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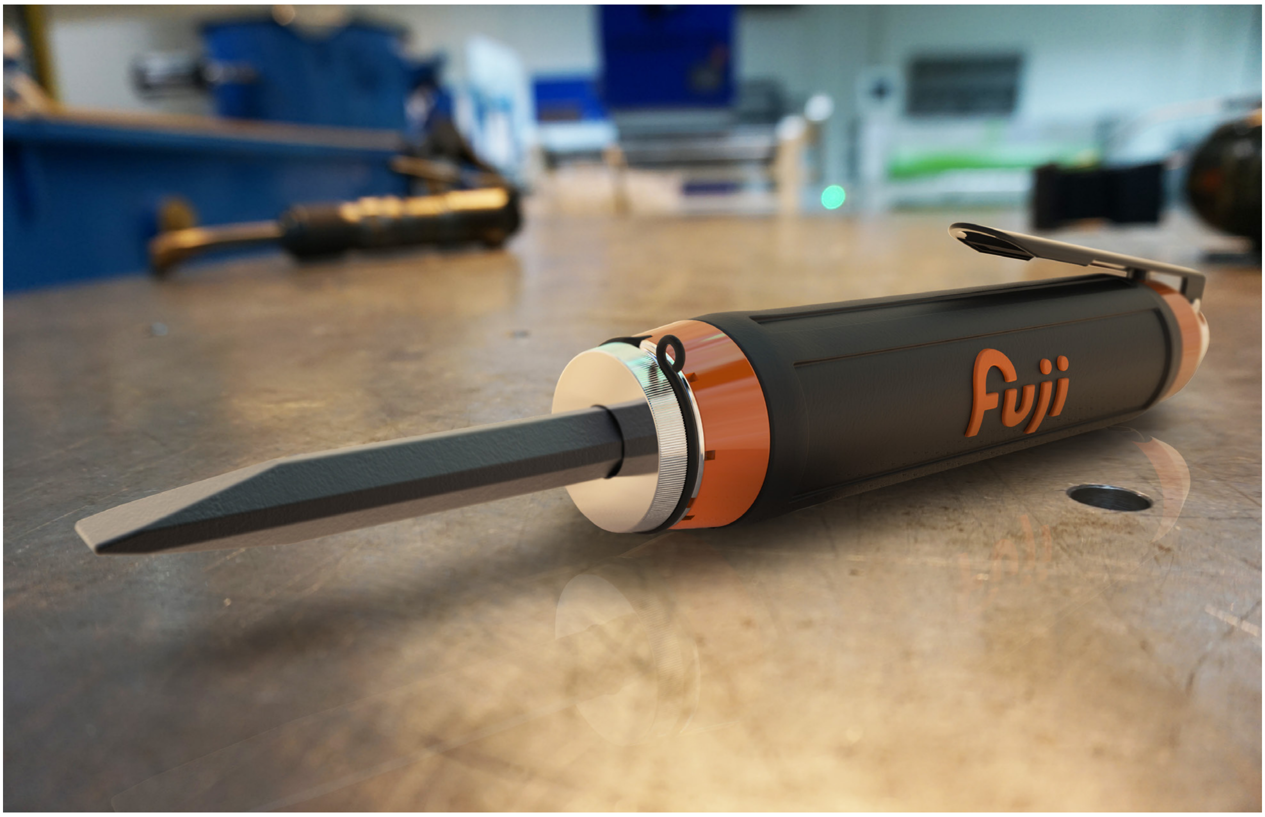

Redesign of a Flux Chipping Hammer

Master of Science Thesis in the Master Degree Programs, Industrial Design Engineering and Product Development

PASCAL CSIKASZ

ROBIN EVALDSSON

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

Department of Product- and Production Development

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ABSTRACT

Pneumatic handheld tools are widely used in heavy manufacturing and repairing industries. They can be designed with few parts and reliable mechanisms, and are suited for frequent and extensive use. Because of these attributes, pneumatic handheld tools are generally preferred over their electrical equivalents in those settings.

This master's thesis deals with the development of one such pneumatic handheld tool, commonly referred to as a *chipping hammer*. Chipping hammers are used to remove spatter and slag resulting from welding processes. It is also employed to chip off rust and other types of coatings from metal surfaces in repair jobs. The chipping hammer is known to expose the operators to high levels of vibrations, which can be hazardous for frequent users.

The project was conducted for the Japanese company Fuji Air Tools. Apart from the issue related to vibration exposure that is symptomatic for chipping hammers in general, Fuji Air Tools considers their chipping hammers to lack visual cues linking the product to their brand. Mitigating vibration exposure and increasing brand recognition, together with a user study to investigate further usage issues, formed the three focal points for the thesis.

Due to that Fuji Air Tools' largest customer base is found in Japan, a major part of the initial study was conducted at the company's headquarters in Osaka. Once the initial study was completed, the following development phase was carried out at Chalmers University of Technology.

The end result is drawings for the design of a prototype of a new chipping hammer. The new hammer mitigates the vibration exposure by means of an isolating mechanism. The exterior design has also been updated to more clearly resemble Fuji Air Tools' visual style and to express the company values more strongly. Furthermore, it features a protective shield at the front, dealing with a clamping hazard identified during the user studies.

Keywords: Pneumatic handheld tools, chipping hammer, ergonomics, visual brand identity, vibration handling, product development

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Pascal Csikasz *Robin Evaldsson*

PREFACE

This master's thesis was conducted for Fuji Air Tools through Chalmers University of Technology. Part of the project was carried out at Fuji Air Tools' headquarters in Osaka, Japan. The thesis comprised 30 ECTS and was performed from September 2015 to February 2016.

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CONTENTS

1. INTRODUCTION

This chapter provides relevant background information linked to the project, gives a problem description, and outlines the project framework and planning. The chapter concludes with an overview of the structure of this report.

1.1 Background

This section contains a brief introduction of pneumatic handheld tools, along with a presentation of Fuji Air Tools, for whom this project has been conducted. It also has a description of the chipping hammers that are the subject of this project.

1.1.1 The pneumatic handheld tool

Pneumatic handheld tools are essential in many industrial operations. In those contexts, they are generally preferred over their electrical counterparts for many reasons. The main advantages are a lower risk of overheating, less sensitivity to moist, and less fragile components. These attributes make pneumatically driven tools optimal for the demanding environments and constant usage often found in factories, repair shops and other industrial operations.

1.1.2 Fuji Air Tools

Fuji Air Tools (from this point onwards referred to as *Fuji*) is a handheld pneumatic tool manufacturer based in Japan. Since their founding in 1943, they produce a wide variety of tools, such as grinders, drills, and wrenches. Fuji's focus is to produce high quality tools for the most demanding industrial applications. Their goal is that their tools shall last for many years and perform well even in dirty environments or on air supply systems that do not always deliver the ideal air pressure. This makes their tools especially suitable for heavier industries such as shipyards, foundries and construction, but they also have customers within automobile assembly. At their headquarters in Osaka, most of the vital functions are gathered in one site, such as the management, sales, R&D, assembly, storage and quality control departments. Historically, Fuji has had less focus on branding and ergonomics than western competitors.

Fuji are represented globally, but their biggest sales are to be found on the domestic market in Japan, followed by China, and then the Southeast Asian countries as a group. Mexico and Brazil account for the largest sales outside of Asia. The company was acquired by Atlas Copco in 2006 through their acquisition of Fuji's parent company, Chicago Pneumatic.

1.1.3 The flux chipping hammer

Among the tools in Fuji's product line-up is the flux chipping hammer, at times referred to as flux chippers or chipping hammers. This tool is used for removing paint, rust, and other coatings on metallic and concrete surfaces, by oscillating a metal chisel at high speeds. The hammer comes in several different models, with variation in size and functionality. Three of them can be seen in figure 1.

Fuji's current series of flux chippers, known as the FCH series, has been the same for the past 40 years. Fuji acknowledges that design factors such as ergonomics and branding has grown more important, and believe that there is an opportunity to improve the tool in these aspects. Relative to most other pneumatic tools it has high values of vibration exposure, which can lead to injuries. It also lacks visual identifiers linking it to the company.

Figure 1. From left to right: FCH-25-1F, FCH-20F, FCH-20-1F.

1.2 Problem description

Chipping hammers are known to produce high levels of vibration and intensive noise, which can lead to ergonomic issues for frequent users. Furthermore, Fuji believes there is room to evaluate and if necessary improve other ergonomic factors as well as the functionality of the tool. They also deem the FCH series outdated in terms of aesthetics and to fail in communicating their brand identity.

1.3 Project framework

The following section describes the framework of the project. It contains the final goals and the research questions, along with the objectives set in order to answer these questions. It also presents the specific deliverables expected from the project team at the end of the project, and the delimitations specifying the boundaries of the project.

1.3.1 Aim

The aim of the thesis is to improve on the comfort and usefulness of Fuji's flux chipping hammers, as well as to make them more appealing and visually connected to Fuji's brand and their values.

1.3.2 Research questions

In order to meet the aim, the following questions will be sought to be answered throughout the project:

How can the effects on humans from vibration in flux chippers be minimized?

- What are the effects of vibrations on humans?
- How can they be mitigated?
- How can this be applied on a flux chipper?

What other improvements can be made to the flux chipper functionality?

- What other issues are associated with the usage of flux chippers?
- How can these issues be solved?

How can the flux chipper be styled to suit the Fuji brand?

- What design elements express Fuji's brand identity?
- How can they best be applied to the flux chipper?

1.3.3 Objectives

In order to improve the flux chipper, the objectives of the project are:

- To develop a vibration mitigation solution suited for the FCH
- To evaluate and suggest additional improvements of the FCH in terms of functionality and ergonomics
- To develop a new aesthetic design suited to Fuji's visual product style and values
- To combine the above mentioned into a new product

1.3.4 Goals & deliverables

The goal of this project is to produce a redesign of the Flux chipper FCH-25, improving on ergonomics, functionality, and aesthetics. This goal is represented by the following items, which are to be delivered by the project participants at the end of the project:

- A project report
- A CAD-model for the redesigned FCH-25

1.3.5 Delimitations

To ensure that the project is performable within the given time limit, and as an aid to make the work more focused and effective, the following limitations are implemented:

- The project will not include the possibility of developing a novel technical principle for the removal of slag and spatter from weld seams and for removing rust and coatings from metallic or concrete surfaces.
- The new design will not alter the mechanical design that powers the oscillation of the chisel.
- The project will use the FCH-25 model as the reference point, in order to keep a narrow project focus. It is assumed that any improvements made on its design have a large chance of being transferable to other flux chippers, and eventually other pneumatic tools.
- Unless a change is absolutely necessary for any specific part of the tool, materials selection and manufacturing processes for the new parts shall correspond to those of the reference tool.
- The project does not comprise any detailed consideration of production costs for the new product.

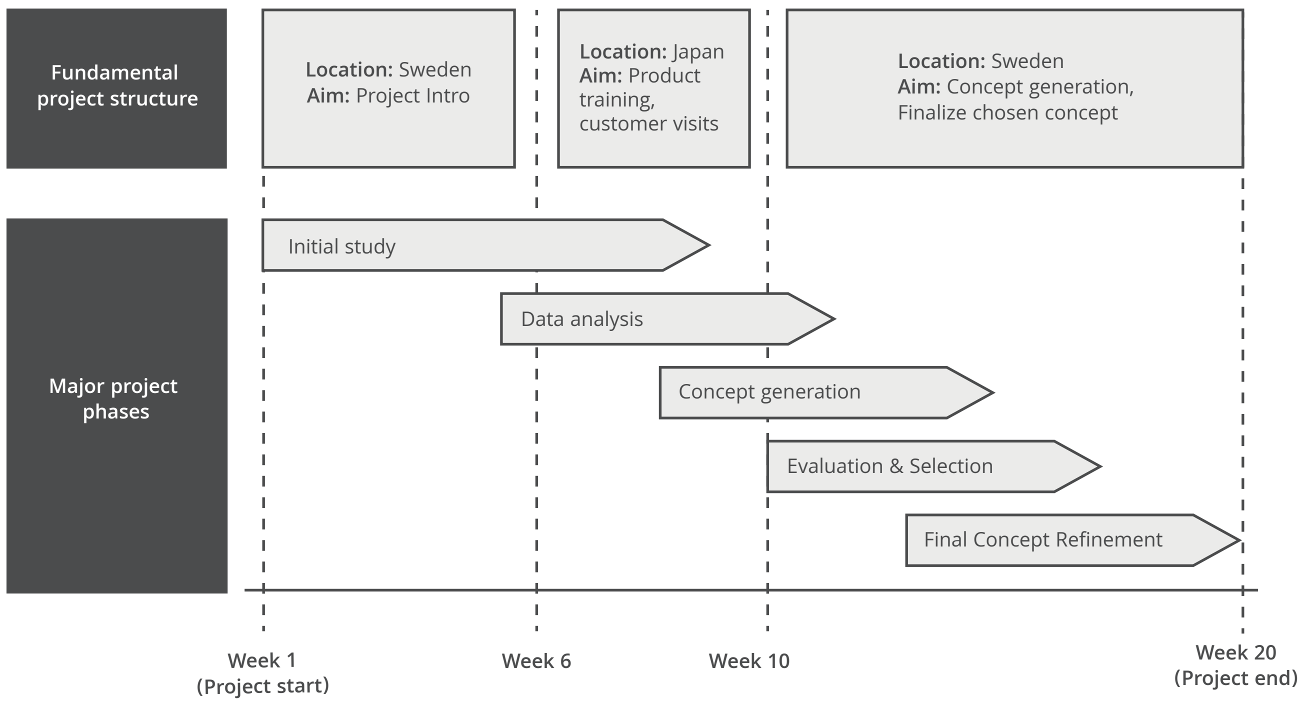

Figure 2. Overview of the project plan.

1.4 Project planning

The fundamental structure of the project was laid out by Fuji. The project was to be initiated in Sweden, during which time the elemental background knowledge related to the project was to be acquired. Then follows a part of the project that was to be carried out at Fuji's headquarters in Osaka. The project group was to spend four weeks there in the purpose of carrying out customer visits, receiving on-site training, and discussing the project with Fuji's R&D staff. The remainder of the work was to be performed in Sweden, with frequent supervision from the company through video meetings and e-mail.

Furthermore, the project team decided to divide the project into five major phases: *Initial Study, Data Analysis, Ideation, Evaluation and Screening*, and *Final Concept Development.*

Figure 2 illustrates the project planning as described above. The fundamental structure of the project as laid out by Fuji is shown in the top row. Below that the overall planning of the five main phases, made by the project team with this structure as a starting point, is displayed.

A more detailed Gantt chart was constructed, with the five phases shown in figure 1 used as main headings , and the identified respective sub-phases listed below them. Furthermore, a risk assessment was carried out and a contingency plan was set up. See appendix I and appendix II for details.

The project was to be carried out during the standard time frame for a master's thesis at Chalmers University of Technology, which is twenty weeks long.

1.5 Report outline

Figure 3 illustrates the general disposition of the report, which covers the entire project and accounts for all the included processes. A summary of what the reader will find in each grouping of chapters is given below.

Project basis - Outlines the project background and describes the theoretical framework for the following data analysis and concept generation processes.

Analysis and synthesis - Gives a chronological description of the execution of the data analysis and concept generation processes, along with the findings that were made.

Final concept - Describes the chosen final concept and the detail developments made on the way there.

Project wrap-up - Includes the suggestions for further work, a discussion, and the final conclusion.

Supportive documents - Lists the sources and appendices referred to in the report.

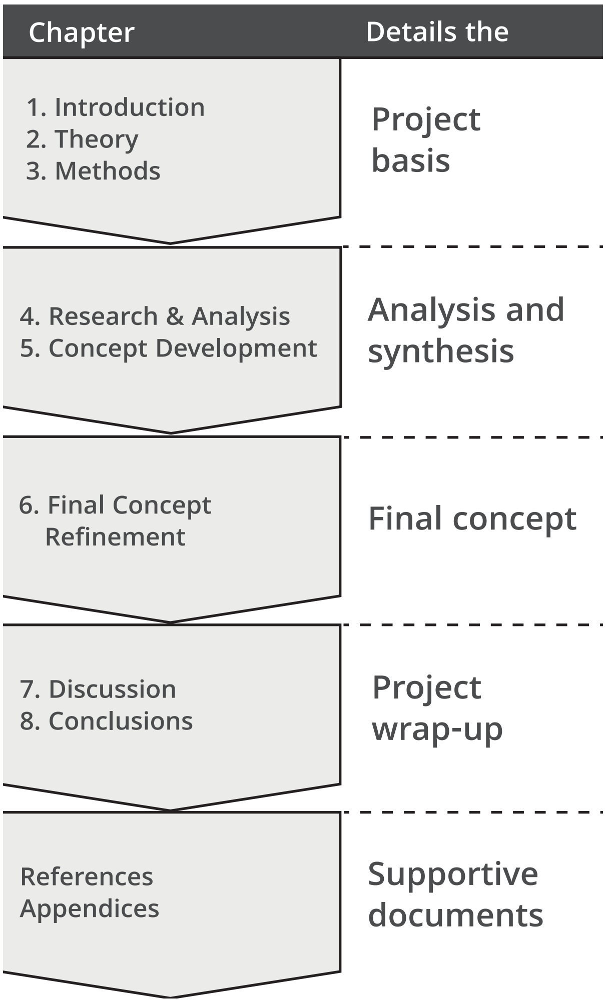

Figure 3. Overview of the report structure.

2. THEORY

The following chapter describes the relevant theory that formed the theoretical basis for this project. It includes sections regarding vibrations, ergonomics as applied to power tools, and a section about product branding.

2.1 Vibration

This section presents the basic theory and concepts of mechanical vibrations, a short description of the causes and characteristics of power tool vibrations, and the general known methods to mitigate them.

2.1.1 Vibration theory

Vibrations are mechanical oscillations around an equilibrium point, and can be described with an amplitude and a frequency. The frequency is the number of oscillations per second, and the amplitude is the size of the oscillations, commonly measured in distance, speed or acceleration. Acceleration is the most commonly used measure, partly due to the fact that the most common electrical equipment used to measure vibration gives acceleration as the output. It is also the unit used in safety regulations for power tools, and will thus be used in this report. The relationship between the acceleration of the system and the excitation force causing it is easily described by Newton's first law, seen in formula 2.1. It also clarifies the influence of the system mass on the vibrations (da Silva, 2006).

$$F = m * a \tag{2.1}$$

Natural frequencies

Vibrations are either free or forced. Forced vibrations occur when the system is compelled to vibrate at a specific frequency by a recurring force. When it comes to free vibrations, there is no recurring force. Instead, these systems vibrate at a frequency determined by the properties of the system. This system-specific frequency is known as the natural frequency, f_n, and as can be seen in formula 2.2, it can be determined by the mass, m, and the stiffness, k, of the system.

$$f_n = \sqrt{\frac{k}{m}} \tag{2.2}$$

If external forces are applied with a frequency close to the natural frequency, resonance will occur. This means that the oscillations will increase in amplitude, leading to disrupted performance and possibly a system breakdown. (da Silva, 2006)

Damping

Beside forces that maintain or amplify vibrations, forces can also have the opposite effect. Damping is the effect that dissipates kinetic energy from a mechanical system and leads it away in a different form, typically as thermal energy.

Damping is part of all mechanical systems, as it is impossible to eliminate it completely. Whether or not it is wanted differs from system to system. In systems with free vibrations, intentional damping can be used to eliminate the vibrations as quickly as possible. In forced vibrating systems, damping is used to stop system breakdowns when the excitation frequency is close to the natural frequency. When the vibrations are wanted, the systems are designed to minimize the damping. Damping also has an effect on the natural frequency of the system, which means that in some cases the damping needs to be optimized in order to distinguish the natural frequency from the frequency of the excitations. When damping is taken into consideration, the natural frequency is calculated with the damping ratio, ζ, according to formula 2.3. The damping ratio is determined by the amount of damping in the system (da Silva, 2006).

$$f_d = f_n \sqrt{1-\zeta^2} \quad \textit{(2.3)}$$

In the study of mechanical systems, there are three primary mechanisms of damping:

- Internal damping is the energy dissipation that takes place within the materials themselves, due to a variation of micro-and-macroscopic processes.
- Structural damping is the energy dissipation caused by rubbing friction and impacts between the internal components of the system. The structural damping of a system is usually significantly greater than the internal damping.
- Fluid damping is the energy dissipation through movement in fluid surrounding the mechanical system, caused by a displacement of system components (da Silva, 2006).

2.1.2 Vibration in pneumatic power tools

To some extent, all automatic tools vibrate. These vibrations come from the oscillating forces on the mass of the tool, from the process of work itself, or from excitation of the natural frequencies of the machine parts. (Lindqvist et. al., 2007)

In terms of designing power tools to avoid vibration, they can usually be divided into the two groups: rotating machinery and reciprocating machinery. The main part of the vibration in rotating machinery, such as grinders, usually arises from unbalanced rotating parts within the machine, or in the inserted tool. For reciprocating tools the source of vibrations is dominated by the oscillating force from the reciprocating mechanism, the impact with the workpiece, and by vibrations transported directly from the workpiece (da Silva, 2006).

2.1.3 Vibration control and design

There are several ways to suppress the vibrations emitted from a mechanical system. To put it simply, the methods can be divided into three slightly overlapping categories.

- Isolate the system vibrating system from its support.
- Modify the design of the system, so that the same level of excitation gives a smaller vibratory response.
- Control the vibratory response with external devices.

This section describes the three methods further and gives some examples of their application. Some elements, such as dampers, are part of several categories and can not be attributed solely to one. The application of the elements does however vary between the categories.

Isolation

A vibration isolator consists of an elastic element and potentially also a damping element, being placed between the source of vibrations and the supporting structure from which the vibrations are to be removed from. Vibrations that would have been transmitted directly to the supporting structure are decreased through the flexibility of the elastic element and the energy dissipation of the damper. The elastic element is often a metal spring, but could also be an air spring or pads made of elastic materials. The energy dissipation is mainly useful when the excitation frequency is close to the natural frequency of the system, and could be achieved through any of the damping means mentioned in 2.1.1. If the natural frequency of the system is well below the operational frequency, no damping is necessary. A typical example of an isolator is a vehicle suspension system, usually consisting of a steel spring and a hydraulic damper.

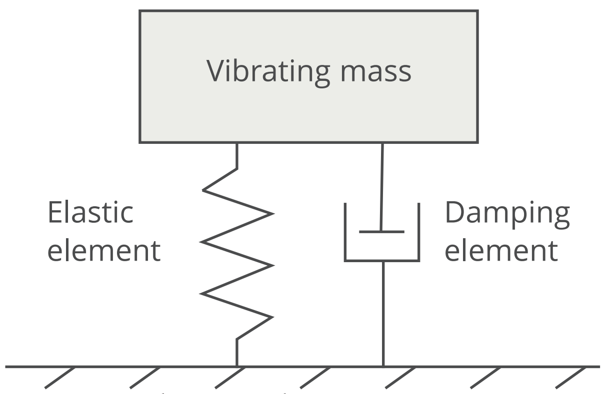

Figure 4. A vibration isolator.

Design modification

Design modification considers methods for balancing machines by modifying existing components in order to even out the exciting forces in the machinery. In rotating structures this is done to assert that the centre of mass of rotating parts coincides with the axis of rotation. When it comes to reciprocating systems the forces can be cancelled out by adding a mass mirroring the motion of the moving parts in the system. This is especially suitable for systems with several components moving in synchronization. One obvious example is an engine with several cylinders, where the cycles of the cylinders can be arranged so that the momentum from the different pistons cancel each other out, as seen in figure 5 (da Silva, 2006).

Vibration control

Vibration control is the name used for a number of techniques to minimize vibrations by adding external devices to the system. These devices sense the level of vibration in a system and applies a force to counteract the effects of the vibrations. These devices can be either passive, meaning that they do not require an external source of power, or active, meaning that they do.

The most common passive devices are absorbers and dampers. An absorber, as seen in figure 6, is a mass-spring system added to the original system. The natural frequency of the absorber is tuned to the frequency of the mechanical system, allowing it to oppose the system motion and thereby reduce the vibration excitation. Since the absorber is tuned to a specific frequency, the frequency spectrum in which it performs well is limited. Therefore this solution is best fitted for systems with a small variation in vibration frequency. Some absorbers also have damping, but the main vibration mitigation is done by the momentum of the absorber cancelling the excitations.

Dampers include all types of intended damping with the purpose of dissipating energy direct from the primary vibrating system. This differs from the damping in isolators and absorbers because the dissipation is the main vibration mitigation principle. In isolators and absorbers, the damping is usually a secondary effect, used to control the natural frequency of the system or to prevent an uncontrolled increase in amplitude when the system vibrates close to resonance frequencies. Dampers are very useful to mitigate free vibrations, and work over a wide frequency spectrum. The disadvantages are that in systems where the vibrations are a part of the process, they will reduce the effect of the system, and that they usually generate heat (da Silva, 2006). Dampers can be constructed in a number of ways. The basic principles are mentioned in section 2.1.1.

Active devices consist of several powered components that sense vibrations and emit a counterforce. They are more flexible than passive devices in terms of frequency range, but are more expensive and requires power input (da Silva, 2006).

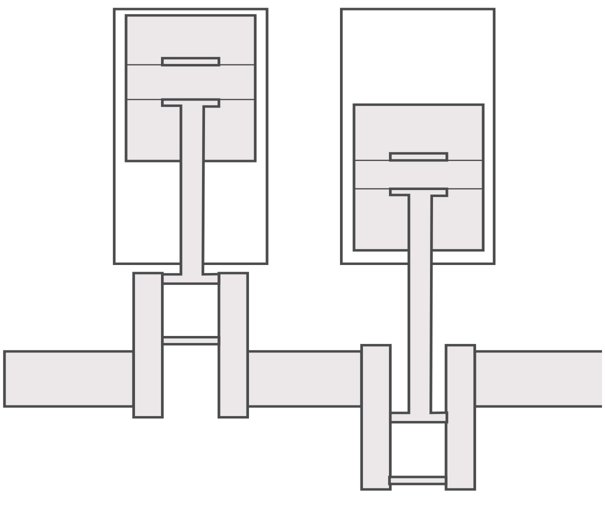

Figure 5. A balanced two-cylinder engine. The piston are placed around the crank shaft so that their movements always oppose each other.

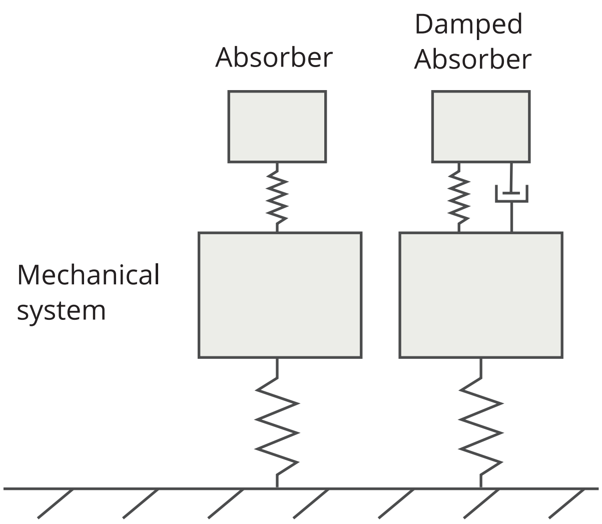

Figure 6. Two vibrating mechanical systems with absorbers, of which one is damped.

2.2 Power tool ergonomics

As defined by the International Ergonomics Association (2016), ergonomics is the science of understanding how to adapt every component of a human-product system to the anatomy, psychology and cognitive capabilities of the intended user. The end goal of ergonomics is to optimize human well-being and total system performance.

The ergonomic topics of particular relevance for this project, and for power tools in general, include the mitigation of hazards originating from vibrations, together with grip and upper limb work theory. The basic principles of these areas will be discussed in the following sections.

2.2.1 Vibration in a human context

The effects felt from vibration vary in degree. According to da Silva (2006), they can be classified by degree of severity, from low to high, as follows:

- Sense and feel
- Distraction and annoyance
- Discomfort
- Minor, moderate, or major health consequences

While the first category can be considered harmless, the subsequent categories will have an increasingly large impact upon daily life and work.

Vibrations are transmitted to humans in the form of either hand-arm vibration or as entire body vibration. Power tools and vehicular steering devices are often the source of the former vibration type, while automated vehicles are the most common source of the latter.

Hand-arm vibrations generally cause more discomfort and leads to permanent injuries more often than whole-body vibrations. This can be attributed to the more fragile nature of the upper limbs than for the human body as a whole. Injuries sustained by hand-arm vibrations are most often confined to the hands themselves. For example, extended usage of power tools is a common cause of White Finger Syndrome, wherein the delicate blood vessels in the fingertips and palms are permanently destroyed by the long exposure to vibration (Lindqvist et. al., 2007). White Finger Syndrome can occur at vibrations ranging from 5 to 2000 Hz, but is particularly likely to arise from vibrations within the range of 50 - 150 Hz.

Vibrations in hand tools are also known to contribute to the contraction of Carpal Tunnel Syndrome (Strasser 2007). Other typical ailments resulting from vibration exposure include recurring sensations of pain and cold in fingers, loss of feel in fingers, and loss of grip strength. (CCOHS, 2016)

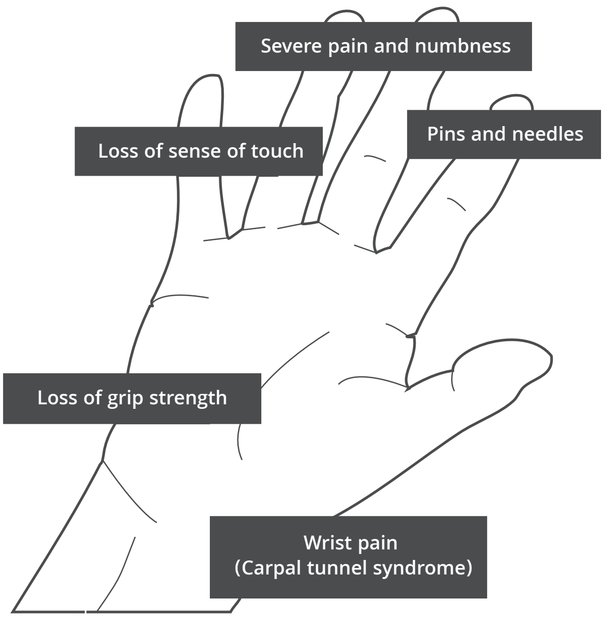

Figure 7. Common physiological symptoms of vibration induced injuries.

Standards and regulations concerning vibration exposure

In the EU, a directive by the name Physical Agents (Vibration) Directive (PA(V)D) is currently in force. It contains guidelines on action and limit values for daily vibration exposure, and outlines the employer's responsibilities to manage the risk associated with the exposure to vibration. The directive has set the action value and the limit value to 2.5 m/s^2 and 5 m/s^2, respectively. One formula for calculating this vibration exposure value is described in Atlas Copco's pocket guide Exposure

Assessment for Industrial Power Tools (2013). It is there referred to as the daily personal vibration exposure. The formula is

$$A(8) = \sqrt{\frac{T}{T_0}} \quad (2.4)$$

Where T is the measured total duration of exposure during a working day in hours, and T_0 is the reference duration of eight hours, and a_{hv} is the root-mean-square *(rms)* acceleration of the contact surface between the held device and the hands. When calculating the rms acceleration, acceleration is first measured in three mutually perpendicular directions x, y, and z. The rms acceleration is then given by the formula

$$a_{hv} = \sqrt{a_{hvx}^2 + a_{hvy}^2 + a_{hvz}^2} \quad (2.5)$$

In case there are several operations with different vibration magnitudes in the work situation examined, the exposure can be calculated according to the formula

$$A(8) = \sqrt{\frac{1}{T_0} * \sum_{i=1}^{n} a_{hvi}^2 * T_i} \quad (2.6)$$

Where n is the number of operations with distinct vibration magnitude, a_{hvi} is the vibration magnitude of operation i, and T_i is the duration of operation i. The acquired value for *A(8)* can then be compared to the table of recommended maximum daily exposure values.

The design of the formulas described above results in that tools with a measured a_{hv} value of 2.5 m/s^2 or less can be used for the entire nominal workday of eight hours without having any accumulating health effects. As can be seen, tools with much higher a_{hv} values can still be used, although for considerably shorter times. Operations with an a_{hv} value between 2.5 m/s^2 and 5 m/s^2 should be evaluated, either in terms of design of the employed tools or in terms of exposure time, or both. Finally, if the a_{hv} value for an operation exceeds 5 m/s^2, it should not be carried out until modifications to tool design or exposure time has been carried out. Table 1 shows the maximal daily exposure times before exceeding the action value and the limit value for values of a_{hv}.

Standards and regulations concerning vibration emission measurements

The International Organisation for Standardisation (ISO) have devised a standard for the procedure whereby the rms acceleration for reciprocating power tools is measured, documented in ISO 28927-9. Within the EU, the Machinery Directive (2006/42/EC) requires manufacturers of machinery to declare the rms acceleration of their products, and for reciprocating power tools, it must have been measured in accordance to ISO 28927-9.

However, because of different workpieces, operator techniques and physiques, and current condition of the tool, there is a large variation in the vibration exposure felt from the same tool. The nominal rms

Table 1. Vibration exposure limits for daily use (Exposure Assessment for Industrial Power Tools, 2013)

a_{hv}	Max daily exposure time before exceeding action value 2.5 m/s2	Max daily exposure time before exceeding limit value 5 m/s2
1.8 m/s2	15 h	62 h
2.5 m/s2	8 h	32 h
3.5 m/s2	4 h	16 h
5 m/s2	2 h	8 h
7 m/s2	1 h	4 h
10 m/s2	30 min	2 h
14 m/s2	15 min	1 h
20 m/s2	8 min	30 min

acceleration value as declared by the manufacturer therefore seldom describes real life situations adequately enough to be used to calculate the daily vibration exposure. Instead, several measurements should be carried out for each work task and then averaged, in order to obtain a more accurate rms value for that specific situation. The Physical Agents (Vibration) Directive advises that the standardised procedure for this type of measurements described in ISO 5349 is used.

2.2.2 Grip

The optimal grip design depends on the type of work and working postures that the tool is intended for. A general rule is that the wrists should be exposed to as little torque as possible, and especially so when force is exerted parallel to the forearms. Table 2 summarizes the main aspects of good handle design for a number of situations.

