CME

Creative Mechanical Engineering

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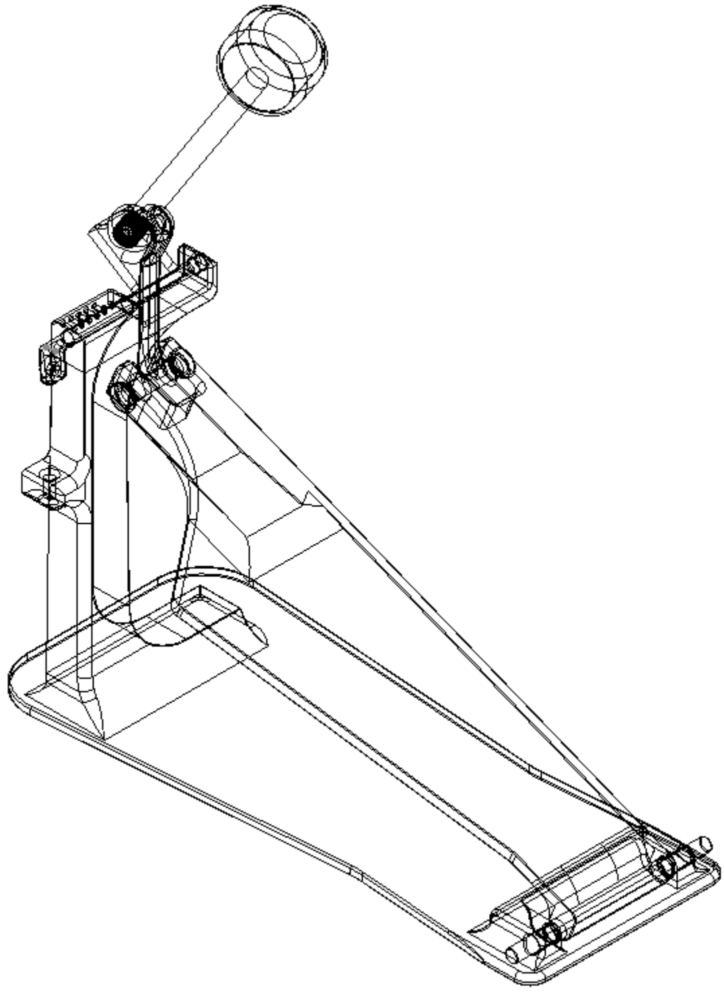

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Introduction

This report presents the process of 3D-printing a kick pedal and the manufacturing and design techniques that were used for this for the course "Creative Mechanical Engineering" of the Eindhoven University of Technology.

Argumentation to support the used techniques is provided, in the form of design choices and calculations. This process lead to the creation of a kick pedal, used for playing the kick drum of a drum kit. The traditional kick pedal is essentially a simple concept: a 'hammer' (head) that is controlled by the foot. However, there are a lot of interesting aspects involved that ultimately form the fundamentals of music. This posed as the basis for our project. The result of our research and modelling can be found at the end of the report, including 3D renders and photos of our model.

Manufacturing & Design

This chapter will be about the manufacturing & design that were implemented for this assignment. A PolyJet 3D printer was used for printing the model. The model is made of 2 different materials: a strong, rigid material (VeroWhitePlus) and a soft, rubber-like material (TangoBlackPlus).

Manufacturing Technique

The 3D printer that we had at our disposal was the Stratasys Objet 350 Connex 3.[1] This printer produces exceptionally smooth, realistic and precise, when compared to other 3D printed objects. This level of production is achieved by implementing PolyJet technology. PolyJet works by printing with photopolymer resins. The working is similar to a traditional inkjet printer: the nozzle prints drops of ‘ink’, a photocurable resin, on a platform These drop are then immediately cured by using UV light, where an inkjet printer would let the ink dry on its own.[2]

This technique of 3D printing is a form of Material Incress Manufacturing, better known as Rapid Prototyping. The goal of this form of manufacturing is not to create production-ready parts, but to create quick prototypes of products in development, so they can be evaluated and tested before they enter production. The advantages of PolyJet when compared to other 3D printing techniques, like the more popular Fused Deposition Modeling (FDM), is that objects turn out much more ‘real’: PolyJet technology allows for printing layers as fine as 16 microns. Most FDM printers do not come close to this level of accuracy. This is, in part, because Poly-Jet is an industry-grade technology. There are little to no consumer 3D printers which print with this technique and which utilise FDM instead. This is because this method of printing is generally cheap-er, because of the lower accuracy.

