MASTER THESIS / PRODUCT REPORT

VIBRASHIFTER

HAND-ARM VIBRATION DAMPING EQUIPMENT

DESIGNED BY ALEXANDER THYRRESTRUP OLSEN
& JENS HENRIK THORDAL SLOTH

Aalborg University
June 2023
MA4-ID8

ABSTRACT

Dette speciale i industrielt design omhandler udviklingen af Vibrashifter, et alsidigt, eftermonterbart, vibrationsdæmpende håndtag der bevarer kontrol af en række vibrerende, håndstyrede maskiner i blandt andet byggeri- og anlægsbranchen.

Projektets udgangspunkt var identifikationen af Hånd-arm Vibrations Syndrom (HAVS) som et sundheds- og samfundsmæssigt problem, der kan opstå ved blandt andet brugen af vibrerende maskiner, afhængig af styrke og udsættelsestid. Dette kan give operatøren arbejdsskader, der belaster dem, deres arbejdsgiver og samfundet på grund af erstatningskrav, bøder, behandlinger og tidlig pension.

HAVS omfatter mange lidelser, men muskelskeletsygdommen karpaltunnelsyndrom og Raynauds syndrom er den hyppigste forekomst. Disse kan medføre gener som fingersmerter, kramper, spasme, tab af førlighed, motorisk kontrol og styrke. Karpaltunnelsyndrom kan kirurgisk behandles, men kræver ofte 3 måneders efterfølgende sygemelding, og arbejdsformen bør ændres for at undgå følgegener. Raynauds syndrom er uhelbredelig og meget udbredt. Det viser sig som anfald udløst af kuldepåvirkning, hvilket jævnligt er del af udendørs arbejde.

Sygdommene udbredes da byggelederne ofte stilles i et svært dilemma, hvor de skal vælge mellem at overholde lovgivningen ved at beskytte medarbejdere mod udvikling af HAVS eller at afslutte projektet inden for den altafgørende tidsramme. Konkurrenceevnen er afhængig af tidsramme og pris. Dette betyder, at brugen af især ældre, men funktionelle maskiner nemt overskrider grænseværdierne for vibrations udsættelse. Blandt andet af økonomiske årsager udskiftes de ældre maskiner dog sjældent til nyere modeller for at mindske vibrationer, men benyttes indtil de ikke længere er funktions dygtige. Her er Vibrashifter et alternativ, der kan hjælpe byggelederne med at beskytte deres medarbejdere uden at gå på kompromis med effektivitet.

ALEXANDER THYRRESTRUP OLSEN
JENS HENRIK THORDAL SLOTH

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THEME: Hand-arm vibration
PROJECT TEAM: 01.02.2023 - 31.05.2023
PROJECT PERIOD: MA4-ID8
MAIN SUPERVISOR: Christian Tollestrup
CO-SUPERVISOR: Erik Lund
ISSUES: 5
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HAND-ARM VIBRATION

Vibrations are quick movements that occur multiple times every second. They may appear to be harmless at first, but long-term exposure has long-term consequences.

Construction is one of the many industries that involves so-called Hand-Arm Vibration (HAV). Here, operation of hand-held gas-driven, electric, or pneumatic machines is a part of the everyday routines. To limit HAV exposure, they may use machines with integrated antivibration technology. However, it seems that this is not sufficient. Time after time, companies exceed the regulatory safety limits defined by public institutions. The number of violations is unknown since they are only registered when officials discover them, which can be challenging.

Obeying the regulations will in most cases hinder the competitiveness of companies. To compete on price, a company relies on efficiency and keeping cost low.

Even though most machine manufacturers updated their products with newer antivibration technology. Many of the highly effective anti-vibrations solutions has however turned out to be neglected by the operators as they often compromise their control in favour of machine isolation. Furthermore, many older machines remain in service as they still function as intended and can be expensive to replace. This results in worn down machines being used until function failure occurs. As machines gets worn, their vibrations magnitude tends to increase as components related to vibration reduction are becoming less effective.

OPERATORS

IMPLICATIONS OF HAV EXPOSURE

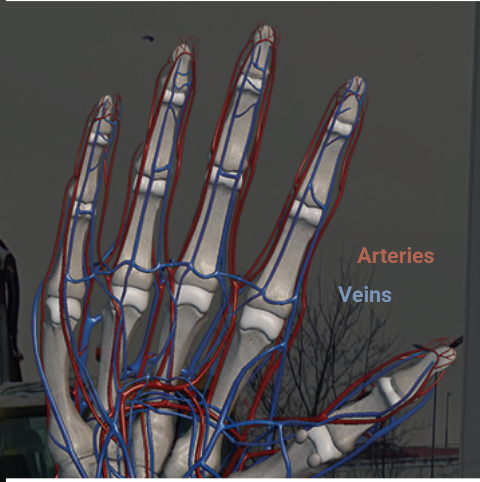
In many companies the owner and the operator are different people. This means that the people who are exposed to HAV are not the ones who make the decisions regarding when to update machines and equipment.

To reach deadlines, the operators typically work outside and year-round, in hot and cold weather. Depending on task, they are exposed to HAV for hours during the day. Though some HAV exposure of some machines is less severe than others, it adds up.

According to a chief physician, there is a mismatch between what is expected by consumers and employers and what is healthy for the operators. As a result, time and efficiency have become the main priority, meanwhile few alternatives exist that can reduce HAV exposure under such conditions, thus the operators only focus on doing their work. There are some operators who are afraid to complain or mention that they have developed illnesses, because of the fear of losing their job.

Carpal Tunnel Syndrome and Raynaud's Phenomenon are the most common HAV-induced illnesses. If they are left untreated, they can become chronic conditions. Vibration exposure can cause both illnesses simultaneously.

Raynaud's Phenomenon

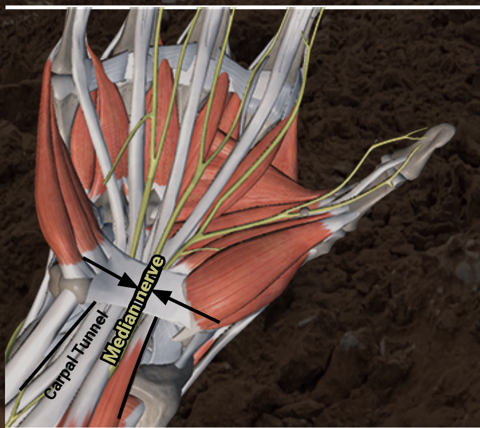


Vibration damage to the small blood vessels cause the vasomotor response to malfunction. The hands become hypersensitive, so cold temperatures trigger attacks that prevents the blood from flowing to the fingers and cause numbness and reduced sense of touch. It is also known as Vibration-induced White Fingers.

