Test Rig Design for Accelerated Life Testing of Chainsaws

A Major Qualifying Project Report

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by:

Olivia Steen (WPI)
Adam Olsson (KTH)
Jacob Andersson (KTH)
Johan Erkers (KTH)
Marcus Söderberg (KTH)
Oskar Lundkvist (KTH)

Sponsored by:
Joakim Arvby
Husqvarna Petrol Handheld Product Laboratory, Husqvarna AB

Date: 17 May 2018

Professor Holly Ault, Advisor
Worcester Polytechnic Institute

Professor Kjell Andersson, Project Supervisor
Royal Institute of Technology

Professor Stefan Björkland, Project Supervisor
Royal Institute of Technology

Abstract

This project presents a conceptual design for a test rig for accelerated life testing of chainsaws. Three different subsystems, loading, oil collection, and handles, were created to reflect realistic operating conditions in the testing environment. The loading subsystem applies forces to the bar that mimic the normal forces felt by the saw during field operation. The oil collection subsystem consists of three chambers to collect the oil mist and aid in the increased air purification. Finally, the handles constrain the saw in a way that mimics the response of a field operator. These subsystems were then integrated, producing the full concept of the rig. Further development and integration of these subsystems will be continued, and a prototype will be built in the coming semester.

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Preface

This project stems from a collaboration between the Royal Institute of Technology (KTH) and Husqvarna AB for the KTH project course MF2076 during the spring semester of 2018, under the Industrial Engineering and Management department at KTH. The project fulfills the Major Qualifying Project for Worcester Polytechnic Institute and a partial fulfillment of the Machine Design master program for KTH students. The design generated in this report serves as the basis for the prototype to be completed by KTH students in the fall semester of 2018.

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1. Introduction

The purpose of this project is to develop and create a test rig for accelerated life testing of Husqvarna 50cc chainsaws. Accelerated life testing is when products are tested at high speeds and stresses for extended periods of time to discover failures; these tests are a necessary part of ensuring the product is safe to use (Intertek Group, n.d.).

Husqvarna currently has test boxes that run chainsaws for many hours to see how the saw takes the wear. However, the conditions in the test box do not match the conditions in the field, so the company relies on field data, which is an expensive and lengthy process. The goal of this project is to design a testing structure that better mimics the field test environment in terms of loading, lubrication, and vibration. This test rig design can then be implemented in future test boxes to limit the amount of field testing required.

2. Background

Chainsaw manufacturers must test new products in accordance with ISO standards to verify the useful lifespan, the time before the first major failure, of the product. The necessary lifespan of a chainsaw depends on the target customer, with professional saws needing to last at least 400 hours (HVA/KTH Project 2018, 2018). The number of useful operating hours can be determined through accelerated life tests.

Accelerated life testing is a form of testing wherein a product is subject to increasing levels of variables encountered in operation. During chainsaw accelerated life tests, the manufacturers must investigate the crucial elements of the machine's duty cycle (the start-up, the operational run, and the run-down) though predefined test cycles (Pesik and Skarolek, 2014). Several methods of accelerated life testing have been done in chainsaw manufacturing, including using a water brake load and user cutting tests.

In a water brake load, water inside a casing is used to simulate the loading the saw would sustain while cutting a log. The casing can fill with a variable amount of water to simulate different loads. The torque of the motor is then derived from the shear forces in the water measured by a load cell inside the casing (Feldkamp and Tedesco, 2003). The drawback to this type of measurement device is that it can only be used in above zero temperature or else the water will freeze (Joesfsson and Henningsson, 2015).

User cutting tests provide the most accurate results, as they are more representative of how the saw will be used in the field. However, these tests are harder to perform as they require a human operator and a large amount of timber. Thus, simulated load tests using water brakes are performed in testing laboratories. These require less man-hours and resources, but do not accurately reflect the engine and chassis loading experienced by the saw in the field (HVA/KTH Project 2018, 2018).

2.1 Current Husqvarna Testing Laboratory Problems

Husqvarna's testing laboratory currently houses 30 chainsaw testing cells. These cells run tests with both water brakes using ISO standard test cycle TC-H17-02, and running the engine with a bar but no chain using ISO standard test cycle TC-H17-01 (HVA/KTH Project 2018, 2018). However, the damages that appear on the saw while cutting timber are not reflected in the test box simulations due to the lack of realistic loading. Therefore, to get a clear idea of the effectiveness of the chainsaw design Husqvarna must rely on field tests, where data is collected from operators using the new saw in non-test environments.

Field testing is a great way to get input on the developed product, however it can be very time consuming, costly and provides feedback regarding the product too slowly. To generate more immediate feedback, Husqvarna wants to upgrade their testing facilities to include test rigs that better simulate reality.

3. Project Requirements

Before the work process of the project could begin, Husqvarna presented several areas that should be addressed in the creation of a test rig to simulate realistic engine and chassis loading. The first focus areas are the chassis and engine; these components must be loaded to reflect the normal cutting forces experienced by the bar during operation. The handles are another important part of the saw. A method for restraining the saw in a way that realistically models the resilience and frequency response of a user holding the handles. A system should also be implemented to collect the used oil, preventing the oil cloud that is currently created in the test cell. Specifics for each of these areas are laid out below. A complete list of requirement specifications and tasks can be found in Appendix A: Project Requirements and Specifications.

There have been several limitations we have kept in mind throughout the concept generations. The solutions must fit in the supplied test box dimensions and utilize a fully assembled chainsaw. There can be no increase in fire hazard, and the solution should be able to be easily implemented and maintained by testing technicians.

3.1 Requirements for Loading Engine and Chassis

The test rigs currently in use at Husqvarna have no way to simulate loading of the bar. A water brake attached to the front end of the bar brakes the chain during a set of test cycles. Although the water brake brakes the chain, it lacks the ability to load the bar in a realistic way due to its placement. The loading system must brake the chain and load the bar in a manner that reflect the normal cutting forces to better represent the fatigue and wear experienced during field testing. To achieve this a number of concept ideas were generated and evaluated.

The saw and bar should withstand 400 hours while the chain is replaced multiple times during the saw's lifetime. But even so, the chain fatigue should be taken into account. The fatigue of the bar will both be evaluated through calculations and simulations in the test rig. The load on the bar in its normal direction will affect the joints where the bar is connected to the main body of the saw. To simulate the normal cutting forces, a change in height and an angle between the bar and horizontal plane are needed. If possible the test rig should be constructed in a way so that the readings represent the actual wear on the engine caused by usage of the saw.

3.2 Requirements for Oil Systems

During field testing most of the excess oil on the bar and chain is absorbed by the cutting material. In the current test box, the saw is run with the standard amount of oil and no cutting material. These conditions are leading to an excess of oil, resulting in runoff and oil mist not reflective of realistic operating conditions. Reducing the cloud of oil mist is a crucial part of creating more realistic cutting conditions.

3.3 Requirements for Restraining the Chainsaw

The main requirement and purpose of the handle subsystem is to mimic a gloved operator using the chainsaw during normal operation. The requirements for the entire test rig system were evaluated and simplified as to which may interfere and depend on the handles subsystem.

4. Concept Generation

To start generating possible concepts, the group used a brainstorming technique called 6-3-5 method. This method consists of six people, or seven in this case, generating three ideas each during five minutes. The ideas are then passed on to the next member for refinement and feedback. The group used a compressed and modified version where each paper was passed on so that each paper was evaluated by two more people other than the original creator. The session then restarted until the group were satisfied with the result. Looking at Husqvarna's requirements and the ideas generated from the 6-3-5, the group decided to divide into the three subgroups described below: loading, oil and handles.

4.1 Loading System

The loading ideas generated in the brainstorming sessions: friction-based concepts, where a friction material is used to brake the chain, and form-based concepts, where geometries complimentary to the chain are used to brake the chain. After evaluation it was decided that the friction based methods would generate too much heat, causing the box temperature to exceed Husqvarna's requirements. The discarded friction based concepts can be found in Appendix B: Friction Based Loading Designs. Below are short descriptions of the possible form-based solutions to fulfill the given requirements.

4.1.1 Form Based Concepts

Cogwheel. The initial idea for a form-based load solution was to have a sprocket that the chain could hook on to, loading the engine in a realistic way. This solution would also make it possible to provide a load on the bar as shown in Figure 1. This method was discarded since the loading scenario of the engine was not that realistic since the solution only providing a point contact between the chain and the sprocket. However, this idea was further developed into a concept involving a chain and timing belt.

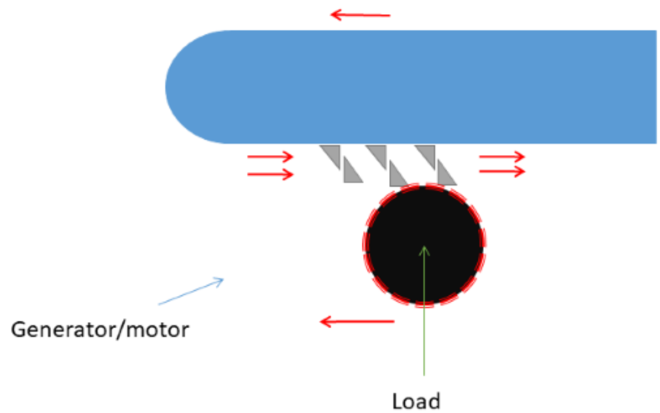

Figure 1 Sketch of Cogwheel Form-Based Concept

Chain and Timing Belt. This solution was developed based on the first form-based idea. Unlike the first solution, the load is distributed over a larger area. This gives a more realistic load case for the engine and the bar load scenarios. Using a chain or timing belt, the idea is to hook into the chainsaw chain as shown in Figure 2. This is the chosen concept to be further developed and will be described in more detail.