One major advantage of PolyJet technology is that it allows for the simultaneous use of multiple materials in a single object. This means that certain parts of an object can be given different properties than other parts. We made use of this extensively in our prototype, as you can read below.

1. ‘Connex3 Objet500 and Objet350’. Retrieved from http://www.stratasys.com/3d-printers/objet-350-500-connex3

2. Rohrbeck, T. (15/11/2017). ‘What is PolyJet 3D Printing Technology?’. Retrieved from https://www.gsc-3d.com/articles/2017/11/what-polyjet-3d-printing-technology

Design Choices

In order to make a working kick pedal, it is necessary to make some adjustments to the traditional model. They are typically made of steel. Steel is a much stronger and heavier material (with a tensile strength (yield) of 350 MPa) than the rigid material we use (VeroWhitePlus with a tensile strength (yield) of 'just' 65 MPa), so it can withstand much higher tensile forces. Since our model had to make use of this other material, we modified the design of a traditional kick pedal to account for the difference in properties. The design decisions that were made to create a working kick pedal are explained below. We will refer to specific parts of the model, which can be found in the next section ("Threedimensional Model").

There was one constraint of the 3D printer we had to take into account while designing the pedal: if some parts of the model were very close to each other (e.g. in the hinges), we had to incorporate a minimal space of 0.2 millimeters in between those parts. This was the advised minimal distance between (moving) parts, so that everything could be printed out correctly and all support material can be removed correctly. One unfortunate, but unavoidable, side-effect of this constraint is that there is a tiny bit of play between the different moving parts. This does not have a very negative effect on the overall model. To reduce the play on the hinge of the footplate (see figure 8 and 9), we thickened the axis at its ends. This can be seen in figure 8 and 9 in blue.

This brings us to another constraint for our design: there needed to be room for the support material to be removed. Because our model has small spaces in between parts, the printer will automatically fill these spaces with support material. This can be removed by spraying it off with a high-pressure cleaner. However, the water from this cleaner needs to be able to reach theses well to clean them of support material. It lead us to making holes in the top part of the design, where the hammer hinge mechanism resides. The holes are small enough that they do not compromise the structural integrity of the model, yet big enough to let water in.

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This hinge consists of two rings (an inner and an outer one). This was a necessary design choice that functions to reduce the wear of the hinge. Because of the limitations of 3D printing, we cannot attach incorporate a bearing into the hinge afterwards. By having two different materials in the hinge mechanism, we replicate the effects of a bearing. The inner cylinder will consist of the rigid material, VeroWhitePlus, while the outer cylinder will consist of the more rubber-like TangoBlackPlus material mixed with VeroWhitePlus. Having the hinge consisting of two materials reduces the wear of usage when compared to a hinge with one material: the softer material on the outer ring serves as a 'cushion' to the harder material, thus reducing the wear of the harder material rubbing against another material. Furthermore, the hinges we use are a little bit thicker than 'normal' hinges (with the exception being the hinge connecting the footplate to the base), since the material is weaker than steel. This larger diameter should make them a strong enough to not break.

In order to save material and in turn cut costs, we removed one 'support pillar' (the part of the kick pedal that holds the hammer mechanism in place) of the kick pedal. Most kick pedals have two pillars to support the hammer mechanism and make it a solid construction. We chose to go for the cheapest option, because we can then save on material; one pillar should be strong enough to resist the forces acting on it. This design is partially based on an existing kick pedal design, by Axis.[3]

Enough stability and strength of the singular pillar is accomplished by implementing two design aspects. The first aspect: we make use of two fillets with a large radius, one at the top and one at the bottom of the pillar. The fillets divide the forces on the pillar over a larger area instead of over just one single (breaking) point. The other aspect is that the downforce on the footplate generated by the drummer's foot is partly compensated by the spring on the right side of the pillar. The spring absorbs a part of the energy by storing it as potential energy when the footplate is pushed down.

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An important design choice, which was made quite late in the process, was that the hammer should be printed separately from the rest of the model. This decision was made to save on support material and thus unnecessary costs. The hammer can be attached to the kick pedal after printing, by using a screw-thread construction (see figure 6). Printing the hammer separately from the rest of the model enables the 3D printer to print it on its side. When the pedal is then used in its normal orientation, the layers of the printed model align vertically with the rest of the pedal. For the printing technique the Objet350 uses, this is not particularly important; however, if this model were to be printed using a consumer-grade printer (most probably using FDM), there is a chance of layers splitting. Printing the model sideways can help to reduce the effect this would have on the structural soundness of the pedal.[4] This method of printing would not be possible if the hammer would be fixed to the whole model. Printing the pedal sideways is convenient in that the whole model is lower. This way, less support material is required.