HAV exposure during operation

Observation from another site

Carpal Tunnel Syndrome



Exposing the palm or wrist to repetitive impacts and compressions irritate the tendons to swell in the carpal tunnel. Swollen tendons compress the median nerve and cause loss of hand strength and mobility.

Construction site in the winter

OPERATION

VIBRATORY TAMPING RAMMER

Among the hand operated machines, the operators dislike the Vibratory Tamping Rammer (VTR) the most. This is not without reason. The purpose of the machine is to compact sticky or soft ground. Because of the high amplitude and a low frequency of its vibrations, the VTR avoids getting stuck by jumping off the ground. This enables it to keep going forward during operation.

Control damping dilemma

Controlling the VTR requires substantial amounts of force and a tight grip. Especially on ground that has not been compacted yet. Here, the VTR is unpredictable because the ground is uneven. Unfortunately, gripping tightly increase the HAV transmission. However, it is necessary while turning, ramming uphill, or pulling backwards.

Permitted operation time

The vibration magnitude (or acceleration) varies considerably depending on the use. According to manufacturers, the vibration magnitude of most VTRs is 6 m/s^2, corresponding to 1 hour of permitted operation. However, our measurements (conducted with a professional accelerometer and collaborator) show vibration magnitudes up to 13 m/s^2. The fact is that the numbers depend on several **parameters.**

This complexity of measurement should complicate the definition of regulations, but the regulations are straightforward. If vibration magnitude exceeds the Exposure Action Value, measures should be taken to change the conditions in order to avoid any health risks. If the vibration magnitude exceeds the Expose Limit Value, it is punishable, and the operation must stop.

Turning

Pulling back

Pushing down in soft, uneven ground

Carefully ramming compact ground

Ground evenness	Ueven	←→	Even
Ground compaction	Soft ground	←→	Compact ground
Control difficulty	High	←→	Low
Vibration magnitude	6 m/s^2	←→	13 m/s^2
Exposure Action Value	5 hours	←→	1 hour
Exposure Limit Value	1 hour	←→	15 minutes

VIBRASHIFTER

200%

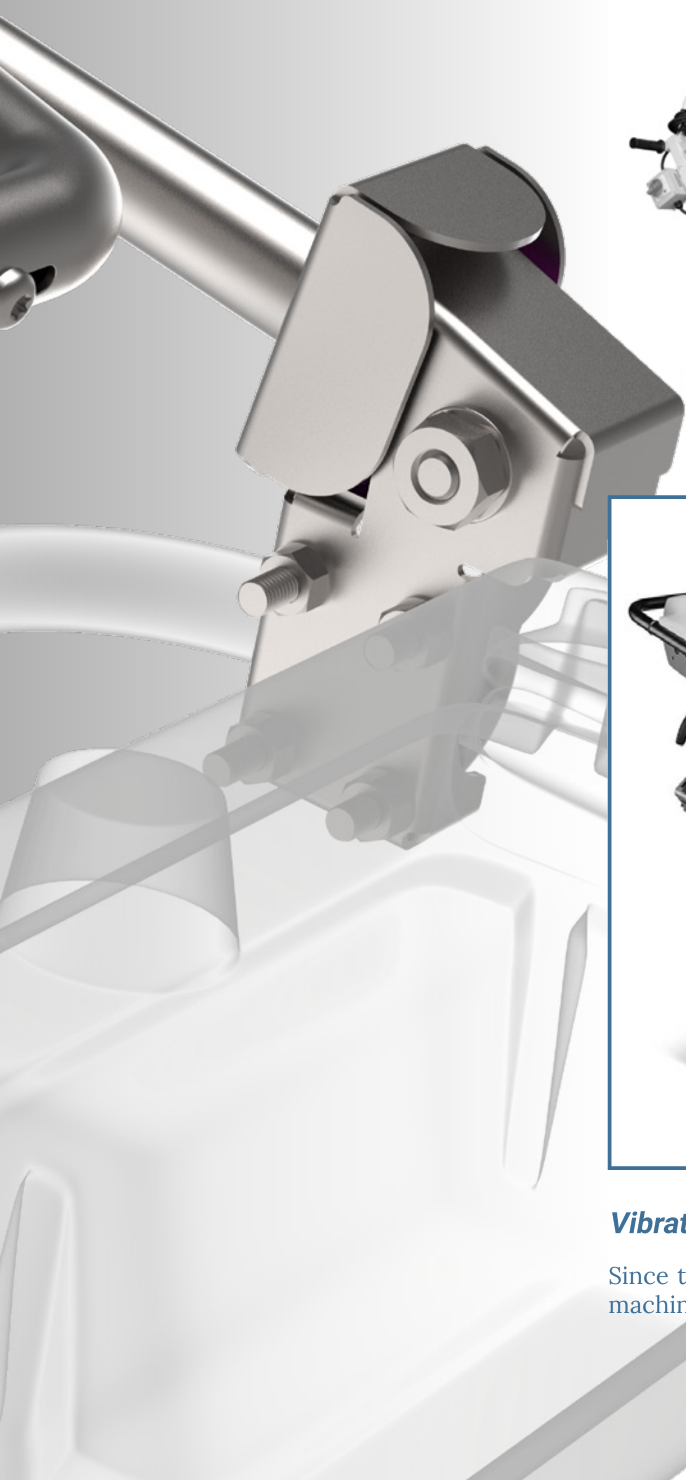
PERMITTED OPERATION TIME INCREASE

MODE SHIFT

Vibrashifter solves the dilemma between control and damping with MODE SHIFT. A feature that allows the operator to quickly adapt to the everchanging conditions of his tasks. Whenever less control is necessary, Vibrashifter provides the option to change mode from high control (and limited damping) to high damping (and less control). The Operator does not need to endure high vibration exposure, when less control is needed.

MACHINE SHIFT

Vibrashifter is not only a product. It is a system that fits several machines.