Figure 2 Chain and Timing Belt Concept Shown Attached to Bar

4.1.2 Chosen Concept

Out of the above evaluated concepts it was decided that the most realistic one to move on with would be the Chain/timing belt solution. This solution requires a modified chain to transfer the torque from the chain to the braking device. This is a basic modification that only changes the assembly order of links. The original chain consists of four different kind of links and is shown in Figure 3 Depiction of Unmodified Chainsaw Chain Segment. The names of the links are as follows: 1) Knife 2) Standard Link 3) Drive Link with Tip 4) Drive Link

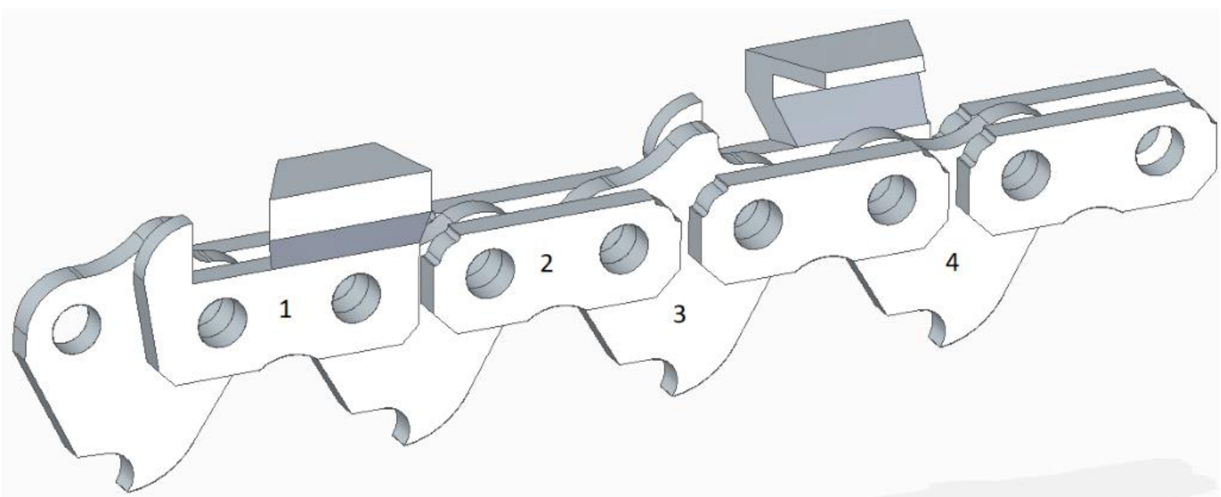

Figure 3 Depiction of Unmodified Chainsaw Chain Segment. The names of the links are as follows: 1) Knife 2) Standard Link 3) Drive Link with Tip 4) Drive Link

The original chain is not suitable to transfer the torque, since its design doesn't allow the chosen solution to interact with the chain in a proper way. The proposal for modification is shown in Figure 4. This chain consists of only link types 2 and 4 to get the drive link shape on both sides of the chain. This shape is convenient for the torque transfer.

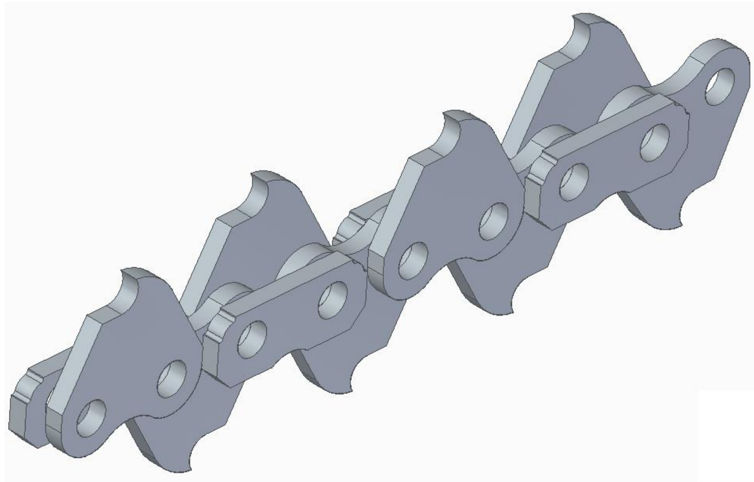

Figure 4 Depiction of Modified Chain Segment

To be able to transfer the torque evenly when the chainsaw oscillates from vibrations, the connection between the vertical force (mounting to the ground) is done by a bridge with its pivot point above the transfer plane, see Figure 5. This whole upper part is connected to the lower part with, still to be chosen, a vertical load/displacement applier. The connection between the chainsaw chain and brake is still to be evaluated further, but two concepts for this presented below.

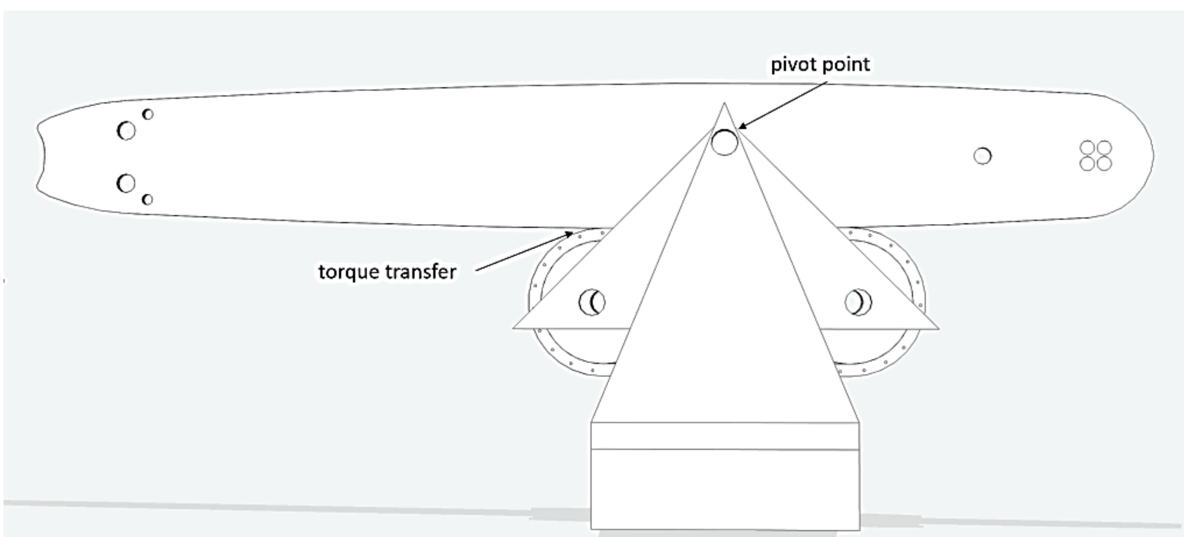

Figure 5 Loading System CAD Highlighting Pivot Point and Torque Transfer

The modified chain is placed on a double timing belt setup, as seen in Figure 6. The timing belts are connected to each other with small steel rods that the chain hooks into, and two sprockets are connected to two shafts, where the brake is mounted. The chain is always in contact with the timing belt rods in order to reduce wear and unnecessary shocks from impact. To cancel out the inertial effects the chainsaw experiences from this the design, an accelerator is connected to one of the shafts as well. This regulates the speed of the timing belts when no load is applied to match the speed of the chain.

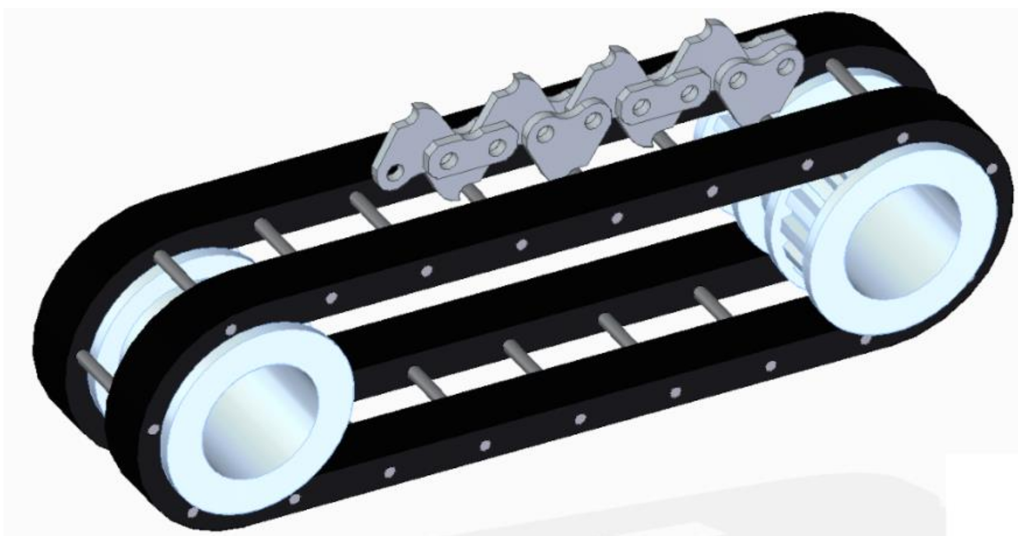

Figure 6 CAD of Modified Chain on Timing Belt

One of the advantages of using timing belts is that they are somewhat flexible and thus spread the load between the points of contact. Timing belts are also suitable for the speed of the chainsaw. One disadvantage is the potential impact of the oil mist, if the timing belts starts to slide the braking would not work. The sprockets, as seen in Figure 7, are paired with a distance in between for the shark fins to have clearance.