We have not included a spring in the 3D model, since this cannot be printed so that it has the desired properties. A spring should be strong and flexible; hence, it is made out of steel traditionally. We cannot achieve that with VeroWhitePlus or TangoBlackPlus. To solve the problem, we decided to attach a spring from a real kick pedal to our model, after printing it. For this, we made two attachment points (see figure 5 and 6) in which we can place a spring that has a hook at each side (see figure 13). The distance between these two points is chosen to be the exact same distance as a slightly stretched spring, which is about 6.7 cm. The spring is chosen to be only slightly stretched and not more, because the force that is applied constantly on the pillar is then minimal. In this way we try to make sure that the model still functions correctly, while we minimise its wear.

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3. 'Axis X Single Pedal'. Retrieved from https://www.axispercussion.com/axis-pedals-old/x-single-pedal/

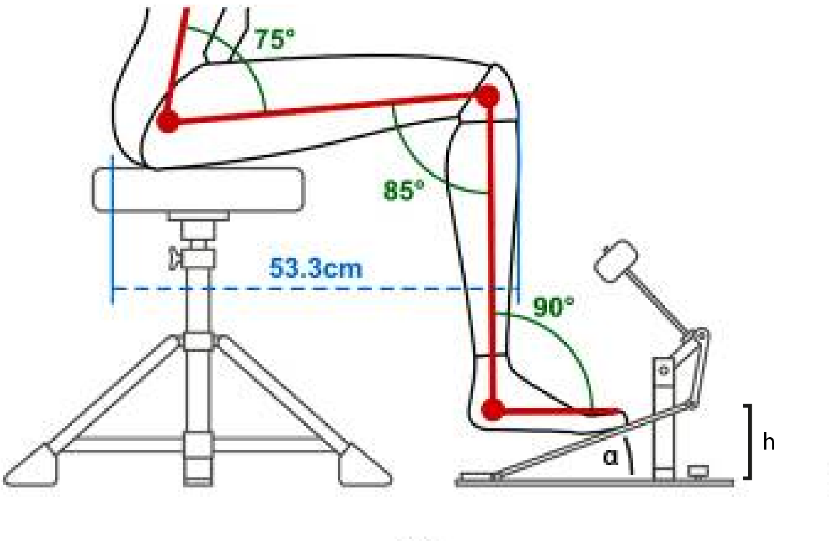
4. Tyson, E. (28/11/2016). 'Pillowing, Stringing and Splitting: What are they and how to stop them'. Retrieved from https://rigid.ink/blogs/news/pillowing-stringing-and-splitting-what-they-are-and-how-to-stop-them

The rod on which the hammer is placed has quite a large diameter, about 2.5 times as large as the standard diameter (see figure 4). The reason for this is again that the material we use is much weaker than the usual steel. It is important that the rod is strong enough, since the lever arm between the hinge and the point of impact (the hammer) is quite long. So the torque that is working in this scenario is rather high.

We tried to minimize the forces working on each part of the model by dividing it over a larger surface area with fillets. These fillets can also be found on the soft parts of the hammer (see figure 4). This is made of the softer (mixed) material to prevent the kick drum and the hammer from damaging. Fillets are also applied over the whole model to make the surface more smooth. This makes it look nicer; we are and always will be Industrial Designers in the end.

Our last notable design choice is that instead of using a chain to connect the footplate with the hammer, we chose to turn it into a hook-like part (see figure 7). This hook can be detached from the hammer and this enables us to lower the footplate, which saves a lot of support material (reducing costs). We also think it looks more aesthetically pleasing.

Calculations



The kick pedal is part of the basic drum kit and is used to play the kick drum. The mechanism of the kick pedal uses the kinetic energy of the artist's foot and transfers it to the hammer (the part that hits the drum). This energy is then partly lost in the kick drum, the other part is stored in the spring. When the artist removes his/her foot from the footplate, the spring restores the original state of the kick pedal (see figure 1).

We used a couple of constants to use in our calculations. These are sometimes based on real data and sometimes we were forced to approximate them.

- The mass of the head is approximately 1 kg.
- The length of the rod is equivalent to 14 cm.
- The length of the footplate is 26.7 cm.
- The angle (α) between the base of the kick pedal and the foot pedal is 20°.

For our calculations, we chose to simplify the situation of a classic kick pedal, by not taking into account aspects which have negligible effects on the results.