Vibratory Tamping Rammer

Since the VTR is the most vibrating and most difficult to control, this machine type is the starting point of the design of Vibrashifter.

MODE SHIFT

MODE 1: HIGH DAMPING

ON COMPACT GROUND

During operation on the compact ground, Vibra-shifter can provide additional damping, because the operator does not need full control. When the ground is compact, it is also even, so the VTR is more predictable. A VTR operator that is ramming the ground in a district heating trench needs this mode 80% of the operation time.

MODE 2: HIGH CONTROL

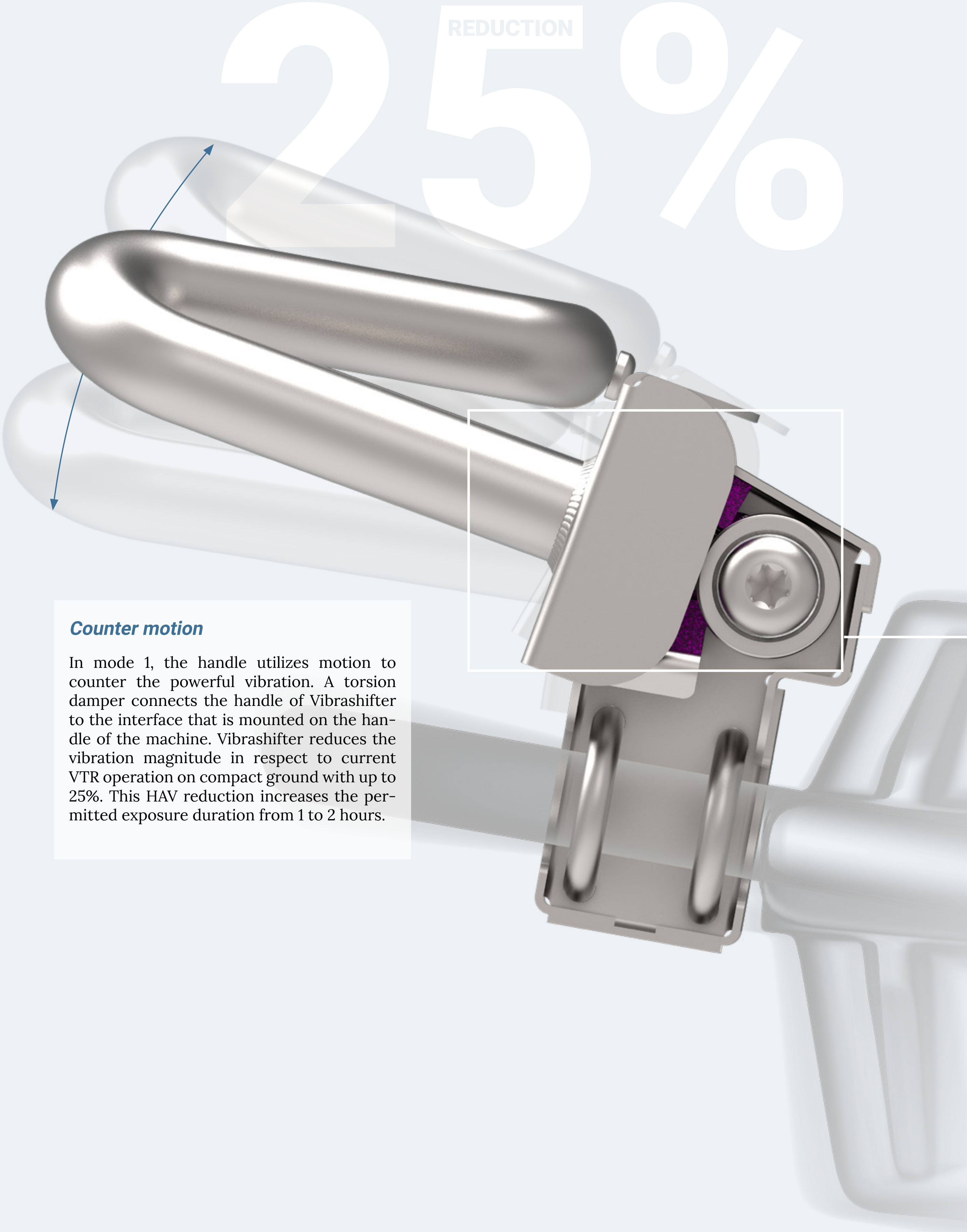
20%
of operation time

District heating trench
Ground absorbs impact

ON SOFT GROUND

Operation time on soft ground is more limited in district heating trench. Nevertheless, when high control is needed, the operator activates the mode 2, by pushing the handle down or up. The shape of the handle allows for the operator to lean over the machine. The stiffness of the handle dampers is calibrated with the force that operator currently apply to push down on the VTR.