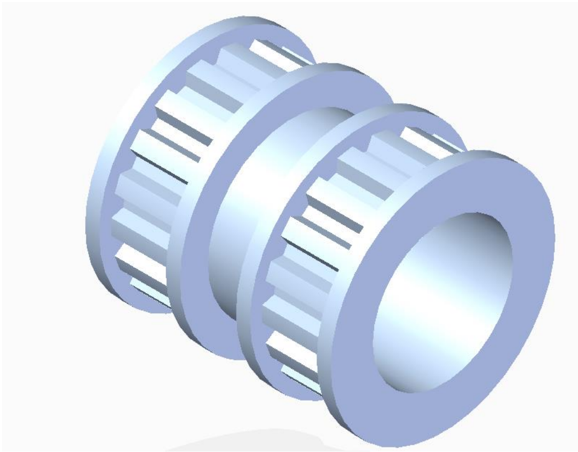

Figure 7 Sprocket Component of Timing Belt Concept

4.2 Oil Collection System

The main purpose of the oil problem solving concept is to increase purification rate in the test-box and increase the oil collection rate. This is achieved by using the concept illustrated in Figure 8, which consists of several different sections. To prevent the mist cloud from causing over-lubrication and contaminating the intake air we have separated the system into its three critical areas. Each area is isolated by a housing that collects the oil for recirculation, preventing the mist from contaminating the test box air. These three critical areas addressed are the bar/chain, clutch cover, and exhaust fumes.

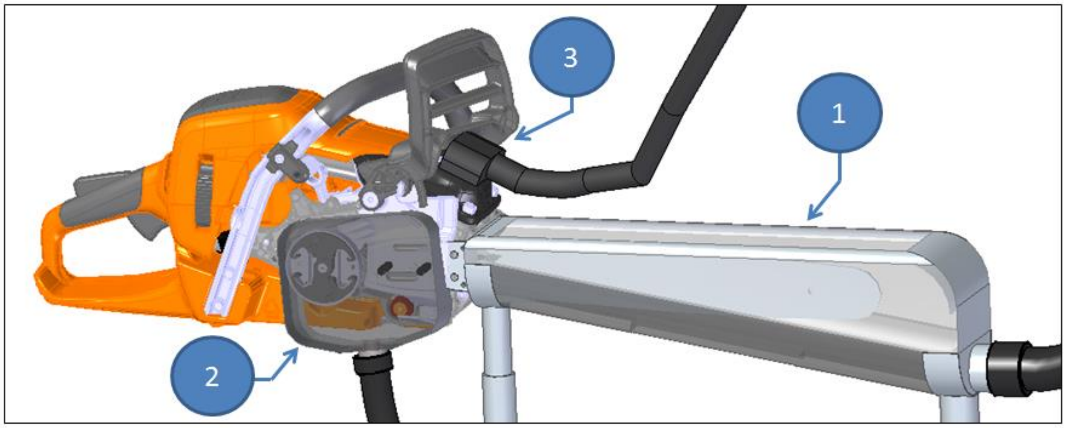

Figure 8 CAD of Three Cover System for Oil and Exhaust Collection. 1) Bar Cover 2) Clutch Cover 3) Exhaust Cover

The Bar Cover. A box encompassing the bar and chain will collect the excess oil coming off the groove. Figure 9 is a concept drawing of the separation chamber. The bottom of this chamber has a sloped surface with suction to draw oil mist to the bottom of the chamber, into the filtration system, and allow it to be collected and recirculated. The dimensions of this chamber must also be able to house the loading device. Another condition that must be addressed is how this separation chamber would affect the heat transfer of the system. The material must have a sufficient heat transfer coefficient to allow for proper heat conduction and keep the bar and ambient temperature at acceptable levels.

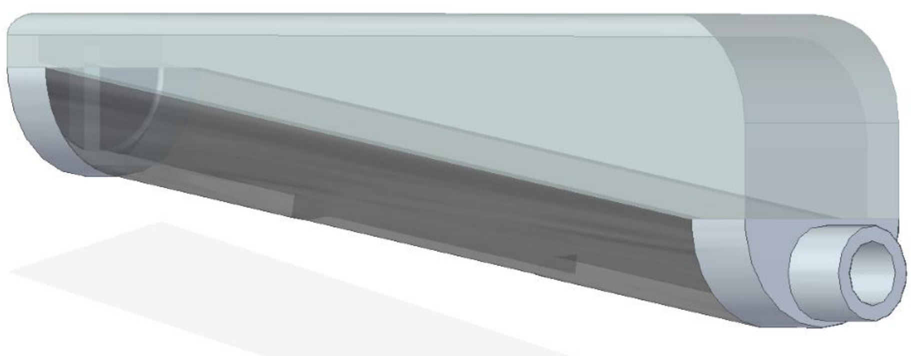

Figure 9 Bar Cover Design

The Clutch Cover. Much of the oil that is not captured in the previous collection system is disposed of as the chain enters the clutch cover, creating an oil pool and oil mist. To prevent this mist, a second separation chamber that covers the area of the clutch is integrated into the system. This chamber must surround all sides of this area to be able to capture all the mist. Similar to the bar and chain chamber, the caught oil will be directed to a reservoir for recirculation. The cover design must keep in mind the parameters set out by the handle design and must not cause overheating in the system. This design is illustrated below in Figure 10. A similar vacuum system is attached to the clutch cover area.

Figure 10 Clutch Cover Design

The Exhaust Cover. The last critical area addressed by the three-chamber system is the exhaust gases that contaminate the intake. The exhaust gases that exit the motor through the muffler (shown in Figure 11) contain a significant proportion of oil. The current system has no way to direct these gases away from the intake, causing dirty air to re-enter the motor. In this solution the exhaust gases are separated from the intake portion of the motor through a hose attached directly over the muffler, filtering the exhaust gases out from the test-box. The vacuum air system must be powerful enough to redirect most of the gases exiting the port into the vacuum tube, as the nozzle should not be directly touching the chainsaw to limit the influence the tubing has on the vibrations of the system. The nozzle should have a wide enough opening to capture most of the exhaust gases.

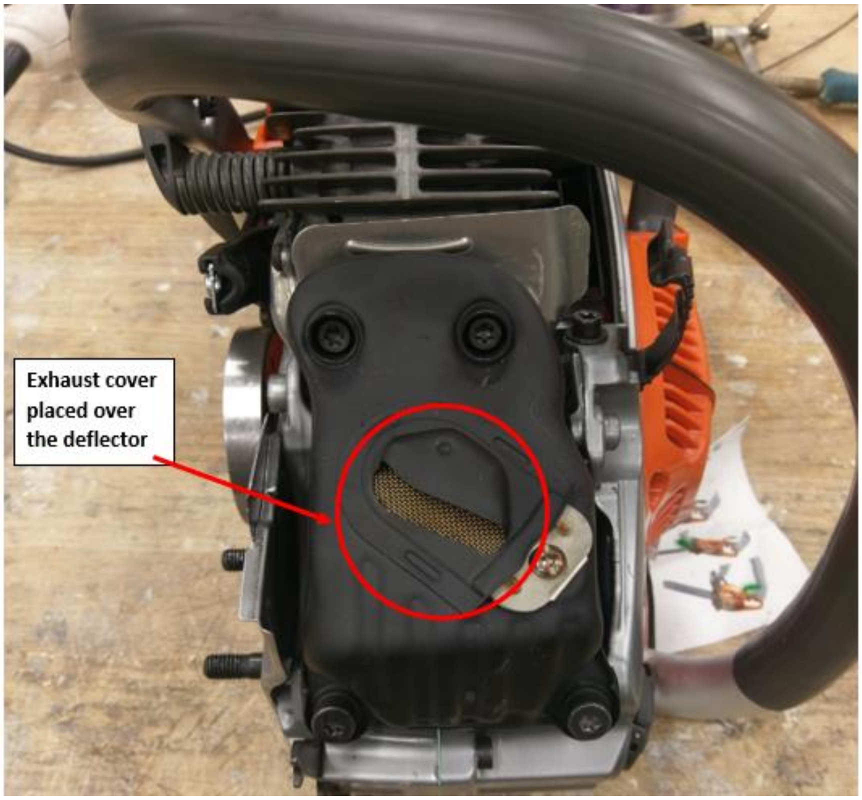

Figure 11 Image of Husqvarna 550 XPG Chainsaw Muffler

This nozzle over the muffler will nullify the exhaust gases, eliminating interference between exhaust gases and intake. A limitation for this exhaust cover is it cannot be made of metal, due to the generation of sparks in the muffler area if a metal nozzle were used. The conceptual design of the exhaust cover is illustrated in Figure 12.

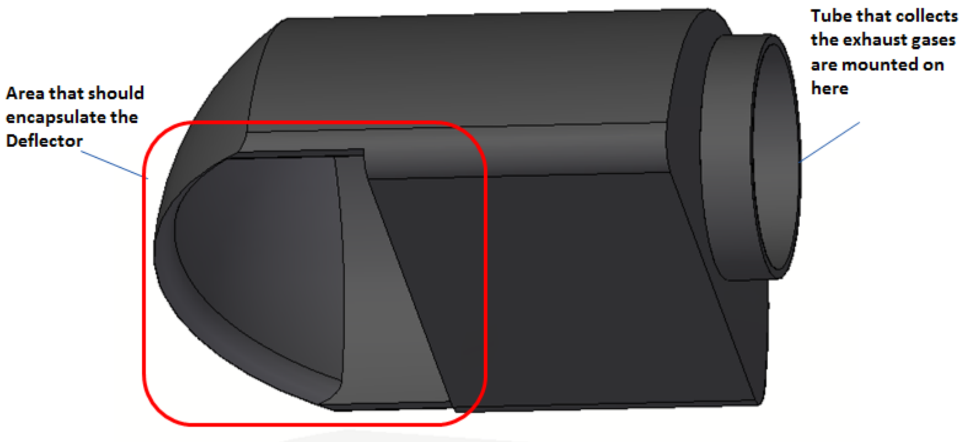

Figure 12 Conceptual Design of Exhaust Cover

4.2.1 Materials Selection for Covers

The materials must also be selected for each of the three chambers. This should be done through a selection matrix of the different criteria. The material must:

- Withstand greater than the ambient temperature in the test box
- Be durable enough to survive the long-term vibrations of the saw system
- Be easy for technicians to remove and replace
- Not interfere with the temperature of the system
- Be easily obtainable and workable
- Not increase fire hazards
- Has a high durability when in contact with oil/corrosive environment

A matrix comprised of ten different materials was created to compare the properties of potential potential materials. The properties were found using the material database CES Edupack. The table table containing the material properties can be found in of oil and added cooling.