- The weight of the footplate, the rod connecting the beater to the pedal mechanism and the spring are not accounted for in our calculations. They do have effects in real life, but these are negligible for our application.
- The movement of the beater will be counted as a situation with constant acceleration, while in real life, this is probably not the case. The difference in results from a calculations, however, would be minimal.
- For the force the drummer exerts on the footplate, we took the simplest stroke on a kick drum pedal possible: letting the leg fall onto the footplate. This means that the force on the footplate equals the force of gravity of the leg of the drummer. For calculating this, we took the weight of an average adult person's leg, which is 15.6% of the total average weight of that person. The average weight of an adult is 75 kg.[5] This results in about 11.7 kg for the weight of the leg, which equals about 114.78 N for gravity on the leg. This is of course simplified: the weight of a leg is not equally contained above the point of impact on the footplate. For our calculations, however, this would make a negligible difference.
- For a normal drum kit, the kick drum would stop the beater as it reaches a more or less vertical position. In our calculations, we did not account for this, as implementing this is beyond our capabilities.

You can see our exact calculations on the next page.

5. Bruggink, J., & Wobma, E. (03/12/2012). Nederlanders steeds langer maar vooral zwaarder. Retrieved from https://www.cbs.nl/nl-nl/nieuws/2012/49/nederlanders-steeds-langer-maar-vooral-zwaarder

Calculation of the spring constant

Constants:

$L_1 = 0.032\ \text{m}$

$L_2 = 0.044\ \text{m}$

$m_{laptops} = 4.18\ \text{kg}$

$g = 9.81\ \text{m} \cdot \text{s}^{-2}$

$F_x = m_{laptops} \cdot g = 4.18\ \text{kg} \cdot 9.81\ \text{m} \cdot \text{s}^{-2} = 41.0\ \text{kg} \cdot \text{m} \cdot \text{s}^{-2} = 41.0\ \text{N}$

Equations:

$x = L_2 - L_1 = 0.044\ \text{m} - 0.032\ \text{m} = 0.008\ \text{m}$

$F_x = -kx$

$$k = -\frac{F_x}{x} = -\frac{41.0\ \text{N}}{0.008\ \text{m}} = -5125\ \text{N} \cdot \text{m}^{-1}$$

Calculation of the height

Constants:

$L_{foot} = 0.267\ \text{m}$

$\alpha = 20\,\%$

Equations:

$$\sin \alpha = \frac{h}{L_{foot}}$$

$h = L_{foot} \cdot \sin \alpha = 0.267\ \text{m} \quad \sin 20\,\% = 0.091\ \text{m}$

Calculation of the energy balance

Constants:

$m_{foot} = 11.7\ kg$

$g = 9.81\ m \cdot s^{-2}$

$h = 0.091\ m$

$k = -5125\ N \cdot m^{-1}$

$x = 0.0090\ m$

$m_{head} = 1\ kg$

Equations:

$$U_{grav} = mgh = m_{foot}gh = 11.7\ kg \cdot 9.81\ m \cdot s^{-2} \cdot 0.091\ m = 10\ kg \cdot m^2 \cdot s^{-2} = 10\ J$$

$$U_{el} = -\frac{1}{2}kx^2 = -\frac{1}{2}\ -5125\ N \cdot m^{-1} \cdot (0.0090\ m)^2 = 0.21\ N \cdot m = 0.21\ J$$

$$U_{grav} = U_{el} + K_{head}$$

$$K_{head} = U_{grav} - U_{el} = 10\ J - 0.21\ J = 9.79\ J$$

$$K_{head} = \frac{1}{2}m_{head}v_{head}^2$$

$$v_{head} = \sqrt{\frac{2 \cdot K_{head}}{m_{head}}} = \sqrt{\frac{2 \cdot 9.79\ J}{1\ kg}} = \sqrt{19.6\ m^2 \cdot s^{-2}} = 4.4\ m \cdot s^{-1}$$

Costs

Printing our model with the Objet350 is most certainly not for free. The price of the print material (VeroWhitePlus & TangoBlackPlus) per gram is estimated at €0,60. This price is estimated, since we use a mixture of these two materials for some parts of the print. Only the separate materials are sold, not the mixture itself. Therefore, we do not know the exact price of all parts of the print.

The estimated (for the same reason as the price per gram) average density of the print material is 1.175 g/cm3. Our model has a volume of 821228 mm3 (equal to 821.228 cm3). According to our calculations, the print material used would be equal to 964.9429 grams. The fully printed model (excluding costs for support material) would then cost around €578,97.