HIGH DAMPING

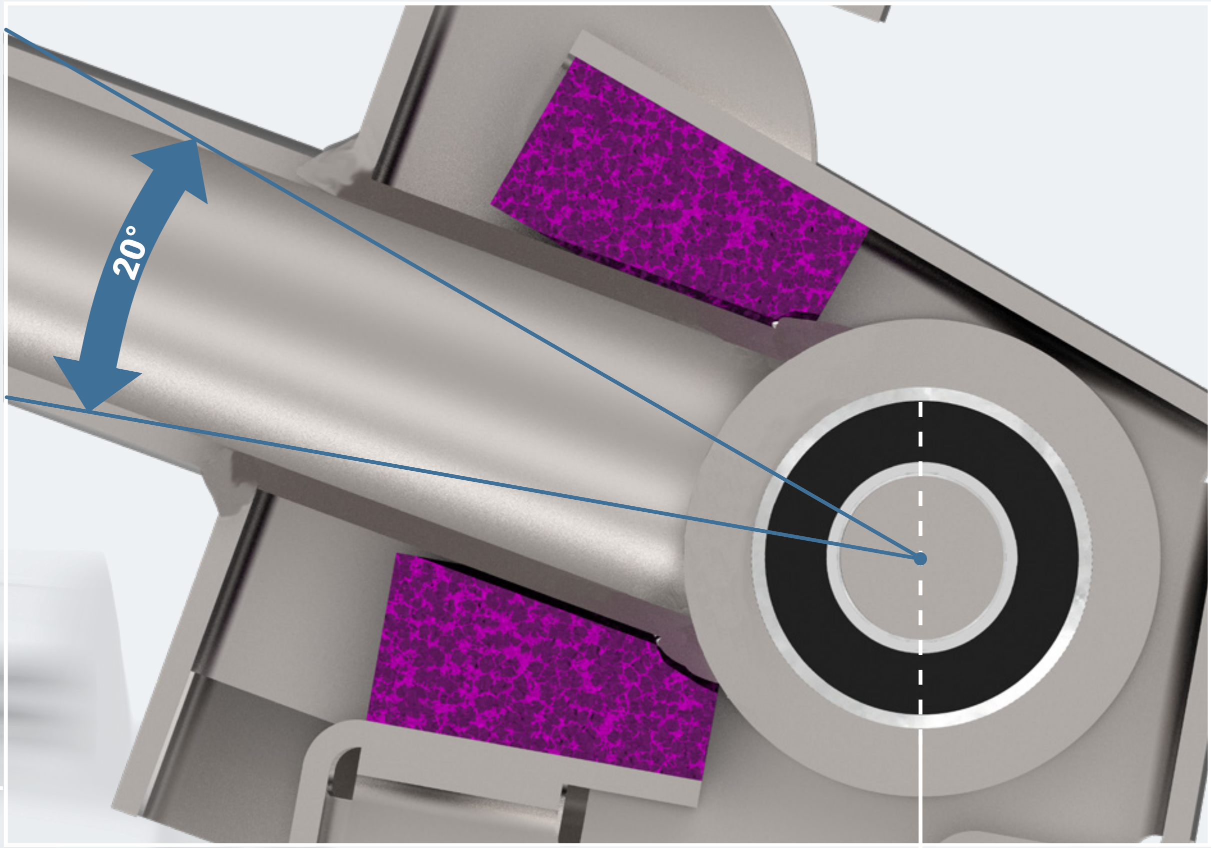


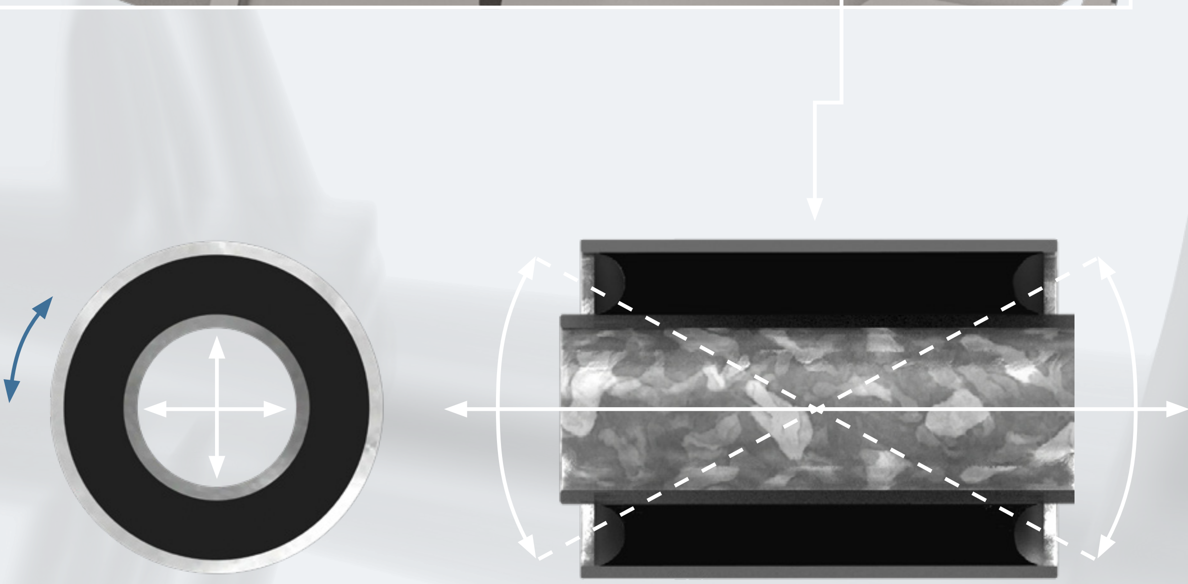
Counter motion

In mode 1, the handle utilizes motion to counter the powerful vibration. A torsion damper connects the handle of Vibrashifter to the interface that is mounted on the handle of the machine. Vibrashifter reduces the vibration magnitude in respect to current VTR operation on compact ground with up to 25%. This HAV reduction increases the permitted exposure duration from 1 to 2 hours.

Torsion damper

Allowing 20° of rotation, the torsion damper enables the Vibrashifter to react to the powerful vibrations of the VTR. This direction is the one with the most displacement of the torsion damper. Its elasticity also dampens radial as well as axial, and rotational vibration in other planes.