Appendix C: Oil Collection Cover Material Selection Matrix.

One of the main requirements of this design is that it cannot increase the fire hazard. This criterion ruled out any material in our matrix that is flammable. The nickel-chromium alloy and stainless steel are then removed due to their comparatively high cost combined with their average machinability and moldability. The remaining three materials were low carbon steel, aluminum alloys and copper. The workability of low carbon steel is lower than that of the aluminum and copper, however the cost of the steel is much cheaper. Comparing the aluminum and copper, both have great workability, but copper is more expensive so to save on costs that material is not selected. Thus, aluminum has been selected as the potential material to create the bar and clutch covers.

This selection should be verified through thermodynamic analysis once the dimensions have been agreed upon to prove that the box systems do not cause significant heating of the saw and ambient air. The options for material for the exhaust cover need further development, as discussed in Section 4.2.4 Future Work on Oil System

4.2.2 Vacuum/Air System

The vacuum system attached to the bar and chain cover must provide enough suction to prevent the pooling of excess oil and collect as much of the excess as possible before the chain enters the clutch cover. Most of the oil needed to be collected in this area is in the form of oil mist, created by the flinging of oil off the bar and chain system. This mist is sucked by the air system and then filtered before the air is returned to the test chamber. Thus, the system must be powerful enough to move the oil particles in the given box area, as well as the filter must be able to accommodate the size of the oil mist particles, which generally range from 0.1 microns to 0.3 microns (Kittelsona, 1998).

The vacuum system attached to the clutch cover works in a smaller volume than the bar cover, but the filter requirements and particle size are the same. The exhaust cover vacuum system should accommodate exhaust gases and, like the previous critical area systems, be able to filter the oil mist particles.

Vacuum systems used to extract oil mist in similar settings were researched to find suitable systems. Oil mist extraction units, such as the ones shown from Sentry Air Systems in Figure 13, are used in machine shops where lubricated tools generate oil mist.

Figure 13 Sentry Air Systems Mist Collector Model # SS-300-MIST (SAS Inc, 2016)

This air system can handle an air volume of up to 100 CFM (cubic feet per minute) and can be supplied with a filter that is up to 99.99% effective on particles with diameters down to .12 microns in size (SAS Inc, 2016). A system such as this could be connected to the tubes attached to the bar cover, clutch cover, and exhaust cover.

Once the specifications of the vacuum system are known, the dimensions of the tubing attached to each cover can be more accurately determined. The pressure generated by the vacuum system is determined by the area of the tube opening. The variance in pressure between the vacuum tube and the surrounding area should exert a large enough force to collect the mist particles.

A rough estimation of these pressures can be found using the Bernoulli equation. This can be used because the area the air is flowing from a larger area (the area of the box) through a smaller area (the area of the tube) with an increasing velocity as it is sucked into the tube due to the pressure difference created by the vacuum system. Bernoulli's equation is listed below.

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \text{ (1)}$$

For all covers, the particles are assumed to start suspended in still air, thus v_1 is zero. The variable h_1 depends on the geometry of the cover, with the max h_1 being used in the estimate. This is the distance of the area to be acted upon in reference to the pipe opening, h_2, which is zero. In these calculations, P_1 is the pressure of the box, assumed to be atmospheric pressure, or P_{atm}, while P_2 is the pressure inside the vacuum system. This P_2 is unknown. To solve for P_2, or P_{vac}, the equation is rearranged to find Equation 2:

$$P_{vac} = P_{atm} + \frac{1}{2}\rho v_2^2 - \rho g h_1 \text{ (2)}$$

The variable v_2 is dependent on the geometries of the tube openings in the individual chambers, as it is defined by Equation 3 in which the flowrate, defined by the flowrate of the air system, is divided by the cross sectional area of the tube opening.

$$v_2 = flowrate/A_{c,tube} \text{ (3)}$$

Once P_{vac} is calculated, the force acting on the oil mist particles can be found as in Equation 4, wherein force is defined as the pressure acting on the particle (P_{atm}) multiplied by the cross sectional area of the particle. If this force is greater than the force of gravity acting on the particle then the tube-vacuum system will be sufficient to move the particles into the filter. These equations can be used in future work to refine the geometries of the tube openings and needed vacuum systems.

$$F_{applied} = P_{vac} * A_{c,tube} \quad (4)$$

4.2.3 Simulation of Exhaust Gas Flow

Before the design of the exhaust cover, the flow of the exhaust gases had to be understood. To understand the movement of the exhaust, the muffler was simulated in the program "COMSOL, 2017". A flow simulation was used to understand the dispersion of exhaust gases out of the muffler. After looking at the velocities and flow directions of the fumes the shape of the exhaust nozzle best suited for capturing them was designed.

The initial velocity of the exhaust gases as they exit into the muffler had to be calculated to act as input parameters into the COMSOL simulation. The ingoing velocity of the exhaust gases entering the muffler were calculated in Equation 5, where dispersion is the stroke volume of the engine in cubic meters and A_{out} is the area of the outtake of the engine measured in square meters.

$$V_{out} = V_{in} = dispersion * \frac{speed\ of\ engine}{2} * A_{out} = 5.371\ [\frac{m}{s}] \quad (5)$$

The geometry of the deflector on the chainsaw was measured, and then modeled in Solid Edge and converted into a COMSOL geometry, which is illustrated in Figure 14. This geometry was then analyzed by also creating an ingoing cylinder to act as ingoing exhaust gases to the deflector, and by creating a larger box act as an empty room, in attempt to track the velocity flow of the model, seen in Figure 15.

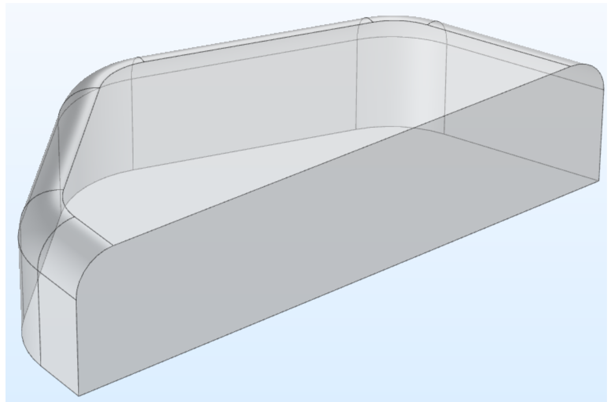

Figure 14 COMSOL Geometry of Chainsaw Exhaust Port Deflector

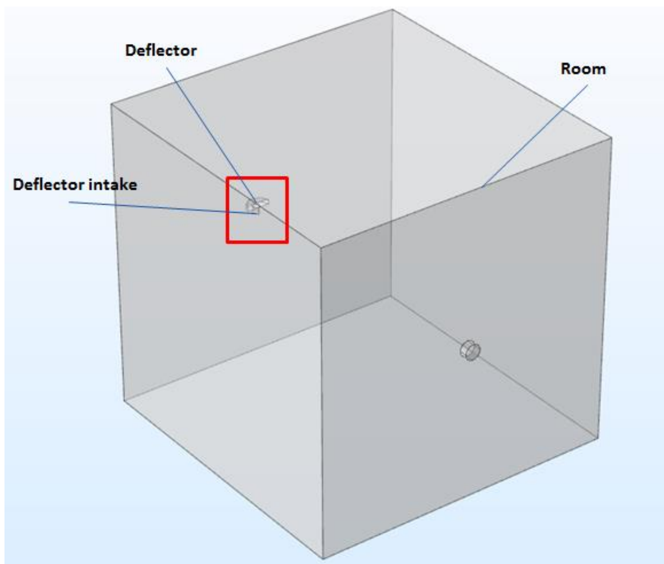

Figure 15 COMSOL Set-Up of Exhaust Port Simulation

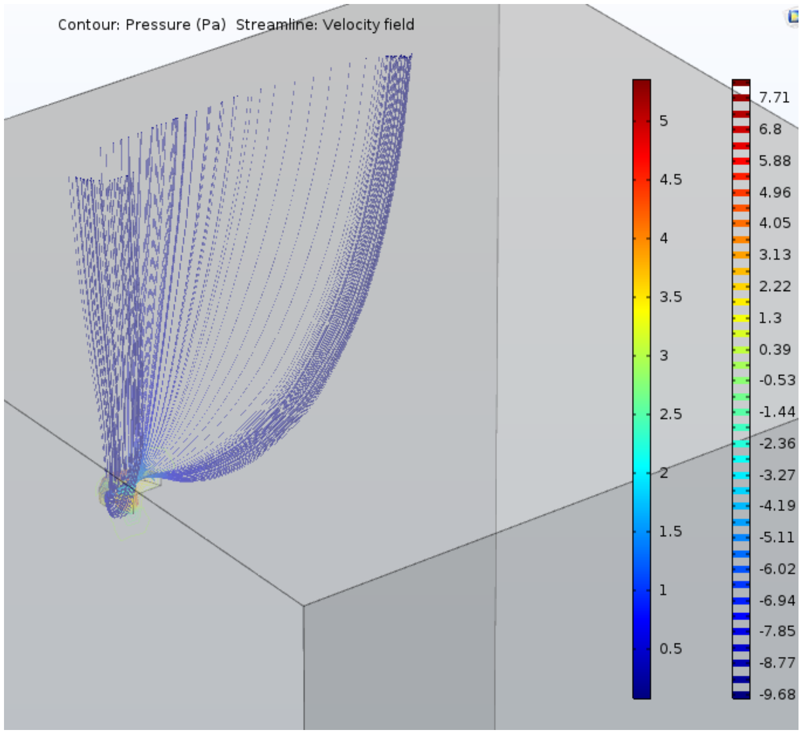

Figure 16 COMSOL Simulation Results, Streamlines of Exhaust Gases Velocity Fields Exiting Muffler

Figure 16 displays the velocity behavior of the exhaust gases from the muffler. This result indicated that most of the exhaust gases are spread upwards and towards the sides of room when exiting the deflector. The result also indicates that the exhaust cover displayed in Figure 16 would capture most of the exhaust gases leaving the deflector, but this will have to be further adjusted and verified during the autumn semester.