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The cost of a traditional kick pedal is much lower than this price, usually between €40,- and €150,-. This particular print is so expensive because it was printed by an industry-grade, high-end 3D printer. What if it was printed with a cheaper 3D printer, like the Ultimaker 2? The accuracy of the print would be significantly lower, but so would the price be. ABS, one of the materials usable with this printer, costs around €15,- to €20,- for 750 grams (based on this, we took €0,0267 per gram as reference price). The density of ABS is approximately 1.03 g/cm3. Our model would equal about 845.8648 grams of ABS. The resulting price (excluding support material) would then be €22,58. The exact costs would be a little higher, since the tolerances and requirements for this printer are very different from the ones we designed this model on.

In the aforementioned argumentation for the design choices, we mentioned several times that we designed our model differently to save on support material and thus costs. It would be interesting to see how much this could affect the estimated price of our print. However, the 3D printer itself calculates how much support material is necessary for the model to be printed correctly. Since we do not have access to this data, we can unfortunately not take the used support material into account for calculating the price for our print.

Threedimensional model

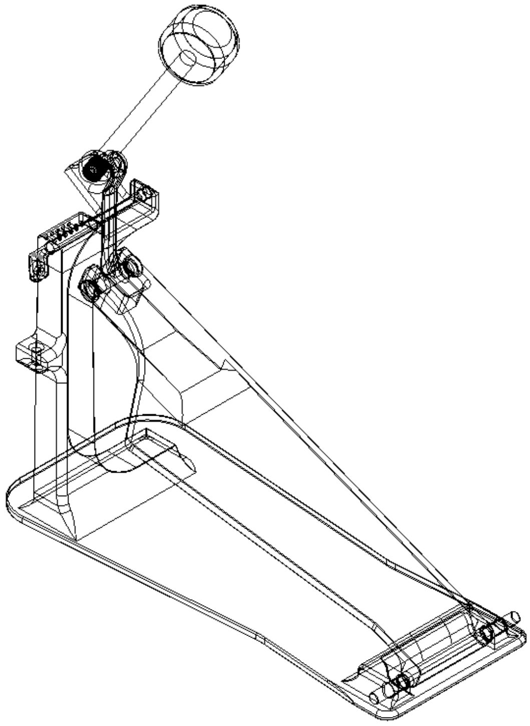

Figure 1 (left) & 2 (right)

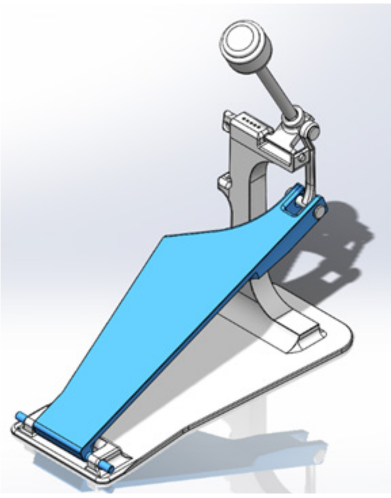

Figure 3:
The footplate
(VeroWhitePlus)

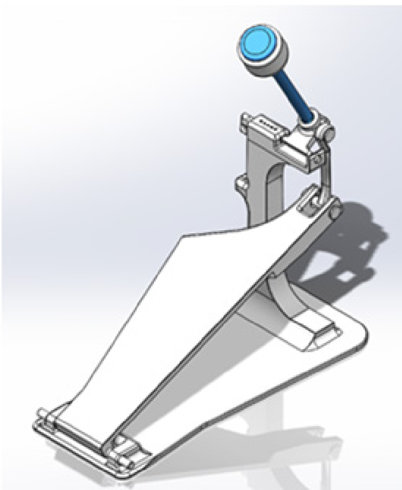

Figure 4:
The hammer & attachment rod
(VeroWhitePlus)

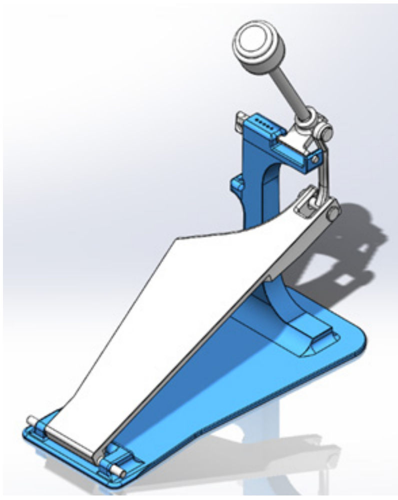

Figure 5:
The base & support pillar
(VeroWhitePlus)