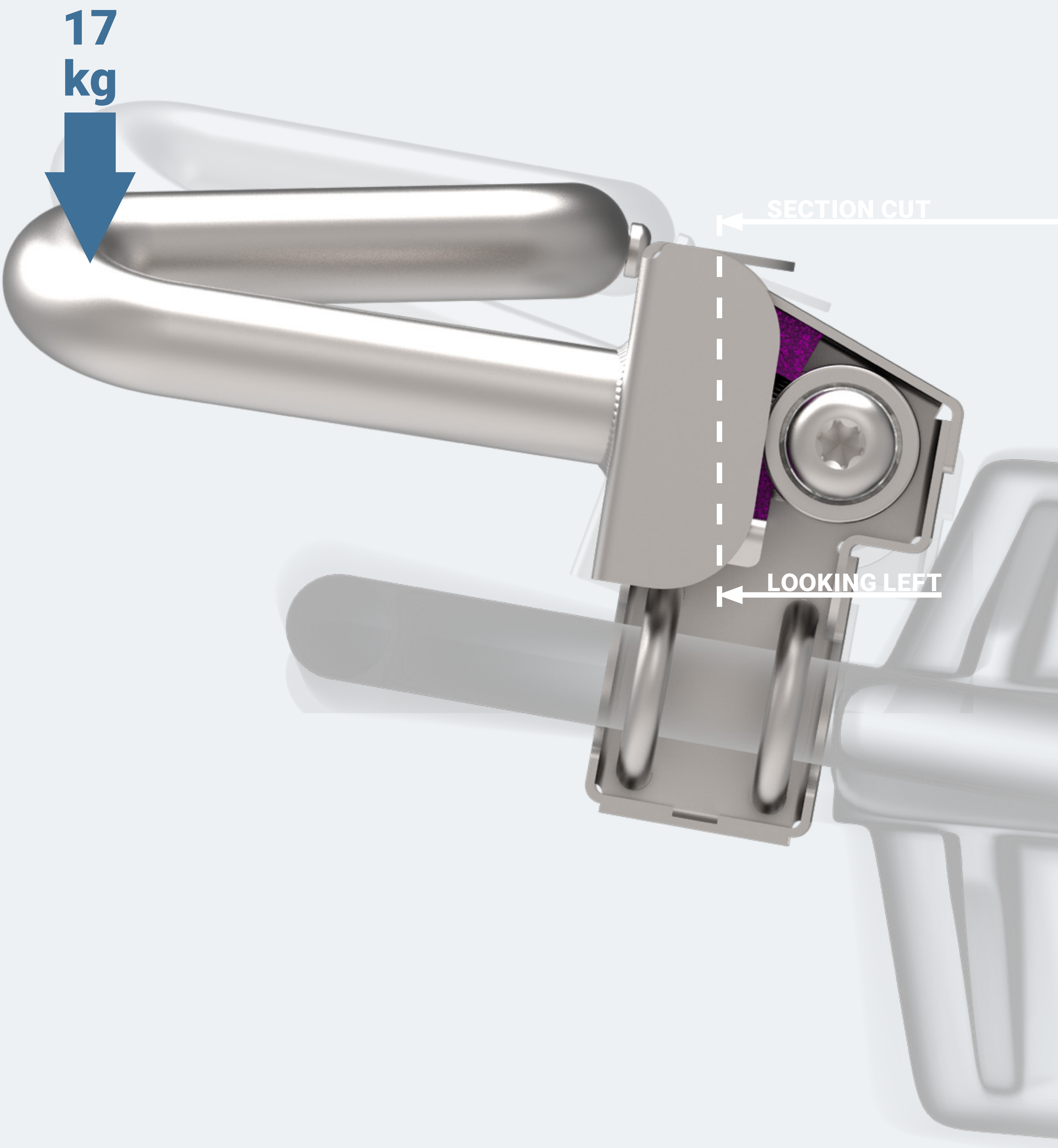




HIGH CONTROL

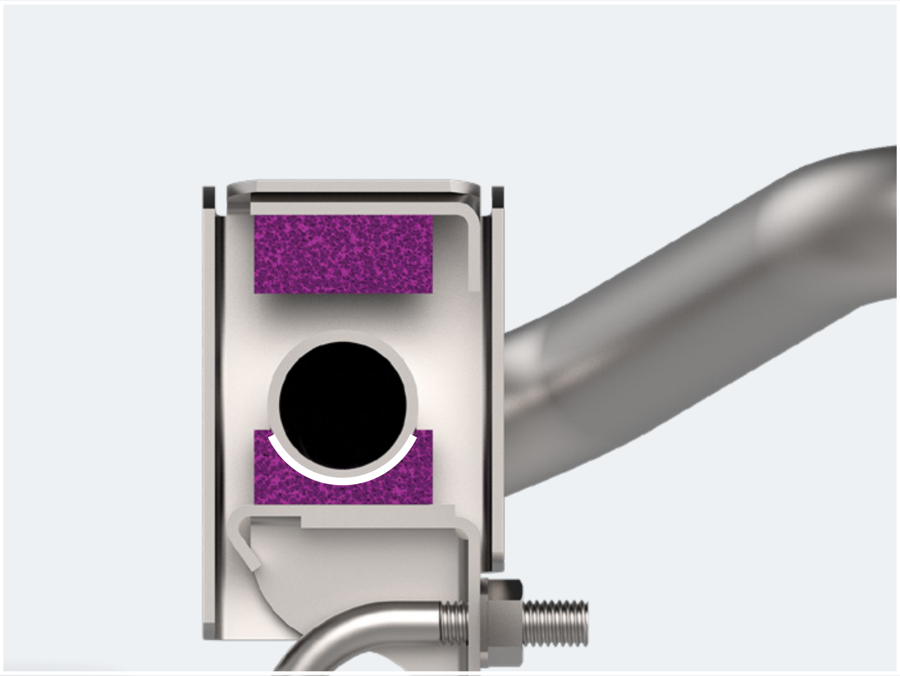
Activate control

When an operator applies downwards (or upwards) force, the stop dampers ensure that forces are progressively decelerated and that the torsion dampers do not get overloaded. In other words, increasing forces increases the stiffness without abrupt dampening.

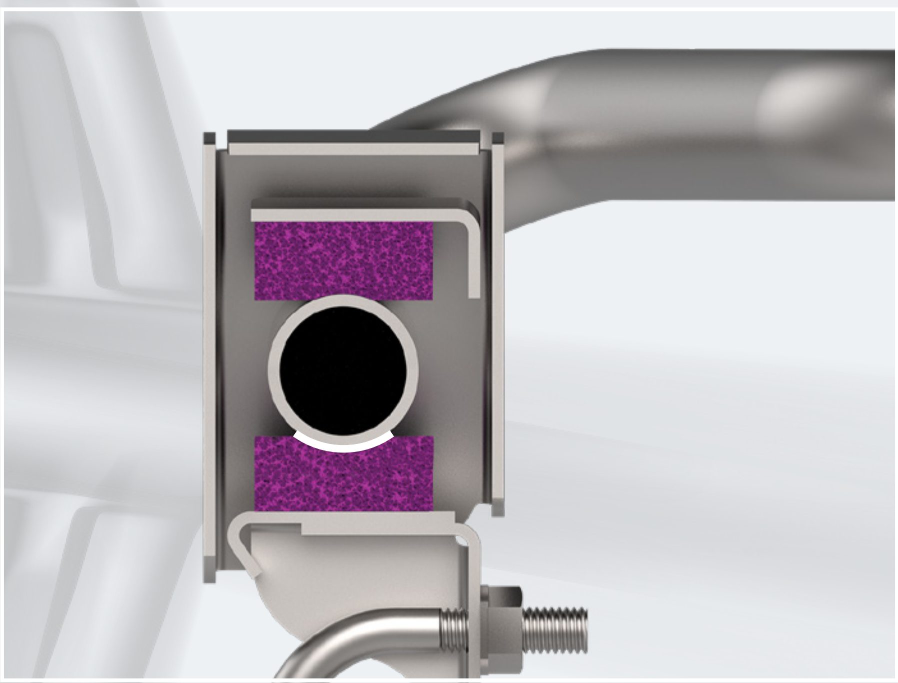


Stop damper

On the top and bottom of each side of the handle of Vibrashifter, there is a stop damper. It consists of Vibrafoam, a foam that is specially designed for damping. The position of the stop dampers and the circular cross-section of the handle come together to provide progressive damping. As the stop damper is compressed, the area of the contact increase.