2.2.3 Weight

Generally, a light tool increases the range of feasible working postures and gives a longer usage time that is comfortable the user. However, a higher weight can be beneficial for the function and comfort of use of the tool in certain situations, as in the case of an angle grinder working on a predominantly horizontal surface. The extra weight provides stability and facilitates the application of force towards the workpiece. Another example where more weight can be of advantage concerns high-vibration tools, where it would assist in absorbing more vibrational energy, leading to a lower vibration exposure for the user. (Lindqvist et. al., 2007)

Another important ergonomic aspect of the tool is the location of its centre of gravity. Generally, it should be located as close to the wrists of the user as possible, so as not to exert any momentum on the wrists in any direction (Lindqvist et. al., 2007). Exceptions to this rule can be found in hammers, ice picks, and other tools that utilize the displaced centre of gravity to facilitate the delivery of blows.

Standards and regulations regarding weight
ISO 11148 states that non-rotary percussive tools having a mass of more than 2 kg shall allow for a two-hand-grip. Conversely, this means that if the tool is supposed to be possible to use one-handed, it must weigh less than 2 kg.

Table 2. Guidelines for handle design (CCOHS, 2016)

Description	Guideline	Reason
Grip Shape	Slightly contoured	Easy grip
Direction of force is in-line with forearm and wrist (typically horizontal)	Bent handle (Power grip)	Minimal wrist deviation
Direction of force is perpendicular to forearm and wrist (typically vertical)	Straight handle	Minimal wrist deviation
Separation distance between handles (for crushing, gripping or clipping tools such as pliers or tongs)	65-90 mm	Maximum grip strength
Handle length	> 100 mm	Keep contact out of palm
Handle diameter (power grip)	30-50 mm	Greater fore and stability
Handle diameter (precision task)	8-16 mm	Greater control
Material and texture of handles	Non-slip non-conductive materials	For comfort and reduces effort required to use tool

2.3 Visual brand identity

This section presents one approach to making the brand of a company visually recognizable through the aesthetics of their products. The approach originates from an article by Dirk Snelders, an associate professor of marketing in the Faculty of Industrial Design Engineering at Delft University of Technology.

Snelders (2010) describes how so called implicit and explicit design cues can be applied on the product. Explicit design cues are intended to be immediately perceived and recognized. This would be large general characteristics covering major parts of the product, such as colours, textures and patterns, or smaller more specific graphic or form elements such as the logo, or the grill of a car. Implicit cues are based on features that are less obvious and that are meant to be perceived on a less conscious level. Implicit cues can be compared to those of a human face, which are inherently recognized but hard to describe.

According to Snelders, the following six drivers can be used to determine a suitable company strategy in the usage of implicit and explicit design cues.

Life-cycle stage of product category - The category of products that the company makes is important to take into consideration when defining a branding strategy. In mature markets, the competing companies have well defined positions. Therefore differentiation between the brands is important. This is done by using explicit cues consistently over the product range. In less mature markets differentiation can be used to gain market shares.

- *Renewal cycle* - For products with a short renewal cycle, innovation is important in order to make previous designs seem outdated. In slowly evolving markets, consistency is of more importance, thus motivating the usage of explicit cues.
- *Brand position* - The market position of the company should affect its design strategy. A dominant market leader has the opportunity of trying out a variety of designs and directions, meaning a variety of explicit cues, with maintained implicit ones. A player with a smaller market share may have to focus on a niche, and express it through consistent usage of explicit cues.
- *Portfolio width* - For a company with a small number of products, every product can have a great impact on the company image and recognition. Therefore the usage of explicit cues becomes important. Larger portfolios, on the other hand, are often kept to reach more market segments. In this case, more flexibility is required to reach out with each product. The explicit cues should be focused more towards lead products, and implicit cues should be used to a greater extent over the entire portfolio.
- *Brand heritage* - For recently emerged markets, or companies, the brand heritage has little meaning to the customer. Therefore, following explicit cues is of little meaning. Here, implicit cues do a better job of conveying the company profile. In a mature company or market, however, a known brand image among the customers can be kept through the consistent usage of explicit design cues.
- *Product history* - Past products usually have big influence on new designs, as old elements are used to find a good balance between familiarity and novelty. In new companies, or companies with a variation of style in the product range, it may however be difficult to show a consistent historical path.

2.4 The FCH-25

This section describes the tool by listing its parts and displaying its function. It also includes a basic description of the systems feeding air to the tool.

2.4.1 Tool description

The following section describes the variation, anatomy and mechanical function of the FCH -25, as well as the difference between the different models. The mechanical function and features of the FCH-20 is similar.

Anatomy

A simplified section view of the FCH-25 can be seen in figure 8. The parts are named below, and will be referenced accordingly throughout the report.

1. Back piece
2. Valve lever pin
3. Valve lever
4. Cylinder
5. Piston
6. Chisel holder
7. Ball
8. Stop ring
9. Chisel
10. Valve cover
11. Valve rod
12. Valve spring
13. Cylinder cover

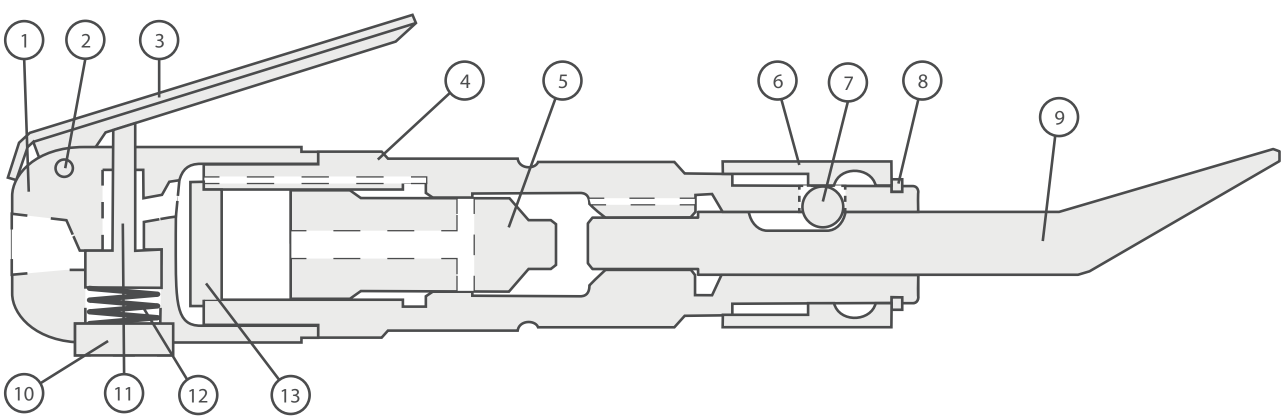

Figure 8. A simplified section view of the Fuji FCH-25.

Mechanical function

Once the lever is pressed, pressurised air enters through the air vent assembly. The function of the air motor works as follows, and as seen in figure 9 to 11.

In figure 9, the piston is in its rearmost position. The pressurised air goes through the holes in the piston, and in to the area behind the it. The pressure puts a force on the piston which pushes it forward.

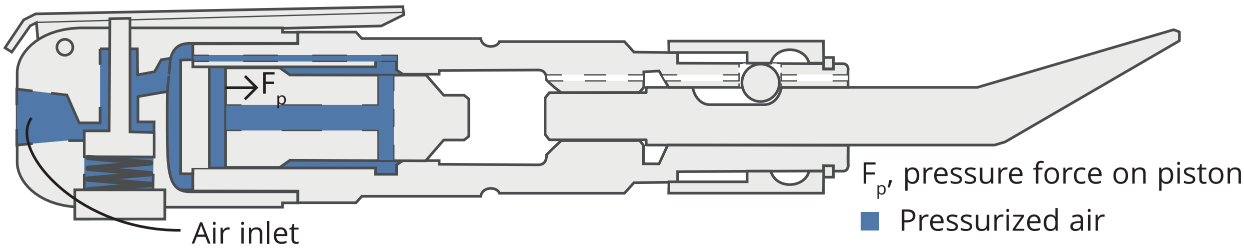

Figure 9.

Figure 10 shows the piston hit the chisel, which goes forward and hits the workpiece. The holes in the piston are closed by the narrow wall of the cylinder, and the pressure force on the small edges of the wider back part of the piston pushes it backwards.

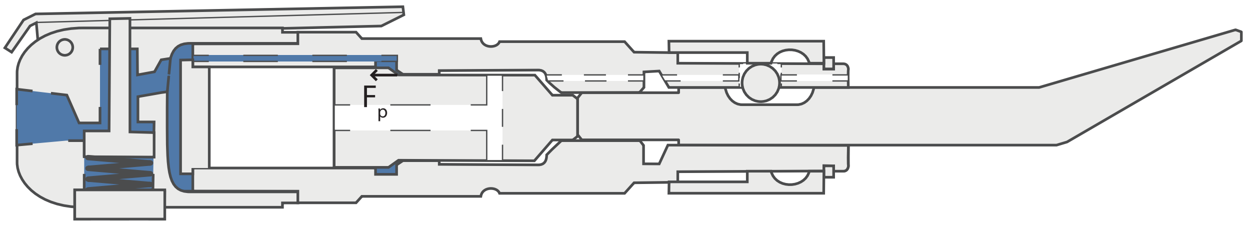

Figure 10.

In figure 11, the piston keeps going backwards until it reaches its original position, and the cycle is restarted. The chisel is pushed back as it is being pushed towards the workpiece.

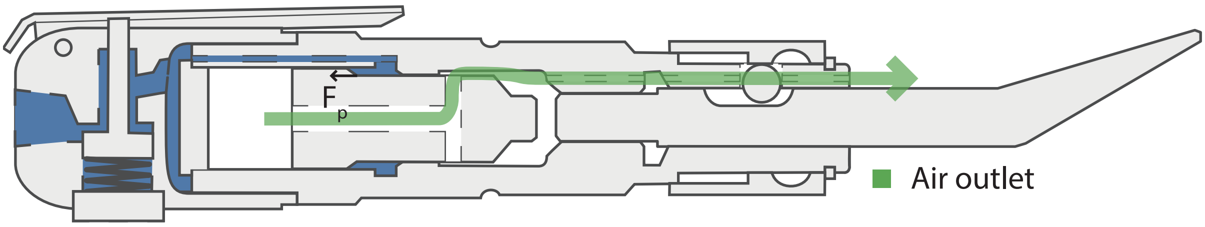

Figure 11.

Other features

As seen in the anatomy of the tool, the tool casing is divided into a back piece and a front section, which are screwed together. As the front section is predominantly round, wrench markings have been included to allow for applying torque when mounting or dismounting the back piece. The back piece can be rotationally locked using the flat surfaces at the rear.

The FCH-25 also include a mechanism for quick, tool-free insertion and removal of chisels. The mechanism comprises a cylindrical sleeve covering the front, which keeps a ball lying in a hole flush with the front section. The ball, in turn, extends down into an elongated slot in the chisel, locking it securely in place. The sleeve is held in place by a spring, and when the user pushes it backwards along the tool to the right position, a milled groove inside the sleeve allows for the ball to be pushed out of its hole, which in turn allows for the chisel to be inserted or removed. See figure 12.

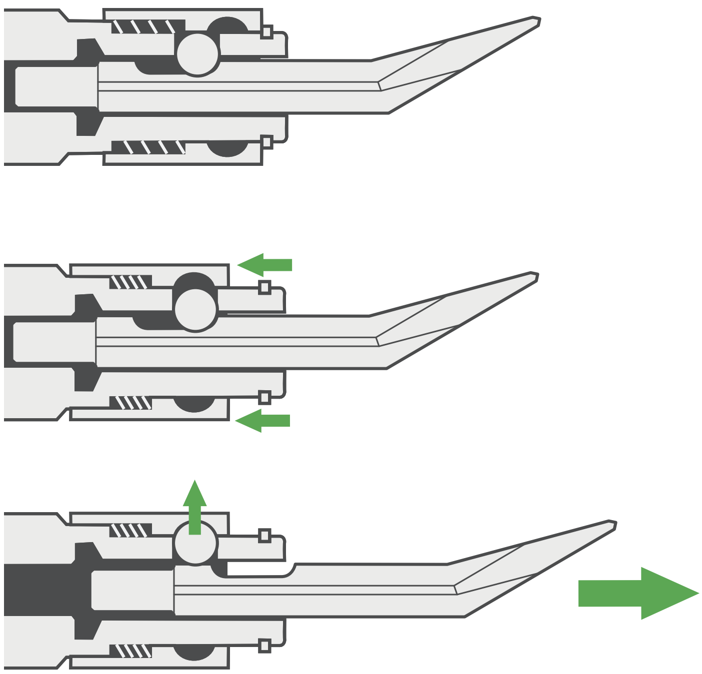

Figure 12. Illustration of the quick release function

2.4.2 The air feed system

As with all pneumatic devices, the FCH needs to be connected to a compressor in order to function. To connect the tool, a quick-attachment adapter is screwed on to the tool's rear end, onto which an air hose can be attached. The quick-attachment adapter is available in different sizes to allow for different hose diameters.

Most large workplaces have air feed systems with a centralised air supply, delivering air through a system of pipes and hoses. If the air supply system has not been carefully designed, containing uneven flows and leakages, some degree of pressure drops will occur at the point where the tool is plugged in. The lower pressure will in turn lower the performance of the inserted tool. Even slight differences in pressure will have a significant effect. For instance, most pneumatic tools are designed for a working pressure of 6 to 7 bars. If the pressure delivered by the air supply system is 5 bars, the output effect of the tool will be around 25% lower than optimal.

3. METHODOLOGY

As laid out in the introduction, the project was outlined to consist of five different phases; initial study, data analysis, concept generation, evaluation and selection, and a final concept refinement. The methods and tools employed in each phase are described in the following sections. For the methods for which this was possible to determine already in the initial phase, a short description of the specific application of the method in this project is provided.

3.1 Initial study

During the initial study, information relevant for the project is to be gathered. Formal data collection methods are necessary to ensure that the gathered data is accurate. Below, a summary of the methods that are to be employed in the initial study is given.

3.1.1 Literature review

Literature reviews serve to compile and understand the background information and current state of knowledge in the relevant field of study (Bligård, 2011). Online publications, textbooks and patents are examples of sources which can be useful.

Project application
Literature reviews will be used to gain sufficient knowledge in the topics deemed relevant to this project. Most essential will be gaining a sufficient knowledge of vibrations, and the problems that they can cause. Additional subjects that will be explored include other ergonomic aspects relevant to power tools, the pneumatic tool market, and product semantics.

3.1.2 Observational studies

Observations are carried out with the aim of understanding how a user may act in certain situations. Through observations, data concerning the user behaviours can be obtained and analysed. This data can then be used to find behavioural patterns, risks and problems for the user.

In cases where direct user studies are not possible, another option is to carry out observations based on documentaries and photographic material. While limited in flexibility, it can serve well to build a general understanding of user needs (McQuarrie, 2012).

Project application
Users of pneumatic tools will be observed in Sweden and Japan. The expected outcome is a deepened understanding of the usage of products of this type, and the problems experienced by the users.

3.1.3 Questionnaire

A questionnaire may be used to quickly obtain user data. The questionnaire can contain either purely quantitative or qualitative questions, or a combination of both, to obtain a diverse set of data for analysis. The data obtained from questionnaires

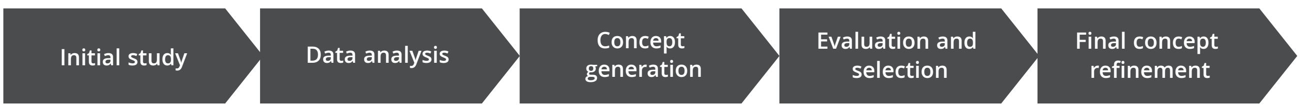

Figure 13. The methodological approach to the project.

is inherently well-structured, but lacks any dynamic interaction between the surveying party and the surveyed (McQuarrie, 2012).

Project application
Utilizing the data from the literature review and the initial user studies, a questionnaire will be put together to be distributed among Japanese users. This will give quantitative data regarding the users' perception of the tools and the brand, in terms of functionality, quality and aesthetics.

3.1.4 Interviews

Interviews serve as a means to obtain both qualitative and quantitative data through conversation with a person of interest. The amount of structure in the interviews vary depending on the purpose of the study. Based on this structure, the interview can be categorized as one of the following three types:

- Structured interviews, where the questions are predetermined and controlled, mainly used to verify existing data or when the area is well defined and details are sought.
- Semi-structured interviews, where the interviewer has a general guide containing the information sought, but additional probing is used to further expand the data set. The probing generally takes the form of follow-up questions or asking the subject to expand their answers with more details.
- Unstructured interviews, which are, as evident by the name, not prepared in the same manner as structured or semi-structured interviews. Instead, the interview follows more of a conversational pattern, with questions dynamically asked and conversation steering the direction of the interview. This is useful when the interviewer has no previous knowledge of the area of investigation or if the area is not well defined. (McQuarrie, 2012)

Project application
Interviews will be performed in a semi-structured manner in Sweden as well as in Japan. This will give qualitative data regarding the users' perception of the tools in terms of functionality, quality and aesthetics.

3.2 Data analysis

Data processing will be conducted with several methods for structuring and interpreting the information. In this section, the analysis methods used in this project are described in further detail.

3.2.1 Affinity diagram

The affinity diagram, at times referred to as "KJ-analysis", is a method for categorising qualitative data. The procedure is as follows: The gathered qualitative data is written down or printed as quotes on separate pieces of paper, typically Post-Its. Each quote is discussed, preferably in a cross-functional team, and grouped with quotes containing similar information. When all data is sorted and grouped, trends, important information and interviewee consensus can easily be mapped. Headlines are then appointed for each group in the diagram. (Bergman & Klefsjö, 2010)

Project application
Data from interviews conducted with the users in Sweden and Japan will be gathered and sorted according to the identified main recurring topics. This will provide an overview of the problems and opportunities for improvements that may exist.

3.2.2 Needs statement

A needs statement is a list of needs or wants which has been compiled using data acquired in previous user studies. As interpretations are not objective by nature, the same customer statement can be translated into different needs by different individuals. The needs should always be expressed in terms of what the product is supposed to do, and leave out details regarding how it might do it. The need should also be expressed with the same specificity as the data it is based on, in order to avoid loss of data resolution. (Ulrich & Eppinger, 2012).

Project application
Statements from interviews compiled in the affinity diagram will be translated into user needs. This will facilitate the subsequent mapping of the statements to formal requirements in the list of requirements. See section 3.2.5 for details.

3.2.3 Design Format Analysis (DFA)

Design Format Analysis is a method for identifying specific visual elements that are typical for a brand. It consists of three stages:

1. Choose which products will be included in the analysis
2. Identify explicit visual cues occurring in each of the products
3. Construct a matrix consisting of the products on one axis and the visual cues on the other axis
4. Assess and indicate the presence of each cue in every product.

Commonly, the presence of each cue in each product is assessed using a scale of type "absent", "present", and "strongly present". It is useful to assign numerical values to the scale to facilitate comparison. The finished design matrix can be used to find the most representative products for a brand. It can also indicate which visual cues are the most ubiquitous within or across product families, and therefore which cues that could be most important to keep in future products. An example is given in table 3, where the most typical cue and the most typical product have been emphasized.

Several considerations need to be made when performing a DFA. In case the brand consists of several different product families, a decision needs to be made on whether the brand is to be analysed across all product families, or within a single product family. (Warell & Nåbo, 2002).

Project application

The Design Format Analysis will be used to identify the core visual elements of Fuji's products. The analysis will include products across Fuji's entire product range, in order to obtain cues that are ubiquitous to the brand. Competitor products will be added in order to distinguish what is typical for Fuji and which characteristics exist within the product category in general. The typical and unique elements identified will be taken into consideration when giving the new product its visual appearance.

Table 3. Design Format Analysis Sample

	Cue #1	Cue #2	Cue #3	Sum
Product #1	Absent	Present	Absent	1
Product #2	Present	Strongly present	Absent	3
Product #3	Strongly present	Strongly present	Present	5
Sum	3	5	1	

3.2.4 Inspiration board

An inspiration board is a collage of images collected in order to convey a feeling or an attribute. The common denominator of the images is usually the message they are meant to convey. The board is mainly used as a source of inspiration during the development of the aesthetic design, but also as a way to compare the expression of various concepts (Nicosia 2014).

Project application
The inspiration board will be used in order to translate the characteristics and values that Fuji wants to convey from words to a visual expression.

3.2.5 Requirements specification

A requirements specification is a document that describes the identified requirements of the various stakeholders included in the scope of a development project. The requirements are described in a uniform list format. It can be designed in many ways, but a generic template containing commonly used inputs for a requirements list is shown in table 4.

The requirement is described, along with a target value, which can be a number, yes/no, or some other value. The factors that lead up to the existence of that requirement are then described under *cause*, and under *origin* the stakeholders generating those factors are indicated. Finally, the fulfilment of the requirement is specified, either as yes/no or as a grading on a scale. (Bligård, 2011).

Project application
The specification will be based on all data collection and analysis results. The requirements will cover user interaction based areas such as ergonomics, aesthetics, performance and manufacturing.

It will be ensured that the requirements specification is relatively complete before moving on to the concept generation phase. However, the document will be dynamic in nature, meaning it will be continuously developed throughout the project, as new and more accurate data is acquired and interpreted.

Table 4. Generic form of a requirements specification list

ID	Description	Type of measure	Target vale	Fulfilment	Origin
1	Product shall weigh less than	kg	5	Yes (3,5 kg)	Ergonomic standards
...	...	...	...	...	...
1+n	Description of requirement 1+n	Type of measurement for requirement 1+n	Target value of requirement 1+n	Level of fulfilment for requirement 1+n	Origin of requirement 1+n

3.3 Concept generation

The concept generation stage ideally results in a large number of distinct concepts, as to ensure a broad base of possible solutions. Below is a description of the employed methods used for the purpose of concept generation and screening.

3.3.1 Brainstorming

Brainstorming aims to stimulate and generate as many ideas as possible within a team. It involves a group of people who spontaneously describe any thoughts and ideas that occur to them during the brainstorming session, through speech and commonly with the help visual aids such as sketching. No critique of the ideas put forth is allowed, and unorthodox thinking is encouraged (Johannesson, 2004).

3.3.2 The 6-3-5 Method

This is a structured type of brainstorming method where six people get together, and each write or sketch three ideas to a given problem in five minutes. The papers are then passed around one step at the time, allowing everyone to come up with new ideas based on the ideas of the previous owner of each paper. Optimally, this method can generate 180 ideas in 30 minutes. The method is flexible in terms of people and time spent (MacNaught, 2007).

3.3.3 Morphological matrix

A morphological matrix is used to generate concepts by combining different sub-solution alternatives into many different total solution concepts. This matrix assists the concept generation by covering all possible solutions. The solutions are formed from sub-solutions and can provide combinations that were not considered before which might be relevant to evaluate (Almefelt, 2015).

3.4 Evaluation & selection

As the number of concepts resulting from the idea generation is ideally large, an evaluation and screening stage is then useful to narrow this number down using comparative tools and methods. Two methods designed for this purpose are described below. Apart from the methods mentioned here, decisions taken in this project will also be supported by feedback from Fuji's marketing division.

3.4.1 Elimination matrix

Elimination matrix is a method used to narrow the number of generated concepts down. The main purpose is to remove evidently disqualified concepts. This is done by evaluating each concept in a matrix format against fundamental criteria, for example "solves main problem", "compatible", "realizable" etc. Concepts that do not meet all these requirements are either given the necessary modifications to make it through, or dropped altogether. (Almefelt, 2015).

3.4.2 Pugh matrix

The Pugh matrix is a screening method to rank concepts according to how well they would fulfil the selected criteria by comparing them to a reference model. For each criteria, each concept is given a '+' if it is measured or assumed to perform better than the reference model, a '-' if it performs worse, or a '0' if it is on par. The total balance is then calculated for each concept by adding every '+' and from that subtracting every '-'. The concept or concepts with the highest final scores (Ulrich & Eppinger, 2012).

3.4.3 Semantic differential

The semantic differential is a method for measuring subjective characteristics of an object. Descriptive words and their antonyms are identified and printed on either side of a valued scale. The test subjects are asked to grade the object in terms of the descriptive words (Osgood, 1957). In product design, wanted characteristics are appropriate as descriptive words.

3.5 Final concept refinement

In the final phase the chosen concept will be developed further, on a level concerning details that are yet to be specified in the concept. This phase is to result in detailed drawings, which should be detailed enough to form the base for a functional prototype of the final concept. This prototype is to be manufactured in Fuji's workshop facilities in Osaka.

3.5.1 Computer Aided Design (CAD)

CAD is the use of computer systems for modelling and analysis of components. With the help of a CAD program, two-dimensional drawings can be created, and with these as a basis, a three-dimensional model can then be built. CAD models provides greater accuracy than hand sketches and the possibility to evaluate a component's appearance, attributes and functionality digitally (Ulrich & Eppinger, 2012).

Project application

The final concept will be modelled in CATIA V5. The model will both serve as a means of developing the most minute details of the design, as well as a basis for digital visualisation in the form of renderings.

4. RESEARCH & ANALYSIS

This section outlines the work processes of the user studies and visual brand analysis, and presents the findings made. The list of requirements is also discussed at the end of this chapter, as it is the main document linking the results of the analysis to the following concept generation phase. The compilation process, along with key parts of this list, are described.

4.1 User studies

In the section below, the procedure of the user studies and key findings from them are presented.

4.1.1 Execution

The user studies included several interviews and observations, as well as a questionnaire. A summary of their execution is given next.

Interviews

As mentioned in the methodology chapter, user studies were carried out both in Sweden and in Japan. A total of 16 workplaces were visited. An interview guide was constructed with the aim to hold semi-structured interviews in mind. It can be found in appendix III.

In Sweden, it was primarily sought after to find work places using chipping hammers regularly, regardless of tool brand, in order to understand the general work process and typical usage. One tram maintenance hall and three shipyards were visited.

Figure 14. A 500 meter long bulk ship is being assembled in Hiroshima, Japan.

In Japan, the visits were carried out together with the company project supervisor, along with a sales representative from the area visited. The companies visited were all customers of Fuji. The interviews were carried out by the supervisor and the sales representatives using a Japanese translation of the interview guide. The takeaways were then relayed to the project team in English after each interview. A total of six shipyards, three bridge manufacturers, two train manufacturers, and one foundry were visited.

The data collected from the interviews was analysed to find recurring themes brought up by the users, in an Affinity Diagram. Using an online tool for creating mind-maps, the quotes were categorised in accordance to the affinity diagram-method. See appendix IV for the full Affinity Diagram.

Questionnaire

The questionnaire was first drafted in a document, using some of the questions from the interview guide, modified to focus on giving more quantitative data, and a few new questions were also included. The questionnaire was distributed in two ways: as printed copies, handed over to the receiving company representative during customer visits in Japan, and as an online form, using the online survey tool Google Forms.

4.1.2 Findings from interviews and observations

Below is a summary of the recurring themes found in the Affinity Diagram.

Typical usage

As expected, the typical observed and described usages of the chipping hammer involve chipping away slag and sputter resulting from welding. However, it was noted that it is also commonly used to remove rust and paint from steel structures, typically in reparations, for example on vehicle hulls. At a foundry visited in Japan, it was also used for removing excess material and smoothing rough surfaces on cast parts.

Ergonomic issues

The most common comment was that the tool vibrates a lot, which causes damage to hands and arms in the long term perspective. This issue was mentioned in nearly every interview. This was to be expected, as the issue with vibrations is at the core of the initial project problem definition, which Fuji had based on previous customer surveys.

Many customers also mentioned “light weight” as an important attribute when choosing a tool.

Figure 15. A propeller is installed on a ship. The weld seems are cleared using a flux chipper.

This is likely connected to the observed and described fact that many users need to work in awkward positions for prolonged time, with the tool held far from the body and at uncomfortable angles. The need to work at welding seams and surfaces in narrow spaces is common, for example in between complex steel scaffolding, leading to limitations in possible working stances.

Another issue related to the common scenario of working in these narrow spaces was described in several interviews. This involved the chisel getting stuck in crevices in operative mode, which caused the whole tool to feed forward into the crevice. The feeding would then continue until the operator let go of the lever or until the resistance in the material overcame the power of the tool. The feeding can happen suddenly and surprise the operator. In case the operator's hand or hands holding the tool are anywhere close to a surface when the feeding happens, there is a risk of clamping. It can also occur that the operator is working with the lever of the tool facing down towards a close-by surface when the feeding happens. In those cases, the clamping and injury risks are even greater, because the operator gets clamped with the lever pressed down and is then unable to deactivate the tool, leading in turn to further clamping. The tool will then run until the power of the tool is insufficient to feed it further into the crevice, or, if the operator is quick to react and has the space necessary, until the air hose is unplugged or the compressor turned off. Although not a very common occurrence, the consequences of it happening are significant.

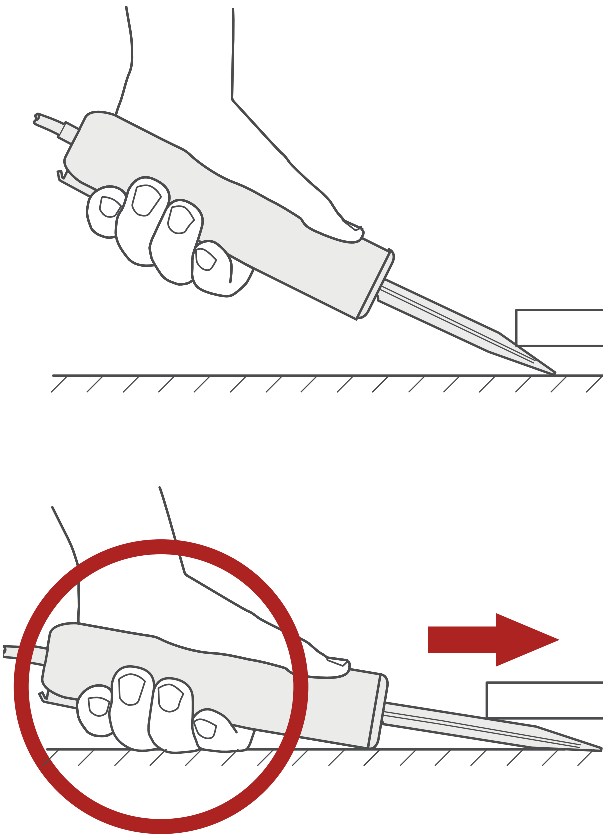

Figure 16. A hand getting clamped while chipping in a narrow gap.

Furthermore, it was observed that a relatively high pressure is often applied on the tool towards the workpiece when working with especially rough pieces or when wanting to speed the work up. Based on acquired knowledge in the field of ergonomics, the current design of the tool is suboptimal for this type of use, although the interviewees mentioned no issues of this type. There is no appropriate surface which is aligned perpendicularly to the user's lower arm to push against, and therefore the user has grip the tool tightly with the wrists at an angle in order to be able to exert this force, leading to unhealthy strain on the wrists.

The existing regulations on vibration exposure were seldom considered in the workplaces visited, even though they were often known to exist. The given reason for this was that it would slow work down too much, or otherwise be too expensive as more employees would be needed in order to get the same amount of work done. It was also rare that the workplaces employed rotational schedules in order to relieve the workers of the strain from the usage of the flux chipper. However, short informal breaks were mentioned to occur, especially at smaller companies.

Anti-vibrational gloves exist as a means of mitigating the exposure from vibrations, but they were rarely used in the companies visited in Sweden. In Japan, the use of protective gear was more pervading overall, and some companies employed anti-vibrational gloves.

Chisel related issues

Depending on the task at hand, different chisels were used. When the main task was to remove coatings from surfaces, such as rust or paint, a wide chisel was preferably used. For weld seams, a pointier chisel was often used. Furthermore, chisels of differing lengths were used depending on the distance to the workpiece. Chipping at a weld seam located far within a narrow space, for example, would require a longer chisel.

For the FCH-20, it is not possible to attach a chisel with a bent or extra wide tip since it is designed so that the chisels are inserted front-first. In one workshop that wanted a bent chisel in a FCH-20, this had been solved by bending the tip of a straight chisel once it had been inserted in the tool. It was then impossible to remove from the front piece without bending it back. However, whenever they wanted to insert a straight chisel into the same tool, the workshop had again worked around this by removing the front piece together with the bent chisel and then replacing it with another front piece.

Chipping hammers where the chisel is attached using a spring in the front and can rotate freely around its axis were seen in some workshops and shipyards visited in Sweden. The users mostly found this property annoying, as the chisel would not always retain its flat side towards the workpiece without it being held in place during operation.

Durability and maintenance issues

On the topic of the durability, users seemed content with the robustness of their chipping hammers in general. However, there were some problems related to durability that were mentioned by Fuji's customers. The most common comment was regarding the lever pin attaching the lever to the back piece, which tended to glide out of the hole or break.

Blaster sand and metal chips occasionally enter the tools, leading to a degraded performance or even a complete stop of the tool. When this happened, the tools were disassembled and cleaned in order to bring proper functionality back.

4.1.3 Findings from questionnaire

Despite distributing the questionnaire both in physical and digital formats, only seven responses were collected in total - six in physical format and one in Google Forms. This was not deemed enough to make any stable statistical analyses, and it was therefore decided that the data would not be used for the following parts of the project.

4.2 Visual brand analysis

The following section describes the analysis of how Fuji's brand is represented in the appearance of their products. First, the procedure is described, after which the results from each method is presented.

4.2.1 Execution

Below, the approach to and the execution of the methods used in the visual brand analysis are outlined.

Approach to Visual Brand Analysis
The visual branding analysis was done using Snelders' (2010) approach, as described in section 2.4. Fuji was graded on scales according to the six drivers, from which the balance of usage of explicit and implicit design cues were derived.

Design Format Analysis
Five different tool types from Fuji were chosen as the base from which design cues were to be identified. After that, a few competitors were chosen, mainly from the Japanese market. A number of tools from each of these manufacturers were picked for the analysis to cancel out cues that are general for the market, and not specific for Fuji.

Inspiration board
The implicit product characteristics desired by the company are presented below, according to the company's own definition.

- *Robust* - Durable, resistant to harsh environments and air efficient.
- *High Quality* - Reliable, professional and with tight performance tolerances.
- *Japanese* - Process driven, simple and does not look "too designed".

Many of the specified characteristics were considered more dependant on manufacturing processes and tolerances rather than the aesthetic design. This applied mainly to resistance, air efficiency, process driven design and the tight performances. Thus, these characteristics were not considered necessary for the ideation of the aesthetics. The demand of keeping the tool from looking too styled was also considered likely to be fulfilled, if a robust design driven primarily by the used manufacturing methods was applied.