4.2.4 Future Work on Oil System

The bar cover will need further adjustments next semester, mainly due to the further development of the loading concept. These require more information from the loading concept and also calculations concerning the temperature of the system. The temperature will be calculated with analytical thermodynamic equations or/and investigated with programs such as COMSOL.

The clutch cover will need dimensioning and thermodynamic analysis. Another interesting factor to investigate would be whether or not the clutch cover solution affects the vibration of the chainsaw system, because that could create issues for the handles concept. This would also need to be investigated for the bar cover and the exhaust cover.

Once the dimensions and vacuum systems are selected, calculations similar to those discussed in Section 4.2.2 Vacuum/Air Systemwill be performed to understand the necessary tube openings and vacuum properties.

The exhaust cover needs verification and selection of a material. It was noted by the project sponsor that the material for the exhaust cover cannot be metal, as that causes sparks and increases fire hazards. Potential materials to solve this problem will need to be further investigated.

4.3 Handle System

To begin the process of designing a handle system, a dynamic model of the system was made so the frequency response of the human hand could be better understood. In accomplishing this goal, extensive research had to be performed regarding Husqvarna's chainsaw range, the magnitude of the forces acting on the bar, the potential damping of plastic materials at specified operating frequencies, and vibration measurement methods. Mathematical models were then used to simulate the behavior of the chainsaw during load. Physical vibration measurements will later be performed to verify the model.

4.3.1 Transmissibility and damping frequency response of hands

While running the chainsaw, an operator is exposed to vibrations, measured in m/s^2 with a specified amplitude and frequency determined by the chainsaw construction and running mode, and the operator is exposed to force impulses when the cutting chain initially touches the log as well as the vibrations caused by the engine. These accelerations are transferred to the user via the points of contact at the two handles and the transferred amount is determined by the transmission ratio T. The transmission ratio is described as the difference in vibration amplitude of two surfaces in contact or as the difference in displacement as a function of time of two surfaces in contact represented in the equation below (Wallin, 2014).

$$T = \frac{F_{out}}{F_{in}} = \frac{x_{out}}{x_{in}} \quad (6)$$

4.3.2 Handle Design Concepts

The first concept has the chainsaw mounted to two static arms with rubber clamps, shown in Figure 17 below. This concepts focus is to only resemble the damping characteristics of human hands. It is easy to implement in the test cell and is good in a maintenance point of view.

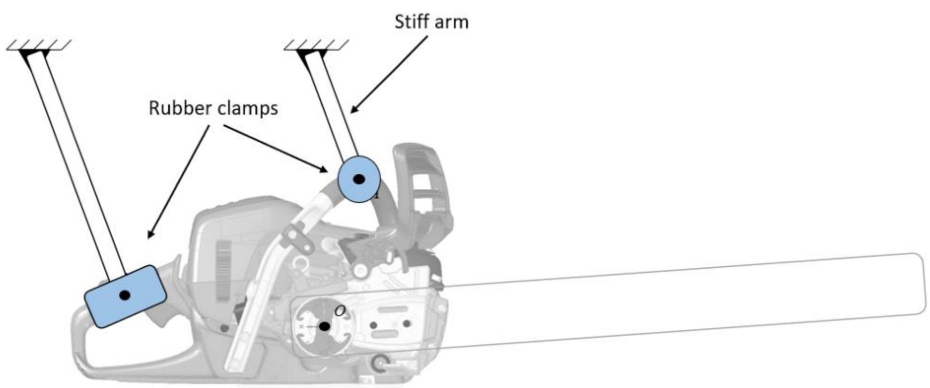

Figure 17 Handles Concept 1, stiff arms and rubber clamps

The second concept is a modified version of the first one. In addition to the rubber clamps, it is hanging in the test cell with adjustable dampers. The purpose of these dampers is to simulate the resistance a user would give to the forces that are applied by the loading group who will add forces on the bar. The dampers can be adjusted to work with different chainsaw models if needed. Concept 2 is shown in Figure 18 below. Other benefits to adjustable dampers include the possibility of simulating user fatigue wherein the user gets weary and cannot provide the same reaction force during a full load cycle.

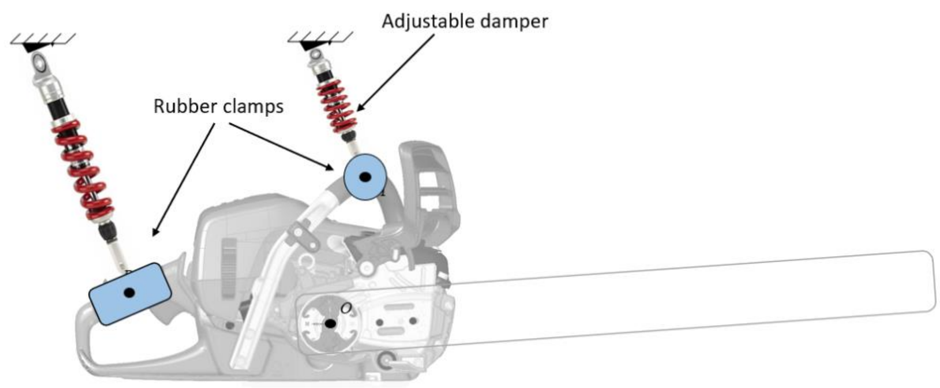

Figure 18 Handles Concept 2, adjustable dampers and rubber clamps

The third concept has a mass attached to the chainsaw handles resembling the hands and arms of a user, also including an adjustable damper so it can be tuned to match the behavior of the human body. Figure 19 below shows the third concept. This concept has an inertia that the other two concepts do not have which might be possible to tune.

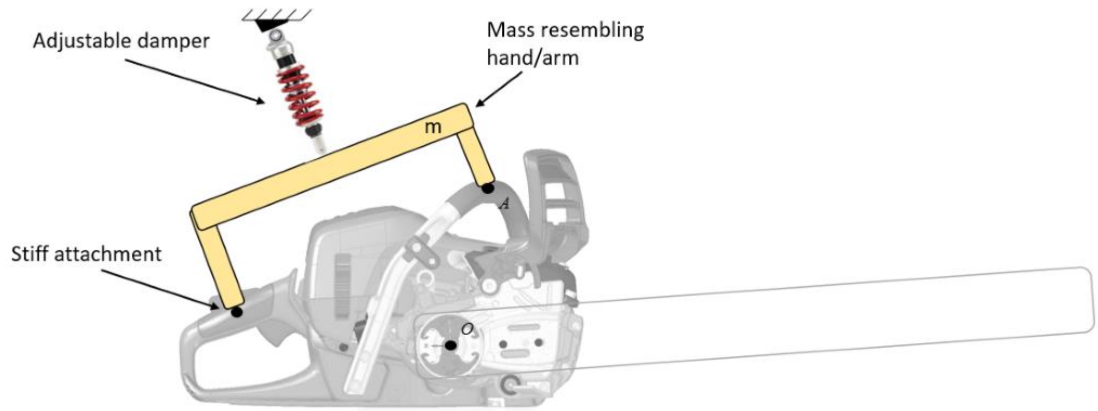

Figure 19 Handles Concept 3, adjustable damper and mass resembling body

4.3.3 Clamping mechanism

The main purpose of the handles is to resemble a user holding onto the handles. The length of the handle should be approximately 100 mm for hands according to studies and 13 mm extra since gloves are used when operating the chainsaw (Lindqvist, 1998). The maximum allowed pressure in the clamping surface is 20N/cm^2 and the clamping mechanism must fit tightly around the handle.

Simulating user fatigue by varying the grip force would be interesting because there are indications that the transmissibility coefficient T may vary as a function of grip force and frequency according to R. Gurram, S. Rakheja & Gerard J. Gouw (1994). The concept for the clamping mechanism was developed where the clamping force can be varied using a compact cylinder. The clamping mechanism concept is shown in Figure 20 below, the picture shows the clamping mechanism for the top handle.

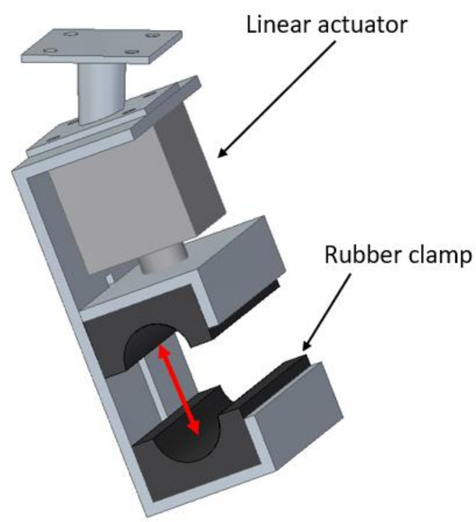

Figure 20 Varying Force Clamping Mechanism Concept

The concept consists of a rubber cylinder in two halves, pushed together by a compact cylinder. The clamping force should be possible to vary between zero and the force that corresponds to the maximum allowed pressure in the clamping surface.