Handle compresses stop damper when it is pushed down



Stable handle position

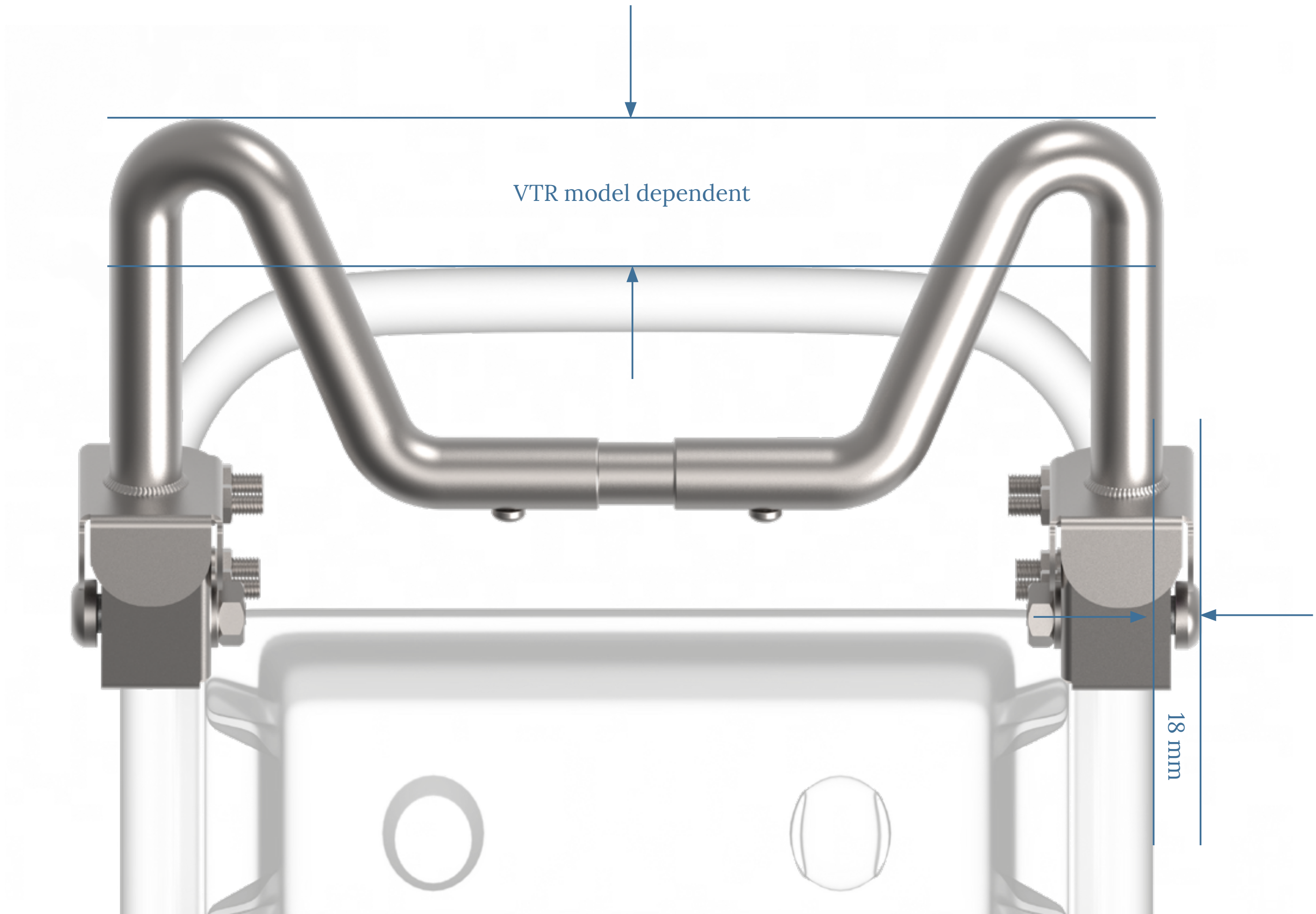
HANDLING

TRANSPORTABLE

Minimal extension beyond the handlebar of the VTR allows the use of current transportation methods.

MORE CONTROL OPTIONS

The handle shape provides additional control options that are advantageous when operating in narrow spaces.



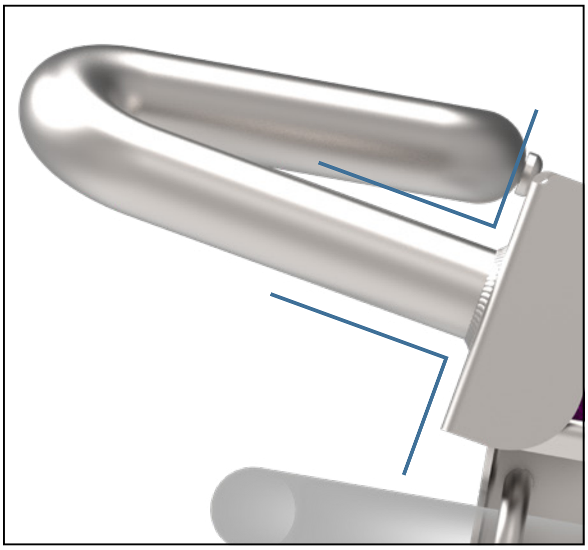
MOVEABLE

Vibrashifter is mounted so it does not get in the way when the operator is moving the VTR by hand.