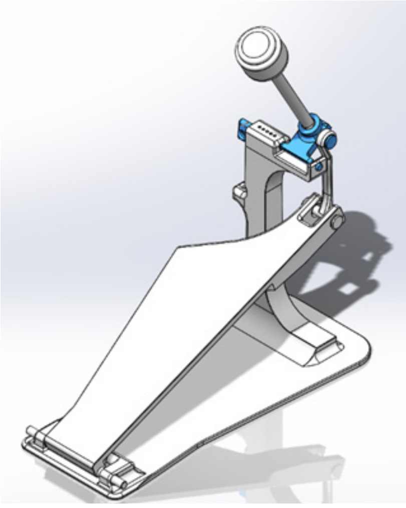

Figure 6:
The beater mechanism
(VeroWhitePlus)

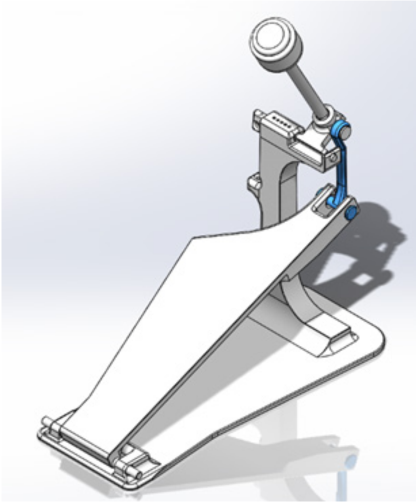

Figure 7:
The hook we use instead of the usual chain.
(VeroWhtiePlus)

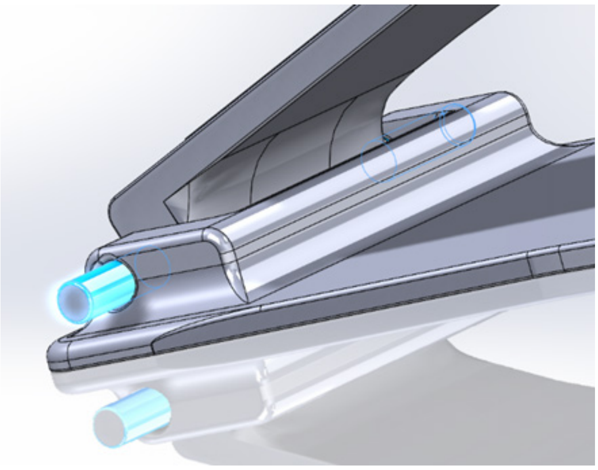

Figure 8:
The footplate hinge
(TangoBlackPlus)

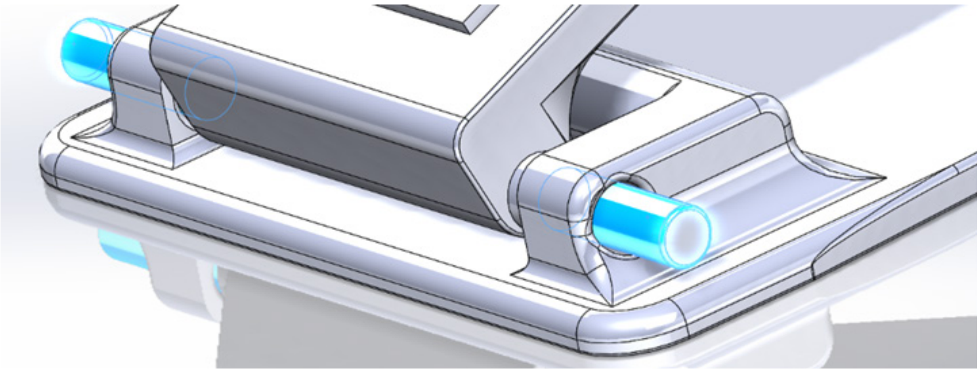

Figure 9:
The footplate hinge
(TangoBlackPlus)