Out of the three listed characteristics, "robust" was considered to be the only feasible to express through a set of images, and also to cover both durable and reliable well in terms of expression. Thus it was chosen for the compilation of the inspiration board. Remaining words were used in the evaluation process later, see section 4.2.2.

4.2.2 Snelders' approach

Flux chipping hammers have been looking practically the same for a long time. Other than introduction of electronic measuring equipment to few series of wrenches, the functionality of the tools have also been largely the same for many decades. Therefore they should be considered to be in a mature stage of their life-cycle.

The products are incrementally improved in terms of durability on a regular basis, but renewal in broader terms take decades for most products.

Fuji's brand position is strong, particularly in Japan. In some tool categories, mainly grinders, they can even be considered a market leader. However, in other product categories Fuji is one of many competitors on the market, not the least when it comes to flux chippers. This point out the importance of displaying the particular strengths that compose Fuji's niche.

Fuji has a wide portfolio, and a consistent design language would make the differentiation between the products difficult. It is however important to remember that Fuji has a very specific market, and that the wide portfolio is a result of their policy to provide several versions of each tool, rather than trying to reach a wide variety of market segments.

Fuji has a strong history, are well known in their main markets and thus have a strong brand heritage to protect.

Although Fuji has had popular products on the market for a long time, their design history is strongly influenced by the designs of a mix of

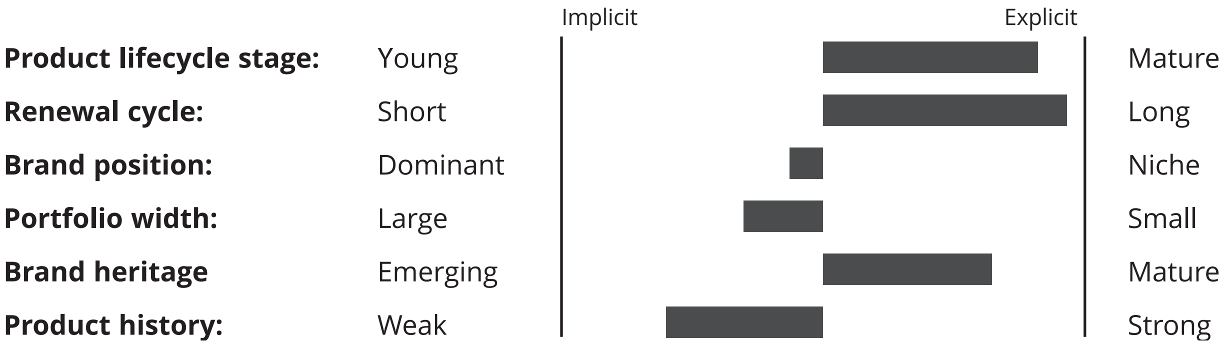

Chart 1. Fuji's brand as graded by the project team according to Snelders six key drivers.

competitors. The lack of prior branding work leaves room for improvement in consistency of their product history.

The conclusion from the analysis is that explicit design cues should be widely included in Fuji's portfolio. The lack of a consistent product history, along with the rather large portfolio and the strong market position, does however motivate the use of implicit cues as well.

4.2.4 DFA

Images of products used in the DFA, along with the resulting table, can be found in appendix V.a and V.b. The main identified cues are described below.

Colour

The most prominent characteristics is, not surprisingly, the orange colour. It is distinct in all the chosen Fuji products, but doesn't appear in any competitor products. In terms of colour, it is however not only orange that is frequently occurring in Fuji products. The glossy finish and the black extending parts appear to a wide extent. They are not unique for Fuji, but as they are common among Fuji's tools they are still important for the recognition of the brand. One characteristic which is less prominent at first glance, but that distinguished itself in the DFA is the presence of parts with shiny steel finish. They are in many cases standard parts used to connect to the air supply or the tool blade, and may therefore not always have had the specific finish for an aesthetic intent. Nevertheless, it makes an important contribution to the overall product impression, and should be considered a part of the visual perception of Fuji as a brand.

Details

Among the recurring details were the riveted ID-plate, which often would be mounted slightly recessed on a flat surface. It appeared among competitors as well, but the graphic style was specific for Fuji. Another detail that stood out was the elevated serial number, often placed just below the ID-plate. A note was made that these properties were limited to cast parts.

Steel wire hooks also distinguished itself as a unique feature for Fuji. A closer look revealed that this is likely to be an effect of the choice of products and the way the various manufacturers have chosen to present them. Many competitor products had mounts for hooks, but no hooks attached. The feature is mainly present among products meant to be used on a specific spot in an assembly line, so that they can be hung in a specific position.

Figure 17. A typical Fuji product

4.2.3 Inspiration Board

The assembled inspiration board can be seen in figure 18. Among the artefacts that were considered robust, examples of mutual characteristics that can be found are high material thicknesses, visible structural elements, rough surfaces and heavy materials.

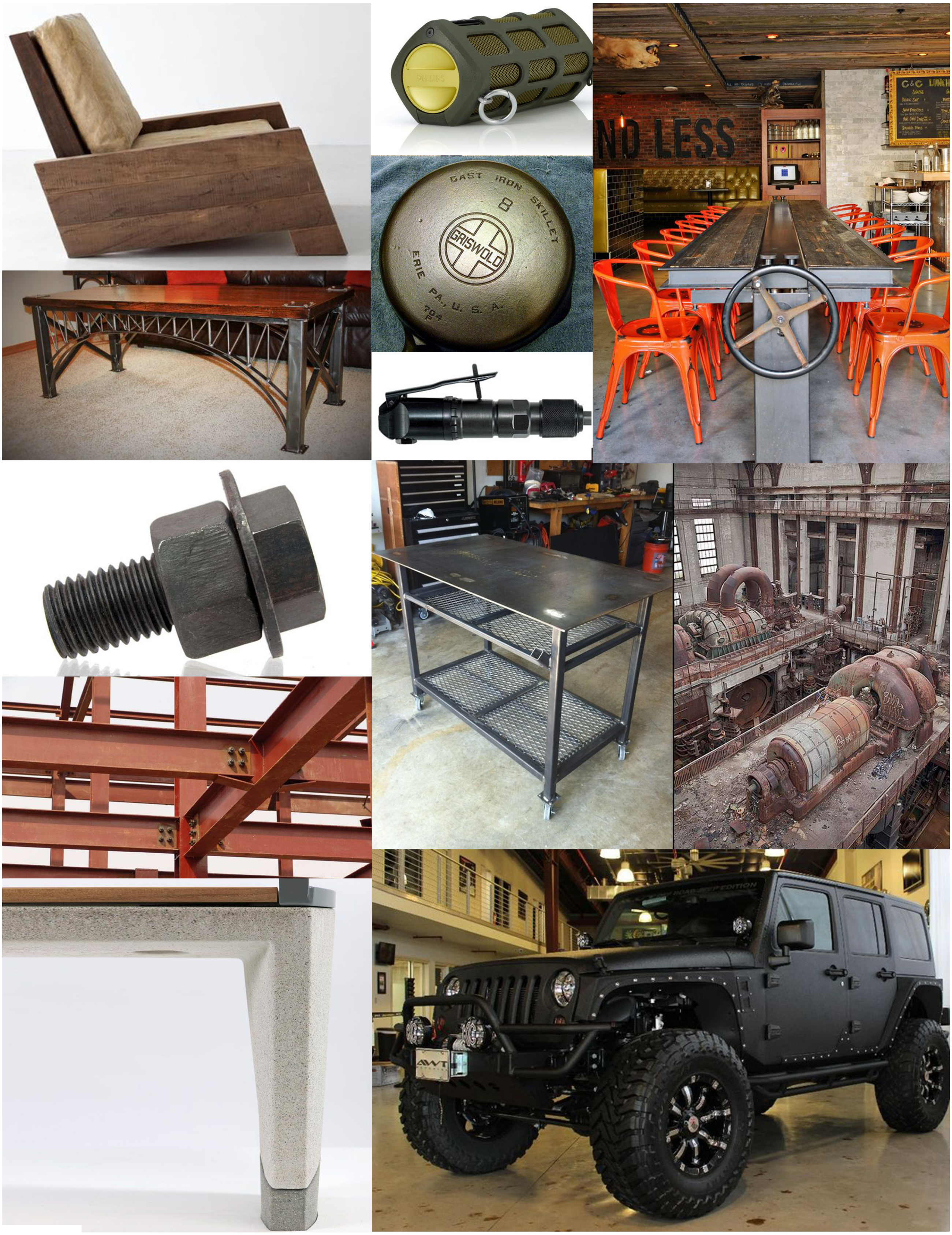

Figure 18. An inspiration board expressing robustness

4.3 Specification of requirements

This section details the process of compiling the list of requirements and presents some of the most significant demands found. It also discusses the requirements that might have to be weighed against each other, and that therefore could potentially result in compromises in the final product.

4.3.1 Execution

Using input from user studies, acquired theoretical knowledge, regulations, and company requests, a list of requirements was compiled. Each requirement was given a target value, which is achieved in an ideal product, and a limit value, above which the product must perform. The method of evaluation was also specified. As an intermediary step for the information gathered in the user studies, the topics identified using the Affinity Diagram were first translated into a needs statement (See appendix VII). These needs were then transcribed as formal requirements.

As mentioned in the methodology chapter, the list of requirements was not simply distilled on a single occasion, but rather continuously developed as new information was acquired. However, it was aspired to have the most essential requirements identified and formalized before moving on to the concept generation phase.

4.3.2 Main requirements

In table 5, the requirements that are considered to be partly or completely unaddressed in the current product, and therefore require extra attention, are listed.

The complete list of requirements can be found in appendix VIII.

Table 5. Extract from specification of requirements

Requirement	Measure type	Target value	Limit value	Method of evaluation	Origin
Protect hands from clamping when chisel gets stuck in narrow spaces.	Binary	Yes	Yes	Functional test	User studies
Have a maximum vibration exposure value of	m/s2	< 2.5	< 5	As specified in ISO 28927	Regulations
Provide gripping areas designed for a convenient, effective means for the operator to exercise full control over the tool.	Subjective	5/5	3/5	Comparison to ergonomic theory	Regulations
Allow for gripping in such a way that normal feed force can be transmitted in an ergonomic way from the hand of the operator to the tool.	Subjective	5/5	3/5	Comparison to ergonomic theory	User studies Regulations
Give the impression of "Robustness"	Ratio	5/5	3/5	Semantic differential	Company request
Give the impression of being "Japanese"	Ratio	5/5	3/5	Semantic differential	Company request
Give the impression of "Quality"	Ratio	5/5	3/5	Semantic differential	Company request
Contain visual elements repeatedly used in previous Fuji designs.	Binary	Yes	Yes	Visual check	Company request

5. CONCEPT DEVELOPMENT

The following chapter details the concept development phase of the project. It starts with a description of the overall process. Then the chosen areas of improvements for which concepts have been developed are listed. The following sections will then describe the generated solutions, followed by the evaluation and selection of a winning solution.

5.1 Phase framework

Below, the areas that were chosen for improvement are outlined, followed by an explanation of the overall process for the concept development phase.

5.1.1 Main areas of improvement

Based on all the data gathered up to this point in the project, the following four areas were settled on as subjects that new solutions should be generated for in formal processes:

- *Vibration mitigation* - how to mitigate vibrations transmitted to the user
- *Aesthetics* - how to convey Fuji's values and current visual brand in the new FCH design
- *Power transmission* - how to facilitate the transmission of force towards the workpiece
- *Clamping protection* - how to protect the user from clamping when feeding occurs

5.1.2 Overall process

Since the mitigation of vibrations was considered to be the main issue, and also to likely have a big impact on the overall configuration of the tool, the solution for vibration mitigation was settled on first. Second came the functionality improvements derived from the usage issues identified in the initial studies. Once the functionality of the tool was fully developed, the styling was applied. Each of these three aspects were processed through several steps of ideation, evaluation and selection. Figure 19 illustrates the overall work flow for the concept development phase.

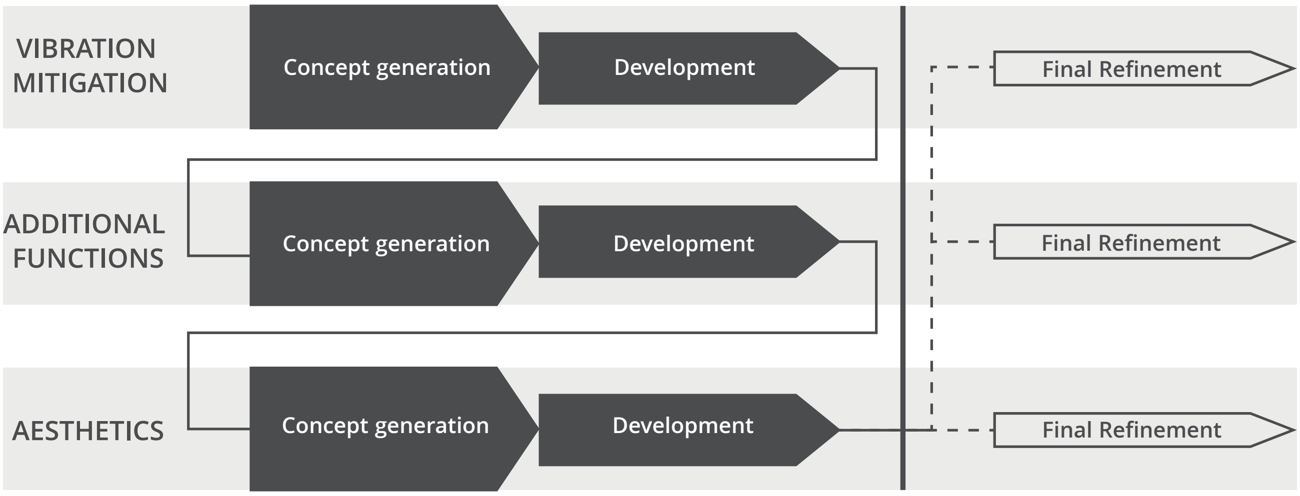

Figure 19. The concept development process used in the project. The dark gray phases are treated in this chapter. The final refinements are treated in chapter 6.

5.2 Vibration mitigation

As has already been emphasized, the main known issue with the tool today is the amount of vibration that users are exposed to during use. This section describes the generated ideas for limiting the vibration exposure to the user, followed by a comparative evaluation and the selection of a final solution.

5.2.1 Execution

The different solutions for mitigating the vibrations are all based on the theory presented in section 2.1. Brainstorming was conducted early in order to come up with new ideas, but all the generated concepts could be categorised under the principles found in theory.

A few methods for mitigation were, for various reasons, considered inappropriate at first glance, and were excluded. The largest excluded category of solutions were active control devices, since they would require an external power source to be introduced to the system. The remaining identified vibration mitigation principles were evaluated against the criteria damping, durability, cost, weight, size, and maintenance. The criteria were weighed according to their estimated importance. For each criterion, the principles (as implemented in a chipping hammer) were given a rating on a scale from 0-4, and then ranked based on their total score. The mitigation principle with the highest score was chosen as the solution to be included in the final concept.

5.2.2 Identified vibration mitigation principles

The identified potential solutions for the mitigation of vibrations are listed in the following pages.

Metal Spring Absorber

An absorber with a mass moving in the opposite direction of the piston could cancel the inertia of the tool. The natural frequency of this solution would have to be synced to the stroke frequency, which is difficult since the variation of air pressure leads to a variation in stroke frequency. This solution would also be useless in mitigating frequencies other than the stroke frequency.

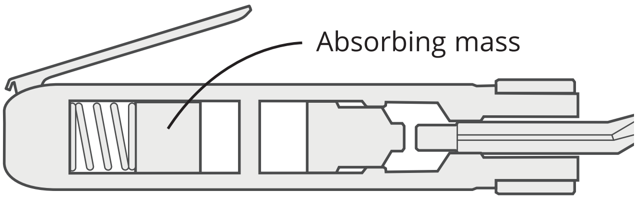

Figure 20. A chipper with a mechanical absorber.

+ Good effect at stroke frequency

- Pressure dependant
- Effective only at stroke frequency

Fixed Balance Mass

A balancing mass that is rigidly synced to the piston movement so that it automatically opposes it at all times would counterbalance the inertia effectively regardless of the current stroke frequency. However, the mechanism would be difficult to construct in a durable way, and without inducing vibrations in other directions due to the new parts. Just like the spring controlled absorber, it would be unable to cancel out frequencies other than the stroke frequency.

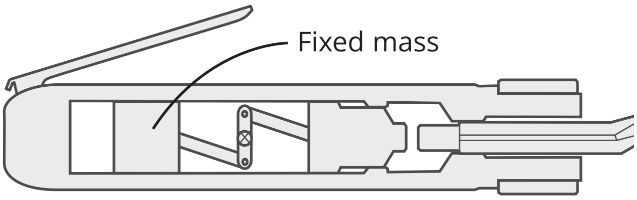

Figure 21. A chipper with a balancing mass.

+ Good effect at stroke frequency

- Effective only at stroke frequency
- Complex design

Damping Handle Material

A damping material in the handle could dampen some of the vibrations through energy dissipation from the internal friction, but the effects are likely to be small. It would be cheap and easy to apply, and would also provide a better grip. This eases the effects of vibrations since the user will need less power when gripping the tool.

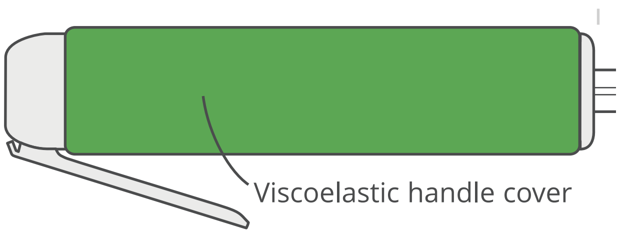

Figure 22. A chipper with a viscoelastic handle cover.

+ Cheap
+ Easy to apply
+ Improved grip

- Small effect

Steel Spring Isolator
A steel spring isolator could isolate well over a wide spectrum of frequencies, as long as the natural frequency of the system could be kept well below the stroke frequency. The design would be easy to implement. The spring would however need replacement from time to time.

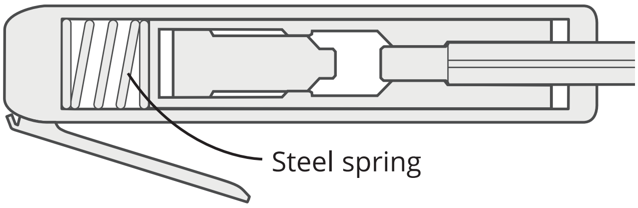

Figure 23. A chipper with a steel spring isolator.

+ Works over a wide frequency range
+ Simple design

– Poor durability

Air Spring Isolator
Just like a steel spring isolator, an isolator with an air spring could isolate well over a wide spectrum of frequencies, if the natural frequency could be tuned right. It would however be slightly lighter and more durable than a steel spring solution.

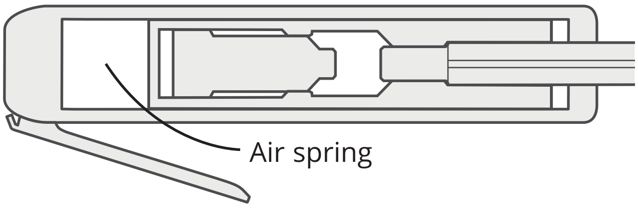

Figure 24. A chipper with an air spring isolator.

+ Wide frequency range
+ Durable

– Complex design

Viscoelastic Pad Isolator
An isolator could be designed using a pad made from a viscoelastic material. It could wear out, but would most likely be simple and cheap to replace. It could however be difficult to find a material with a stiffness low enough to fit a wide range of frequencies.

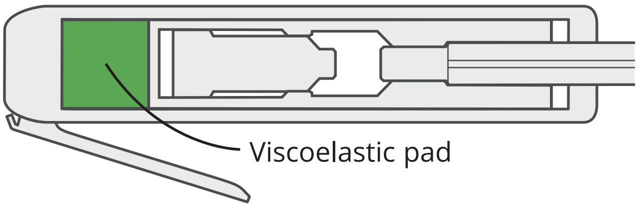

Figure 25. A chipper with a viscoelastic pad isolator.

– Poor durability
– Too stiff for good isolation

5.2.3 Comparison and selection

As can be seen in table 6, the vibration mitigation principle that scored the highest in the evaluation matrix was the Air Spring Isolator. The key reasons for this were its potentially wide coverage of frequencies, along with that it consists of relatively few components, making it durable and easy to maintain. The other considered version of an isolator mechanism, utilizing a steel spring instead of air as the elastic element, came second. It lost out to the winner on the aspects of durability, cost, and maintenance. The second place was shared with Damping Handle Material, which has limited vibration mitigation potential and instead owes its high score to its unmatched advantage regarding cost, weight, and size.

Table 6. Evaluation matrix for vibration mitigation principles. A light green background in the ranking row means the solution was suggested to Fuji, and a dark green background indicates that the solution was incorporated into the final concept.

Factor	Criterion weight	Absorber	Fixed Balance Mass	Damping Handle Material	Steel Spring Isolator	Air Spring Isolator	Viscoelastic Pad Isolator
Vibration Mitigation	3	1	2	1	3	3	2
Durability	2	3	1	2	3	4	2
Cost	1	1	1	4	2	3	2
Weight	2	2	2	4	2	2	2
Size	2	3	2	2	3	4	2
Maintenance	2	3	2	2	3	4	2
Total score		24	21	31	31	34	24
Rank		**4**	**5**	**2**	**2**	**1**	**4**

The decision was made to use and further develop the Air Spring Isolator principle in the final concept. A note was made that a damping material in the handle would be possible to combine with the isolator principle, and because it would add to the mitigation of vibration while not adding much to cost, it was also brought along to the final concept phase.

5.3 Power transmission

As was noticed in the user studies, situations where it is necessary to exert a high amount of force towards the workpiece are common when working with chipping hammers. This section describes the generated ideas for facilitating the transmission of force towards the workpiece, followed by a comparative evaluation and the selection of a final solution.

5.3.1 Execution

The power transmission issue was approached through several iterations of idea generation. Brainstorming sessions were performed within the project team, as well as with external people in a workshop using the 6-3-5 Method. The initial collection of ideas was screened subjectively by the project team, and a few ideas were chosen and further defined. These ideas were then evaluated using the criteria grip ergonomics, size, weight, and cost in an evaluation matrix. The criteria were weighed according to their estimated importance. For each criterion, the solutions were given a rating on a scale from 0-4, and then ranked based on their total score.

5.3.2 Potential solutions

The generated potential solutions for making the transmission of power more comfortable and ergonomically correct are listed below.

Flat Back

As the name indicates, the Flat Back concept comprises a flat surface at the back of the tool that is perpendicular to the tool's working direction. The user would transmit force through pushing with one palm on the surface. The surface has the same diameter as the housing, and may include some degree of bulging for the best possible fit to the palms. Furthermore, the transition between this surface and the walls of the housing may include some degree of rounding at the edges for additional comfort. The air hose would be attached on a swivel, allowing the user to turn the hose downwards whenever he or she wants to utilize the flat surface.

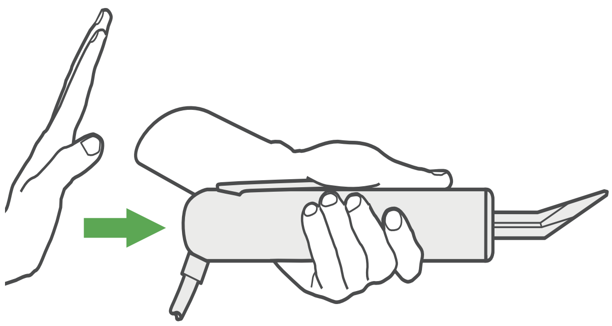

Figure 26. A chipper with a flat surface for ergonomic power transmission.

+ Allows ergonomically good grip for high force transmission

- Requires moving air inlet
- Compromised accuracy when back surface is used

Permanent Pistol Handle

A pistol handle can be added to the back piece, allowing for the ergonomically ideal grip for transmitting force from the user to the tool. The handle may simply be positioned at the back of the cylinder, forming a regular pistol shape. Alternatively, it could be connected by an arc to allow for alignment of the force with the arm, not only in terms of the parallel angle but also in position. This would eliminate any torque from the wrist.

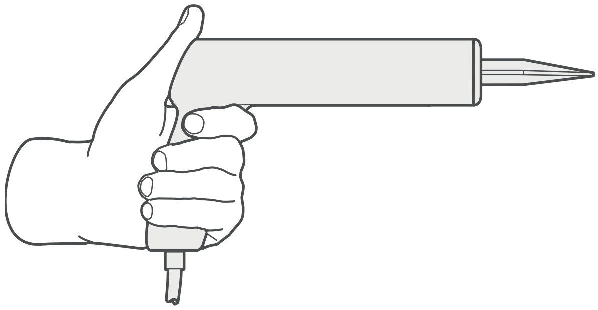

Figure 27. A chipper with a regular pistol handle.

\+ Allows ergonomically optimal grip for high force transmission

\- Makes it similar to existing hammers
\- Makes regular grip difficult
\- Makes it difficult to reach narrow areas
\- Adds significant weight

Modular Pistol Handle

A handle that can be attached and detached when necessary would solve many of the difficulties regarding power transmission. It would be as slim and space-efficient as possible when needed, and then changed for an ergonomically optimal solution when the required space is available.

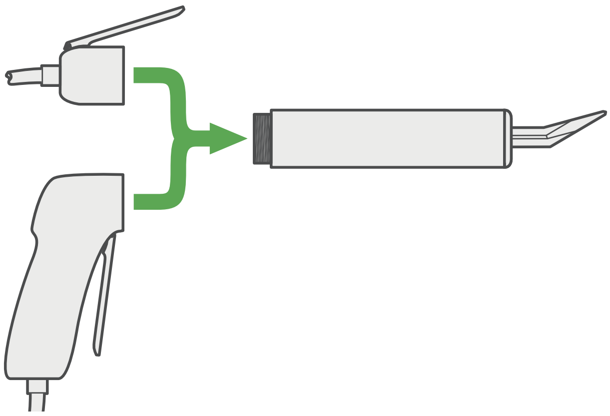

Figure 28. A chipper with interchangeable back pieces.

\+ Allows ergonomically optimal grip for high force transmission

\- User must keep track of extra parts
\- User must perform additional tasks when changing handles

Foldable Pistol Handle

This concept comprises a section of the tool that can be rotated or folded in a way so that it provides a pistol type of grip. This would involve having an additional handle geometry attached somewhere on the tool, which is to take as little space as possible when folded in, and to form a sufficiently shaped geometry for acting as a pistol grip when folded out. The most feasible version comprises a lengthwise extension of the tool and a joint around which this extension can rotate.

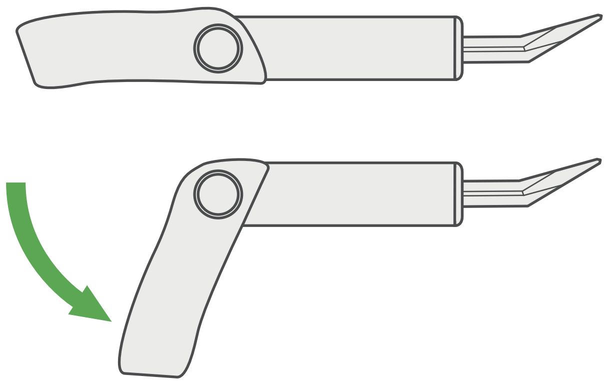

Figure 29. A chipper with a rotatable handle.

+ Allows ergonomically optimal grip for high force transmission

- Adds significant weight
- Requires extension of tool length
- Complex design

Corkscrew Grip

The corkscrew grip concept is based on a regular pistol type grip, with the crucial difference being how the handle is connected to the housing. Instead of connecting to the tool at the top of the handle, there is a short, flat rod extending from the middle of the handle that joins the housing at its centre. The rod would protrude between the user's long finger and ring finger.

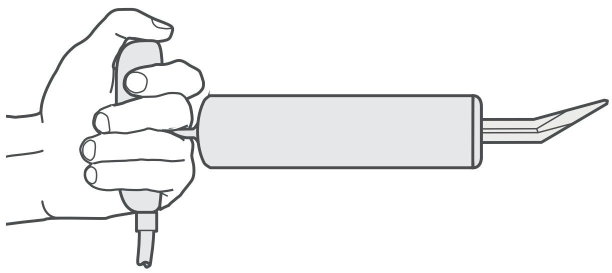

Figure 30. A chipper with a corkscrew type grip.

+ Allows ergonomically optimal grip for high force transmission

- Adds significant weight
- Discomfort between fingers
- Makes it difficult to reach narrow areas

5.3.3 Comparison and selection

As table 7 shows, the concept that came out on top was the Flat Back. While not solving the power transmission issue to the maximum extent, it has advantages in that it departs relatively little from the current product in terms of size, weight, and cost. The reasoning behind the given score for the second placed concept, Modular Handle, was that it should be just above the average of the scores the concept would get when in either of the two different configurations.

Table 7. Evaluation matrix for force transmission solutions. A light green background in the ranking row means the solution was suggested to Fuji, and a dark green background indicates that the solution was incorporated into the final concept.

Factor	Criterion weight	Flat Back	Permanent Pistol	Modular Pistol	Foldable Pistol	Corkscrew Grip
Grip ergonomics	3	2	4	3	3	2
Size	2	4	1	3	2	2
Weight	1	4	1	3	1	3
Cost	1	4	2	1	1	3
Total score		22	17	19	15	16
Rank		**2**	**5**	**1**	**4**	**3**

These two concepts were presented to Fuji. Regarding the concept Flat Back, the company remarked on that the concept involved a rotatable air inlet. They assessed that when in folded down position, it would protrude at an angle that is too impractical for the user, getting in the way and changing the feeling of balance. Instead, they saw promise in the concept Modular Pistol Handle. However, they believed that the idea had to be modified so that it was not based on simply changing between two types of back pieces. Instead, the handle would have to be possible to attach more directly on the tool. However, at this point in the project, time was lacking for the development of a novel attachment mechanism. Therefore, no solution for enhanced power transmission was included in the final concept.

5.4 Clamping protection

The following solutions deal with the clamping risk that is present whenever the tool is wedged stuck in a narrow space and starts to feed forwards as long as it is operative. This section describes the generated ideas for protecting the operator from clamping, followed by a comparative evaluation and the selection of a final solution.

5.4.1 Execution

The clamping issue was approached through several iterations of idea generation. It was one of the topics considered in the brainstorming workshop mentioned in section 5.3.1. The initial collection of ideas was screened subjectively by the project team, and a few ideas were chosen and further defined. These ideas, which are presented below, were evaluated in a matrix format. The best solutions from the matrix were presented to the company, together with whom a final choice was made.

5.4.2 Potential solutions

The generated solutions for clamping protection are listed below.

Front Shield

Adding a shield to the tool ensures that the relative angle to the underlying surface stays above a set value, depending on the size and position of the shield, and the length of the chisel. Putting this shield at the front of the tool minimizes the required size. In this way, both clamping of the hand and locking of the lever in pressed mode is avoided independently of lever position.

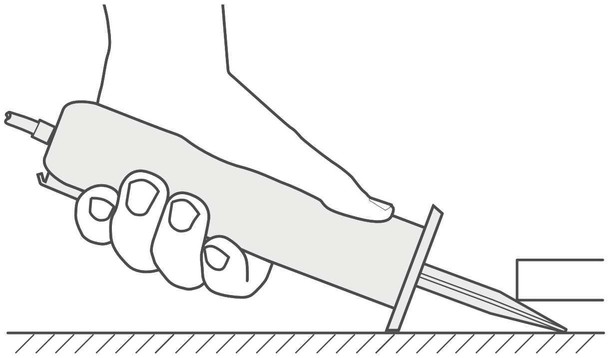

Figure 31. A chipper with a front shield protecting the hand from getting clamped.

+ Minimizes injuries from clamping
+ Minimizes occurrences of tools stuck in on-mode

- Adds weight
- Makes it difficult to reach narrow areas

Overarching Structure

The concept Overarching Structure comprises an arch that runs from the back of the tool to the front of it, covering the user's hands. The arch is attached so that it can be rotated around the tool's main axis, allowing the user to adjust its position according to the work situation. Since full protection depends on the user positioning the shield correctly, it cannot always be guaranteed.

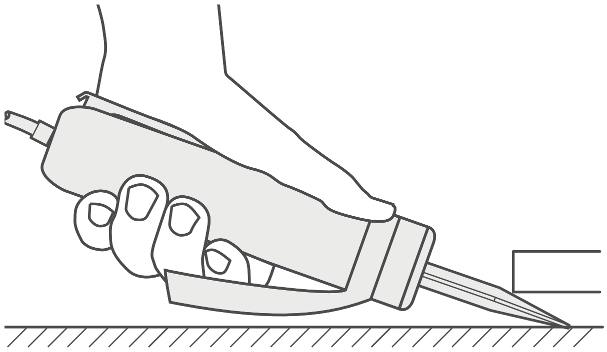

Figure 32. A chipper with a cover protecting the handle from clamping.

+ Decreases occurrences of tools stuck in operating mode
+ Decreases injuries from clamping

- Makes reaching narrow areas hard
- Adds weight
- User has to perform additional task in rotating structure

Rotatable Lever

If the lever is on the side of the tool opposed to the processed surface, the user will always be able to release the dead man's switch if the chisel gets stuck. By allowing the handle to rotate in relation to the chisel, this enables the users to protect themselves by adapting their usage. However, a freely rotatable handle could possibly allow for unwanted rotation of the chisel. To avoid this, the solution would have to lock the relative angle between the chisel and the lever once the lever is pressed. Since full protection depends on the user positioning the lever correctly, it cannot always be guaranteed.

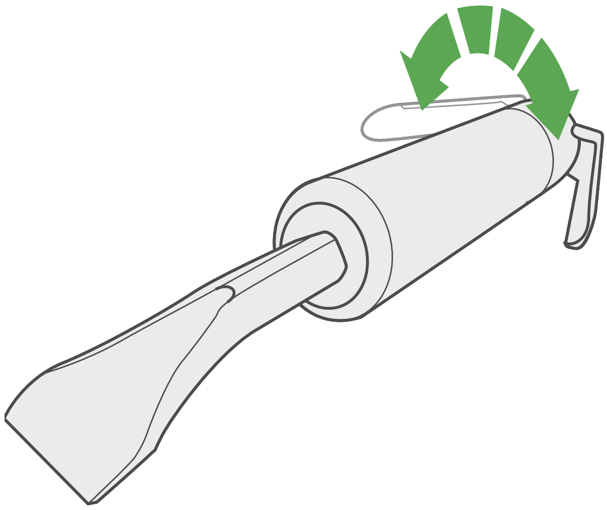

Figure 33. A chipper with a rotatable handle.