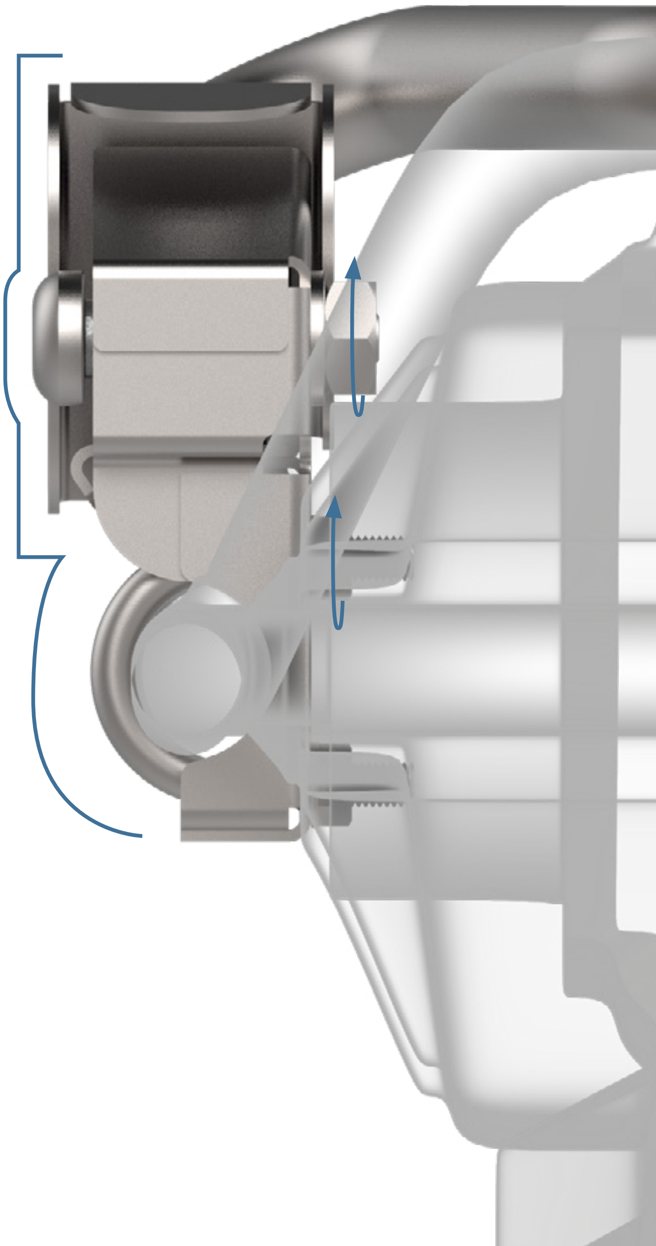
The nuts of the bolts are tightened from the inside, so they do not intersect with the operator or anything else the VTR passes by.

Safety bracket

On the end the of handle, a bracket keeps the fingers safe from the getting caught in the damping mechanism.

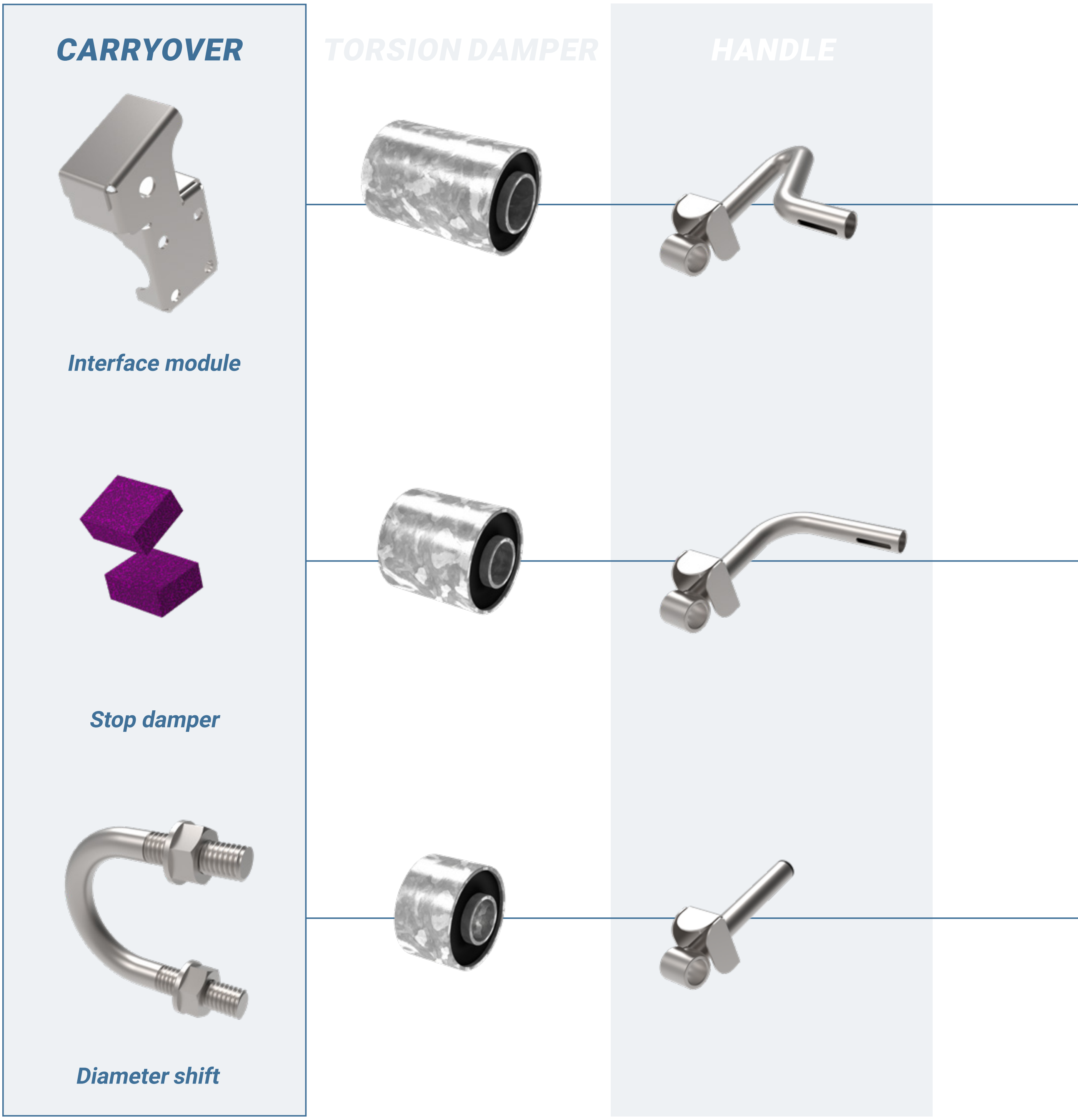


Side view of handle and safety bracket

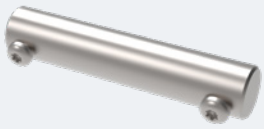


MACHINE SHIFT

Vibrashifter is a system that is compatible with the machines presented on the page to the right. Every product for the machines includes the carryover components. The stop damper is available in different material stiffness.