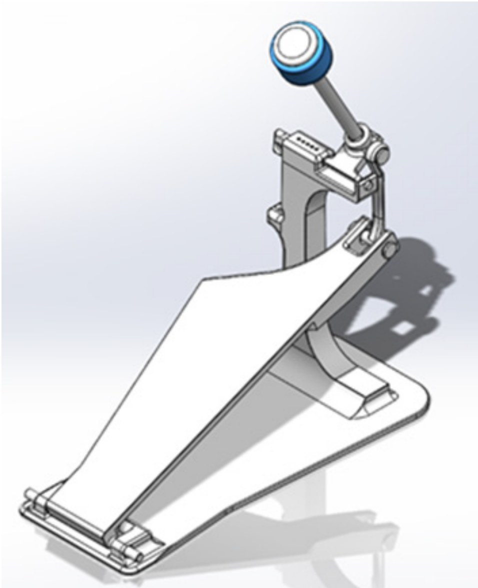

Figure 10

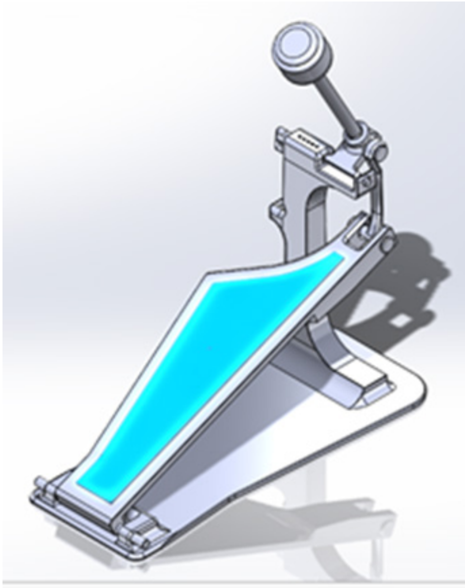

Figure 11

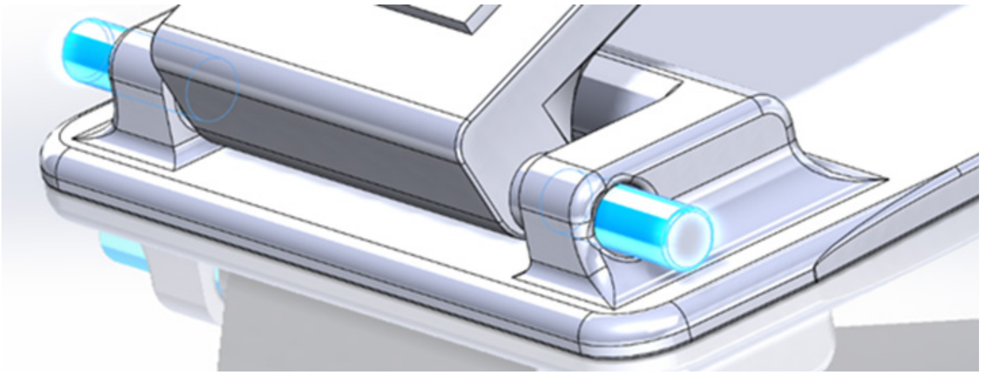

Figure 12

Figure 13: the spring of a kick drum pedal

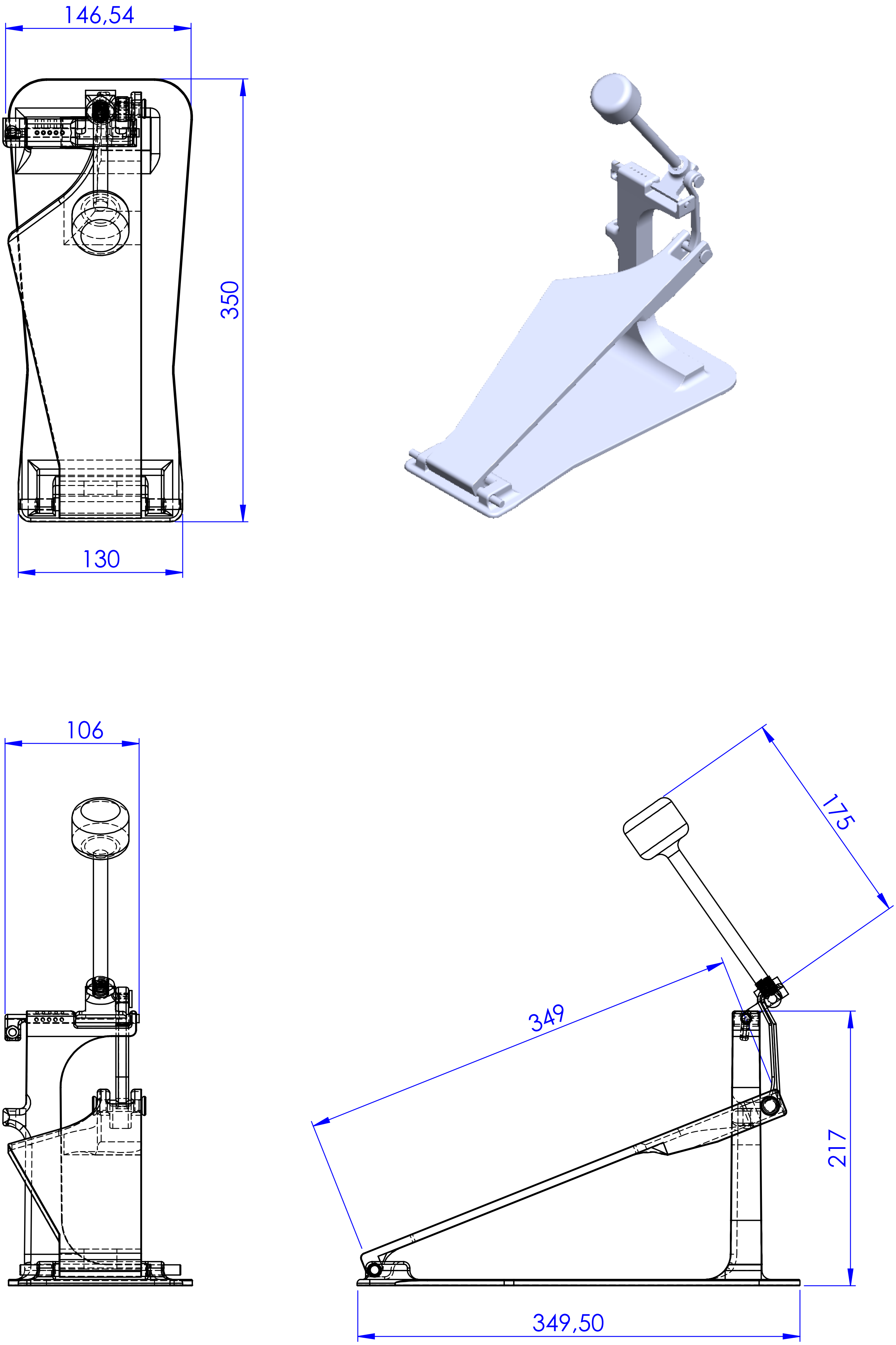

Figure 14: Technical drawings for the 3D model

Product Photos

Unfortunately, due to the printed model not being available on time, we were not able to include images of this in the report. Therefore, we can also not analyse the results of our research.

Appendix

Team Reflection

For this practical assignment, we have chosen to replicate a kick pedal from a drum kit, since two of our four group members are in fact drummers. They liked to idea of trying to 3D-print a kick pedal. The several different moving elements in this construction made for an interesting challenge for all of us. In general, we expected to learn mostly about the theoretical side of manufacturing and mechanical principles. While we certainly did study this, we did not expect to be putting this knowledge to use in a practical assignment. This was a welcome and informative surprise, though.

The teamwork in our group was divided as follows: two group members focussed on the practical work of designing the model in SolidWorks; the other two members mainly worked on calculating how the model would work in real life and writing the report. The communication between team members about their tasks was adequate for the most part. The division of work, however, was not equal, since most of this practical assignment consisted of creating the model of our kick pedal. This division was necessary: not all members could work on the model simultaneously. Besides, four different people working on the same model is bound to go wrong. For the final product, this was the best task division.

We gained a lot more modeling experience by working with SolidWorks. This will certainly come in handy in the future. Furthermore, it was really interesting to try and calculate things for a 'real' application. We are used to getting all the necessary data and context that enables us to make the calculations, but this was different. Apparently, nobody has ever decided to measure how hard the head of a kick pedal beats against a kick drum. This forced us to make a lot of assumptions and ignore a lot of factors. This was a good practice for future assignments, so it was good that we tried to calculate things already.

