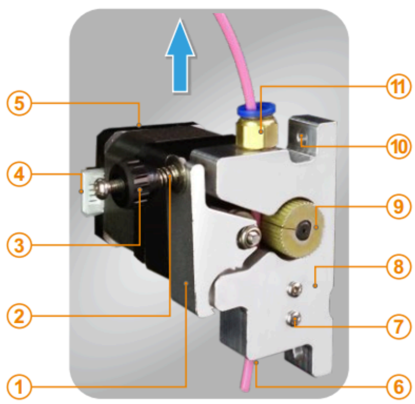


1. Power switch
2. U disk slot
3. Touch screen
4. Leveling nut
5. Leveling spring
6. Build platform
7. X stepper motor
8. New Printer head
9. Filament guide pipe



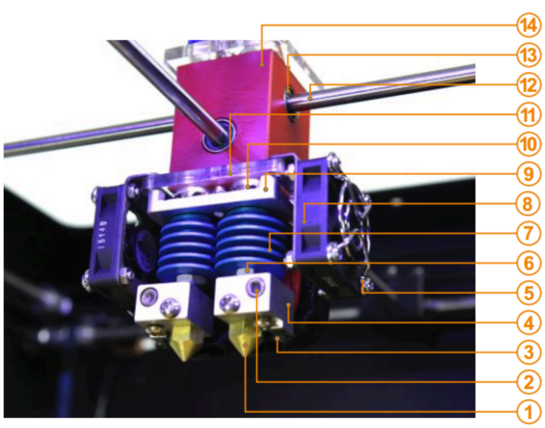
12. Power socket
13. Spool holder
14. Filament
15. Z stop limit
16. Filament inlet
17. X stop limit
18. Filament feeder 1
19. Compression nut
20. Filament feeder 2

Filament Feeder



1. Pressure arm
2. Pressure spring
3. Pressure nut
4. Wire socket
5. Geared motor
6. Filament inlet
7. Filament sensor
8. Feeder body
9. Feeding wheel
10. Fixed hole
11. Pipe joint

Printer Head



1. New Nozzle
2. New Heating tube
3. Thermostat tube
4. New Heating block
5. Fan duct
6. Heat Break
7. Heat Sink
8. Cooling fan
9. Head Al. frame
10. Adapter plate
11. Head adjust
12. Linear axis
13. Linear bearing
14. Head main block