The alternative to having a concept with adjustable grip force would be to clamp with an unvaried, constant force. One way to do it is by using the same method that is used on bicycle wheels, the quick release technique. A concept proposal using this technique is shown in Figure 21 below.

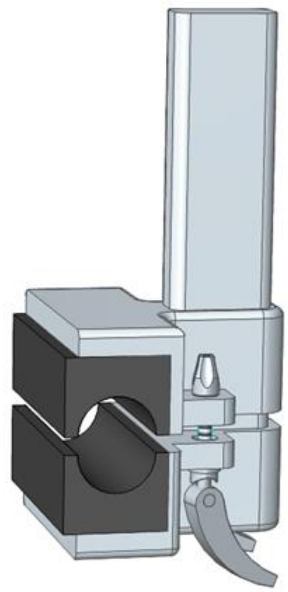

Figure 21Constant Force Clamping mechanism Concept

The selection of material for the clamping concepts is a complicated matter due to the required properties specified below. The material needs to have good durability to oil as well as good fatigue and damping properties. Ideally there would be no oil on the clamping mechanism, but the oil collection subsystem cannot be assumed to 100% eliminate oil in the test cell and must therefore be resistant to the used chain lubrication.

A lot of rubbers have bad durability against oil. There are some synthetic rubbers that are durable to oil, but natural rubber is often better when it comes to most factors. An alternative to having rubber would be PE-foam, due to its good durability against oil. Its relative damping ratio and fatigue strength are, however, lower compared to natural rubber. Apart from the aforementioned properties, the most crucial material property to study when choosing a material is how the mechanical properties such as damping, and spring coefficient of chosen rubber may be affected by the variance in temperature.

4.3.4 Free body diagram

Models of the system were created to design and dimension the components for the concepts. A free body diagram is performed for the XY plane and the XZ which is shown in Figure 22 and Figure 23 below. The loading group will apply a set of forces on the blade in point C. There are reaction forces in point A, the midpoint of the position where the user is holding the front handle and point B, the midpoint of the position the user is holding the rear handle. The dimensions shown in the figure were measured in the CAD-model of the chainsaw provided by the sponsor.

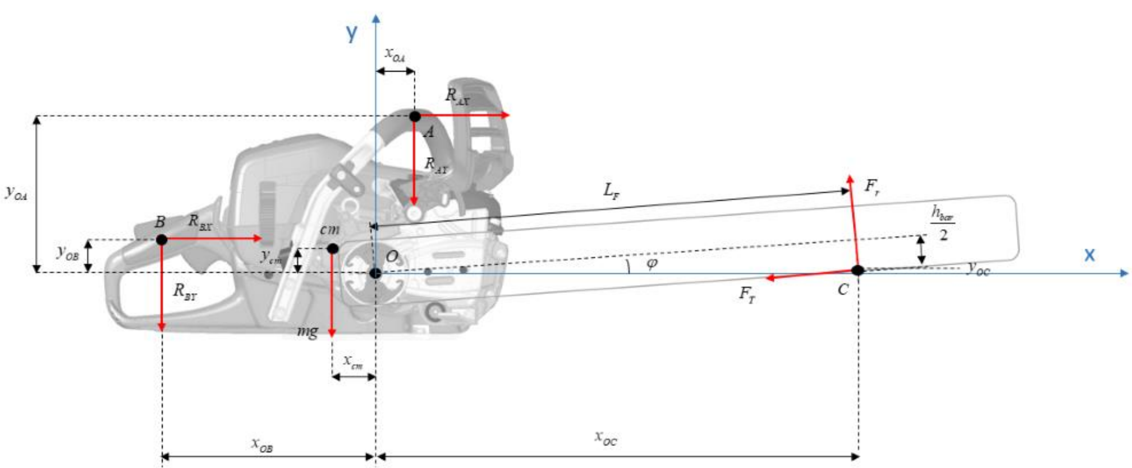

Figure 22 Free body diagram of the chainsaw in the xy-plane

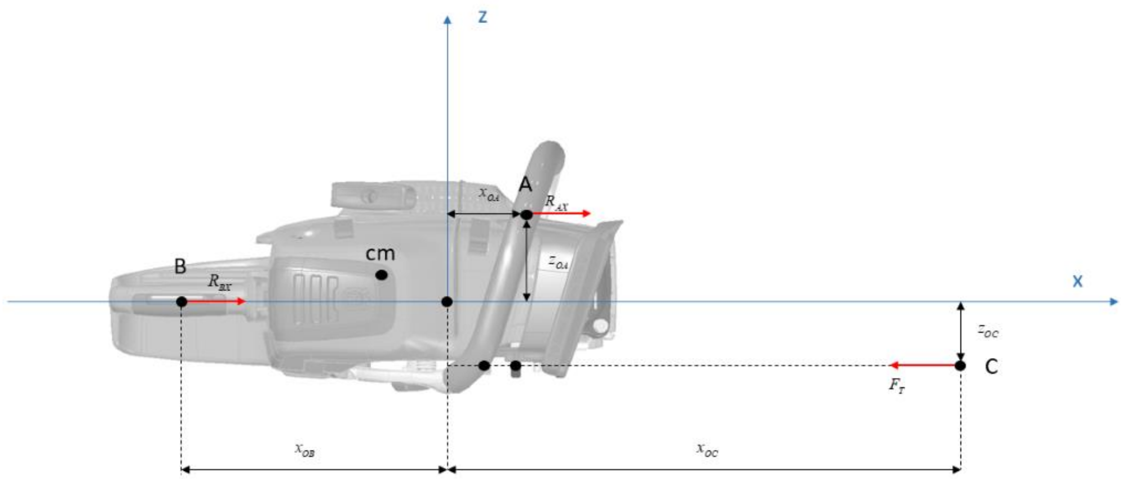

Figure 23 Free body diagram of the chainsaw in the xz-plane

4.3.5 Dynamic models

A dynamic model is preferred to dimension the springs and dampers that will be attached to the handles. It will also simulate how all parts of the system behave when running at different chainsaw engine speeds and loaded externally. The model has the potential to be used by Husqvarna for other purposes such as ergonomic studies or optimization of geometry.

The model will be loaded with vibrations from the motor as well as external forces on the chainsaw bar. The dynamic model is divided into several steps due to complexity. The first model is of the chainsaw treated as one body and the second one takes the internal spring and dampers into account. The following assumptions are made for the two models to simplify the design process.

Assumptions and simplifications:

- The chainsaw body itself is assumed to be rigid compared to the springs and dampers attached.

- The forces are only acting in one plane. This simplifies the calculations and can be derived, assuming that forces acting in the z-direction are taken up by the log if there are any at all.
- The inertial effects from the movement of the chain along the bar are neglected.
- Forces and displacements are only working in the same direction as the dampers and springs, which means a damper in x-direction does not take any forces in the y-direction.
- Point forces and masses are assumed for all interactions between parts and rigid walls.
- A numerical method is used to calculate the results in Matlab.

The first model is shown in Figure 24 below. It has 3 degrees of freedom, it can translate in x and y direction and rotate around the center of mass and is attached in the cell with a spring and damper in each direction for both rear and front handle. Inputs needed by this model are the inertia for the chainsaw, the position of the center of mass, the vibrations from the motor, the loading forces Fy & Fx as well as the mass of the chainsaw. A Matlab code is written to calculate the position, velocity and acceleration of the handles with a defined set of dampers and springs.

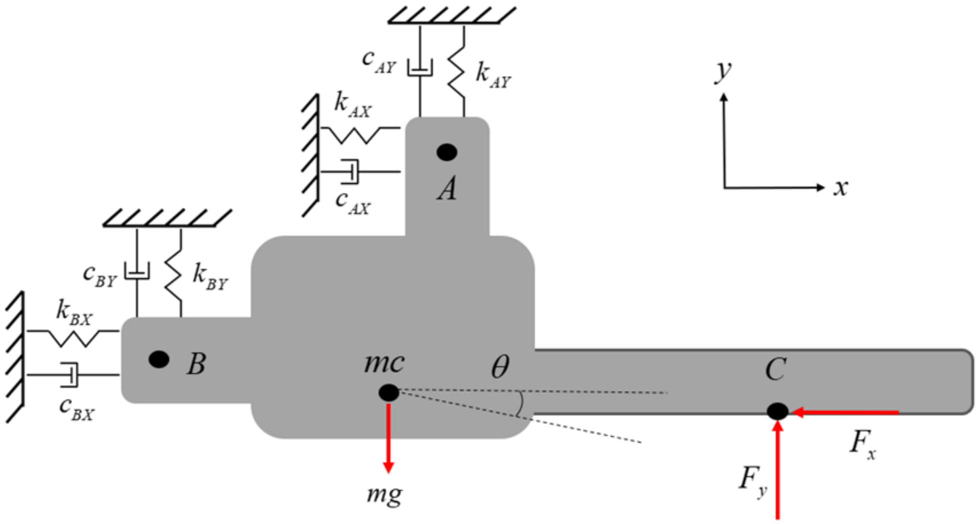

Figure 24 First dynamic model

Equations of the system are obtained and using them and the inputs on the external forces the results are calculated using ODE45 in Matlab. The equations are shown in Appendix D: Equations of First Dynamic Model. The final step of the dynamic model is to sum the accelerations in the handles and compare them to the values measured during next semester as well as the values Husqvarna's own measurements.

Further development for the dynamic model gives the opportunity to take the internal springs and dampers of the chainsaw into account of the observed behavior. There are several springs and dampers between the handles and the motor and blade which need to be taken into account to resemble the actual chainsaw properly. The second model is shown in Figure 25 and it will be modeled in Matlab during next semester. It has 6 degrees of freedom, x- and y-direction for both masses as well as rotations around the center of masses.