One point of improvement is the way we handled these calculations. The situation and the forces we used were quite simplified when compared to the real situation. This is not necessarily bad, as some factors had negligible influence on the behaviour of the forces acting on the pedal. We might have over-simplified some parts of the calculation; an example is that we ignored the turning mechanism onto which the drum head was attached. In our defence, this was quite complicated to include in; however, it would have improved the accuracy and trustworthiness of our calculations a great deal. For the sake of these two elements, we would like to incorporate this improvement in future projects.

In addition to the force calculations by hand, we wanted to confirm the calculations using the Solid Works simulation add-in. Unfortunately, we didn't have enough material properties to properly test the model. We used standard values that were given on the Objet website, yet these basic properties weren't sufficient for the simulation. We asked Chet if he could give us the missing values but he told us that we should take the printed material to the test and find out these values. We found this to be inappropriate for our project and that is why we have chosen to restrict the calculations to the ones made by hand. The simulations would have provided interesting insights and pre-knowledge of whether our model would be structurally sound.

Task Division*

- Introduction (Jules)
- Manufacturing & Design Techniques
    - Manufacturing Technique (All)
    - Design Choices (All)
    - Calculations (Jef & Jules)
    - Costs (Rick, Jef & Jules)
- Threedimensional model (Paul & Rick)
- Product Photos (All)
- Task Division (Jules)
- Team Reflection (All)
- Report Layout (Jef)

*The making of the 3D model made up the largest part of the assignment.

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