+ Decreases occurrences of tools stuck in operating mode
+ Decreases amount of injuries from clamping

- User has to perform additional task in rotating lever
- Complex design

Double Lever

Adding another lever on the opposite side of the tool would ensure that one lever always could be released. The tool would only operate when both levers are pressed down simultaneously. The concept includes no protective element for the hands. However, the double levers mean that the operator would always be able to turn off the tool, which can decrease risk of injury in cases of the tool getting stuck.

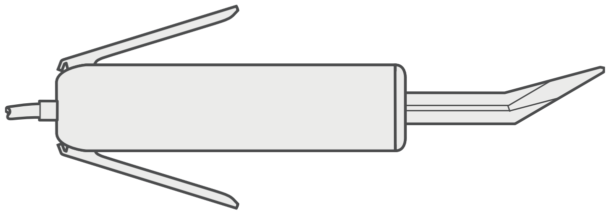

Figure 34. A chipper with double levers for clamping protection.

+ Minimizes occurrences of tools stuck in operating mode
+ Decreases injuries from clamping

- Users gripping options are limited
- Complex design
- Adds weight

5.4.3 Comparison and selection

The generated solutions for clamping protection were evaluated in the matrix below. As can be seen, the concept that scored the highest was the concept Front Shield. This is mainly attributed to that it protects the user from clamping, even if the operator happens to have the lever facing the workpiece when the tool gets stuck and starts to feed. Also, it scored high in usability, because it does not require the user to do any adjustments to ensure constant protection. The Lever Rotation concept came second, despite requiring these kinds of adjustments. Its high score is much owed to that it would be the most space and weight efficient solution out of the considered solutions, not compromising with the capability of the current product to reach narrow spaces.

Table 8. Evaluation matrix for clamping protection. A light green background in the ranking row means the solution was suggested to Fuji, and a dark green background indicates that the solution was incorporated into the final concept.

Criterion	Criterion weight	Front Shield	Overarching Structure	Rotatable Lever	Double Lever
Safety	3	4	3	2	2
Space efficiency	2	2	1	4	3
Usability	2	4	2	2	2
Weight	1	2	1	4	3
Cost	1	4	2	2	2
Total score		30	18	26	21
Rank		**1**	**3**	**2**	**3**

These two concepts were brought up for discussion with Fuji. Their preferred solution was Front Shield, which was also chosen for further development and incorporation into the final concept.

5.5 Aesthetics

This section outlines the process whereby the aesthetic design of the tool was developed. It describes the developed concepts, and the evaluations process along with the results.

5.5.1 Execution

Sketching sessions in which ideas for the aesthetics were generated on paper started early in the project. As the project proceeded, the sketching became more directed and the paper was gradually replaced by digital files. The inspiration board was used to influence the designs towards a robust impression. Variations of the different parts were combined into one Photoshop-document, allowing simple testing of a wide variety of part combinations.

As the number of concepts grew, it became clear that they could be categorized into four main stylistic directions: One that was more basic and close in appearance to other Fuji products, one that emphasized on expressing sturdiness, one that implemented sharper lines, and one that implemented curvier forms. As using this categorization would facilitate the following selection steps, it was decided that the preferred configuration for each direction was to be found. While the four directions were distinct enough from each other to constitute a wide stylistic base to continue working from, the “robust” expression and the visual elements typical for Fuji products, as identified through the DFA, were included to a varying extent in all of them.

A semantic differential was constructed (see appendix IX.a) to evaluate the expressions of the concepts. The words used in the semantic scale were words taken from Fuji’s key values, along with words that by the project team were considered close to or part of key values. The products were assessed by a group of 16 people. The result was used as guiding information for the company, who were left to do the final selection.

5.5.2 Concepts

The four concepts for the styling are presented on the following pages. Sketches of the concepts, accompanied with short descriptions of the how the intended expressions are implemented, are supplemented by the results of the semantic evaluation. The desired attributes are placed on the right side of the chart for the semantic scales and their antonyms on the left .

Figure 35. Samples from the aesthetic development phase.

Fuji Original

The first concept was designed to be as similar as possible to current Fuji designs. Most of the parts are the same, or very similar to those of other Fuji products. Clear examples of this are that the rubber cover and the lever are the same as the ones that are used on a wide variety of products today. The back piece has the same shape as the current FCH series. If the existing back-piece could be used would depend on the diameter of the final design.

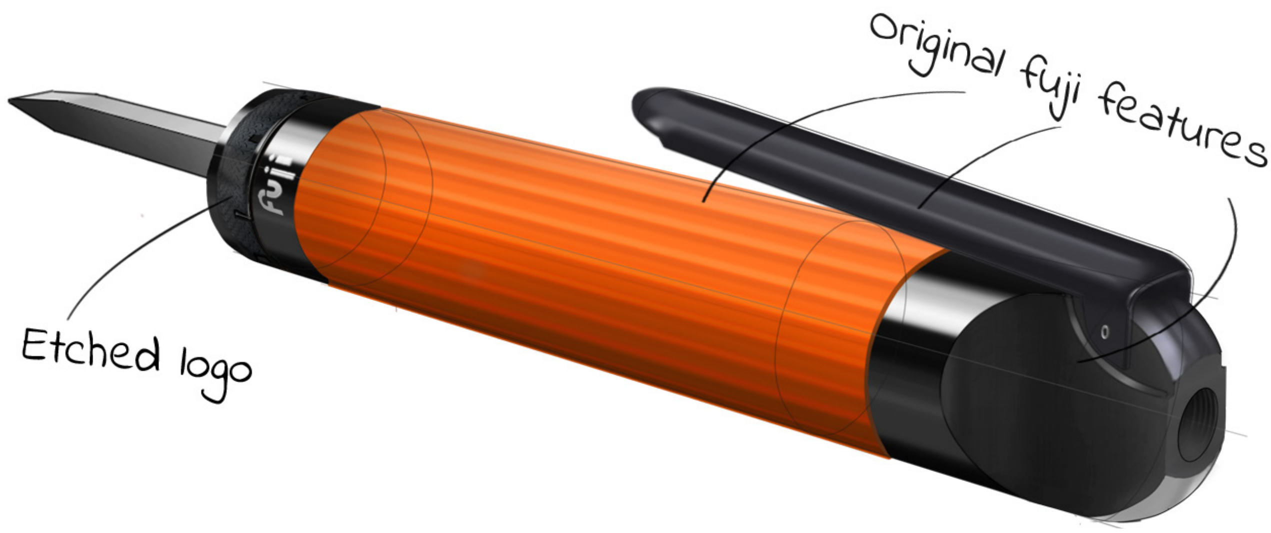

Figure 36. A chipper design resembling current Fuji products.

Chart 2. The concept Fuji Original as graded according to the semantic scale by the respondent group.

As chart 2 shows, the most prominent results for the concept Fuji Original are found in the attributes “Robust” and “Consumer oriented”. The latter It also had positive scores for “safe” and “reliable”. It was regarded as neutral in terms of “blunt-precise” and “weak-powerful”.

Powerful

The second concept was made to look powerful. The back piece was made slightly thicker, to give a sturdier impression. The lever has been given a more square form and a solid base. It is also more rigidly attached to the back piece than in the other proposals, being sunk into the back piece. The pattern on the rubber is taken from the cast pattern on Fuji's grinders, and is known as the "Fuji ridge". The grinder is one of their most popular products, and according to the company, the ridge is strongly identified with the Fuji brand.

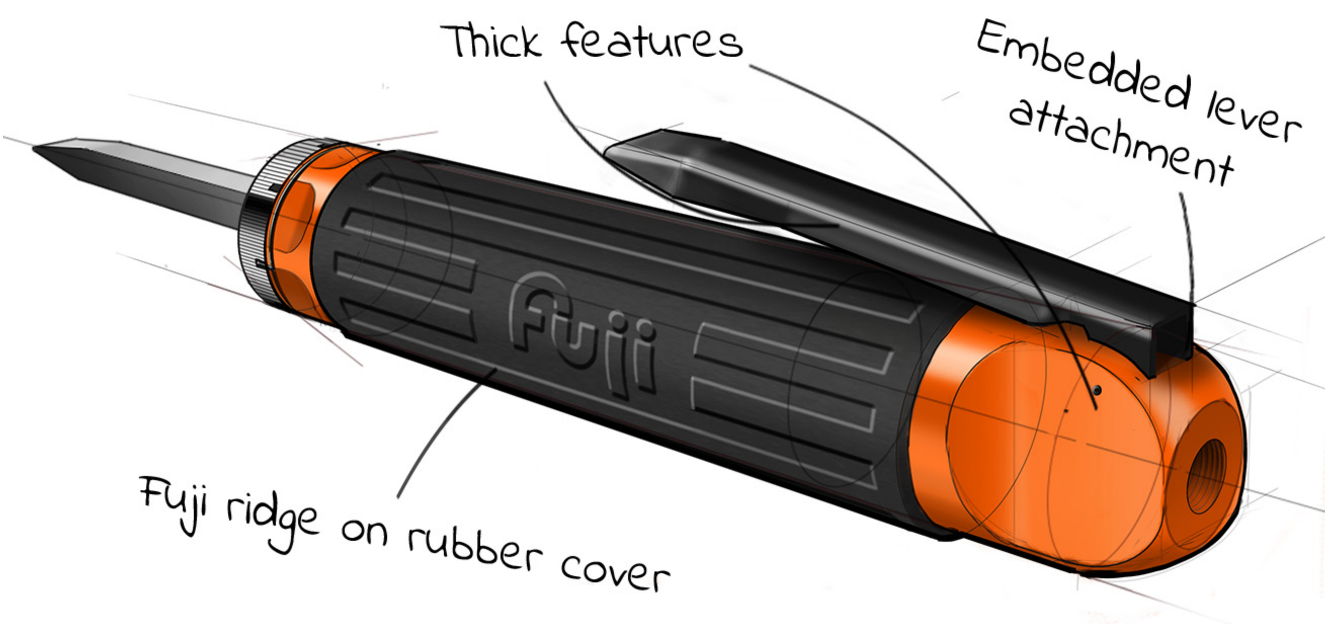

Figure 37. A concept intended to emphasize the attributes "powerful" and "robust".

Chart 3. The concept Powerful as graded according to the semantic scale by the test group.

The concept Powerful received high ratings overall, with slightly less high scores for "precise" and "professional". Regarding its main intended expression, "powerful", it scores the best out of the four concepts in the study.

Sharp

The third idea is somewhat similar to Powerful, but more focused on precision, or sharpness. The slanted front and the pointy lever, along with the lengthwise lines in the rubber, gives the tool a clear direction. The big rubber coverage along with the transverse "grip-lines" in the rubber are intended to give a functional impression.

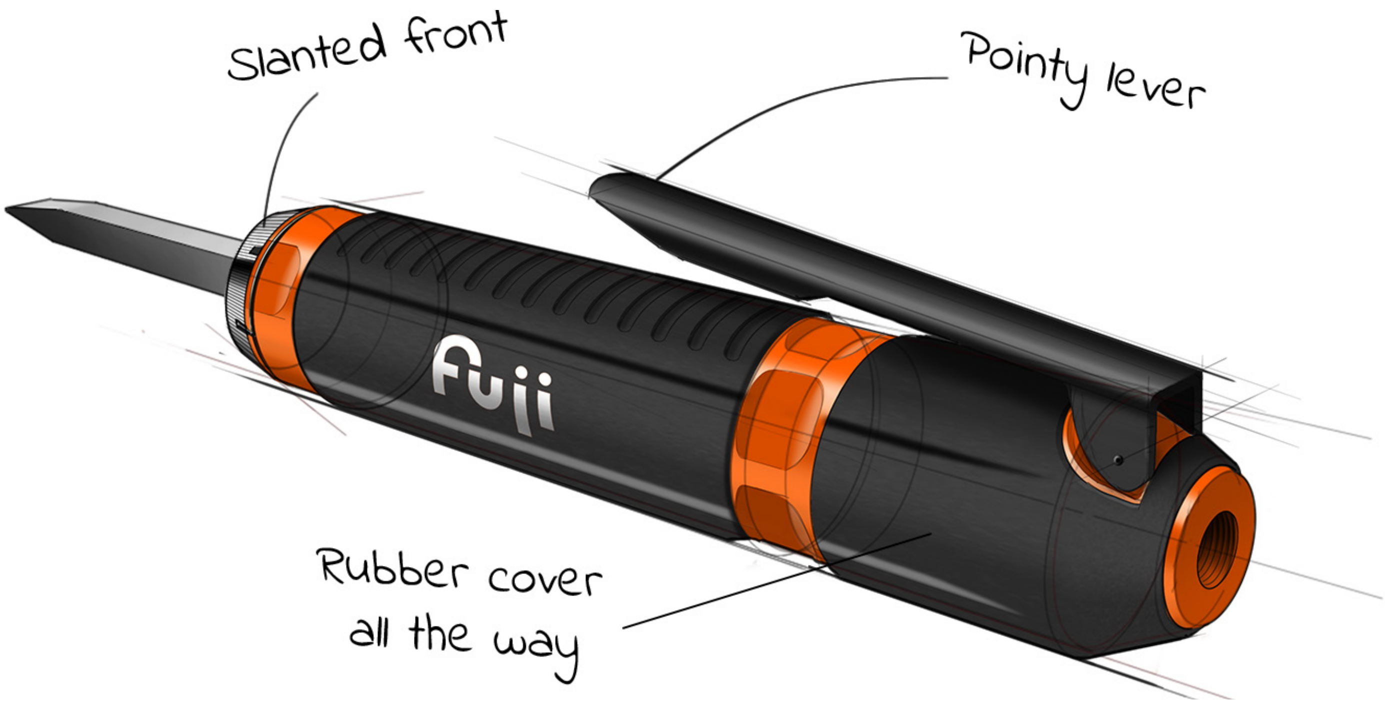

Figure 38. A concept intended to express sharpness and precision.

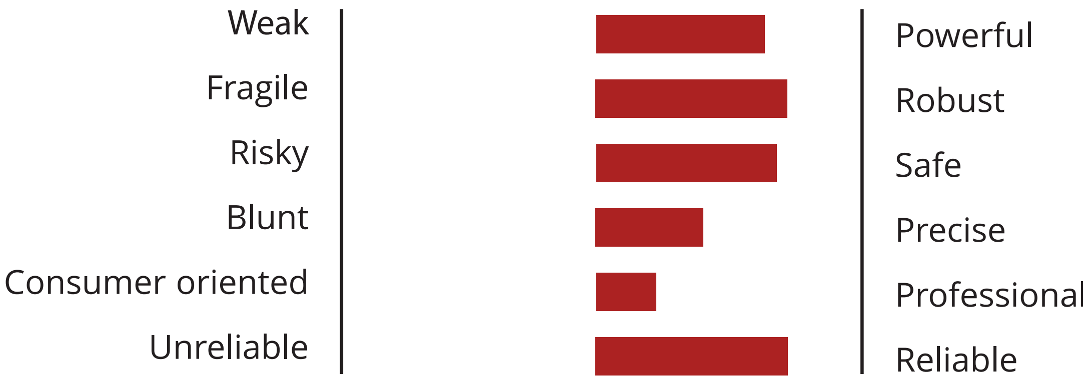

Chart 4. The Sharp-concept as graded according to the semantic scale by the test group.

Sharp scores almost as high as Powerful for all attributes. However, as the concept was designed to emphasize on precision, it did not score outstandingly high for "precise" and "professional", as was hoped. Instead, it received about same scores as Powerful for these attributes.

Elegant

The last concept is the one that aesthetically stands out the most among the others. The elegant impression is given by the round and curvy shapes can be seen in the front and back of the tool, as well as on the lever and the edge of the rubber cover. The orange colour is used as an accent and more clean steel is shown.

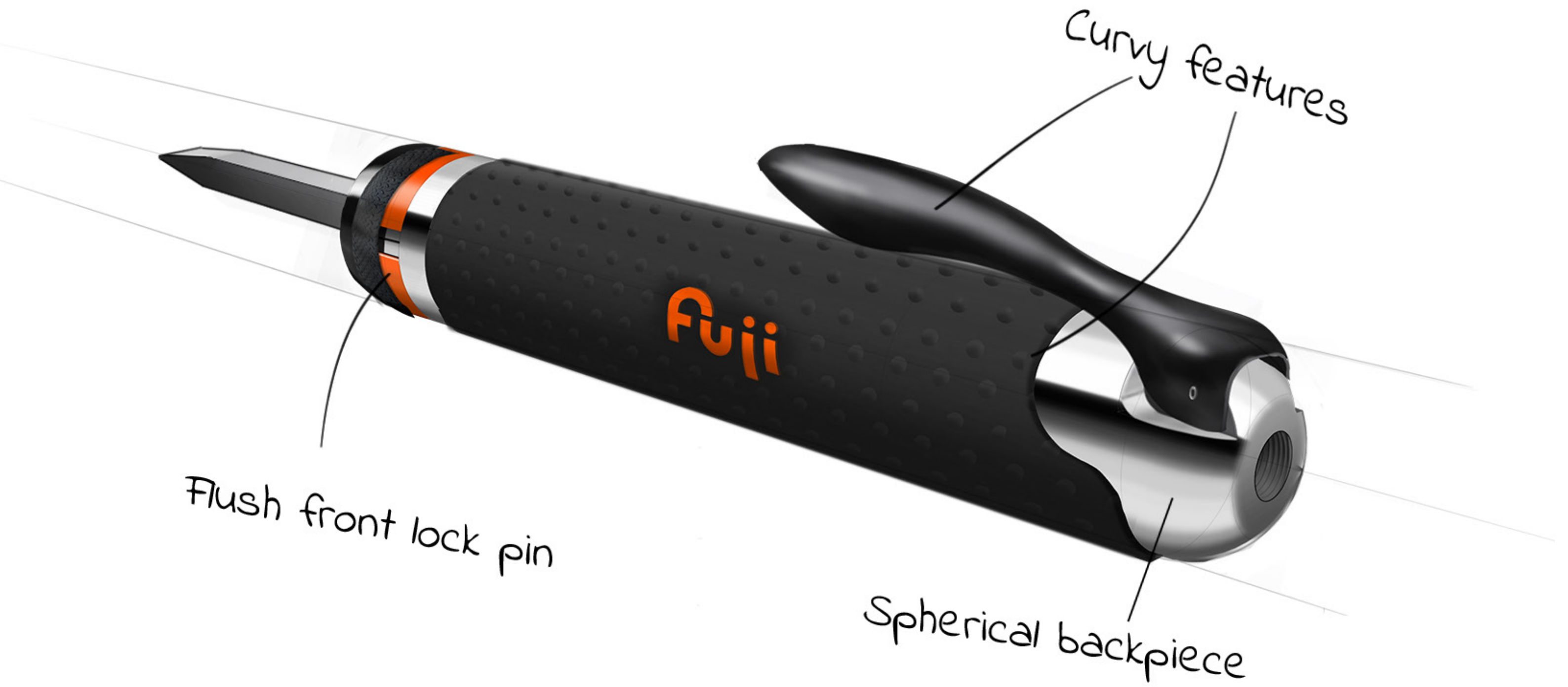

Figure 39. A chipper expressing elegance.

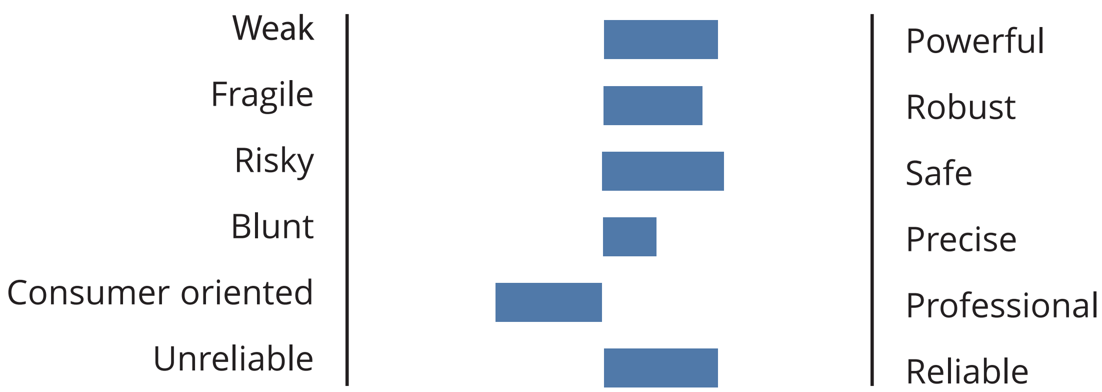

Chart 5. The concept Elegant as graded according to the semantic scale by the test group.

The concept Elegant scores well in most aspects. The exception is found in "consumer oriented/professional". As the concept was intended to move away from the more industrial expression found in the previous three concepts and instead have a more inviting appearance, the result was expected.

5.5.3 Semantic evaluation

The results of the semantic evaluation are shown in the graph in chart 6. The total score, given that all the graded words are equally weighted, is presented in the bar chart to the right in chart 6. It shows that Sharp came in as close second after the Powerful, in terms of expressing the characteristics sought for. For the full results, see appendix IX.b.

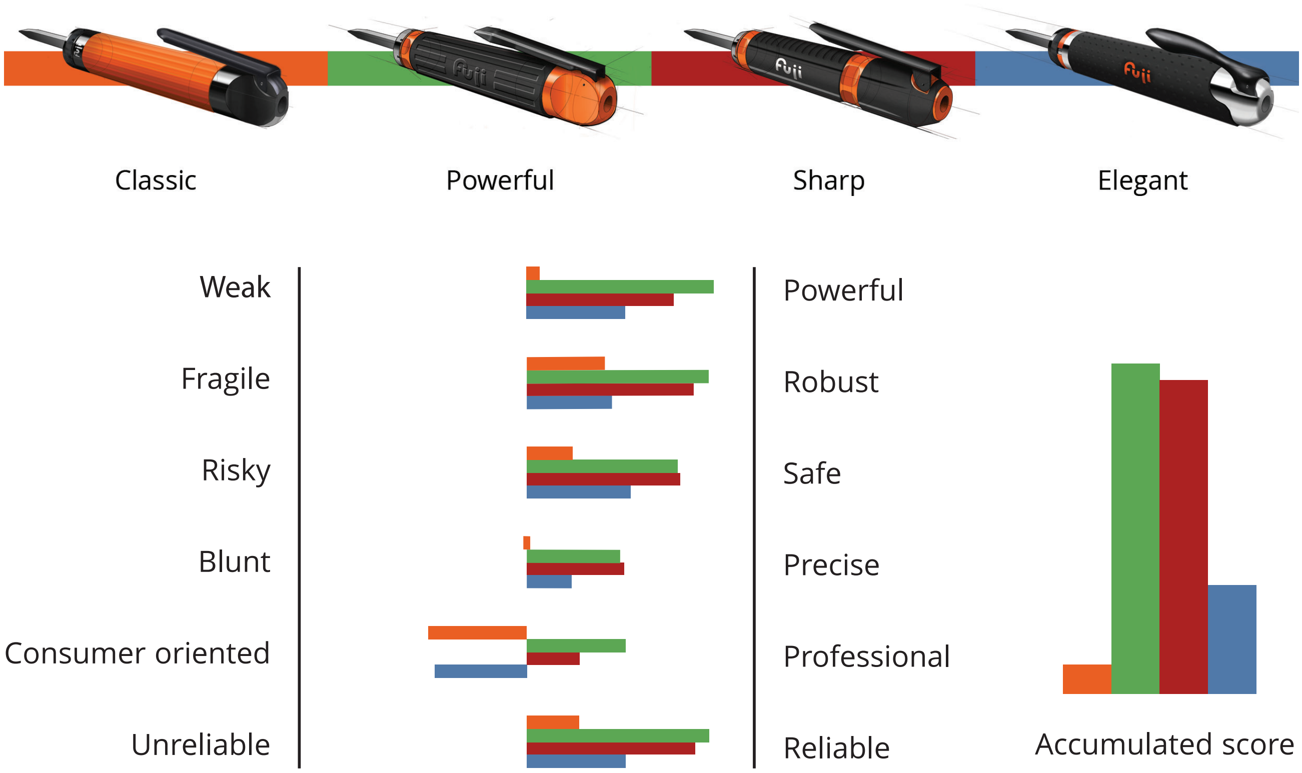

Chart 6. A compilation of the results from the semantic differential, with an accumulated score of all the descriptive words.

5.5.4 Concept selection

The company's choice was in accordance with the semantic scales, even before the scales were presented to them. They asked for a combination of Sharp and Powerful, with an addition of more orange-coloured surfaces.

6. FINAL CONCEPT REFINEMENT

The following chapter describes the final developments made on the chosen solutions and presents the synthesis of these solutions into a final concept.

6.1 Vibration isolator

This section presents a suggestion regarding the mechanical design of the tool, in order to assure that the isolator solution is manufacturable. Before the sample solution is presented, the procedure and the theory behind the calculations is presented.

6.1.1 Execution

In order to calculate the potential and the dimensions of an air spring isolator, a further investigation into vibration theory was made. A method for calculating its dimensions based on other metrics of the tool was developed. Finally, through discussions with professors at Chalmers University of Technology, a suggestion for the mechanical design was drafted.

6.1.2 Design

The principle of the isolator, as presented in section 2.1.3, is physically separating the vibrating part from the handle with a spring. Since forces from the air pressure is acting directly on the cylinder in the current FCH, the cylinder is the vibrating part in this case. Thus the cylinder needs to be placed within a housing, to be held, according to fig 39. The inside of the cylinder follows the design of the current model. The rest of the design is constructed with this as the starting point. The cylinder was split in two parts in order to allow inserting the piston, and for manufacturing reasons. This split was positioned in front of the channel inserting air into the cylinder in order to avoid routing air through the threads.

Getting air from the inlet through the housing and in to the cylinder, is done by adding two overlapping pipes between the cylinder and the housing. The pipes have holes that overlap when the cylinder is pressed backwards, and thus more pressure is added to the air spring, according to figure 40. This way, the pressure in the spring will automatically increase with the force exerted to the tool. As the pressure increases, the depth around which the cylinder oscillates will increase, and the air input to the spring is reduced. Through this self-adjusting mechanism, the spring will get a pressure equalling the force constituted by the user and the workpiece.

The minimum length of the spring, based on the cylinder amplitude, will depend on the length of the air pipes. To allow decompressing the spring with a distance equal to the amplitude of the cylinder vibrations, this length can be calculated by adding the distances presented in figure 41, according to formula 6.1,

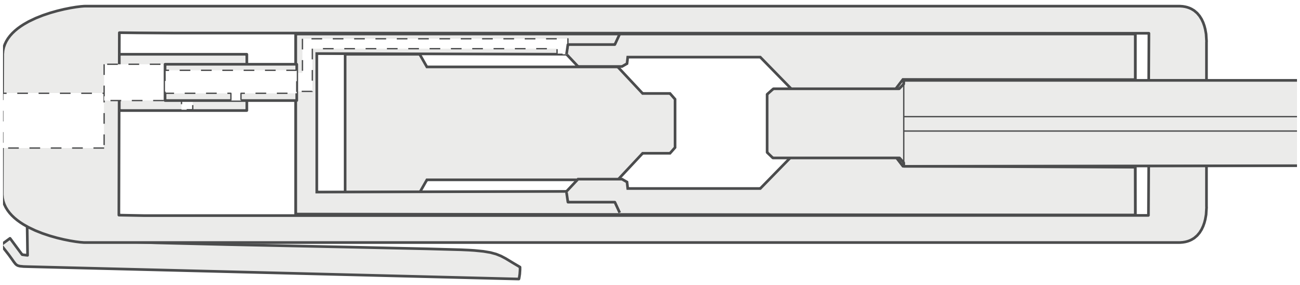

Figure 40. Early design of the chipper, with isolator pipes and the line of division in the cylinder defined.

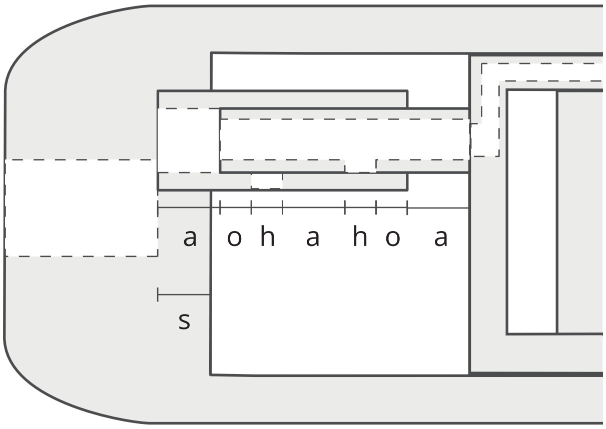

Figure 41. The dimensions of the isolator pipes.

$$l_{spring} = 3 * a + 2 * (o + h) - s \quad \textit{(6.1)}$$

where *a* represents the cylinder amplitude, *o* the overlap length and *h* the diameter of the holes in the cylinders. The overlap needs to be big enough to ensure that air leakage is minimized, and *h* should be long enough to allow oscillations at maximum pressure. *s* represents the wall thickness in the back of the housing, which allows the pipe to be sunk in order to shorten the spring, and thus the tool. In the FCH-25, this thickness is 14 mm, and thus it will be in the new tool as well.

In order to prevent the chisel to rotate in relation to the housing, the cylinder has to be locked around its axis. This is accomplished by positioning the pipes off-centred.

Just like the cylinder needs to be divisible in order to mount and demount the piston, the housing needs to be divisible for the sake of the cylinder. Thus, it was divided into two parts. The split was put at the front of the tool, according to figure 42, in order to allow a power grip on the housing and a more precise grip for twisting the lighter lid. This design should allow the rear part of the housing, meaning everything except the lid, to be produced in one part.

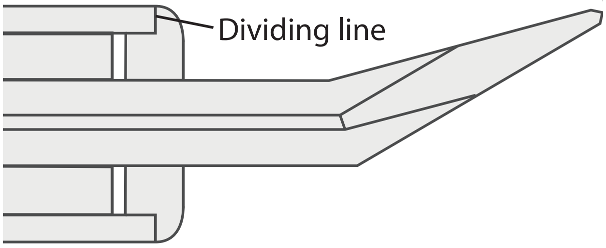

Figure 42. The dividing line in the housing.

6.1.3 Theory

The dimensions of the spring determines its ability to mitigate vibrations. The ratio of the vibrations applied to an isolator to the vibrations emitted from it is termed *transmissibility*. Thus, a good isolator has low transmissibility. How this is calculated from the properties of the tool is presented below.

These calculations do not take the vibration amplitude of the isolated mass into consideration. This is important for the design of the spring since the isolator will work by allowing the mass to vibrate. How this can be calculated is presented at the end of the section.

Transmissibility

The transmissibility, denoted *T*, can be calculated from the frequency ratio, *r*, along with the damping ratio, ζ, according to formula 6.2.

$$T = \sqrt{\frac{1 + 4 * \zeta^2 * r^2}{(1 - r^2)^2 + 4 * \zeta^2 * r^2}} \quad \textit{(6.2)}$$

The frequency ratio is the ratio between the frequency of the excitations, f_e, and the natural frequency of the system, f_n, according to formula 6.3. This applies regardless if the vibrations are considered in terms of force or motion (da Silva, 2006).

$$r = \frac{f_e}{f_n} \quad \textit{(6.3)}$$

As can be seen in formula 6.4, which is derived from formula 6.2, successful isolation is achieved when the ratio of the excitation frequency to the natural frequency is above √2, from where it increases. This region of the frequency spectrum is known as the *isolation region* (da Silva, 2006). The relation between transmissibility and frequency ratio is seen in chart 7.

$$r > \sqrt{2} \rightarrow T < 1 \quad \textit{(6.4)}$$

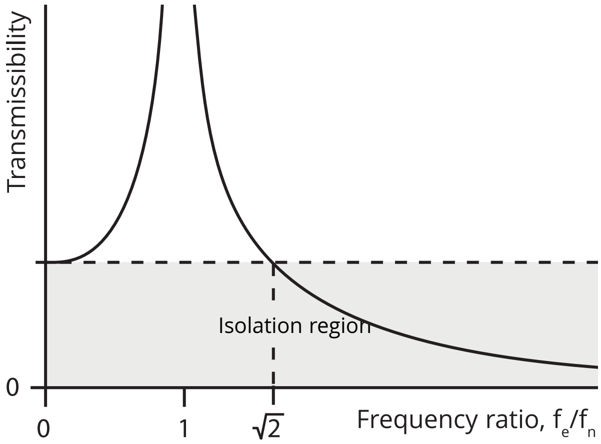

Chart 7. The transmissibility of an isolator, depending on the frequency ratio.

Thus, they key to a good isolator is a low natural frequency in relation to the excitation frequency, along with a low damping ratio.

In this case, the excitation frequency is the operational frequency of the tool. The damping ratio is difficult to calculate, but is minimized by minimal dissipation in the tool. The natural frequency of the system is, as stated in section 2.1.1, dependant on the mass of the vibrating system, and on the stiffness of the spring, according to formula 6.5.

$$f_n = \sqrt{\frac{k}{m}} \qquad (6.5)$$

The mass, *m*, is in this case the mass of the cylinder, the piston and the chisel together. This is a simplification, since the mass is inconsistent due to the relative motion of the piston and the chisel.

To minimize the natural frequency, the stiffness should be minimized. The stiffness of an air spring is calculated according to formula 6.6, where *p* is the pressure in the air spring, *A* is the area on which the pressure constitutes force, *L* is the depth of the air spring and γ is the adiabatic gas constant. The adiabatic gas constant for air is 1,4 (Presthus, 2002).

$$k = \frac{pA\gamma}{L} \qquad (6.6)$$

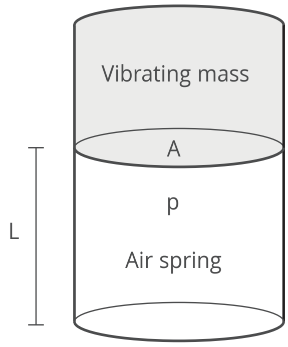

Figure 43. Air Spring

In the flux chipper isolator, the bottom area of the cylinder has the area *A*. It is defined by the piston diameter and cylinder wall thickness. The pressure will be determined by the force applied to the tool. When the tool is pressed towards a workpiece, the load on the isolator will be greater and the pressure will increase. Since the air is supplied by the compressor, the maximum pressure in the spring will be that of the air supply. If the tool is running without contact with the workpiece, no external force is applied. In this case, the pressure in the spring will oscillate with the cylinder position close to ambient pressure.