Both of the models will be compared and verified against the measured results as well as the data provided by Husqvarna to determine the validity as well as the usability by the models.

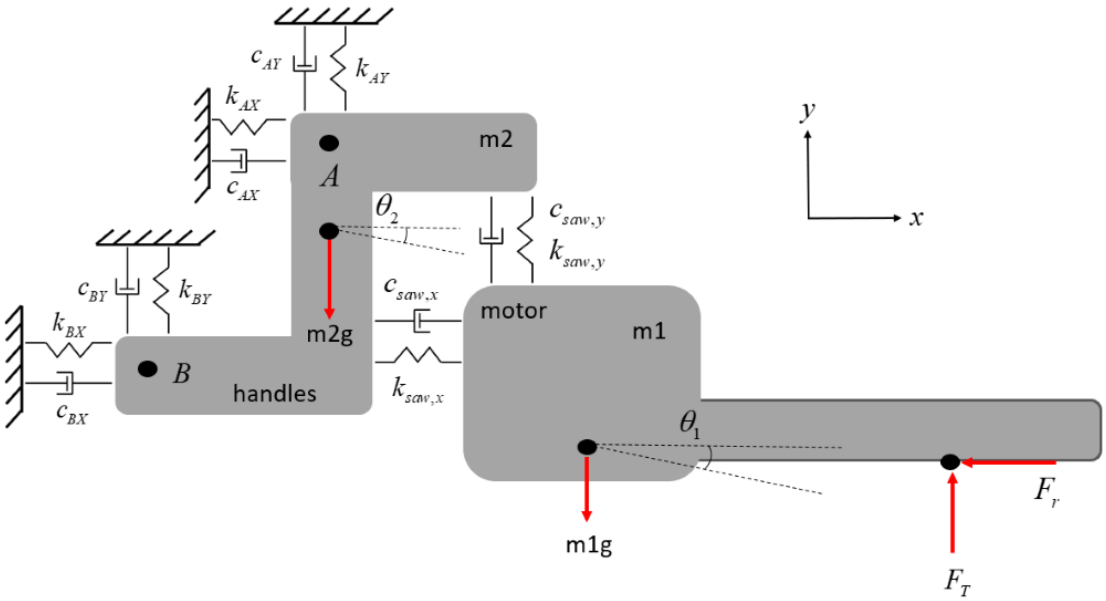

Figure 25 Second dynamic model

4.3.6 Final Handle Concept proposal

To compare the concepts with each other and get an overview a Pugh's evaluation matrix is made. In the matrix different requirements on the handles subsystem is weighted on a scale 1-5 and concept one is used as a reference. The other two concepts are then given a plus or a minus if it is better or worse than that concept when it comes to meeting the requirements. This gives an overview of which concept has which edge, some of the requirements have been assumed. Hand resemblance is set to be the most important requirement and it can only be verified by measurements. The matrix is shown in Figure 26 below.

WEIGHTED

		Stiff arm	Adjustable dar	Mass
Criteria	**Weight (1-5)**	**Concept 1 (reference)**	**Concept 2**	**Concept 3**
Adjustability	2	0	+	+
Easy to remove/mount chainsaw	4	0	0	0
Works with different chainsaws	2	0	0	-
Low effect on loading & oil group	2	0	0	0
Estimated lifetime (assumed)	2	0	-	-
Complexity	3	0	-	-
Rate of service (assumed)	3	0	-	-
Hand resemblence (assumed)	5	0	+	+
Sum		**0**	**-1**	**-3**

Figure 26 Pugh's evaluation matrix of the handle concepts

The conclusion from this matrix is that the concepts are similar when it comes to meeting the requirements that can be evaluated on a conceptual stage. All the concepts can for example use the same clamping mechanism and should have equally low effect on the other two subsystems.

The first concept seems to meet these requirements best, followed by the second one. However, it is clear that the most important requirements such as hand resemblance need to be evaluated based on measurement results. The dynamic model might give some hints on what kind of design is better but measurements are needed to draw a proper conclusion and select concept. The third concept will be not be used as it seems difficult to succeed with adding a tuned mass.

When it comes to clamping mechanism concept it is undecided which of the concepts that may provide the best solution and therefore measurements are needed to show the effects on the vibration levels from the variance in clamping force.

4.3.7 Future Work on Handles Design

With the free-body diagrams and main ideas for the dynamic model derived, the future work on the model would be creating a finished MatLab code. This model may give insights as to which conceptual design best models human hands. However, to understand which concept is able to mimic these vibrations, vibration tests must first be completed. The physical testing methods will need to be drawn up and the tests performed. The data from the results will identify which dampers and springs systems to use.

5. Conclusion

The conceptual design for a test rig for accelerated life testing of chainsaws that better reflects realistic operating conditions was addressed thought the generation of conceptual designs in three different subgroups. A design for a device to apply a load mimicking that of the normal forces felt by the saw is applied to the bar, as seen in Section 4.1.2 Chosen Concept. Section 4.2 Oil Collection System shows the three chambers making up the oil collection system. These chambers collect the oil mist generated by the excess oil as well as separate the exhaust to aid in an increased purification rate in the test cell. Finally, the handles seen in Section 4.3.3 Clamping mechanism were applied to constrain the saw in a way that mimics the response of a field operator.

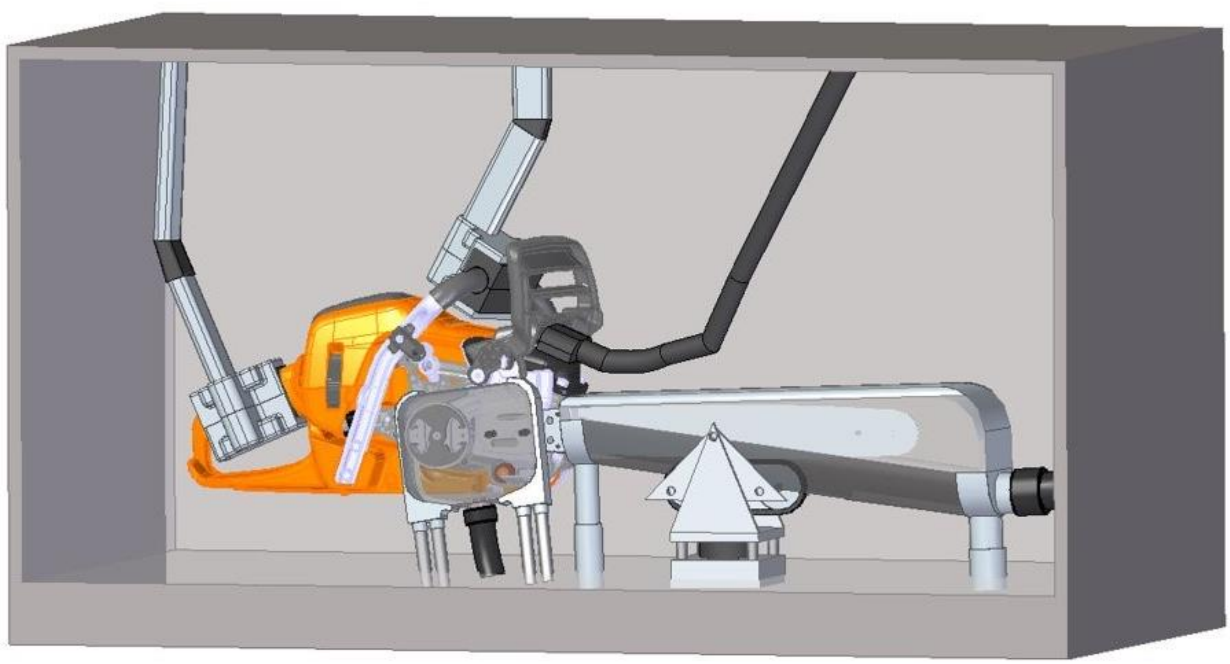

Figure 27 Final Concept Design

All three concepts are combined in the figure above, Figure 27, showing the final integrated system. Further work must be done on to understand the interactions between the three concepts. Vibrations are one potential negative interaction. It is important that the loading system and the oil system do not have a significant effect on the vibrations of the chainsaw because that could interfere with the vibrations results extracted from the handles as well as alter the performance of the chainsaw.

The most critical interaction to address is between bar loading and bar cover. The bar cover should be large enough to encapsulate the loading solution and collect the oil that lubricates the different loading surfaces. Once the loading device is finalized, the interactions between both of these components can be evaluated.

With most of the conceptual work completed, the remaining work to be completed in KTH next autumn will be able to focus on detailed dimensioning and understanding the fully integrated system. After the finalization of these designs, the full prototype will be built and tested to evaluate the effectiveness of these concepts.

References

B. Lindqvist. *Verktygsergonomi.* Atlas Copco, Stockholm, 1998.

Feldkamp, K., & Tedesco, A. (2003, December 11). Water Brake Dyno. Retrieved from http://courses.me.berkeley.edu/ME102B/Past_Proj/f03/Proj11/discuss.htm

Gurram, R., Rakheja, S., & Gouw, G. J. (1994). Vibration transmission characteristics of the human hand-arm and gloves. *International Journal of Industrial Ergonomics,13*(3), 217-234. doi:10.1016/0169-8141(94)90069-8

HVA/KTH Project 2018 [Interview by J. Arvby]. (2018, March). At *Husqvarna Petrol Handheld Product Laboratory*.