The remaining undetermined variable affecting the natural frequency, and thereby the transmissibility, is the spring length. From formula 6.6 we can see that a long spring gives a low stiffness. Formula 6.5 shows that this gives the system a low natural frequency, and through chart 7 we can see that this, giving us a high frequency ratio, is necessary for good isolation. Thus, a long spring is beneficial for good isolation.

Amplitude

At ambient isolator pressure, the amplitude of the cylinder can be calculated using the integration of the formula for linear momentum,

$$m_1 * l_1 - m_2 * l_2 = 0 \qquad (6.7)$$

where *m* is the mass and *l* is the displacement of the interacting objects. The momentum of the piston, as well as the momentum of the chisel, will result in an opposed momentum on the cylinder. As the total displacement of the chisel and piston relative to the cylinder is known, the movement of the cylinder can be derived from formula 6.6 according to formulas 6.8 through 6.10.

$$l_1 + l_2 = l_{tot} \qquad (6.8)$$

$$m_1 l_1 = m_2 * (l_{tot} - l_1) \qquad (6.9)$$

$$l_1 = \frac{m_2 * l_{tot}}{m_1 + m_2} \quad \textit{(6.10)}$$

Therefore, the total displacement of the cylinder is the sum of the displacements caused by the chisel and the piston.

Apart from the amplitude at ambient pressure, the amplitude at maximal pressure also needs to be calculated in order to set dimensions for the air pipes. This can be calculated using the change in pressure. Given that the variation of length, *L*, in the air spring (distance from bottom to equilibrium point of oscillations) is considered small, the stiffness, *k*, can be considered linear to the pressure. Thus

$$\frac{k_a}{k_b} = \frac{p_a}{p_b} \quad \textit{(6.11)}$$

can be derived from formula 6.6, where *a* represents the conditions at atmospheric spring pressure, and *b* represents the conditions at any other pressure. Hooke's law states that

$$f_x = k * x \quad \textit{(6.12)}$$

where *F* is the force applied to the spring and *x* is the compression of the spring from the equilibrium position. In this case, *F* is the varying force from the movements of the cylinder. Since this force is caused by the air flow, which is constant, this force should be the same, regardless of the external conditions. Thus, the spring stiffness is linear to the oscillation amplitude, as seen in formula 6.13.

$$\frac{k_a}{k_b} = \frac{x_b}{x_a} \quad \textit{(6.13)}$$

Formula 6.10 and 6.12 gives

$$\frac{p_a}{p_b} = \frac{x_b}{x_a} \quad \textit{(6.14)}$$

stating that an increase in spring pressure would lead to a conversely linear decrease in amplitude. Thus, using formula 6.13 with the amplitude at ambient pressure, the amplitude at any other chosen pressure can be determined.

6.1.4 Dimensioning

The following section presents the method to calculate the dimensions of the isolator, along with an example based on numbers from a design made by the project group.

Method

Based on the design described in section 6.1.2, and the formulas derived in 6.1.3, the following steps for calculating the air spring dimensions were derived:

1. Determine the maximum and minimum amplitude of the cylinder vibrations, using formula the sum of 6.9 and 6.13.
2. Calculate the length of the spring based on the pipe lengths, according to formula 6.1
3. Calculate transmissibility according to formulas 6.2. Use the frequency ratio from formula 6.3, in which the natural frequency is found in formula 6.5. The stiffness for formula 6.5 comes from formula 6.6. If the level is considered satisfactory, use the derived dimensions. If not, proceed to step 4.
4. Apply one of the following design modifications:

- Increase the mass of the cylinder
- Increase the length of the spring
- Consider ways to decrease the damping ratio, i.e. minimize interface friction within the housing
- Repeat steps 1-3.

Example

The following example determines the dimensions of the isolator on a flux chipper designed by the project team. The complete design of the chipper is specified in the drawings in appendix XI. It follows the method presented above. Many of the dimensions of the parts may be changed before the prototype is manufactured. Thus, these calculations will likely have to be remade for the final version. However, this design is deemed good enough to serve as an example for the calculations and to approximate the feasibility of satisfying the requirements for the final product.

The data in table 9 is retrieved from the Bill of Materials that can be found in appendix X.

Table 9. Part masses for the new design

Part name	Mass
Cylinder assembly	535 g
Inner cylinder back piece	118 g
Outer cylinder back piece	94 g
Cylinder front	310 g
Ball	4 g
Isolator Tube Inner	10 g
Straight Chisel (400 mm)	443 g
Piston	208 g

According to Fuji, the maximal chisel stroke is 10 mm. The piston can maximally move 32 mm in its chamber. However, because of the air pressure and the chisel getting in the way, its speed is decreased well before it reaches the walls. Thus, the distance will be smaller. For the sake of the calculation, the distance is estimated to be 29 mm. In order to use the configuration with the largest impact on the cylinder amplitude, the largest chisel in Fuji's catalogue is chosen.

Putting this data into formula 6.9, with m_2 being the mass of the piston and the chisel respectively, gives

$$l_{cyl1} = \frac{152 * 29}{535 + 152} = 6,41[mm]$$

$$l_{cyl2} = \frac{443 * 10}{535 + 443} = 4,52[mm]$$

Thus, the total amplitude of the cylinder, is

$$l_{cyl1} + l_{cyl2} = 10,93 \approx 11[mm]$$

With a maximal pressure equal to the operational pressure, 5 bar, formula 6.11 gives

$$\frac{p_a x_a}{p_b} = \frac{1}{5} * 11 = 2,2[mm]$$

An overlap of 3 mm is assumed enough to prevent significant air leakage, even though that is a matter of manufacturing tolerances. For the sake of keeping the tool short, the outer pipe is sunk maximally into the housing. This gives

$$3 * a + 2 * (o + h) - 14 =$$
$$3 * 11 + 2 * 3 - 14 = 34[mm]$$

Chart 8 shows the transmissibility depending on a pressure depending on the force applied by the user.

With a damping ratio assumed low, these values should be able to make a big difference on the emitted vibrations. No design modification was deemed necessary for the first prototype.

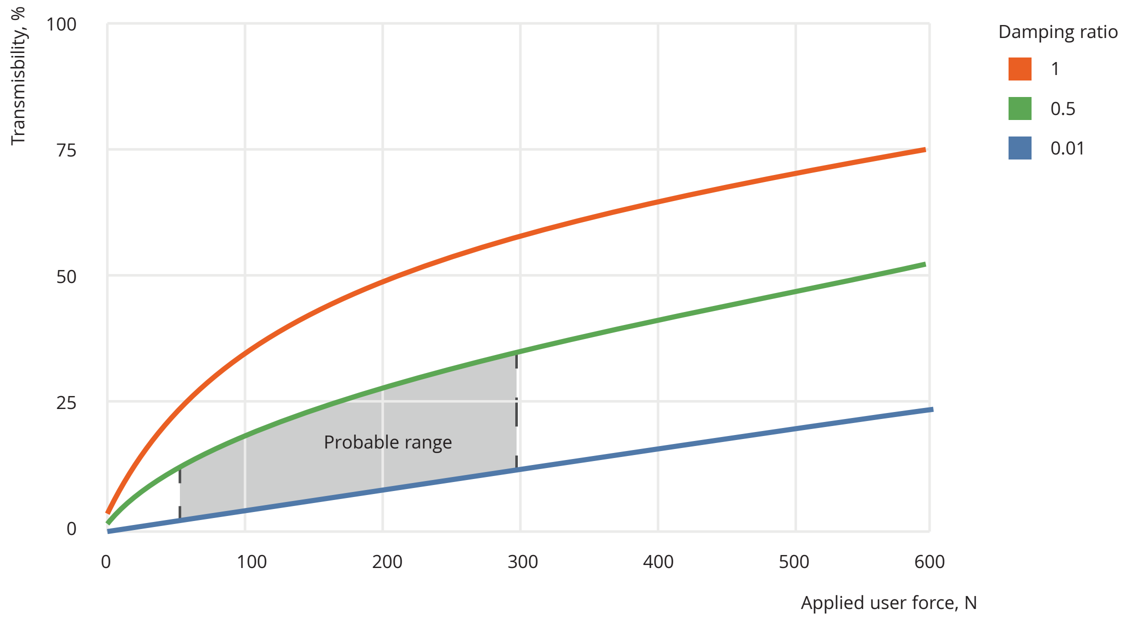

Chart 8. The transmissibility of the final concept depending on the force applied by the user, at three different damping ratios. The area representing the probable range of damping ratio and applied force is marked in gray.

6.2 Front shield

This section details the final developments made concerning the front shield. It first describes the execution and then outlines the resulting design.

6.2.1 Execution

Some modifications on the shield concept chosen for clamping protection were made based on the feedback given by Fuji. The exact manner in which the shield was to be incorporated into the final concept was decided on, and calculations regarding dimensioning were carried out.

6.2.2 Design

The request from Fuji was that the shield should be an optional add-on part instead of a permanent feature, as it was believed it would match user preferences and behaviours better. It was realized that an add-on shield could be easily combined with the lid mechanism sealing the housing described in section 6.1.3, which would entail that no extra mounting interfaces are required. The lid would simply be made in two different versions: one “regular” lid that is flush with the housing surface, and one that protrudes from the housing in the shape of a disc, providing the shielding structure. This simple configuration allows the operator to attach or detach the shielding lid at their convenience. Furthermore, the opportunity to change between the two lid types arises automatically every time the chisel is to be changed.

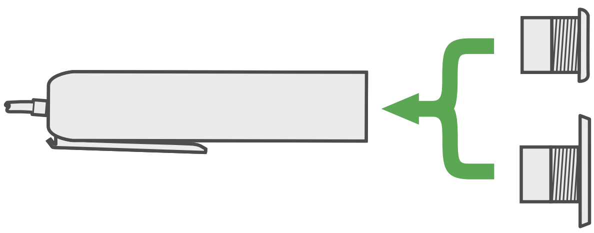

Figure 45. Switching the front lid for the shield.

6.2.3 Calculations

Because the shield should be as small as possible to maximize reach into narrow areas, while still giving sufficient protection from clamping, calculations were made to optimize the shield size. These calculations are based on a “default scenario”, in which the operator is holding and operating the tool with one hand, with the outside of the index finger located 70 mm from the front of the housing. The total length of the employed chisel type is 155 mm, as it is the most commonly used type, and it protrudes a maximum of 90 mm out of the housing. Furthermore, the operator is working on a flat surface. The scenario is illustrated in figure 44, and is assumed to represent typical usage well.

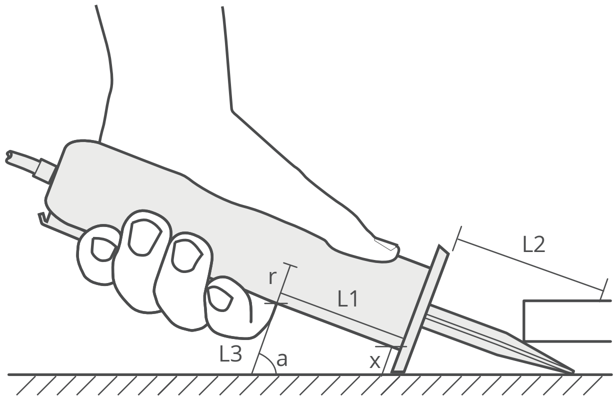

Figure 44. The scenario upon which the shield size has been calculated, together with

With all of the variables mentioned in the scenario fixed, the necessary shield size for the desired minimum clearance between the workpiece and the outside of the index finger can be determined. The size of the shield will set the minimum possible angle between the flat workpiece and the tool, which in turn will entail a minimum gap between the workpiece and the outside of the index finger. The protrusion of the shield, x, can be calculated using the formula

$$x = \frac{L_2 * (L_3 + L_4)}{(L_1 + L_2)} - L_3 \qquad (6.15)$$

It was assumed that a clearance of 40 mm at the point of the index finger would provide enough protection in clamping situations. Furthermore, the radius of the housing is 22 mm. Substituting these numbers into formula 6.15, together with the set maximum chisel protrusion of 90 mm and index finger position of 70 mm from the front of the housing, yields a shield protrusion relative to the surface of the housing of

$$\frac{90 * (22+40)}{(70+90)} - 22 = 12,875 \approx 13[mm]$$

This results in a total shield radius of 35 mm. The resulting minimum angle between the workpiece and the tool is 23,4°, and the shield perimeter was given a slant of the same inclination.

The final design of the shield can be seen in figure 52 on page 57.

6.3 New chisel attachment

One requirement from the user studies states that it should be possible to utilize any type of chisel in the tool. The quick release mechanism currently employed in the FCH-25 and FCH-20F meets this requirement. However, if the tool is to be completely isolated, the housing has to cover the front of the tool as well. This section describes the approach to this problem and the resulting final design.

Classic quick release

The classic quick release utilizes the mechanism for quick insertion of chisels featuring on the FCH-20F and FCH-25 models today. As the chisel is inserted with the shaft first, the mechanism allows for any type of chisel, regardless of tip angle and width. If incorporated into the new FCH design, the mechanism would be attached to the cylinder in the exact same fashion as on today's FCH-25. However, this design would entail that the housing cannot extend all the way to the front, as there would be no gap between the cylinder and the housing under which the quick release mechanism could slide. In turn, the front part of the tool would remain unisolated against vibration.

New chisel attachment mechanism

The suggested design for chisel attachment is tailored to fit a model where the isolated housing covers all gripping surfaces of the tool. As outlined in section 6.1.3, there is a screw-on lid attached to the front of the housing which prevents the cylinder from sliding out. The chisel is in turn secured by a ball resting in a drilled hole in the cylinder wall, which protrudes down into a track in the chisel, much similar to the design of the currently used quick release function. A draft angle in the hole prevents the ball from falling out into the cylinder. In order to remove the chisel, the lid has to be unscrewed far enough for the ball to have room to be displaced out of its cavity, moving into the space which the inwards extending portion of the lid previously filled when screwed all the way in. The length of this portion will be such that the lid will not have to be unscrewed all the way out for the ball to have room to be displaced. In this way, loose parts are avoided in the process of attachment and detachment. Figure 47 shows the procedure of detaching a chisel in three steps. The steps for attaching a chisel are identical to the inversion of these steps.

6.4 Aesthetics

This section details the final work performed concerning the appearance of the tool. It first describes the course of action that was taken to develop the appearance further, and then presents the final outcome.

6.4.1 Execution

After deciding on basing the design on the concepts Sharp and Powerful, a number of new suggestions were developed based on prior sketches. Some late changes to the structure of the housing also resulted in necessary modifications to these suggestions. Fuji's subsequent comments were then incorporated in a new round of proposals. This process was repeated until a satisfactory design had been established. The definitive shape of the most minute details were then determined during the modelling of the final concept in CATIA V5.

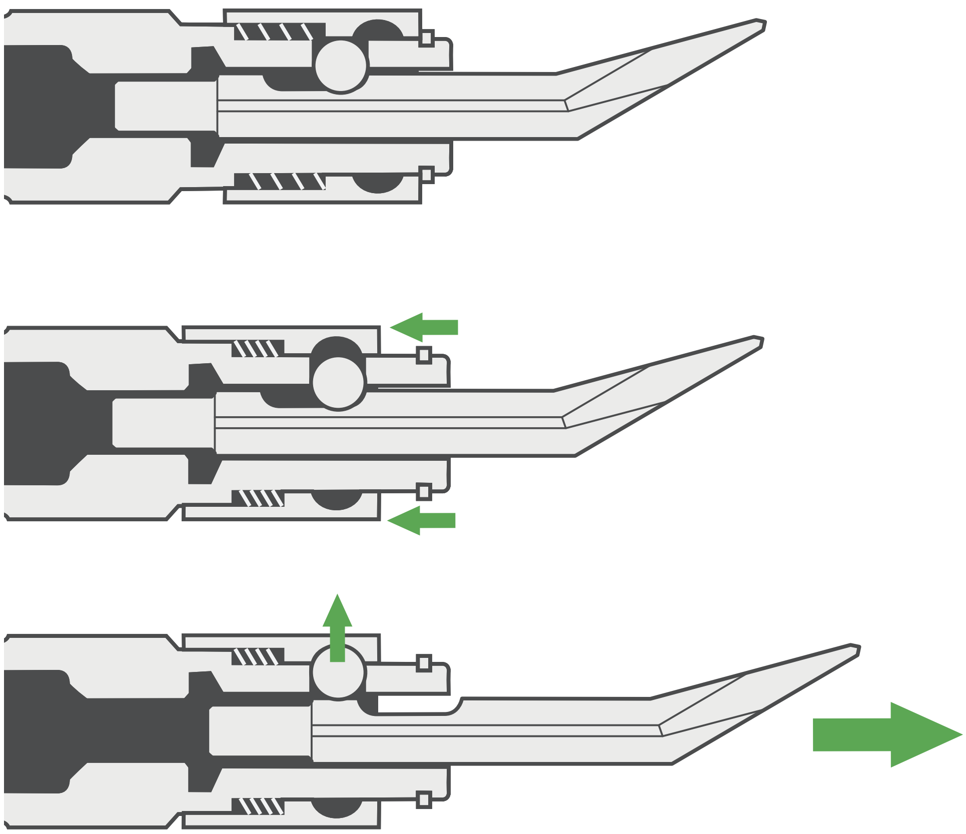

Figure 46. The steps for removing a chisel using the current quick release function.

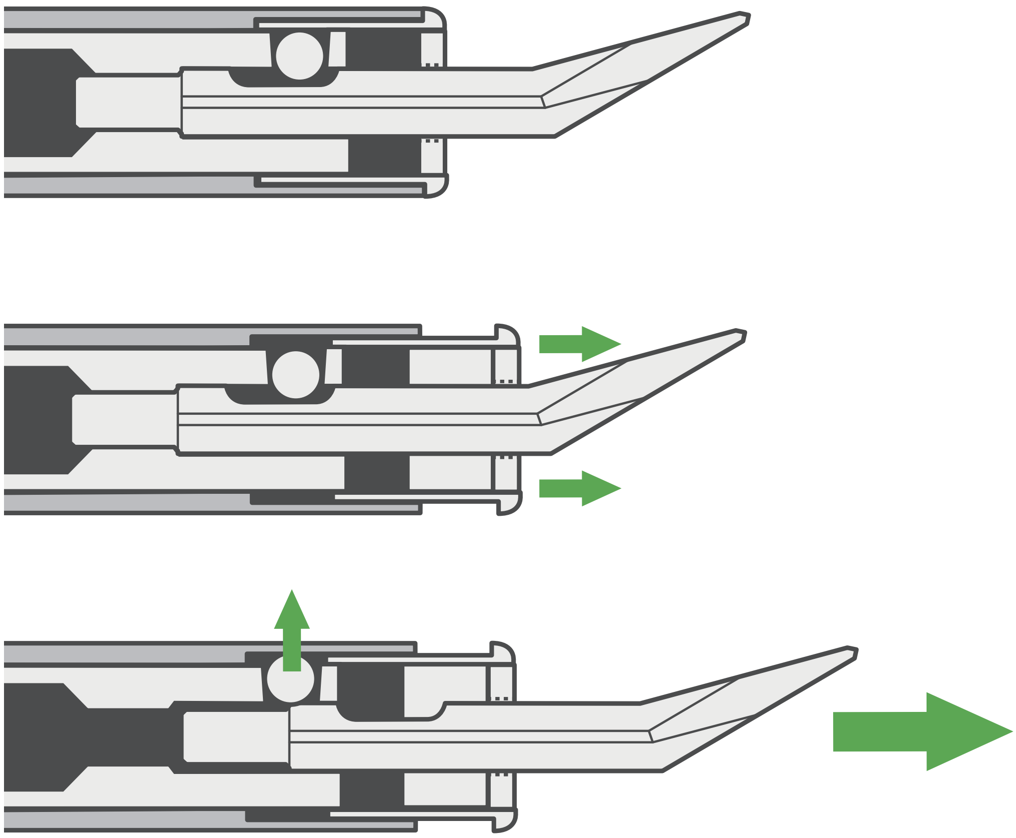

Figure 47. The steps for removing a chisel using the new chisel attachment mechanism.

6.4.2 Final aesthetic design

The renders on the following pages show the final aesthetic design.

The orange surfaces are the clearest links to Fuji's visual style. The logo is clearly presented in generously sized orange letters against the black rubber. Also, the rubber pattern has been changed from the pattern in the original Sharp concept to a pattern resembling that of the concept Powerful, which builds on Fuji's ridges.

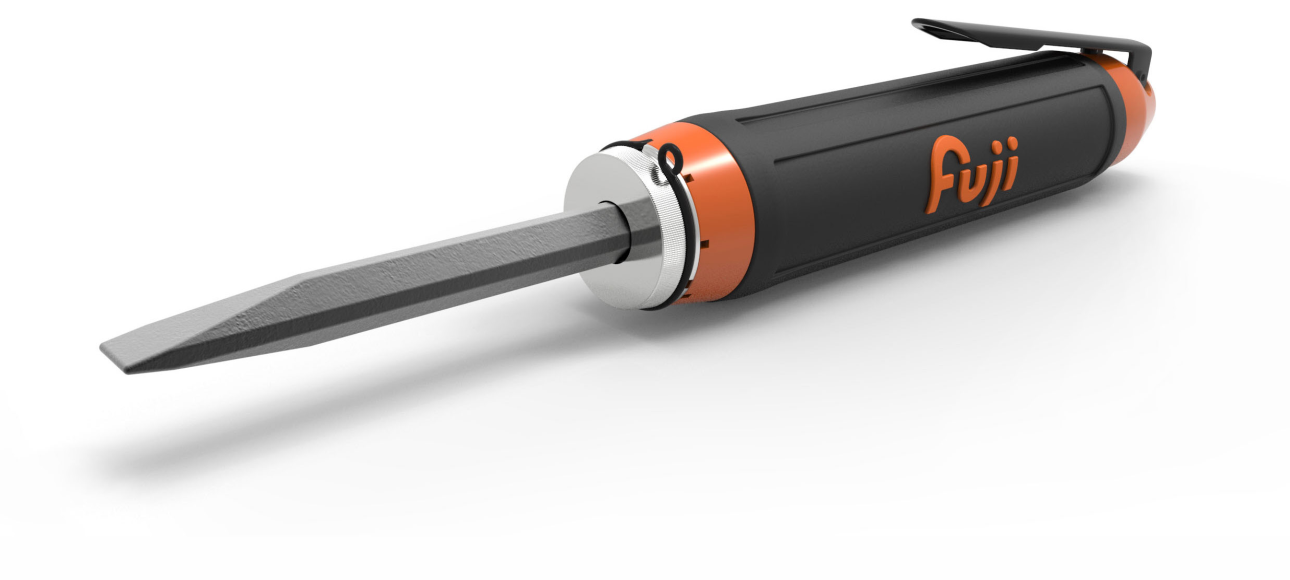

Figure 48. New chipper design

The back piece has also been given a new shape, departing from the previously milled-out, two-sided narrowing of the rear and instead sporting a rotationally symmetrical, conical tapering. This gives it more coherent surface transitions.

Figure 49. New chipper design, rear view

Figure 50. New chipper design, front and side views

The front lid has been given a shiny metal finish, which was one of the cues identified in the DFA, and which clearly distinguishes it from the rest of the housing. It also features shallow grooves around the perimeter, which gives a better grip when screwing it on and off. The protective optional shield is visually similar to the regular lid, sporting the same grooves and surface finishing, but having a larger diameter.

Figure 51. Chipper with shield protecting hand from clamping

As it was realized that the housing could be made in one solid piece, the wrench markings included originally in Sharp and Powerful became obsolete. The markings were deemed to contribute to an impression of robustness, but this was outweighed by the fact that including them would probably confuse users if they could not be used to actually disassemble the housing. Thus, their disappearance was motivated. With the wrench markings out of the picture, the previously divided rubber cover was instead joined together into one piece, providing more grip-friendly surfaces for the user.

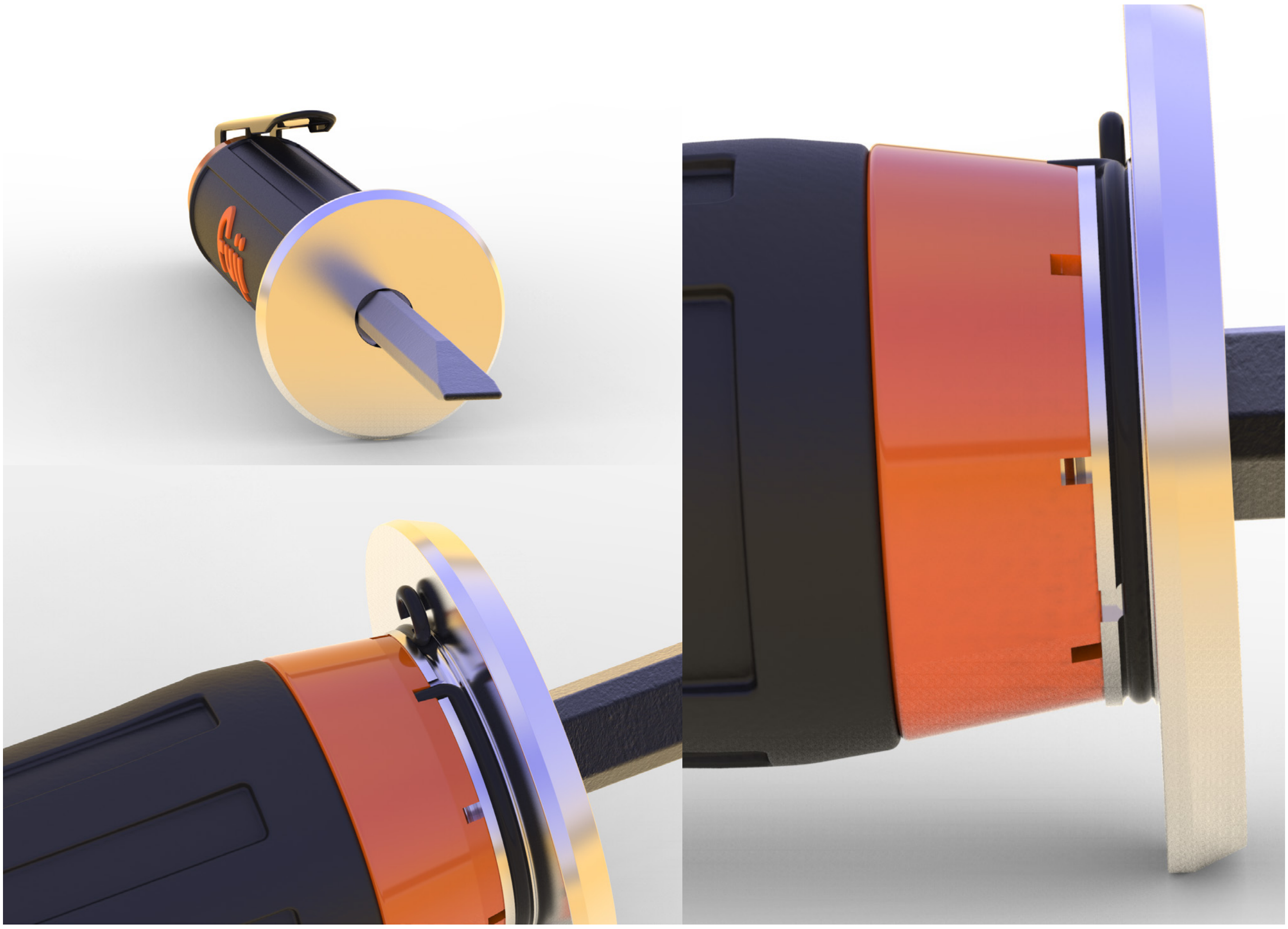

Figure 52. Front shield from three angles

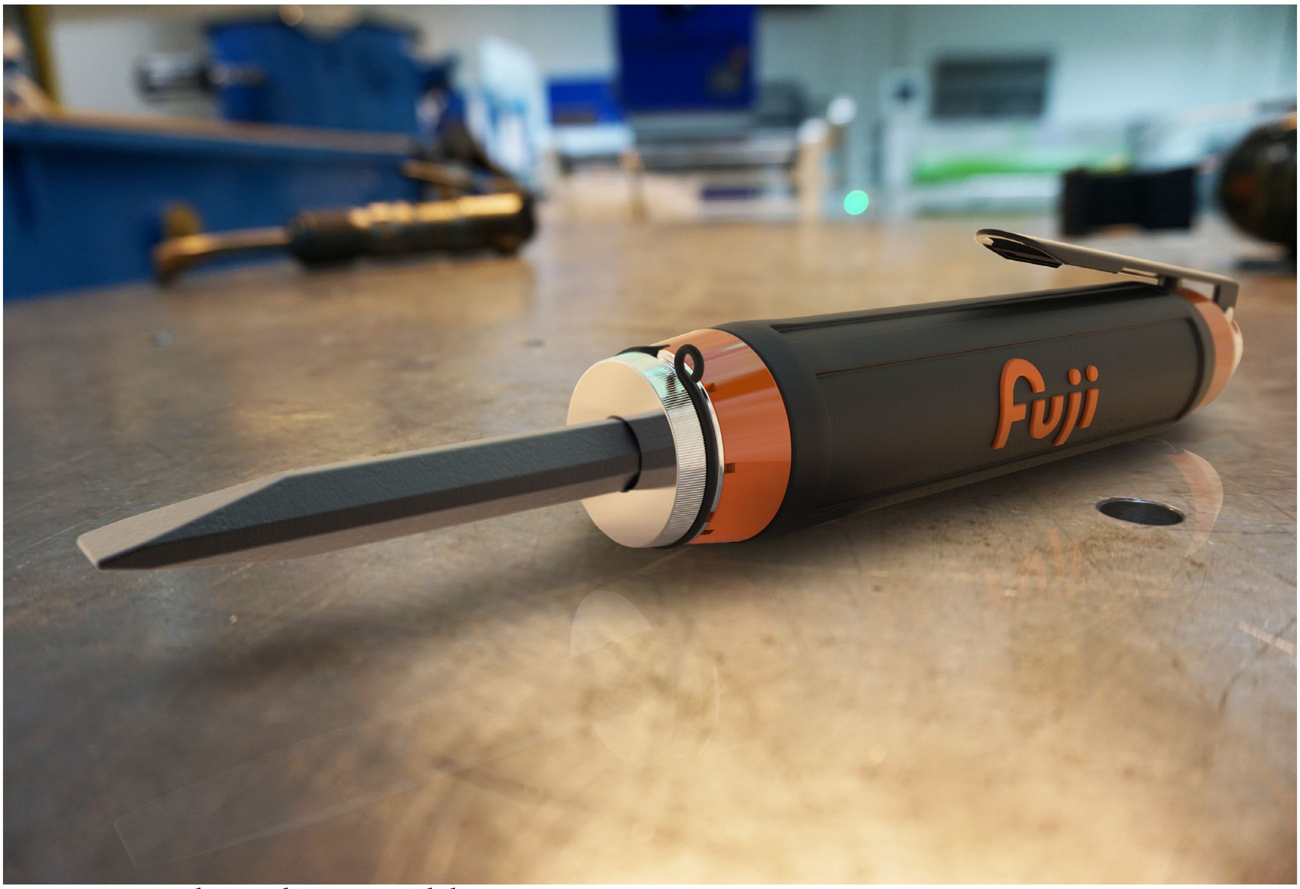

Figure 53. New chipper design in workshop

6.5 Follow-up on requirements

The following section provides a comparison between the final concept and the specification of requirements compiled after the initial study, which can be found in appendix VIII. Most of the requirements are considered fulfilled. Of those, most fulfil the target value, while some only reach the minimum degree of fulfilment. There are also a number of requirements for which the fulfilment cannot be verified without testing a physical prototype. Finally, there is one requirement that is considered unfulfilled. The requirements not confirmed as being completely fulfilled, are described below.

6.5.1 Requirements not reaching the target value

Requirements 26, 27, 11 and 8, listed in table 10, have been fulfilled to the minimum degree, but do not reach the target value.

Regarding weight and length, the target values are set based on the FCH-25. An small increase here is considered an acceptable trade-off for lowered vibration values. The diameter values are set according to ergonomic theory, and are acceptable. It should also be taken into consideration that the goal is to scale the design down to match the FCH-20, which is more popular than the FCH-25. For that model, the diameter will be closer to the optimum. The clamping protection is considered fulfilled as long as the shield is mounted. However, as the shield is optional, it can not be considered completely fulfilled.

6.5.2 Requirements lacking verification

Requirements 9, 12, 16 and 17, listed in table 10, have not been verified.

Vibration exposure and noise levels have to be measured from the finished prototype, and thus can not be verified. Since the suggested FCH design includes a number of new parts, the requirement regarding losing components will also have to be tested. This is also dependent on the detail decisions made by Fuji prior to manufacturing the prototype. Regarding collection and removal of airborne dust particles and fumes, the verification is arbitrary. The ISO document that specifies it does not convey how the verification is supposed to be done. This verification is therefore left to the company, since they are responsible for labelling the tool as fulfilling ISO-standards.

6.5.3 Unfulfilled requirements

Requirement 18, seen in table 10, concerns providing an ergonomic grip for transmission of high feed force from the hand of the operator.

Since the final concept includes no means for the operator to transmit force towards the workpiece while keeping his or her wrists in their natural position, this requirement is not considered fulfilled.

Table 10. Extraction from specification of requirements

#	Criteria	Type of measure	Target value	Limit value	Fulfil-ment
8	Have a total length, excluding the chisel, of	mm	< 205	< 240	Limit value reached
9	Not lose components during expected use, including handling and occasional dropping	Binary	Yes	Yes	?
11	Protect hands from clamping when chisel gets stuck in narrow spaces.	Binary	Yes	Yes	Partly
12	Have a maximum vibration exposure value of	m/s2	< 2.5	< 5	?
16	Emit a maximum level of noise of	dB	< 80	< 87	?
17	Facilitate the collection and removal or suppression of airborne dust particles and fumes generated by the work process.	Binary	Yes	Yes	?
18	Allow for gripping in such a way that high feed force can be transmitted in an ergonomic way from the hand of the operator to the tool.	Subjective	5/5	3/5	No (2/5)
26	Have a weight of	kg	< 1.5	< 2	Limit value reached
27	Have a handle diameter of	mm	34-38	30-50	Limit value reached

7. DISCUSSION

The following chapter discusses the project regarding aspects such as planning, execution, and the final outcome.

7.1 Working in Japan

This section describes factors concerning the communication with the company that have affected the project.

7.1.1 Cultural differences

Several cultural differences between Sweden an Japan were noticed during the visit. Erin Meyer (2014) discusses one difference between Sweden and Japan on a scale of what she calls *High vs. Low context cultures*. A low context culture, like Sweden, is a culture in which most of the intended message conveyed in a conversation can be understood from simply understanding the spoken words. In high context cultures, of which Japan is the prime example, the ability to communicate efficiently relies on "reading the air". This means that a lot of the communicated information is conveyed indirectly, or "between the lines". Japanese people are used to this and skilled at understanding these, to people from low-context cultures, seemingly hidden messages. This became apparent when our colleagues disliked our ideas. They would rarely give a negative answer or clearly show disliking for any ideas or suggestions. Instead, they would carefully suggest an alternative or in other ways hint that other options should be considered. This understanding took some time to come to, but has since been a useful insight. According to Meyer, this stems from a fear of losing face, and it also goes in the opposite direction, as they are very keen on not making others losing face. It is a very polite way of communication, but before this insight is reached and understood by people who are inexperienced with this method of communicating, as the project team were a prime example of, it can be slightly inefficient.

Another cultural difference is the Japanese relation to work. At Fuji, the employees often spend long hours at the office. Even though the bell rings at 5 p.m., very few engineers left the office at that time. They seemed content with working hard for the company. In return, the company takes very good care of its employees. Lunch was provided and healthy activities such as morning stretching and devoted relaxation time during lunch was part of the everyday routine. The project team received a very warm welcome, with all essentials provided, including accommodation, a meal budget and travel money. This allowed us to put more focus on work.

The hierarchic nature of Japanese organizations was something the project team was well aware of before the trip to Japan. However, it was not something we experienced in the everyday work at the office, where the atmosphere was relaxed and all the colleagues knew that we were more used to informal communication. Where it was noticed, though, and where it most likely affected the project to some extent, was during the customer visits. During these visits, manners and appearance was of great importance. We were told to wear our best pants and shirts, and how to introduce ourselves. The supervisor explained to us that visiting salesmen and representatives for Fuji were below the workers in the hierarchy. Implicitly understood, foreign interns without understanding for neither language nor culture, were about as far down as the hierarchy goes.

7.1.2 Linguistic barrier

Another barrier to bridge concerned language, as the proficiency in English varies in Japan, and the project team speaks no Japanese. Among most of the R&D employees at Fuji, the everyday English was good. The difference became distinguishable when discussing specific matters such as vibration physics and mechanical design. During these discussions, communication was slightly slower. To bridge this gap, a large amount of sketches and formulas were used. This made it a lot easier to reach mutual understanding, and our shared background within mechanical engineering proved itself useful. Math and basic mechanics could be considered the most universal language used in the process. With patience, of which the Fuji employees had plenty, a mutual understanding could be achieved in most matters.

It should be added that English training was offered and utilized by most employees at the department. The opportunity of practicing English was also one of the big incentives for the company to receive the project team.

The linguistic barrier became most evident during customer visits. Read more about this in section 7.3.2.

7.1.3 Geographical distance

Once the phase in Japan was over, sketching and reading facial expressions was no longer possible. A few video meetings were held, with participation from the Swedish manager at the site in Osaka. These meetings were however difficult to arrange due to busy schedules and time difference, which made the mail correspondence vital. Writing in English generally worked well, and a lot of graphic material was produced during the process to facilitate communication.

7.2 Planning

This section discusses how well the scope was adapted to the project team and the time frame, and how the time frame was utilized.

7.2.1 Scope

The scope of the project involved a wide variety of tasks, where vibration damping, ergonomics, user studies and aesthetic work were the main areas. Out of these, ergonomics and user studies were familiar to the project group, while vibration handling and branding were relatively new fields. While branding proved to be comprehensible, vibration handling was more difficult and took more time to grasp.

For project planning in general, it can be said that a wider scope is a trade-off for the depth of the result. Including many parts logically means that the result of each part will be less developed than it would have been with a narrower scope. This applies to this project as well as any other.

7.2.2 Time plan

The time plan that was set up was based on the original suggestion by Fuji. As described in the introduction of this report, this meant spending six weeks in Sweden and four weeks in Japan for the initial study. During this time, literature reviews, customer visits and aesthetic studies were performed. What also has to be taken into consideration is that both the report and the mechanical designs were planned to be turned in three weeks prior to the presentation, which cuts more time from the ten final weeks. In retrospect, time from the initial study could instead have been better used in the development and finalizing phase of the project.

The boundaries set by the time plan were naturally not set in stone. Several processes considered part of the analysis and the concept generation could be, and were, initialized in Japan. Getting to concepts in terms of ergonomics and functionality did however require finishing the user studies, which continued until the final days of work at the Fuji office.

This imbalance in the time plan should have been reflected over earlier, and the project team should have taken the given opportunities to take time from the initial study to the development phase. This is considered the single action that, would it have been taken, would have had the greatest positive impact on the results of the project.

7.3 Application of chosen methods

This chapter discusses some of the outcomes of the methods used in this project and the consequences of how they were applied and adapted to fit our purposes.

7.3.1 Questionnaire

Through our supervisor at the Fuji R&D department, the marketing department was tasked with the process of distributing the forms to customers of Fuji. The questionnaire was distributed to factory managers or workshop foremen in paper form, but also in a digital format. The reasons for the low number of respondents are not entirely known. One possible reason in the case of the digital form, which rendered only one response, is that it is unlikely that the form was distributed as a web URL directly to individual workers at customers of Fuji. The workers seldom access computers during the shifts, and may not have personal e-mail addresses connected to the company. Instead, it might have been sent only to foremen responsible for relevant personnel, and this might have kept the form from reaching a larger number of users. The reason for the low number of respondents in paper form is also unknown. Even though printed questionnaires are likely to be a more accessible format than digital forms at sites for heavy industries, they rendered only six responses. A likely reason is that many of both the foremen and workers did not see the benefit of filling the questionnaire out, and thus chose not to spend time with it.

It would perhaps have been more rewarding to deploy a questionnaire in Sweden, since the process could have been run solely by the project team. The lack of quantitative data potentially entails that some of the decisions were taken without the adequate statistics to back them up.

7.3.2 Interviews

The number of interviews was most probably unnecessarily high. Several interviews had first been conducted in Sweden. The company then arranged eight trips in Japan. This was considered by the project team to be slightly excessive, but it was accepted on the reasoning that it would be better to have too much user data than too little. A saturation in the answers started to become noticeable while still several visits remained. The final visits where however conducted anyway, due to the fact that some the sites differed significantly from the previously seen ones, and thus could provide new insights. There was also a personal interest from the project team to see the sights, since they were impressive and interesting to see.

Due to the linguistic barrier, the interviews carried out in Japan could not be performed by the project team directly, but instead were carried out by company representatives in Japanese with the project team as accompanying observers. Although a limited amount of translation was provided during these visits, the majority of the collected information was relayed in English at a later occasion. It safe to assume that this led to some distortion of the data collected, but the extent of this is unknown. Furthermore, the indirect nature of the interviews, as seen from the project team perspective, severely limited the possibilities to modify and shape the interview dynamically according to the given answers.

7.3.3 DFA

The DFA method was novel to the project team at the inception of this project. It was quickly realised to be a very versatile and useful tool in any situation where visual commonalities among a set of objects are to be investigated.

However, a few questions arose as the method was carried out. What happens if the company that is analysed does not work actively with the visual branding, as was explicitly stated by Fuji? Even though visual links might be found, they are potentially unintentional or simply a result of necessary manufacturing steps. Whether or not they are desirable to emphasize would then depend on whether these cues actually adds to, or at least not detracts from, the company's brand image in a good way - which in turn is a subject for an entirely different analysis.

Another dilemma concerned which products to include. There had to be some form of initial informal assessment that the analysed products were representative of Fuji as a whole, which warranted the inclusion of products from several different product families. At the same time, a too diverse line-up would perhaps result in weak and very general visual overlaps, and potentially miss out on visual cues that could be important for individual product groups.

The project team believes that the chosen cues incorporated into the final aesthetic design are appropriate, and that the mix of products used gave a good balance between too general and too specific, in accordance to the discussion above. The Fuji orange, which predictably came out as the clearest visual cue by far, is obviously no accidental element already incorporated in most of Fuji's products. Furthermore, it does not detract from their desired brand identity.

7.3.4 Semantic Differential

Ideally, the semantic differential survey would have been executed with actual users as the respondent group, in order to maximize the validity of the study. However, due to time constraints, the semantic differential survey was instead carried out among colleagues on the Industrial Design Engineering master's programme at Chalmers. Furthermore, a total of sixteen responses were collected, which likely is on the low side for a quantitative survey. These two factors are potential question marks regarding the validity of the results seen in the semantic differential.

7.4 Recommendations

Prior to introducing this concept to the market, several aspects needs to be further developed, depending on the results of the prototype evaluation. These aspects are summarized below, sorted according to the three main components of the project: vibration mitigation, additional functionality and aesthetics.

Due to the difficulty in calculating the effect of the vibration isolator, making and evaluating a physical prototype is likely the most efficient way to reach the desired result, in terms of isolation ratio and tool efficiency. In order to do this, adjustments to weight of various parts, depth of the isolator and manufacturing tolerances may be required.

Developing a detachable handle for improved grip ergonomics was postponed due to time lacking for the requested solution. It is however still considered a feature that would benefit the user. Before developing concepts for how such a detachable handle could be implemented, further customer reviews regarding the acceptance of loose accessories should be conducted.

The aesthetic design should be evaluated and refined through several iterations. Company requests as well as user feedback regarding acceptance and brand recognition should be taken into consideration during these iterations.

8. CONCLUSION

This final chapter wraps the project up by comparing the results to the initial goals and research questions.

The aim of the thesis was to improve on the comfort and usefulness of Fuji's flux chipping hammers. The predefined issue to solve in terms of ergonomics concerned the high exposure to vibrations, but other issues were also to be identified. The aim was also to make chipping hammers more appealing and visually connected to Fuji's brand and their values. The following three main questions were answered in order to meet the aim:

How can the effects on humans of vibration from flux chippers be minimized?

Vibrations from flux chippers cause several types of injuries to the musculoskeletal and neurological systems in hands and arms. The general principles for vibration mitigation can be summed up as isolators, balancing forces within the system or addition of external balancing systems. In a pneumatic flux chipper, the principle of vibration isolation by an air spring was assessed to be most suitable.

What other improvements can be made to the flux chipper functionality?

Beside vibrations, the risk of getting the hand clamped was identified as an ergonomic issue. The best identified solution for this is to attach a shield at the front of the tool, which prevents clamping in the typical working scenarios. Other than that, more work can be done in finding ways to allow the user to apply force to the tool without stressing the wrists, which also was an identified area of improvement.

How can the flux chipper be styled to suit the Fuji brand?

The clearest existing visual characteristic for Fuji is the orange used on many tools today. Glossy finishing, shiny plain steel finish and the usage of black on protruding parts were also found to be typical. Furthermore, a high material thickness, visible usage of hard materials and visible assembly elements were identified as key characteristics in order to express robustness. These elements can be transferred to a flux chipper in countless ways, and the selected aesthetic design incorporates these elements in the best way among the many produced suggestions.

Summary

The suggested FCH design described in chapter 6 comprises a vibration isolator, improved functionality in terms of the clamping reduction shield, and a new aesthetic design incorporating important visual cues for Fuji's brand. Through this design, all the project objectives are considered to have been reached.

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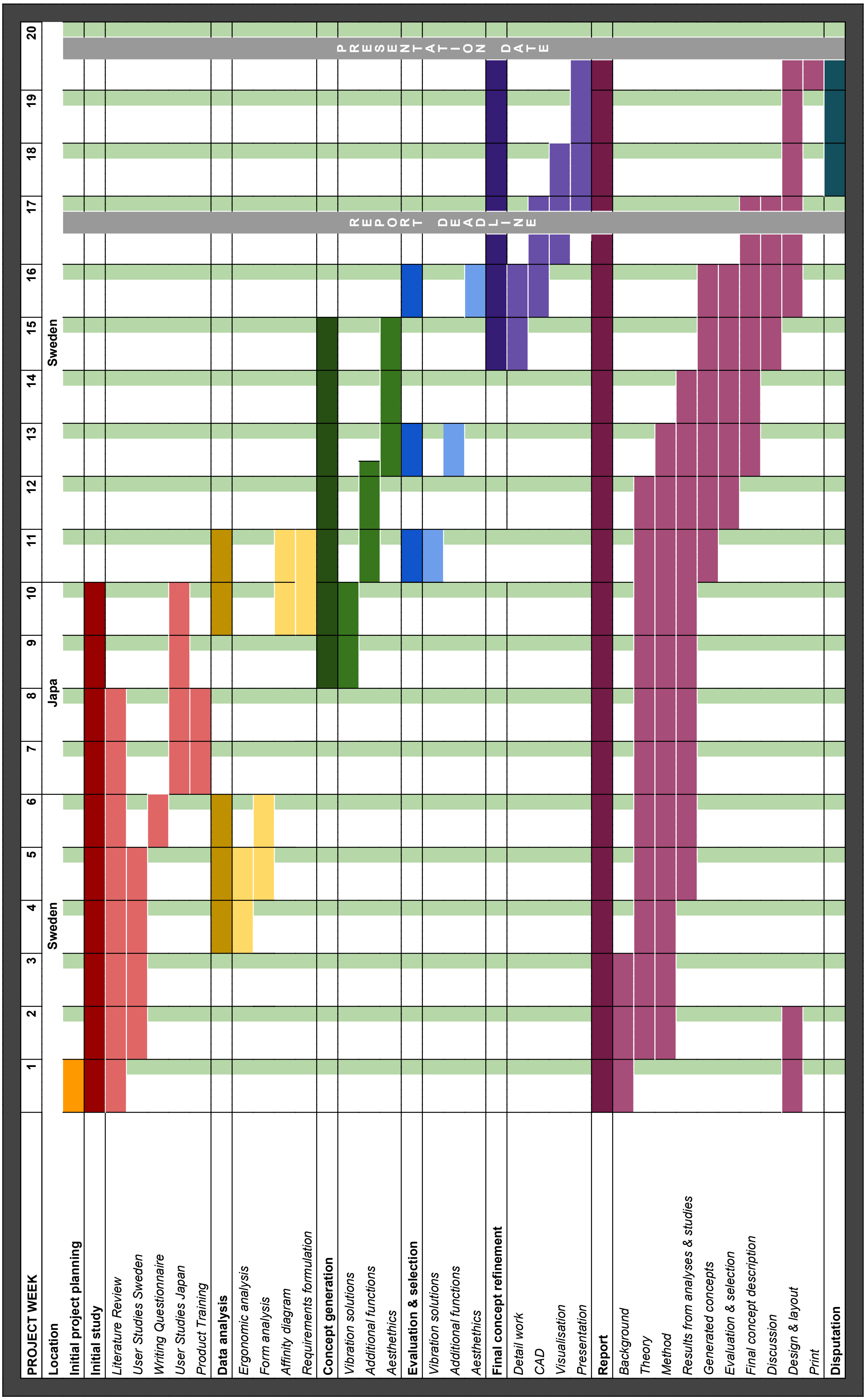
APPENDIX

Appendix I. GANTT chart.



RISK ASSESSMENT & CONTINGENCY PLAN

This chapter maps uncertain events and conditions that may effect the project procedure and/or the result. It also presents estimations of the event probabilities and severities, followed by a contingency plan for the most critical events.

Identified risks

The following risks were identified by the project team.

Disease or injury in project team

Since the project team consist of only two members, a disease forcing either or both to pause the work would be likely to delay the work. The risk of injury is elevated due to a part of the project being spent in industrial environments using potentially dangerous equipment.

Project owner discontent with final result

Fuji Air Tools are investing resources in the project, and will have expectations regarding the final result. If these expectations are unmatched or misinterpreted, the result will be useless to the company and the value of the experience will be decrease for the project members.

Examiner discontent with final result

If the project report fails to match the expectations of the examiner, or the requirements from the school and institution, it will have to be rewritten and delayed.

Insufficient saturation from user studies

If users are too difficult to find, or other issues such as permits or schedule barriers prevent the project team from reaching saturation in the user study results, the quality of the final concept will be reduced. For the sake of assuring this validity it is also vital to gather both quantitative and qualitative data from the users.

Insufficiently explored range of solutions

An insufficient review regarding theory and existing solutions regarding the issues will limit the concept generation, which in turn will lead to potentially effective solutions being overlooked. This can also be caused by a limited idea generation phase.

Risk Assessment

Table 1 lists the risks, along with an assessment of the likelihood and the impact severity of the event. Both these parameters are graded on a scale from 1 to 5, where 5 represents the most likely and severe event. Events with a high product value are most vital in terms of contingency planning, but all events with an impact above 2 needs to be adressed.

Risk	Likelihood	Impact	Product
Disease or injury	1	2	2
Discontent owner	2	4	8
Discontent examiner	2	4	8
Insufficient user studies	2	3	6
Insufficient solution range	3	3	9

Contingency Plan

The following section presents preventive measures taken in order to avoid the risks with an impact graded higher than 2 in chapter 3.2.

Discontent owner

In order to secure a satisfied project owner at the end of the project, close communication will be vital. Since the company is Japanese, the communication is complicated by distance as well as the linguistic obstacle. Therefore, weekly updates will be sent, as well as frequent video meetings. Contact will be established and maintained with several individuals at Fuji Air Tools.

Discontent examiner

To secure a satisfactory academic result, close contact must also be maintained with the examiner. Plans and decisions will be vented through the examiner and written deliverables will de turned in for review well in advance of deadlines.

Insufficient user studies

In order to get enough data to work from, user studies will be performed in Japan as well as Sweden. Users will be found through Fuji marketing as well as through an independent seach effort from the project team. User studies will be performed with users from a wide range of industries and appliances.

Insufficient solution range

An extensive range of solutions is assured through an exhaustive an varied concept generation phase, but it is also vital that the literature review and user studies cover all the factors contributing to the discovered issues.

GUIDE FOR INTERVIEWS

Initial questions

What is the main function of your company?

Which are your main tasks?

For how long have you been working in the business/ on this job?

Areas of use

What is the main use area for the Flux Chipper?

In what situations do you normally use it?

How often do you use it?

For how long do you use it each time? (estimation of average)

Do you use several types? If yes, what differs between them?

- Size
- Angle of chisel (which one is better? Different use areas?)
- Grip type
- Funcitonality (blow, hand protector, safety lever etc)
- Other aspects (material, grip form etc)

Do you ever switch chipper during the workday?

Between which ones, and why?

Do you use any accessories? If yes, which and in what purpose? How well do they work together with the flux chipper?

Could you describe a typical scenario where the Flux chipper is involved?

What do you do with the chipper when you don't use it?

Where is it kept between the shifts?

Ergonomics

What do you think of chippers with a pistol grip compared to straight chippers?

Does the work ever require extra pressure to be put on the chipper? If yes,

When?

How often?

How do you change your working stance?

Do you ever apply any type of structured rotation at work in order to minimize the physical workload?

Are there any typical working positions? If yes,

Which are the most commoin?

Which are the toughest ones?

What do you do yourself to minimize the load?

Did you, during your career, get in contact with any RSIs? (yourself or among colleagues)

Do you experience vibration as a problem during any time during work?

How is vibration related issues treated in the workplace?

Did you experience, or do you know of, any work related accidents (involving a flux chipper) if yes, what happened and what was the outcome?

What safety precautions are applied at work?

How is the chipper gripped?

One or two hands?

Lever up or down, operated with thumb or other fingers?

Does the environment (weather, temperature, humidity etc) affect the usage of the chipper?

Maintenance

For how long does a tool last?

What maintenance do you apply to the machine?

What maintenance do you apply to the chisel?

Purchase

How often do you purchase new tools?

Do you get a chance to affect what tools are purchased?

What factors are important to you when choosing a tool?

Additional general questions

Can you think of any particular issue that commonly appears during work?

Is there anything (function, property or otherwise) that you believe is especially good/bad with any type of chipper?

Have you used other chippers? (other types, brands etc)

Is there anything in particular that you liked/disliked with any of them?

Do you have any extra comments about FCH?

Questionnaire about Flux Chipping Hammers

About this questionnaire
Thank you for filling out this questionnaire. The questionnaire is a part of a development project between Chalmers University of Technology in Sweden and Fuji Air Tools, with the goal to develop a more user-friendly Flux Chipping Hammer. The answers gathered from this survey will strongly assist this purpose and your participation is of great value.

For how many hours do you estimate that you use a pneumatic percussive tool, such as a flux chipper, each week?

On average, ………. hours.

For what purpose is the flux chipper used in your workplace? (multiple choices acceptable)

- ☐ Clearing weld joints
- ☐ Rust removal
- ☐ Paint removal
- ☐ Other (please specify) : ………………………………………………..

What climates do you typically use the flux chipper in? Check the option(s) that fit the best.

- ☐ Outdoors
- ☐ Indoors (varying temperature, e.g. temporary workshop)
- ☐ Indoors (room with climate control and consistent temperature)

Are there any tasks in your routine work that require you to put more force on the flux chipper than others?

☐ yes, (specify the tasks): ………………………….☐ No, It's always the same

If yes, how big part of the chipping work is this?
Please mark your estmation on the line.

Never Always
|-----------------------|-----------------------|-----------------------|-----------------------|
0% 25% 50% 75% 100%

How often do you grip the tool with both hands during work?
Please mark your estmation on the line.

Never Always
|-----------------------|-----------------------|-----------------------|-----------------------|
0% 25% 50% 75% 100%

Is the tool ever disassembled at the workplace?

☐ No, it is never disassembled
☐ Yes, It is disassembled by other staff
☐ Yes, I do it myself

If yes,
How often is it disassembled? ………. times per☐ month☐ year
In what purpose is the tool disassembled? ……………………………………………

How often do you remove/change the chisel from the machine?
….. times per☐ month☐ year
In what purpose do you remove/change it? …………………………………………..

How often do you sharpen the chisel? ………. times per☐ month☐ year
For what purposes does the chisel need to be sharpened? ………………………………

What angle do you prefer on the chisel?
☐ straight☐ bent (ev infoga bilder)

What protective/extra equipment do you use during the usage of the chipper?
☐ protective goggles ☐ weld mask ☐ gloves ☐ ear muffs ☐ earplugs☐ other:............

Have you experienced that any part (e.g. springs) of a Fuji Flux Chipper has broken?
If Yes, please specify:……………………………………………………………

Did you or any of your colleagues experience any issues or injuries during usage of a flux chipper? If so, please describe:

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

Do you want to add or remove any feature or property from the flux chipper?

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

Your Information

Company name: ………………………………………….
Trade:☐ Shipyard ☐ Mechanical workshop☐ Foundry☐ Other (please specify) :...........
What is your main work function:...............................
For how long have you been working in the business:................ years☐ Other (bilder)

Which chippers do you use in your daily work:☐ FCH 1,☐ FCH 2, ☐ FCH 3

Appendix V. Affinity Diagram

Legend

F - Falkvarv
G - Gotenius Varv
HZ - Hitachi Zosen
JFE - JFE Engineering
JMUT - Japan Marine United Tsu
JMUA - Japan Marine United Ariake
JMUH - Japan Marine United Hiroshima
K- Kawaju (Kawasaki)
M - Mitsui Zosen
NSB - Nippon Sharyo Bridge
NSI - Nippon Sharyo Heavy Duty Industrial Vehicles
NST - Nippon Sharyo Train
S - Showa Manufacturing
V - Vagnhallen Slottskogsvallen
Y - Yokokawa Bridge
Ö - Ö-varvet

The tool is used with either one or two hands

"Even a light chipper is heavy to use in the long run. By then it's nice to be able to use two hands to steer it properly." - F

"We mostly use one hand when chipping, and we usually grab the lever with the whole hand (not using the thumb.)" - M

"In narrow spaces, I use only one hand. Other than that, roughly about 80% of the time, I use two hands." - HZ

"I always grip with two hands, unless it is in a narrow space." - JMUT

"I alsways grip it with two hands." - JFE

"I grip it with both hands, with the chisel downwards (thumbs upwards)" - NSB

"I sometimes work with both my hands, but this small one (FCH-20) is OK with one hand. It's not that heavy" - F

"I operate the lever with my thumb." - JFE

"We generally grip it with two hands, with the lever on the upside." - NSI

"Lever up or down is a personal choice." - JMUT

"We almost always use two hands, with the lever on the upside" - Kawaju

The tool is often used several hours per day

"We never have any kind of schedule for work rotation. It can happen that you'll be chipping for several days" - G

"If you work a full day, for many hours with the chipper, of course it tingles a bit, or you feel numb. - G

"Last week I used the chipper almost every day, but right now it's not that much. We use it often, but it varies a lot - F"

"Sometimes we use the chipper a lot, several days in a row." - G

"The guys who chip paint don't like tools that vibrate too much, since they use it a lot." - F

"We use the chipper around two hours everyday per person." - NST

"Everyone has their on chipper, and their own task. So we never rotate" - F

The tool is used in a wide variety of stances

"I pick a small tool if I'm working a lot upward" - G

"When you work upward with the tool a lot, the weight becomes significant." - G

"We worked with a guy, who jokingly asked 'cant we just turn the boat upside down?', because working above your head is exhausting and uncomfortable" - Ö

"It's tough when you are going down the ballast tanks. You go down through a small hatch and then crawl your way around." - Ö

"Sitting, standing. All possible stances" - JMUT

"We work at a workbench at around 20% of the time. The rest of the time we do all kinds of work inside boats." - Ö

"We stand up most of the time." - NSB

"We can often sit down and work here. But sometimes, we work on the undercarriage from beneath the tram and then the working positions can get uncomfortable." - V

"We avoid working with our arms in raised positions. We can turn the beams around if we need to work on a different area" - NSB

"We work in all kinds of positions, but the most common one is probably pushing the tool downwards towards the work piece" - Kawaju

"Sometimes it can be quite acrobatic. You work on all sizes of constructions and in all angles" - G

"We work in any position imaginable. You could be standing on your knees, our you could be lying on your back or your stomach. You might have to hang in one arm and chip with the other." - Ö

"We work in any position imaginable" - NSI

"Since you have to reach everything, you'll twist your ankles in any possible way." - G

"I mostly work by the table, so the postures are mostly OK. The guys in the boats are way worse off" - F

"We work in standing and sitting positions. Sometimes, we rotate the workpiece in order to avoid working on a height above the shoulders" - M

The hand can get injured when chisel gets stuck in narrow space

"There is a risk of getting clamped. Some of them have a cover for that. With those, at least you won't get your hand stuck." - G

"I've also had the chipper stick. The tool pulls you in if the chisel gets stuck. Then you have to bash it out" - F

"The chisel has gotten stuck, with the hand pressing down the lever. The hand got squeezed and damaged on the back." -JFE

"If the chisel get's stuck in a narrow space, it can pull itself stuck. If the hand gets stuck it will also lock the lever in on-mode." - G

"I dont know anyone who got badly clamped using a chipper, but there is definitely a clamping risk" - F

"The chisel can get stuck, and then the hand gets stuck as well." - JMUA

"Once, the fingers where sandwiched between a wall of work and the tool. The chisel broke." - Y

"You can get clamped. If the chisel gets stuck in a narrow space, it pulls in and you get stuck" - G

The lock lever is too inefficient

"We don't have tools with safety levers, and it's nto a problem not having one." - NSB

"If you compare to a grinder, it not that dangerous if a chipper starts running when you put it away. It doesn't really need a security lock." - Ö

"Who needs a coward-lock?" - G regarding broken lever

"We have no experience with the safety levers, never used them." - NST

"I think the lever works pretty well" - F

"I control the lever with my thumb" - F

"We don't use it here. It seems like the safety mechanism might fail. We think the version without the safety lock looks more reliable, so we tend to go with that one." - NSI

"We don't want a safety lever. It's not quick enough" - JFE

"I don't like the lock lever. It gets in the way." - JMUA

"We don't use safety levers. It is not easy to use. If the tool ahd a safety lever, we would cut it off." - JMUT

The tool needs to be oiled

"We oil the tool every two weeks or so." - Ö

"When they work poorly, we oil them up" - G

"I usually pour some oil into the tool. Mauybe once every other day" - F

"We change the oil. Fuji helps out with more elementary repairs such as disassembling the tool for cleaning the insides." - NSI

"Some tools allows for the attachment of a container with oil in the rear end. But most often, you use a lubrication pitcher." - Ö

"Lubricators, oilers and regulators are used within bigger companies." - Y

"We oil the tool once a day, after we finished working with it." - Kawaju

"We only oil the tool. Fuji does any kind of more complicated repairs" - NSB

The chisels need to be resharpened occasionally

I sharpen the chisel some times, because I have to. When I chip paint I like it slightly sharper" - F

"When the chisels get to round and bulky, we sharpen them" - G

"We maintain the chisel by sharpening it and hardening it with a burner" - Y

"We have a subcontractor who charpens the chisel for us" - JMUA

"A sharp chisel is necessary for narrow corners. Sometimes for the beads." - G

"If the chisel is too sharp you can get cut marks in the material" - G

"We whet the chisel about as often as we receive a new tram. Then we change the chisel itself about once a month, according to which work needs to be carried out" - V

"I think the chisel is always the same. Until it gets worn out. Sometimes it happens that we whet it then. But I have never experienced a chisel change. " - Ö

"The only thing we do with the chisel is grinding it to make it sharper" - NSB

"We grind the chisel to sharpen it, and harden it by heating" - JFE

Particles enter the tool and impede perfomance

"If the tool doesn't work, we leave it to the repairshop" - JFE

"If we get sand in them, they'll stop working. We turne them in to get them cleaned." - G

"The only issue is when you get sand in the tool. The tiniest grain can make a difference. That's when you have to take it apart to clean it" - F

"Water, blester sand or steel chips in the machine is a common reason to take it apart. This happens about 5 times per year." - Y

The chipper is used for...

"We use the chippers to remove rust, paint or sputter. Sometimes we also use it to remove filler, instead of grinding it. This makes it less dusty, as it comes off in larger chunks instead." - V

"We use it to remove rust and cleaning slag in weld beads" - G

"The main use area is cleaning welding spatter" - Y

"I use it mainly to remove spatter" - HZ

"If the spatter is loose, you can just pick it of. If it is stuck, I use the chipper. Depends on the bead" - F

" FCH20, 25. For big parts, we use the FCH25. For precision parts, we use FCH20." - S

"I use the small chipper for smaller work, like clearing beads" - F

"If I know that I'll only be working on small strings of rust all day, I'll pick a small chipper. But if there are thick patches of rust or big beads, I'll pcik a big one." - G

"We use the chipper for weld joints, to remove sputter. And also sometimes for rust." - Ö

"If there is a lot of spatter, we change to a more powerful tool (FCH 25)" - NSB

"We mostly use FCH25, but use FCH20 for smaller joints because it is lighter." - JMUT

"When we want low power, e.g. when we want to vibrate sand away from new casts, we switch to FCH20." - S

"If you have cut open a hatch to get down into a machine room - then you can chip away the paint instead of grinding it. Then you get large flakes instead of a lot of dust."- Ö

"For longer jobs, like clearing paint, and preparing before welding, I prefer the larger tools." - F

"I mostly use the smaller ones, ecause I msotly do smaller jobs (welding). It's good for spatter" - F

"We use it to remove rust and spatter in weld beads" - G

"We probably use the FCH20 when we're working with a short weld joint length, because it's lighter and it does the job" - Kawaju

"The casts have air bubbles in them, so we have to push harder in order to caulk them. We do this every day." - S

The tool is used outside year round

"It is used a lot in varying climate. It can get rusty." - Y

"In the summers, the tools can get hot. In the winters it gets cold. It was a bigger problem in the shipyards I have worked in. Then the tools got really cold and were unconfortable to hold." - V

"During the winter, we use air heaters in the system to keep the tools from freezing" - Y

Appendix V. Affinity Diagram

Injuries related to chipper usage

"It has happened that you have had your hands come in contact with a hot surface when chipping." - M

"Chips and dust scatter, and can get in your eyes. You don't always wear goggles" - G

"Sometimes, when we work in narrow spaces, the vibrations make the hands and fingers slam against the surrounding surfaces" - NST

"RSI:s are more common among people who work all day long with chippers, grinders and other vibrating tools. We don't do that in here" - F

"You can get white fingers. When it's cold, you really feel it. " - Ö

A small size is preferable

"We use the grinder when we can, but sometimes there's just not enough space. Then we use the chipper." - Ö

"I use the little one (FCH-20) the most, because it is handy" - F

"The small ones are nice to handle. because I can bring it in my pocket." - G

"Length is not that important. You work with what you've got" - F

Small parts of the chipper occasionally break

"We have a new chipper that has a spring for attaching the chisel, which often breaks, even if you follow their directions on air pressure levels." - V

"It has happened that a spring that keeps the chisel in place has come loose. Then the chisel has sometimes ejected like a spear" - V

"These tools have been the same ever since i started, 41 years ago. We got a new one a couple years ago, and it looks exactly the same" - F

"Most of our tools are old. 30 years at least. They last longer, the new ones break too easily." - G

"The spring in the front breaks sometimes" - regarding caulking hammer. - G

"Who needs a coward-lock?" - G regarding broken lever

"Unfortunately, the safety lock often breaks. I sometimes try to fix them, because they are pretty good. Without it, the tool can start when you put it away" - F.