Intertek Group. (n.d.). HALT Testing & HASS Testing. Retrieved from http://www.intertek.com/performance-testing/halt-and-hass/?gclid=CjwKCAiA-9rTBRBNEiwAt0Znwy4zoIVlmIx-glOcjeMocWeS5i8LIxgUxhYpka5uTsljfrG7C5XxzRoCRAUQAvD_BwE

Joesfsson, E., & Henningsson, H. (2015). A Study of Small Engine Tests. *Tekniska Hogskolan Hogskolan I JonKoping.* Retrieved from http://www.diva-portal.se/smash/get/diva2:860427/FULLTEXT01.pdf

Kittelsona, D. B. (1998). Engines and nanoparticles: A review. *Journal of Aerosol Science,29*(5), 6th ser., 575-588. Retrieved from https://doi.org/10.1016/S0021-8502(97)10037-4.

Pesik, I., & Skarolek, A. (2014, May 1). *Dynamic model of a chainsaw*. At *Technical University of Liberee*. Print.

(SAS) Sentry Air Systems, Inc. (2016). CNC Machine Mist Collection. Retrieved from https://www.sentryair.com/200mistsentry.htm

Wallin, H. (2014). *Ljud och Vibrationer.* Universitetsservice, Stockholm.

Appendix A: Project Requirements and Specifications

The following table contains the project specifications and tasks as defined by our sponsor.

Requirement specification

Requirement	Background	Fulfillment
The solution must be implemented in the existing test box.	The test boxes should look like rig 29.	
Testing should be performed with complete product.	Verification of all the components makes the internal tests more efficient. Reduces the need to wait for field test results.	
The chain brake should be enabled to activate / reactivate on suspended product.	For a good environmental work and ergonomics.	
The equipment should be able to cope with the flow 0-1500 m3/h in the general ventilation and 0-200 m3/h in exhaust ventilation.	The specification for future long-term testing.	
The risk for fire should not increase with the solution. Risk analysis need to be done.	Security is very important.	
Chain oil collection in the test box should be at least 50% better than today.	Chain oil on the product does not provide a relevant testing. Oil coming up in the exhaust hose will decrease the life time of the catalyst and the degree of purification out from the endurance test system.	
The solution will work together with the current and future control system (software and hardware). The running modes should be able to adapt as today.	Today, testing is carried out with and without load of the engine. The equipment (water brake) works well with the control system.	

Requirement	Background	Fulfillment
Lubrication of the chain should be work environmentally good.	Working environment.	
General solution for Husqvarna entire chain saw range, with just small adjustments when switch between different products.	Several variants make the work harder for the operator.	
Degree of purification and collection rate of exhaust gasses out from the test cell should not deteriorate. Collection: At least 95% Degree of purification: At least 75%	Authority requirement.	
Bar temperature must not be higher than the current solution (70°C).	The temperature of the bar decreases the life time of the cutting equipment.	
The solution have to cope with the ambient temperature in the test box according to test code TC-H17-02 (20-37°C).	Internal requirement measured 5 cm from the starter.	
The solution must not increase the temperature substantially on vital components.	Engine components such as cylinder, piston, main bearings, crank case etc. are sensitive components that need to be tested as relevant as possible.	

Appendix B: Friction Based Loading Designs

Disc Brake. One of the initial ideas where to brake the chain using a standardized disc brake solution. This concept would be divided in two sections, one that can be seen in the below drawing that brakes the chain, the latter to apply a load to the bar. The loading concept are described in general under other headings in this chapter and therefore not discussed further here. The braking pads would brake the chain from the sides as can be seen from the top view in the conceptual drawing below, where the clamps would be fixated using a rack that would be fixated on the floor. The clamps would be dimensioned according to the necessary force needed but using standard components as much as possible.

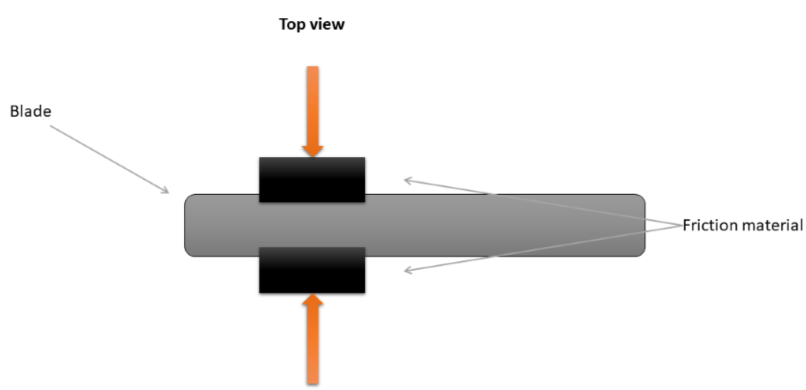

Figure 28 Disc Brake Concept Sketch

Vertical Loading. A second friction-based concept was evaluated, where loading and braking would be applied using a single vertical movement. The friction material would be applied to a broader plate that would cover the chain's width and brake it while the plate would be moved upwards to apply a load to the bar. The chain would have to be modified to replicate the engagement between a regular saw chain and a log to avoid the standard chain getting stuck in the friction material.

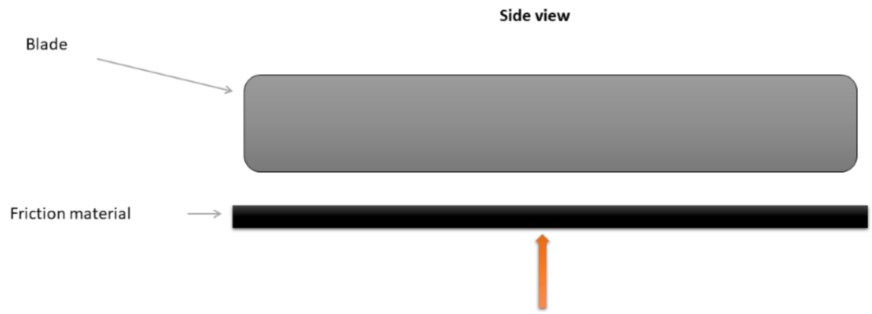

Figure 29 Vertical Loading Concept Sketch

V-Shaped Braking. Below a concept, based on the other two friction concepts, will be described. The thought was to combine the advantage of the disc brakes braking solution with the loading of the bar in a more realistic way than for the "Vertical loading friction concept". The thought was to better be able to control the friction applied when loading the bar with the "normal force", the angle of the "V" would be optimized to replicate the situation of the chain engaging a log. One major problem here was to find a suitable friction material sturdy enough to avoid wear, creating guidelines in the material and therefore alter the angle in an unwanted way. All the above friction concepts including the present one would require the absence of oil and added cooling.

Appendix C: Oil Collection Cover Material Selection Matrix

	Flamability	Working Temperature	Durability to Oil	Machinability	Moldability	Cost (SEK/kg)	Toxic Rating
Stainless Steel	non-flammable	-272C to 750C	Excellent	2 to 3	3 to 4	48-50	non-toxic
Low Carbon Steel	non-flammable	-68C to 350C	Excellent	3 to 4	3	5-7	non-toxic
Cast Al Alloys	non-flammable	-273C to 130-220C	Excellent	4 to 5	4 to 5	16-18	non-toxic
Ni-Cr Alloy	non-flammable	-272 to 900C	Excellent	3	3	119-131	non-toxic
Wood (plywood)	Highly flammable	-100C to 120C	Acceptable	5	3 to 4	5	non-toxic
CFRP (carbon fiber)	Slow burning	-123C to 140C	Excellent	1 to 3	4 to 5	321-356	non-toxic
PLA	Highly flammable	-20C to 45C	Acceptable	4 to 5	4 to 5	22-30	non-toxic
PET	Highly flammable	-123C to 67C	Excellent	3 to 4	4 to 5	15-17	non-toxic
PMMA	Highly flammable	-123C to 56C	Excellent	3 to 4	4 to 5	24-25	non-toxic
Copper	non-flammable	-273C to 300C	Excellent	4 to 5	4 to 5	43-51	non-toxic

Appendix D: Equations of First Dynamic Model

Equations used in the first dynamic model. Where the lengths are the distance from each point to the center of mass in the x- and y-direction.

$$y: -m\ddot{y} - (k_{AY} + k_{BY}) \cdot y - (c_{AY} + c_{BY}) \cdot \dot{y} + (k_{AY} \cdot L_{AX} + k_{BY} \cdot L_{BX}) \cdot \theta + (c_{AY} \cdot L_{AX} + c_{BY} \cdot L_{BX}) \cdot \dot{\theta} + F_y = 0$$

$$x: -m\ddot{x} - (k_{AX} + k_{BX}) \cdot x - (c_{AX} + c_{BX}) \cdot \dot{x} - (k_{AX} \cdot L_{AY} + k_{BX} \cdot L_{BY}) \cdot \theta - (c_{AX} \cdot L_{AY} + c_{BX} \cdot L_{BY}) \cdot \dot{\theta} + F_x - m \cdot g = 0$$

$$mc - counterclockwise: -J\ddot{\theta} - (k_{AY} \cdot L_{AX} - k_{BY} \cdot L_{BX}) \cdot y - (c_{AY} \cdot L_{AX} - c_{BY} \cdot L_{BX}) \cdot \dot{y} +$$
$$(k_{AX} \cdot L_{AY} + k_{BX} \cdot L_{BY}) \cdot x + (c_{AX} \cdot L_{AY} + c_{BX} \cdot L_{BY}) \cdot \dot{x} +$$
$$(k_{AY} \cdot L_{AX}^2 + k_{BY} \cdot L_{BX}^2 + k_{AX} \cdot L_{AY}^2 + k_{BX} \cdot L_{BY}^2) \cdot \theta +$$
$$(c_{AY} \cdot L_{AX}^2 + c_{BY} \cdot L_{BX}^2 + c_{AX} \cdot L_{AY}^2 + c_{BX} \cdot L_{BY}^2) \cdot \dot{\theta} + F_y \cdot L_{CX} - F_X \cdot L_{CY} = 0$$