"The piston and cylinder can get worn out" - Y

"The pin can get worn out" - Y

"I have to change electric tools several times per year. But the pneumatic machines last" - F

"The lever pin is too weak" - JFE

"The locking clutch fell out" - Y

"The holder spring can break" - Y

The chisel holder gets worn out some times" - Y

"The chisel can get worn out" - Y

"Many of these old ones lose their power, but this one is good (about a Fuji chipper)" - F

"It has happened that the square holder of the chisel has been worn out" - NST

"Quick release wears out quicker than threaded container." - JMUA

The tool is stored on nearby surfaces

"When we don't use it, we hang it on the wall together with other tools." - NSI

"When we don't use it, we either put it on our carts or hang it on the wall" - NSB

"I put it on the floor when I'm not using it." - JMUH

"When I don't use the tool, I put it somewhere close" - JMUA

"When I don't use it, I just put it somewhere close, on the ground or another surface" - JMUT

The operator sometimes pushes hard against the work piece

"I use extra pressure on the tool when I work in deep gorves. On flat surfaces I don't need as much pressure" - Y

"If there is a lot of spatter, you need to push the tool harder against the working surface" - Kawaju

"When there is a lot of spatter, we have to apply more force" - JMUH

"How much pressure I put on the tool depends on the thickness of slag and spatter" - JFE

"If the operator is further away from the compressor, he gets a higher pressure loss. Then more power has to be applied from the operator" - JMUH

"I use pretty much the same pressure on the tool all the time" - HZ

The tool is used with a variety of chisels

"If you are a painter, and you see that the rust can come off easy, they might want to change to a wide chisel, so that they can remove a lot quickly. If the rust is more resiliently stuck, they might want to change to a narrower chisel." - Ö

"It depends. We took a regular, straight chisel and bent it sharply. This was to reach narrow spaces without damaging surrounding surfaces. However, that chisel is now stuck in the retainer because of its bent shape, and so we need to switch the whole retainer when we want to switch to a flat chisel." - M

"I only use the straight chisels, but I know some guys use the bent ones" - F

"A sort tool with a short chisel feels like it vibrates less." - JMUH

"A bent chisel is good to avoid collateral damage to surrounding surfaces." - Kawaju

I use both FCH20 and 25, and I like the straight chisel better" - HZ

"The angle of the chisel is important. That is why you whet the chisel. You want to be able to work flat to the working piece, as it is the most effective. If you work at a steep angle, you risk penetrating the steel plates." - V

"I like the wide chisels. I usually don´t use the pointy ones all that much." - G

"We use the longest available chisel to reach into pipes." - NST

"We prefer to use the bent chisel when chipping at crosspieces above tracks, because then we can easier avoid scratching the surface of the tracks." - NST

Important factors when purchasing chippers

"When you buy new tools, you look for something that is good and cheap." - Ö

"The boss buys the new tools" - F

"I try to affect the purchase. New things should be ergonomic and not vibrate too much." - F

"The brand is important. I trust Atlas and such. Brands that I've had for a long time, and know works." - F

We've bought some from the old shipyards in Gothenburg, but today we buy new stuff." - F

I took these old chippers from a guy who retired" - F

"We want tools with less vibration" - NSB

"Price and durability are important when we are buying tools" - G

"If you buy the cheap ones, you lose in the long run. Because they break." - G

"This tool was bought on an auction." -G

"I inherited my chipper from the guy who worked in my spot before" - F

"We bought some tools from the shipyards in Gothenburg that got closed down." - F

"The worker decides which tool he wants, and then the tool manager buys it, depending on the budget" - HZ

"The operators choose the tools. They try them out and pick the ones they like" - NSB

"Which chipper you use depends on which on-site workshop you are at" - JMUH

"We use FCH20F, because it's the model we've always used" - JMUH

"The tool has to be easy to use and also provide power!" - Kawaju

"We have a big chipper that is good. It has a long shaft, so that you can reach everytwhere. It's the power that it has that makes it good!" - Ö

"We use the FCH20, because we have used it for a long time and we know it works" - NST

"The one with the spring (FCH20F) has less power, and might be used where spatter is easy to remove" - JMUH

Suggested new functionalies

"A swivel for the air hose would be nice" - G

Q: What would you think of a swivel on the hose?
A: "I don't think anyone would want that" - F

"Quick release function is nice, unless it costs too much" - HZ

"For our part, here, the quick release function is almost redundant. It could almost have been permanently attached." - Ö

"We have a few chippers with the quick release function. But I don't like it, because the chisel can come loose." - Ö

"I've seen the ones with a "shield on", but I don't use it. It might be useful I guess, but it would be heavier" - F

"The clamping cover is a bit bulky, it makes it harder to reach tricky places" - G

"If the chipper has the hand guard, you also don't get any sputter on your hands." - Ö

"I like when there is a blow-function" - G

"The blow function is good. When you chip, all the flakes and the dust disappear." - Ö

Light weight is important

"Light weight is most important. Second comes high power" - JMUH

"Generally, we want lighter, cheaper and less vibrating chippers" - Y

"High power and light weight are the most important factors" - JFE

"Light weight is most important. Second is high power. After that it is important that it is easy to grip." - JMUT

"Light weight is the highest priority for us when buying new tools." - NST

Appendix V. Affinity Diagram

The tool is often roughly handled

"Everyone has their own FCH25, but the FCH20s are shared" - JFE

"When we don't use it, we put it in our toolboxes" - JMUA

"We keep the tools in a big metal bucket. The pistol type chipper might take too much space when stored." - M

"Between the shifts, we leave the cans (toolboxes) where we work." - JFE

"You don't want to worry about being careful when putting away the tool." - Ö

"The small ones are nice to handle. because I can bring it in my pocket." - G

"When I don't use the tool, I put it in my tool bag along with all my other tools" - Y

"If I'm going to weld somewhere, I bring the cutter and the welding equipment. That needs electricity. And I bring the chipper too, and then I need an air hose too. If you could cut down on the different equipments needed, you could save time and money." - Ö

"We keep the tools in old paint cans, that we use as tool boxes." - JFE

"The new ones don't last if they get tossed or fall around. Which they do." - G

"I'm not leaving my spot to switch tools. That would take too much time" - G

"The chippers are handier than blestering equipment to move around" - F

"We share the chippers among us" - NSI

"When we're not using the chippers, we keep em' on a tool trolley. We try to keep the trolley close so that we can quickly switch tools as desired" - Kawaju

When we don't use it, we put it in our toolboxes" - JMUH

"Everyone has their own FCH25. We share the FCH20s. " - S

It is common to work with the tool in narrow spaces

"I like to work with two hands when the available space allows it and you need precision." - Ö

"The wide chisel is difficult to use in corners" - JMUH

"Bent chisel is better. It is easier to reach narrow spaces without damaging surrounding area" - JFE

"It is easier to get to tricky places using a straight chipper" - G

"We use the standard 200 mm long chisel. Sometimes, a shorter chisel can be good for more narrow spaces." - M

"Straight grip is often the best. Then you don't have a handle in the way, and you can reach narrower spaces." - Ö

"If we work in a more narrow space, we use a chipper with a long, bent chisel." - NSI

"We use bent chisel, to reach narrow spaces without causing damage to surrounding surfaces." - JMUT

"It depends. We took a regular, straight chisel and bent it sharply. This was to reach narrow spaces without damaging surrounding surfaces. However, that chisel is now stuck in the retainer because of its bent shape, and so we need to switch the whole retainer when we want to switch to a flat chisel." - M

"We prefer the straight grip, because the pistol grip makes it harder to reach" - NST

Opinions on Pistol Grips

"I prefer a straight grip over a pistol grip" - NSB

"With pistol grip, the feeling is that the tool might bounce of the surface" - JMUH

"The pistol grip is useful for situations where you need more power. But the straight grip gives more stabiility." - V

"I tried the pistol grip, but I didn't like it." - JMUA

"Straight grip is often the best. Then you don't have a handle in the way, and you can reach narrower spaces." - Ö

"Straight grip is better, because holding it is easier and more steady." - JMUH

"We prefer the straight grip, because the pistol grip makes it harder to reach" - NST

"We would be ready to try a pistol grip chipper, but it would be very important that the reach would not be impeded." - NSI

"The pistol grip is for heavier work, as you can put more pressure on it." - G

"I think pistol type grip would be good." - Kawaju

"If you always work at a work station, then pistol grip can be beneficial." - Ö

"When we weld two plates together, we need to put more pressure on the tool." - JMUT

Appendix VIa. DFA Table

DFA Fuji Tools	Orange Body	Glossy Finish	Black extremities	Flanged splitting surface	Segmented handle	Black trigger/lever	Cube shaped Main Body	Cylindrical front	Clean metal connectors	Disc shaped head	Clean metal fasteners	Riveted metal ID-plate	Non continuos body shape	Clean metal part	Standard lever	Handle top straight S-curve	Rounded Edges	Bottom of Handle in Main material	Black polymer handle	Wire hanger	Projecting hanger holes	Body endings formed after extremities	Striped rubber pattern	Elevated serial number	ID-plate attached in sink	Logo engraved	Cast logo	***Total***
Heavy Duty Corner Drill	2	2	2	2	2	0	0	1	1	0	0	2	1	1	0	0	2	0	0	0	0	2	0	2	2	0	0	***24***
Impact Wrench (Orange Handle)	2	2	1	2	0	2	2	2	2	0	0	2	0	1	0	0	2	0	0	2	2	0	0	2	2	0	0	***28***
Angle Grinder	2	2	2	0	0	0	0	1	1	2	2	0	1	0	0	0	1	0	2	0	0	2	2	0	0	0	2	***22***
Impact Wrench (Black Handle)	2	2	2	1	0	2	2	2	2	0	0	2	1	1	0	2	2	2	2	2	2	1	0	2	2	0	0	***36***
Die Grinder	1	1	2	0	2	0	0	2	0	0	0	0	2	2	2	0	0	0	0	2	0	0	2	0	0	2	0	***20***
Typicality	**9**	**9**	**9**	**5**	**4**	**4**	**4**	**8**	**6**	**2**	**2**	**6**	**5**	**5**	**2**	**2**	**7**	**2**	**4**	**6**	**4**	**5**	**4**	**6**	**6**	**2**	**2**	

Benchmark	*Orange Body*	*Glossy Finish*	*Black extremities*	*Flanged splitting surface*	*Segmented handle*	*Black trigger/lever*	*Cube shaped Main Body*	*Cylindrical front*	*Clean metal connectors*	*Disc shaped head*	*Clean metal fasteners*	*Riveted metal ID-plate*	*Non continuos body shape*	*Clean metal part*	*Standard lever*	*Handle top straight S-curve*	*Rounded Edges*	*Bottom of Handle in Main material*	*Black polymer handle*	*Wire hanger*	*Projecting hanger holes*	*Body endings formed after extremities*	*Striped rubber pattern*	*Elevated serial number*	*ID-plate attached in sink*	*Logo engraved*	*Cast logo*	***Total***
Toku Wrench	0	2	1	1	0	2	2	2	0	0	0	0	0	1	0	0	2	0	0	0	0	1	0	0	0	0	2	***16***
Toku Angle grinder	0	2	2	0	2	0	0	1	0	2	0	0	1	1	0	0	1	0	2	0	0	1	2	0	0	0	0	***17***
Toku Die Grinder	0	2	1	0	0	0	0	2	0	0	0	1	0	2	1	0	1	0	0	0	0	0	0	0	0	0	2	***12***
Yokota Wrench	0	1	1	2	0	2	0	0	2	0	0	2	0	2	0	1	0	2	2	0	0	0	2	0	2	0	0	***21***
Yokota Angle Grinder	0	2	2	0	0	0	1	0	0	2	0	2	1	0	0	0	0	0	2	0	0	1	2	0	0	0	2	***17***
Yokota Die Grinder	0	2	2	0	0	2	0	2	1	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	2	0	***15***
Uryu Wrench	0	2	0	2	0	1	2	2	2	0	0	0	0	0	0	0	2	0	0	2	2	0	0	0	0	0	2	***19***
Uryu Wrench Yellow	0	2	2	2	0	1	2	2	0	0	0	2	0	0	0	0	2	0	0	2	2	0	0	0	2	0	0	***21***
Uryu Angle Grinder	0	1	2	0	0	0	0	2	0	2	0	2	0	0	0	0	0	0	1	0	0	1	2	0	2	0	2	***17***
Uryu Die Grinder	1	1	2	0	0	0	0	2	0	0	0	0	2	2	2	0	1	1	0	0	0	2	2	0	0	0	0	***18***
Ingersoll Rand Wrench	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	***8***
Ingersoll Rand Angle Grinder	0	1	1	0	0	2	0	2	0	2	0	0	1	2	1	0	2	0	2	0	0	0	0	0	0	0	0	***16***
Ingersoll Rand Die Grinder	0	0	2	0	0	2	0	2	0	0	0	0	0	2	1	0	0	0	0	0	0	2	0	0	0	0	0	***11***
Chicago Pneumatic Wrench	0	1	2	0	0	2	2	2	0	0	0	0	2	0	0	0	1	2	2	0	0	1	0	0	0	1	0	***18***
Chicago Pneumatic Angle Grinder	0	2	2	0	0	2	0	2	0	2	0	0	2	0	2	0	2	1	0	0	0	1	0	0	0	0	0	***18***
Chicago Pneumatic Die Grinder	0	2	2	0	0	2	0	2	0	0	0	0	0	0	2	0	1	0	0	0	0	1	0	0	0	0	2	***14***
Atlas Copco Wrench	0	2	2	1	0	2	2	2	0	0	0	0	0	1	0	1	2	2	2	0	0	0	1	0	0	0	2	***22***
Atlas Copco Angle Grinder	0	0	1	0	1	2	0	1	0	2	0	0	0	0	0	0	0	1	1	0	0	2	0	0	0	0	0	***11***
Atlas Copco Die Grinder	0	0	2	0	0	1	0	2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	***7***
NPK Wrench	0	2	0	2	0	0	2	2	1	0	0	0	0	1	0	0	2	0	0	0	2	0	0	0	0	0	2	***16***
NPK Angle Grinder	0	2	1	2	1	2	2	2	0	2	0	1	1	0	1	0	2	0	1	0	0	1	0	0	1	0	0	***22***
NPK Die Grinder	0	2	2	0	0	2	0	2	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	2	***13***
Total	**1**	**31**	**32**	**12**	**4**	**27**	**17**	**38**	**6**	**14**	**0**	**10**	**12**	**17**	**13**	**2**	**24**	**9**	**15**	**4**	**6**	**16**	**11**	**0**	**7**	**3**	**18**	
Inverted total	**43**	**13**	**12**	**32**	**40**	**17**	**27**	**6**	**38**	**30**	**44**	**34**	**32**	**27**	**31**	**42**	**20**	**35**	**29**	**40**	**38**	**28**	**33**	**44**	**37**	**41**	**26**	
Weighted Total *(Sqrt(Typicality*Inverted total))*	**19.7**	**10.8**	**10.4**	**12.6**	**12.6**	**8.2**	**10.4**	**6.9**	**15.1**	**7.7**	**9.4**	**14.3**	**12.6**	**11.6**	**7.9**	**9.2**	**11.8**	**8.4**	**10.8**	**15.5**	**12.3**	**11.8**	**11.5**	**16.2**	**14.9**	**9.1**	**7.2**	
Rank	**1**	**15**	**17**	**7**	**7**	**23**	**17**	**27**	**4**	**25**	**19**	**6**	**7**	**13**	**24**	**20**	**11**	**22**	**16**	**3**	**10**	**11**	**14**	**2**	**5**	**21**	**26**	

Appendix VIb. DFA Products


Fuji Heavy Duty Corner Drill


Fuji Wrench (Orange handle)


Fuji Angle Grinder


Fuji Wrench (Black handle)


Fuji Die Grinder

Toku Wrench


Toku Angle Grinder


Toku Die Grinder


Yokota Wrench


Yokota Angle Grinder

Yokota Die Grinder


Uryu Wrench Gray

Uryu Wrench Yellow

Uryu Angle Grinder


Uryu Die Grinder

Appendix VIb. DFA Products

Ingersoll Rand Wrench

Ingersoll Rand Angle Grinder

Ingersoll Rand Die Grinder

Chicago Pneumatic Wrench

Chicago Pneumatic Angle Grinder

Chicago Pneumatic Die Grinder

Atlas Copco Wrench

Atlas Copco Angle Grinder

Atlas Copco Die Grinder

NPK Wrench

NPK Angle Grinder

NPK Die Grinder

Appendix VII. Needs Statement

Factor	Need	Requirements
The tool is used with either one or two hands	The tool allows for a wide variety of grips	1. The tool can be efficiently operated using only one hand. 2. The tool allows for a comfortable two-hand grip
The tool is hung on walls	The tool is hangable	The tool allows for hanging on straight hooks extending perpendicular from a vertical surface with length X. The tool allows for hanging over the edge of a vertical surface with a thickness of Y.
The tool is placed on horizontal surfaces	The tool is safely placed on horizontal surfaces	The tool can not start unintentionally when lying on or being placed on a horizontal surface.
The chipper is often used several hours per day	The tool can be used for as long as necessary	The vibration exposure from the tool to the hand is less than The tool weighs less than X kg
It is common to work with the tool in narrow spaces	The tool fits in narrow spaces	1. The highest distance between the two farthest points in a cross-section (ZY plane) of the main body is less than 2. The total length of the tool, excluding the chisel, is less than 3. The tool has no extremities extending further from the tool surface than
The tool is used with a variety of chisels	The tool allows for attaching all available Fuji chisel types	The tool allows for attaching all available Fuji chisel tip types
The hand is injured when the chisel gets stuck in narrow spaces	The hand(s) is(are) protected when working in narrow spaces	The hands are protected from clamping when chisel gets stuck in narrow spaces
The chisels needs to be resharpened occasionally	The tool allows for simple sharpening of chisel	The chisels can be removed and reinserted in less than X seconds by an average user
The tool needs to be oiled	The tool allows for simple lubrication	Lubrication is possible by inserting oil through air inlet.
The tool is placed among other tools in closed containers such as tool boxes, cart shelves and buckets.	The tool allows for volume efficient storage.	See factor 9
Sputter and particles fly into the eyes and face	The tool protects the user's eyes and face from sputter and particles	No sputter or particles from the processed surface can reach the eyes of the user.

Appendix VIII. List of Requirements

#	Area	Criteria	Type of Measure	Target Value	Limit Value	Method of Evaluation	Fulfilment	Origin	Specific Source	Comment
1	*Functionality*	Allow for hanging on straight hooks extending perpendicularly from a vertical surface.	Binary	Yes	Yes	Functional check	Y	User interviews		Possible to hang using the lever
2	*Functionality*	Allow for hanging over the edge of a vertical surface with a thickness of 10 mm and a height of 50 mm	Binary	Yes	Yes	Functional check	Y	User interviews		Possible to hang using the lever
3	*Functionality*	Not have perpendicular extremities extending further from the tool body during operation than	Millimeters	< 20	< 30	Measure	Y	User interviews		Fulfilled when lever is pressed down
4	*Functionality*	Allow for attaching all available Fuji chisel types	Binary	Yes	Yes	Functional test	Y	User interviews		Implementing a modification of the already existing quick attachment solution
5	*Functionality*	Allow removing and reinserting chisels, by an average user, in less than	Seconds	30	60	Functional test	Y	User interviews		Implementing a modification of the already existing quick attachment solution
6	*Functionality*	Allow removing and reinserting chisels, by an average user, without the usage of tools	Binary	Yes	Yes	Functional test	Y	User interviews		Implementing a modification of the already existing quick attachment solution
7	*Functionality*	Allow lubrication by inserting oil through the air inlet	Binary	Yes	Yes	Functional test	Y	User interviews		Same degree of fulfilment as in original FCH, which meets the requirement
8	*Ergonomics/ Functionality*	Have a total length, excluding the chisel, of	Millimeters	< 205	< 240	Measure	y (232,5)	User interviews		
9	*Safety*	Not lose components during expected use, including handling and occasional dropping	Binary	Yes	Yes	Functional test	?	Regulation	ISO 11148, 4.2.6	Needs verification for new parts in isolator mechanism
10	*Safety*	Remain inactive when lying or being placed on a horizontal surface.	Binary	Yes	Yes	Functional check	Y	User interviews		Same degree of fulfilment as in original FCH, which meets the requirement
11	*Safety*	Protect hands from clamping when chisel gets stuck in narrow spaces.	Binary	Yes	Yes	Functional test	y	User interviews		Only fulfilled when user employs the developed optional add-on shield
12	*Ergonomics*	Have a maximum vibration exposure value of	m/s2	< 2.5	< 5	As specified in ISO 28927	?	User interviews, Regulations	Physical Agents (Vibration) Directive	Can not be verified until the prototype is finished.
13	*Ergonomics*	Not have sharp edges or angles or rough or abrasive surfaces.	Edge radius [mm]	r > 3	r > 1	Measure	Y	Regulation	ISO 11148, 4.2.1	Same degree of fulfilment as in original FCH, which meets the requirement
14	*Ergonomics*	Be possible to lay aside on a plane or surface and remain in stable position.	Binary	Yes	Yes	Functional test	Y	Regulation	ISO 11148, 4.2.2	Should function as with the current tool, where the lever stops the tool from rolling.
15	*Ergonomics*	Blow outlet air in the opposite direction of the user	Binary	Yes	Yes	Functional test	Y	Regulation	ISO 11148, 4.3	
16	*Ergonomics*	Emit a maximum level of noise of	dB	< 80	< 87	As specified in ISO 15744	?	Regulation	ISO 11148, 4.4	Needs verification through prototype testing.
17	*Ergonomics*	Facilitate the collection and removal or supression of airborne dust particles and fumes generated by the work process.	Binary	Yes	Yes	?	?	Regulation	ISO 11148, 4.6.2	
18	*Ergonomics*	Allow for gripping in such a way that high feed force can be transmitted in an ergonomic way from the hand of the operator to the tool.	Subjective	5/5	3/5	Comparison to ergonomic theory	N	User studies, ergonomic theory	Lindqvist, 2007	New tool design does not allow the optimal grip type for feed force in the tool direction.
19	*Ergonomics*	Be equipped with a single control device for starting and stopping	Binary	Yes	Yes	Functional test	Y	Regulation	ISO 11148, 4.8.1	Same degree of fulfilment as in original FCH, which meets the requirement
20	*Ergonomics*	Have a control device that is adapted to the handle, or to the part of the tool being gripped, so that it can be held comfortably in the run position, and so that the operator can activate it without releasing the grip on the handles.	Subjective	5/5	3/5	Comparison to ergonomic theory	Y	Regulation	ISO 11148, 4.8.1	Same degree of fulfilment as in original FCH, which meets the requirement

#	*Area*	Criteria	Type of Measure	Target Value	Limit Value	Method of Evaluation	Fulfilment	Origin	Specific Source	Comment
21	*Ergonomics*	Cease to be powered when the start-and-stop device is released.	Binary	Yes	Yes	Functional test	Y	Regulation	ISO 11148, 4.8.1	Same degree of fulfilment as in original FCH, which meets the requirement
22	*Ergonomics*	Not be possible to lock in the running position.	Binary	No	No	Functional test	Y	Regulation	ISO 11148, 4.8.1	Same degree of fulfilment as in original FCH, which meets the requirement
23	*Ergonomics*	Have a start-and-stop device designed, positioned or guarded such that the risk of unintentional start is minimized.	Binary	Yes	Yes	According to ISO	Y	Regulation	ISO 11148, 4.8.2	As current tools, one purchase option is with the lock-off lever. This option fulfills this requirement.
24	*Ergonomics*	Require a small force for keeping the device in the run position	N	Yes	Yes	Functional test	Y	Regulation	ISO 11148, 4.8.3	Same degree of fulfilment as in original FCH, which meets the requirement
25	*Ergonomics*	Be possible to start and run using only one hand.	Binary	Yes	Yes	Functional check	Y	User interviews		Same degree of fulfilment as in original FCH, which meets the requirement
26	*Ergonomics*	Have a weight of	Kg	< 1.5	< 2	Measure	y	User interviews, Regulation	ISO 5349	Only fulfilled when the lighter chisels are used.
27	*Ergonomics*	Have a handle diameter of	Millimeters	34 - 38	30 - 50	Measure	y	Ergonomic theory	Atlas Power Tool Ergonomics	
28	*Ergonomics*	Have a handle length of	Millimeters	>180	>150	Measure	Y	Ergonomic theory	Canadian Centre for Occupational Health	Can be held along the entire housing length
29	*Ergonomics*	Allow for the start-stop device to be operated independently of the angle between the tool and the hand around the X axis of the tool	Binary	Yes	Yes	Functional test	Y	User interviews		Same degree of fulfilment as in original FCH, which meets the requirement
30	*Ergonomics*	Be grippable and operable with a power grip regardless of the direction of the chipper in relation to that of the thumb(s) of the user	Binary	Yes	Yes	Functional test	Y	User interviews		
31	*Ergonomics*	Have a center of gravity placed close to center of gripping area.	Millimeters	< 10	< 30	CAD Check	Y	Company		
32	*Ergonomics*	Surface temperatures of the tool that are held during use or that can be inadvertly touched shall follow the provisions of ISO 13732-1 and ISO 13732-3 (Ergonomics of the thermal environment).					Y	Regulation	ISO 11148, 4.3	Well fulfilled, as the original FCH is considered to fulfil this requirement, and the new model also incorporates a rubber cover that isolates the user from the metal.
33	*Manufacturing*	Mechanical components should be made from steel	Binary	Yes	Yes	Design Specification check	Y	Company		
34	*Aestethics*	Express Fuji's desired characteristics.	Binary	Yes	Yes	Company feedback	Y	Company		Aestethic design was developed in cooperations with Fuji marketing through an iterative process.
35	*Aestethics*	Fit into Fuji's product range.	Binary	Yes	Yes	Company feedback	Y	Company		Aestethic design was developed in cooperations with Fuji marketing through an iterative process.
37	*Aestethics*	Contain vital design elements repeatedly used in previous Fuji designs.	Binary	Yes	Yes	Visual check	Y	Company, Theory	Karjalainen	

SEMANTIC DIFFERENTIAL

	3	2	1	0	1	2	3	
Weak	○	○	○	○	○	○	○	Powerful
Robust	○	○	○	○	○	○	○	Fragile
Safe	○	○	○	○	○	○	○	Risky
Blunt	○	○	○	○	○	○	○	Precise
Professional	○	○	○	○	○	○	○	Consumer oriented
Reliable	○	○	○	○	○	○	○	Unreliable

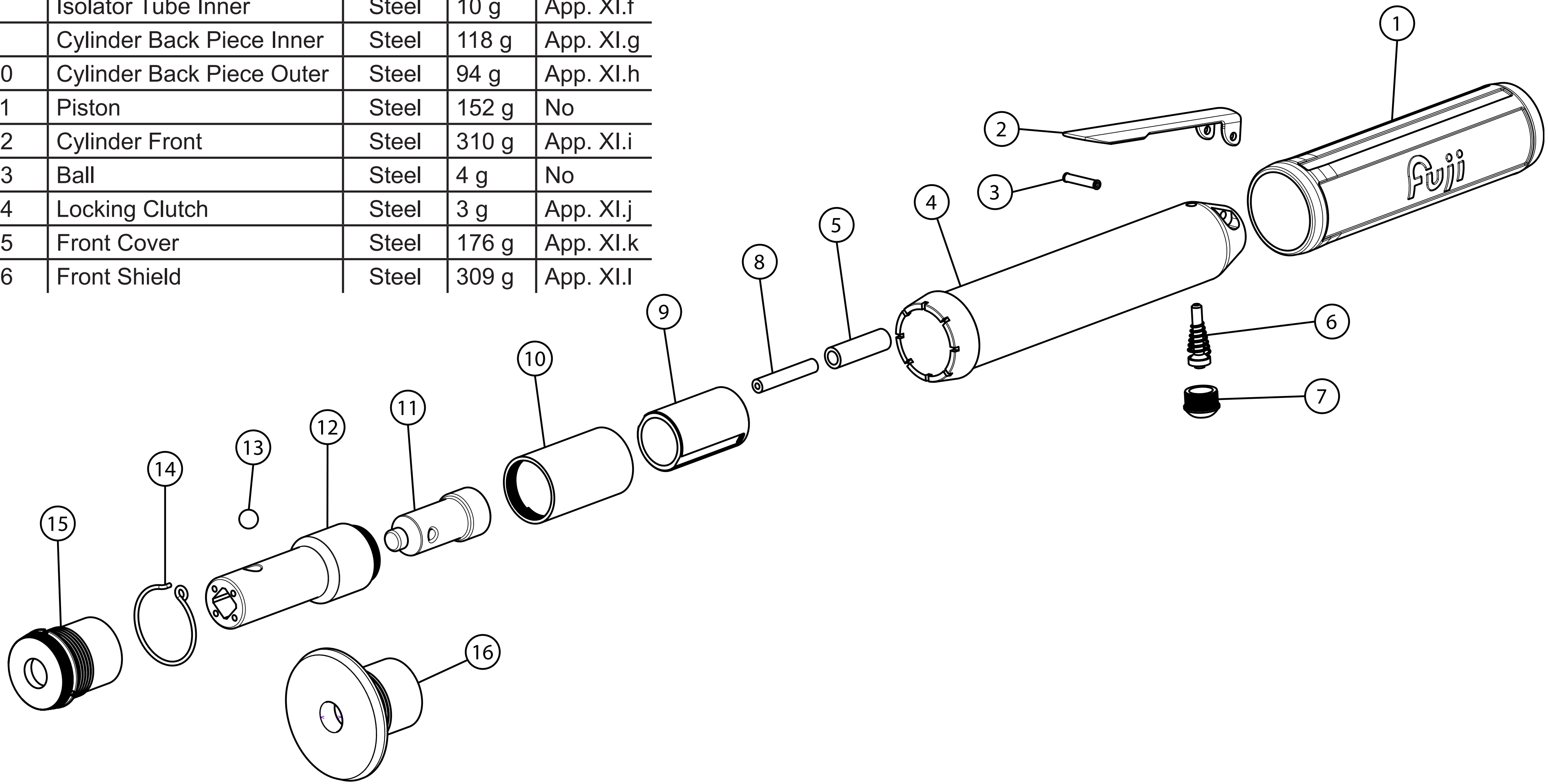
Appendix IXb. Semantic Differential Results Table

	Classic	Powerfu	Sharp	Elegant
Powerful	2	36	28	15
Robust	12	35	32	13
Safe	7	29	30	16
Precise	0	18	18	7
Professional	−15	19	10	−14
Reliable	8	35	32	15
Total	14	**158**	**150**	52

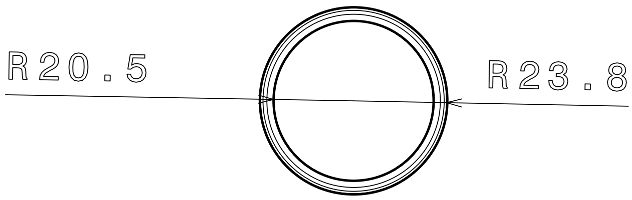
Subject #	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	
Concept #1: Classic																	
Powerful	1	1	0	1	1	2	1	2	−1	1	0	−1	−1	−2	−2	−1	***2***
Robust	1	1	1	1	3	−2	2	3	−2	1	0	1	2	2	−1	−1	***12***
Safe	3	1	−1	2	3	0	3	−1	−2	0	0	−1	0	2	−1	−1	***7***
Precise	3	1	1	1	3	−1	−1	1	−3	−2	0	2	−1	−2	−1	−1	***0***
Professional	0	1	−1	−2	0	−1	−2	−1	−3	2	−2	−3	−1	0	−3	1	***−15***
Reliable	2	1	−2	−1	3	−1	2	3	0	0	1	0	0	2	−1	−1	***8***
Total	10	6	−2	2	13	−3	5	7	−11	2	−1	−2	−1	2	−9	−4	***14***
Concept #2: Powerful																	
Powerful	2	2	2	3	2	1	3	3	2	3	3	2	2	2	1	3	***36***
Robust	2	2	2	1	3	2	1	3	2	3	2	3	3	3	1	2	***35***
Safe	3	2	2	3	3	1	3	0	−1	2	3	0	2	3	1	2	***29***
Precise	3	2	2	0	1	0	2	0	2	1	3	1	0	−1	1	1	***18***
Professional	2	2	1	2	2	2	−2	−1	3	2	2	1	2	−1	0	2	***19***
Reliable	2	2	2	3	3	1	3	2	2	3	3	2	2	2	1	2	***35***
Total	14	12	11	12	14	7	10	7	10	14	16	9	11	8	5	−2	***158***
Concept #3: Sharp																	
Powerful	1	1	2	3	3	1	2	1	0	2	3	1	1	2	2	3	***28***
Robust	1	2	2	3	3	1	2	2	1	1	3	2	2	3	2	2	***32***
Safe	2	2	2	3	3	2	2	1	1	2	3	1	1	2	1	2	***30***
Precise	2	2	3	0	0	2	1	0	1	2	3	1	−2	0	2	1	***18***
Professional	−2	0	2	2	1	0	−1	−2	−1	1	2	2	0	2	2	2	***10***
Reliable	0	2	3	3	3	2	2	2	2	2	3	2	1	2	1	2	***32***
Total	4	9	14	14	13	8	8	4	4	10	17	9	3	11	10	12	***150***
Concept #4: Modern																	
Powerful	1	1	3	2	2	1	−1	1	1	1	1	1	0	3	−1	−1	***15***
Robust	0	1	2	1	2	2	−2	2	−1	0	1	2	1	3	−1	0	***13***
Safe	2	−1	1	3	1	1	3	1	0	0	1	1	1	2	0	0	***16***
Precise	1	0	1	2	0	0	−3	1	1	0	1	2	0	0	0	1	***7***
Professional	−3	−2	−1	0	−3	2	−3	−2	−2	−1	1	0	−1	2	−1	0	***−14***
Reliable	0	0	1	2	2	1	−1	2	2	0	2	2	0	3	−1	0	***15***
Total	1	−1	7	10	4	7	−7	5	1	0	7	8	1	13	−4	0	***52***

Appendix X. Exploded View with Bill of Material

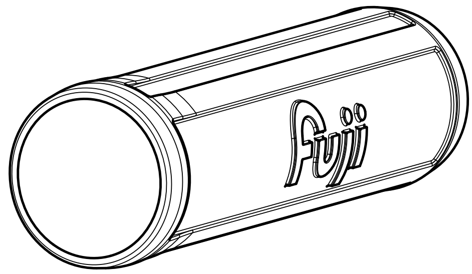
Part nr	Part Name	Material	Mass	Attached drawing
1	Handle Cover	Rubber	51 g	App. XI.a
2	Throttle Valve lever	Steel	42 g	App. XI.b
3	Throttle Valve Lever Pin	Steel	2 g	No
4	Housing	Steel	828 g	App. XI.c
5	Isolator Tube Outer	Steel	16 g	App. XI.d
6	Throttle Valve Assembly	Mixed	8 g	No
7	Throttle Valve Cover	Steel	10 g	App. XI.e
8	Isolator Tube Inner	Steel	10 g	App. XI.f
9	Cylinder Back Piece Inner	Steel	118 g	App. XI.g
10	Cylinder Back Piece Outer	Steel	94 g	App. XI.h
11	Piston	Steel	152 g	No
12	Cylinder Front	Steel	310 g	App. XI.i
13	Ball	Steel	4 g	No
14	Locking Clutch	Steel	3 g	App. XI.j
15	Front Cover	Steel	176 g	App. XI.k
16	Front Shield	Steel	309 g	App. XI.l



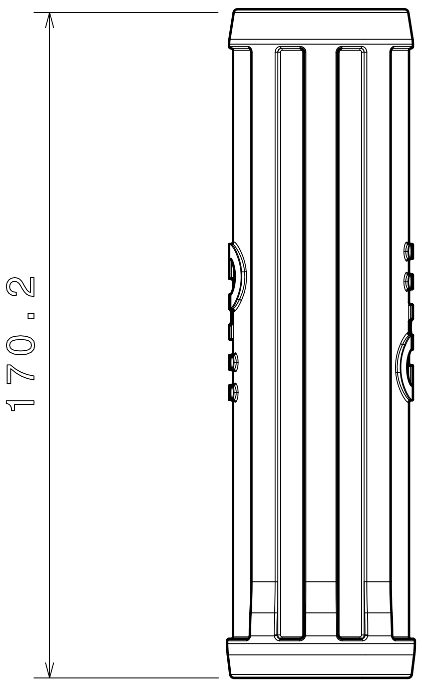
Appendix XI.a. Drawing of Handle Cover



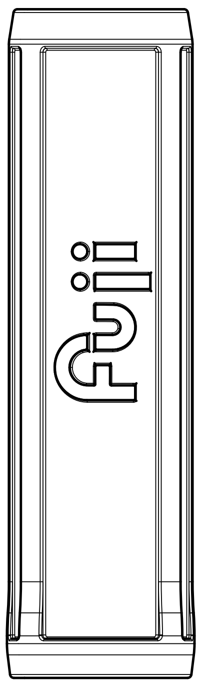
Front view



Isometric view

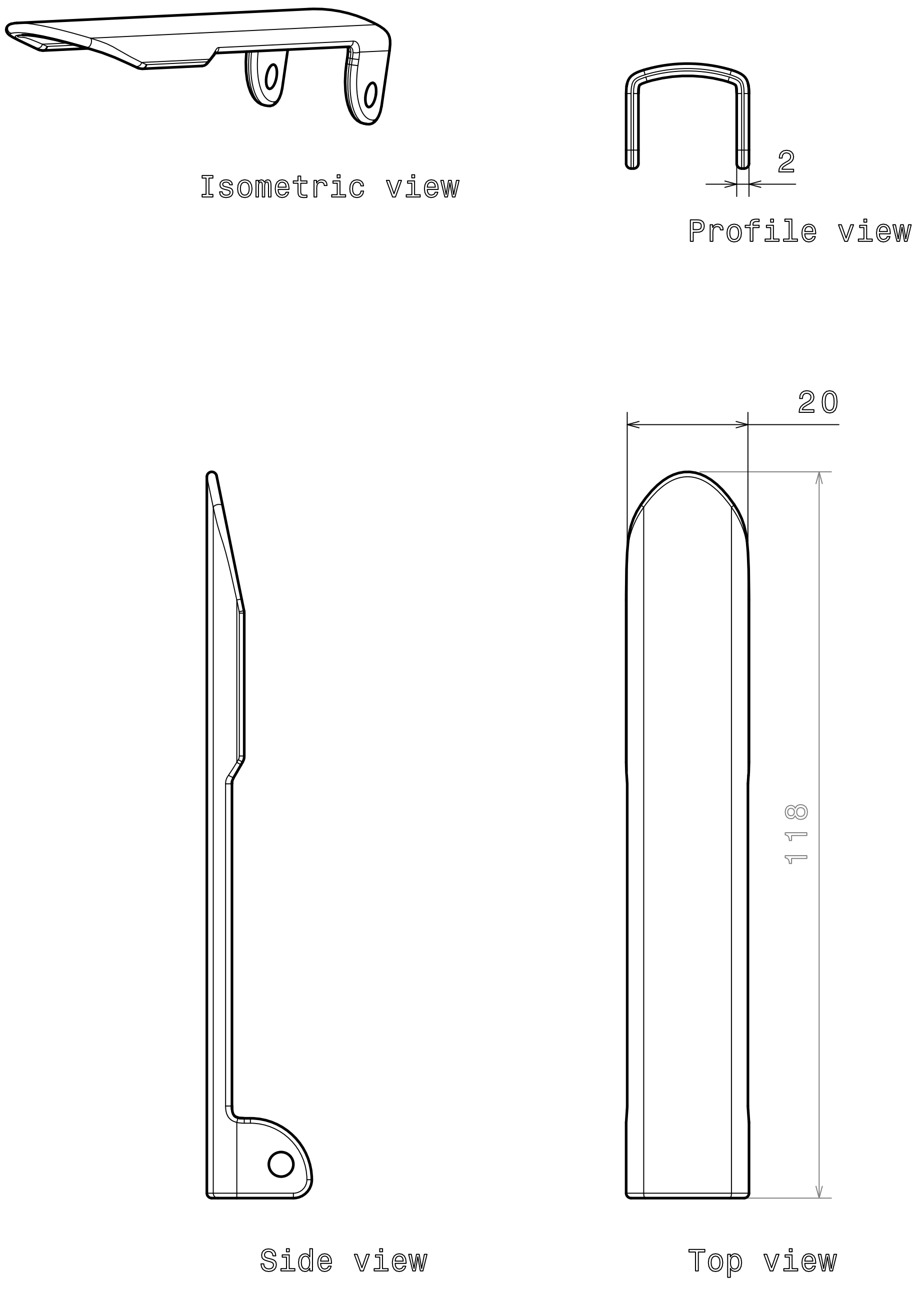


Top view

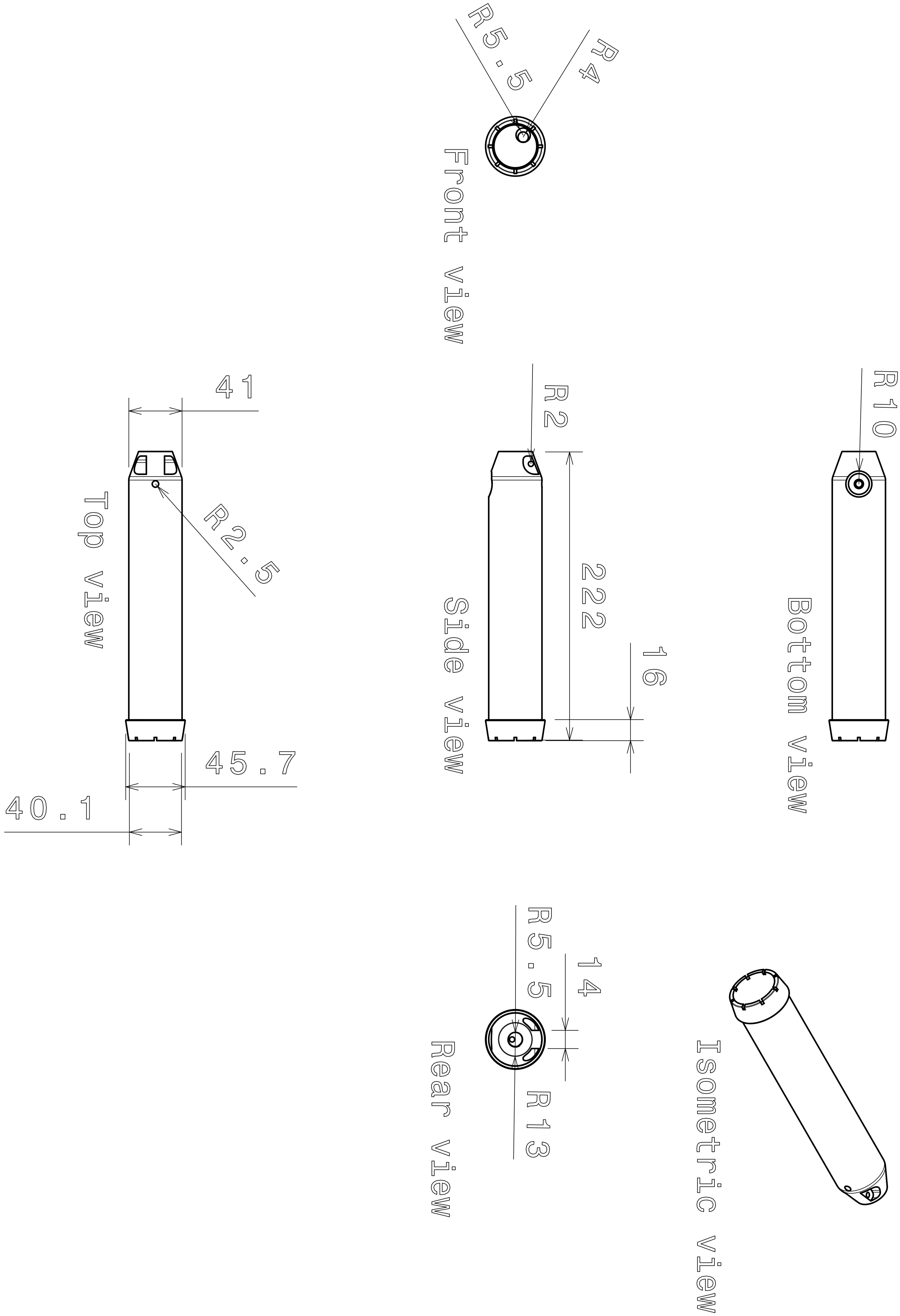


Side view

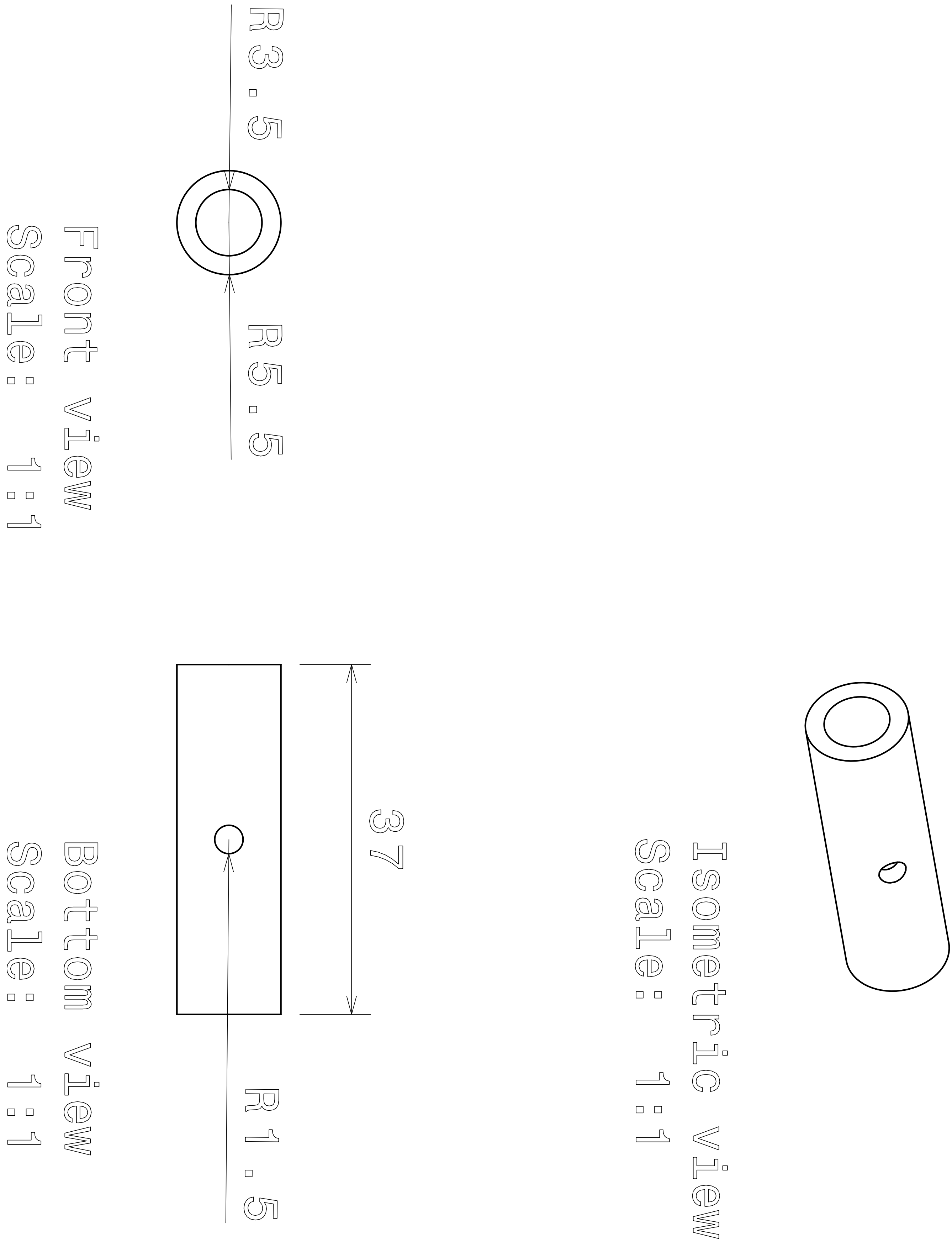
Appendix XI.b. Drawing of Throttle Valve Lever



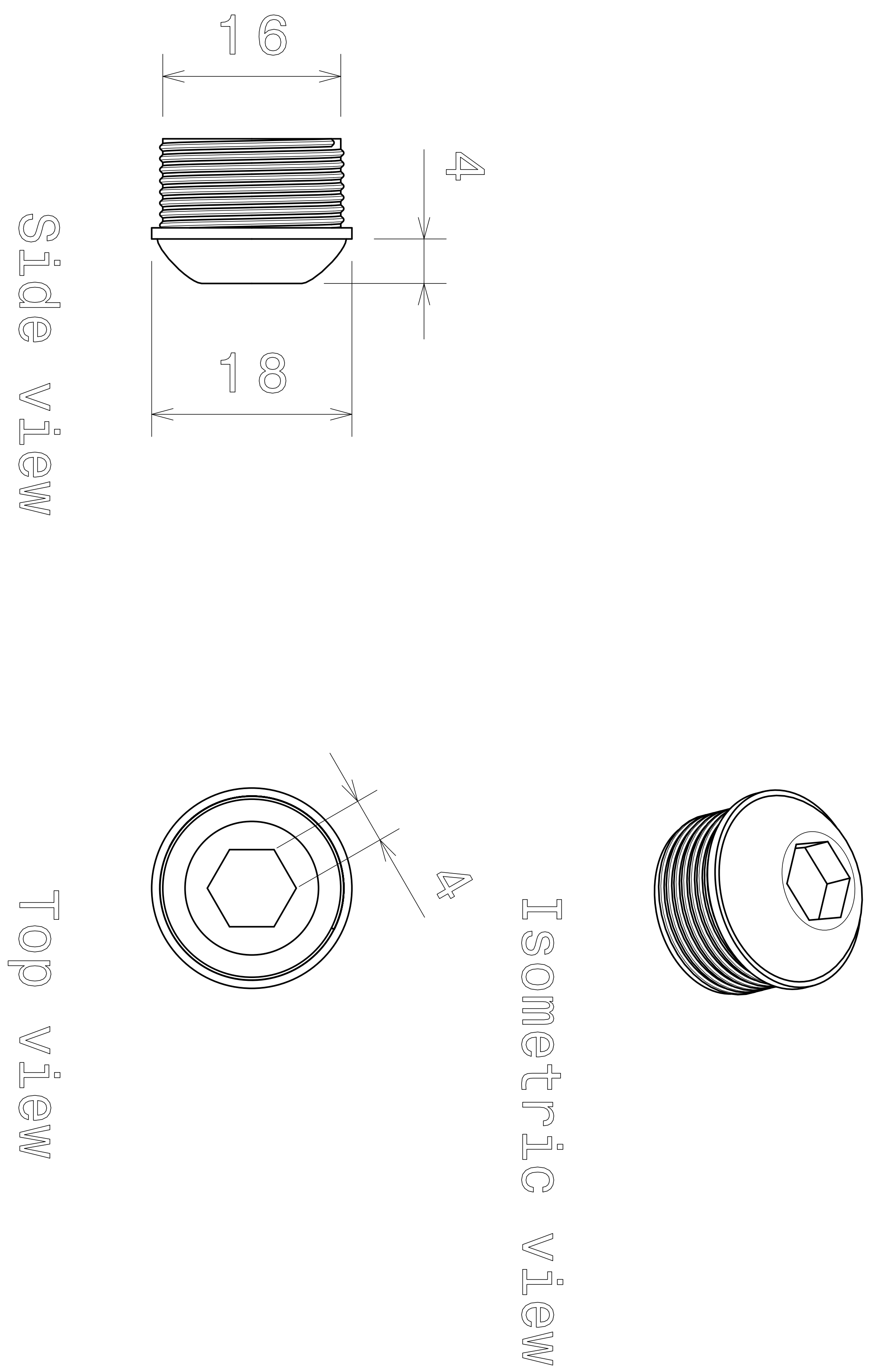
Appendix XI.c. Drawing of Housing



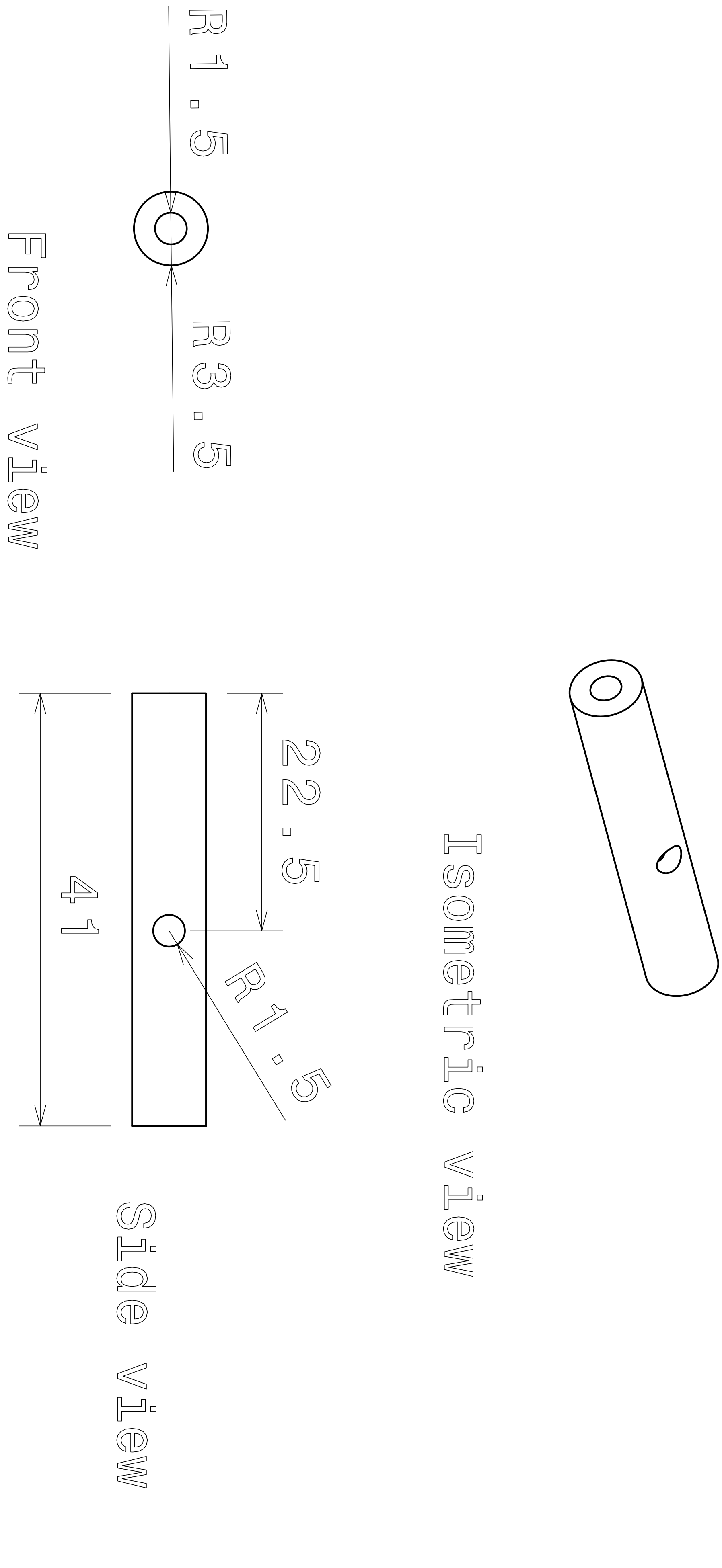
Appendix XI.d. Drawing of Isolator Tube Outer



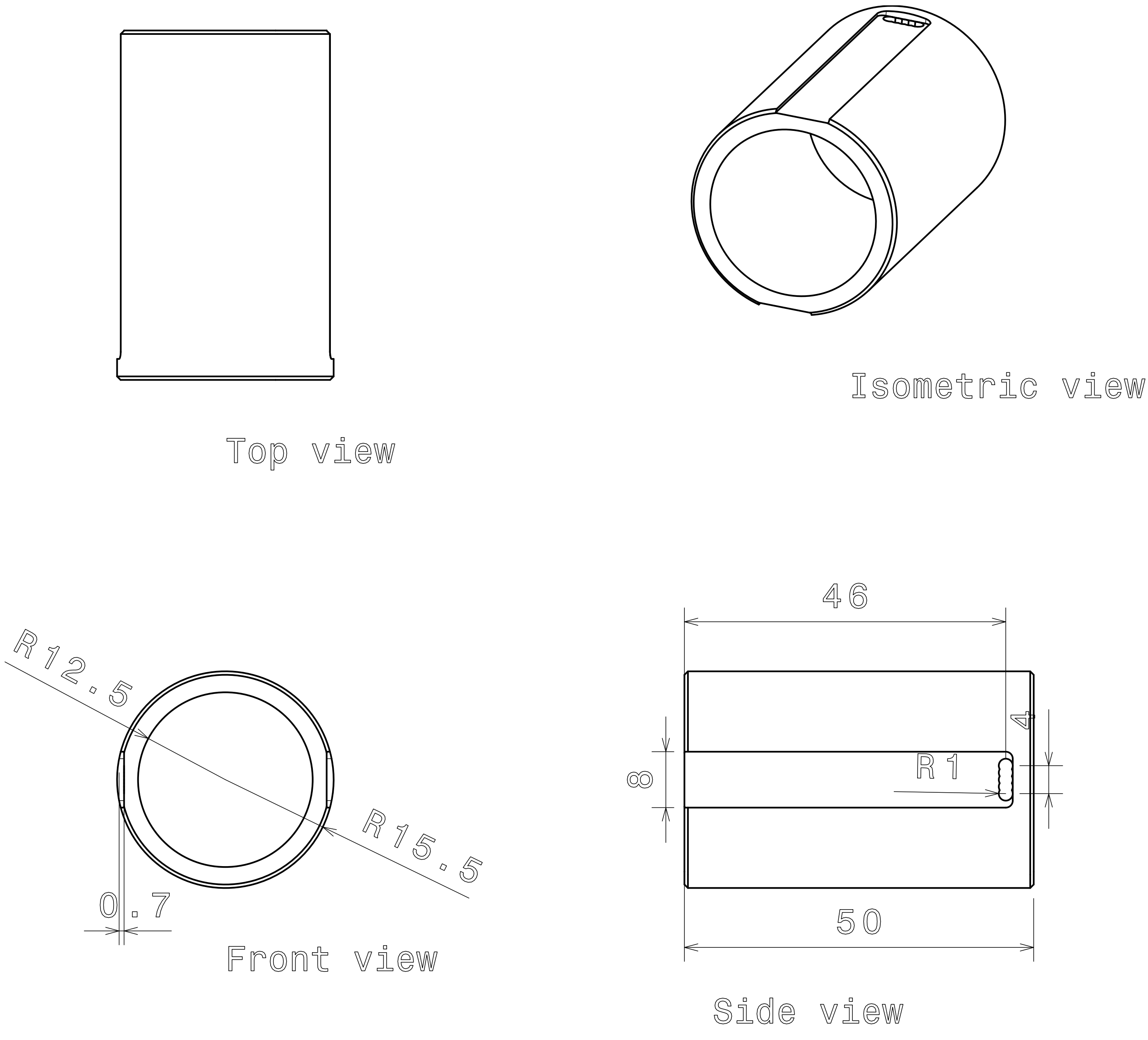
Appendix XI.e. Drawing of Throttle Valve Cover



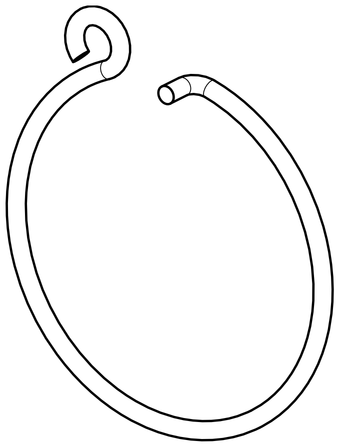
Appendix XI.f. Drawing of Isolator Tube Inner



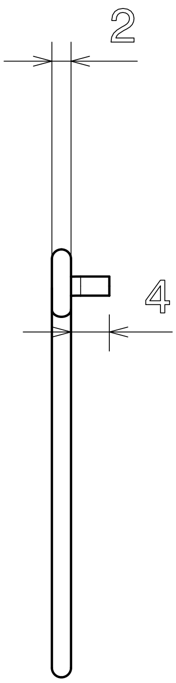
Appendix XI.g. Drawing of Cylinder Back Inner



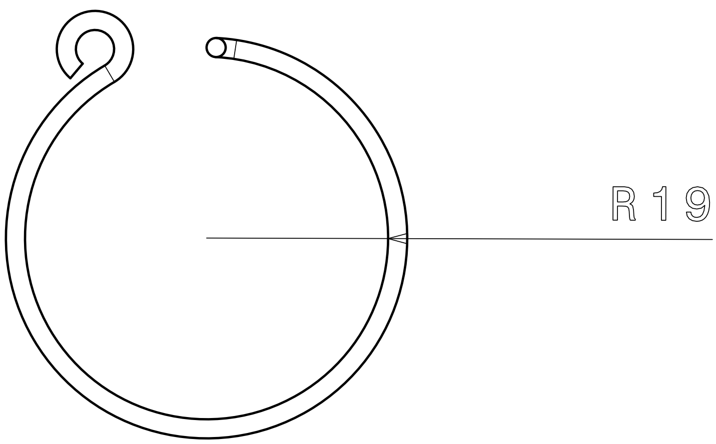
Appendix XI.h. Drawing of Locking Clutch



Isometric view

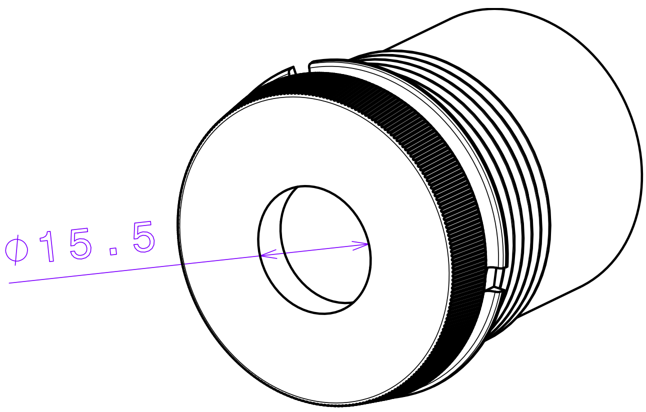


Side view

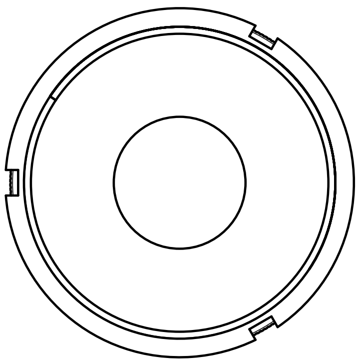


Front view

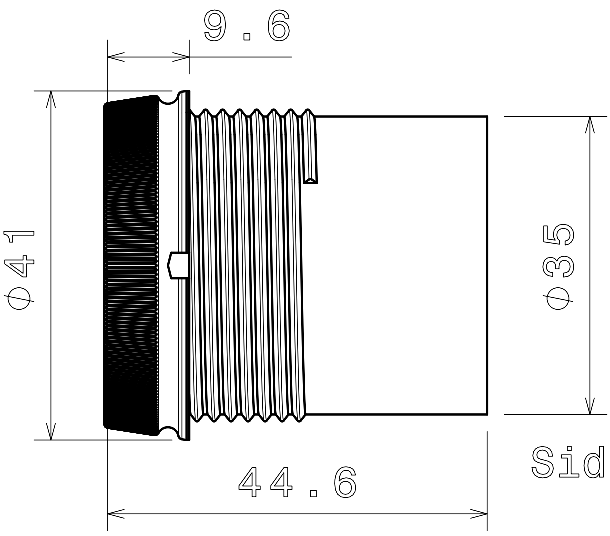
Appendix XI.i. Drawing of Cylinder Cover



Isometric view

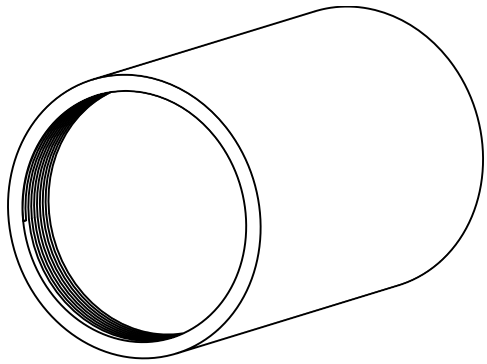


Front view

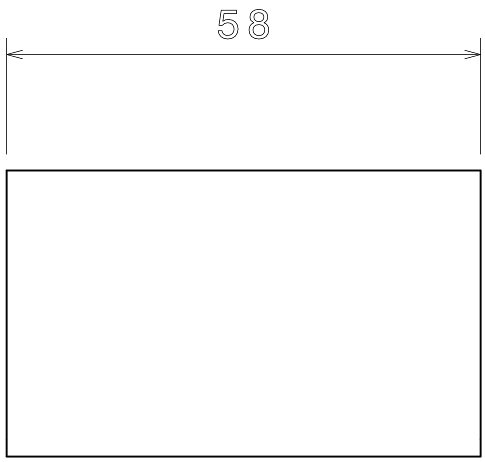


Side view

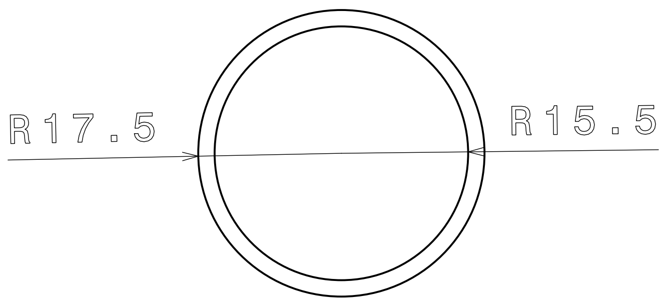
Appendix XI.j. Drawing of Cylinder Back Outer



Isometric view

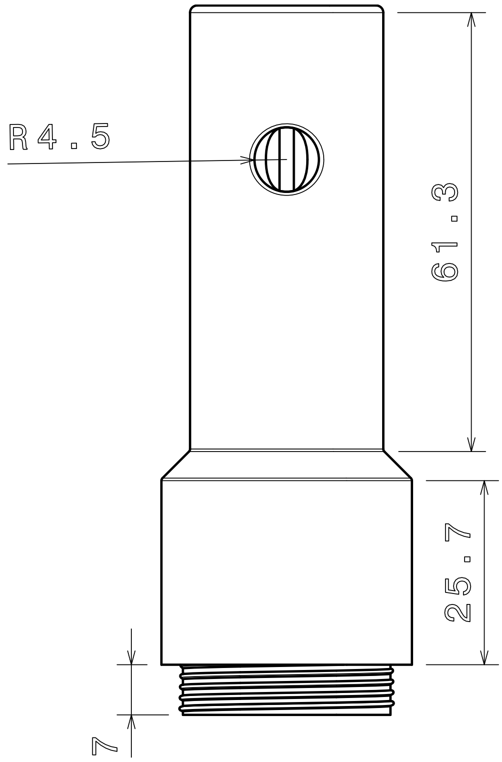


Side view

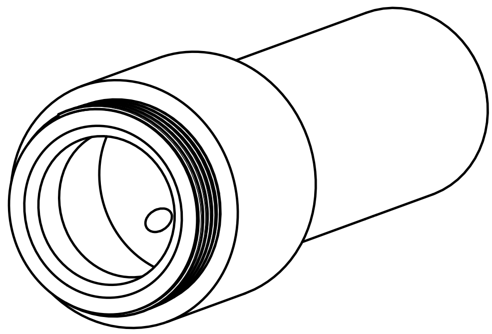


Front view

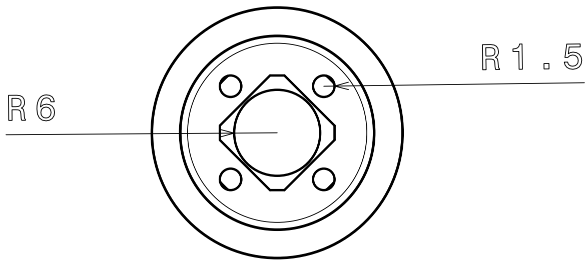
Appendix XI.k. Drawing of Cylinder Front



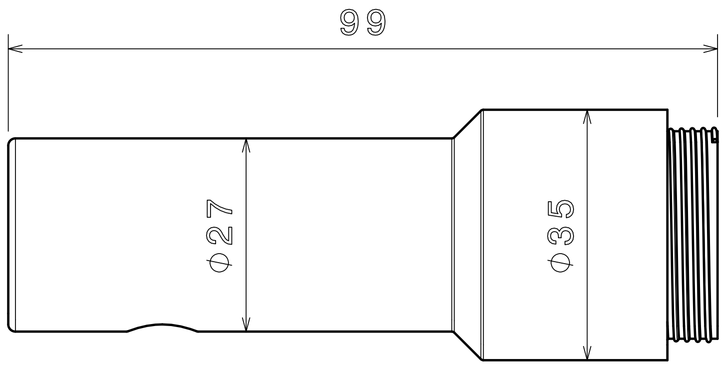
Top view



Isometric view



Front view



Right view

Appendix XI.I. Drawing of Front Shield