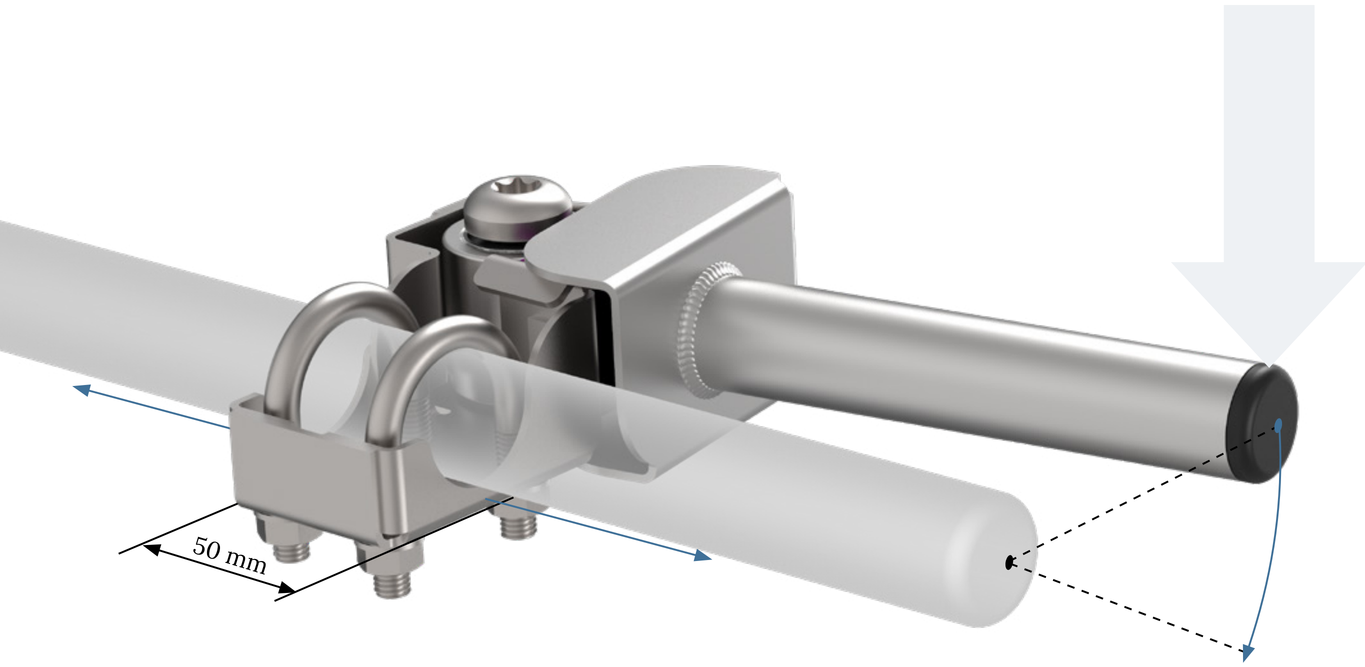


WIDTH SHIFT



DIAMETER SHIFT

For some machines it makes the most sense to put separated handles on because they are not as difficult to control as the VTR. For instance, on the floor stripper Vibrashifter is attached like this:

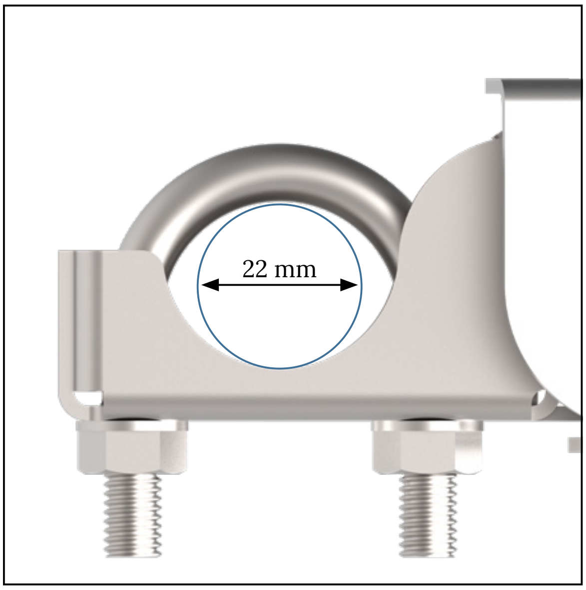


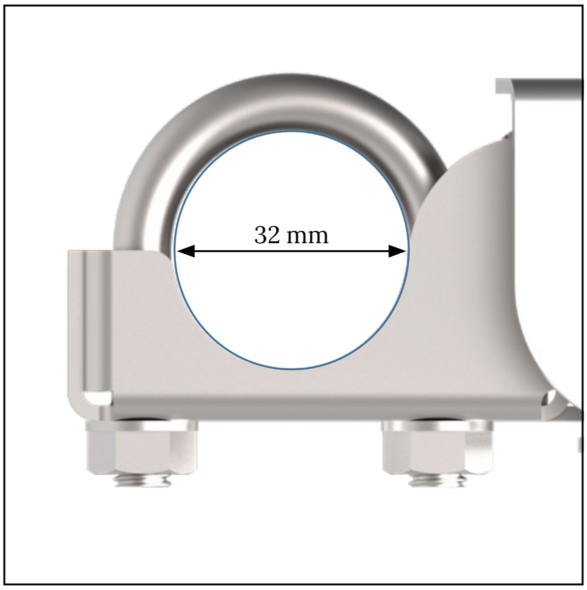
Versatile interface size

A short interface of 50 mm makes is possible to mount many places

Fastened to withstand rotation

Though this handle type is separated, they are still stably mounted on the machine. The U-clamps can withstand up to 25 kg pulled at 170 mm distance.





WIDTH SHIFT

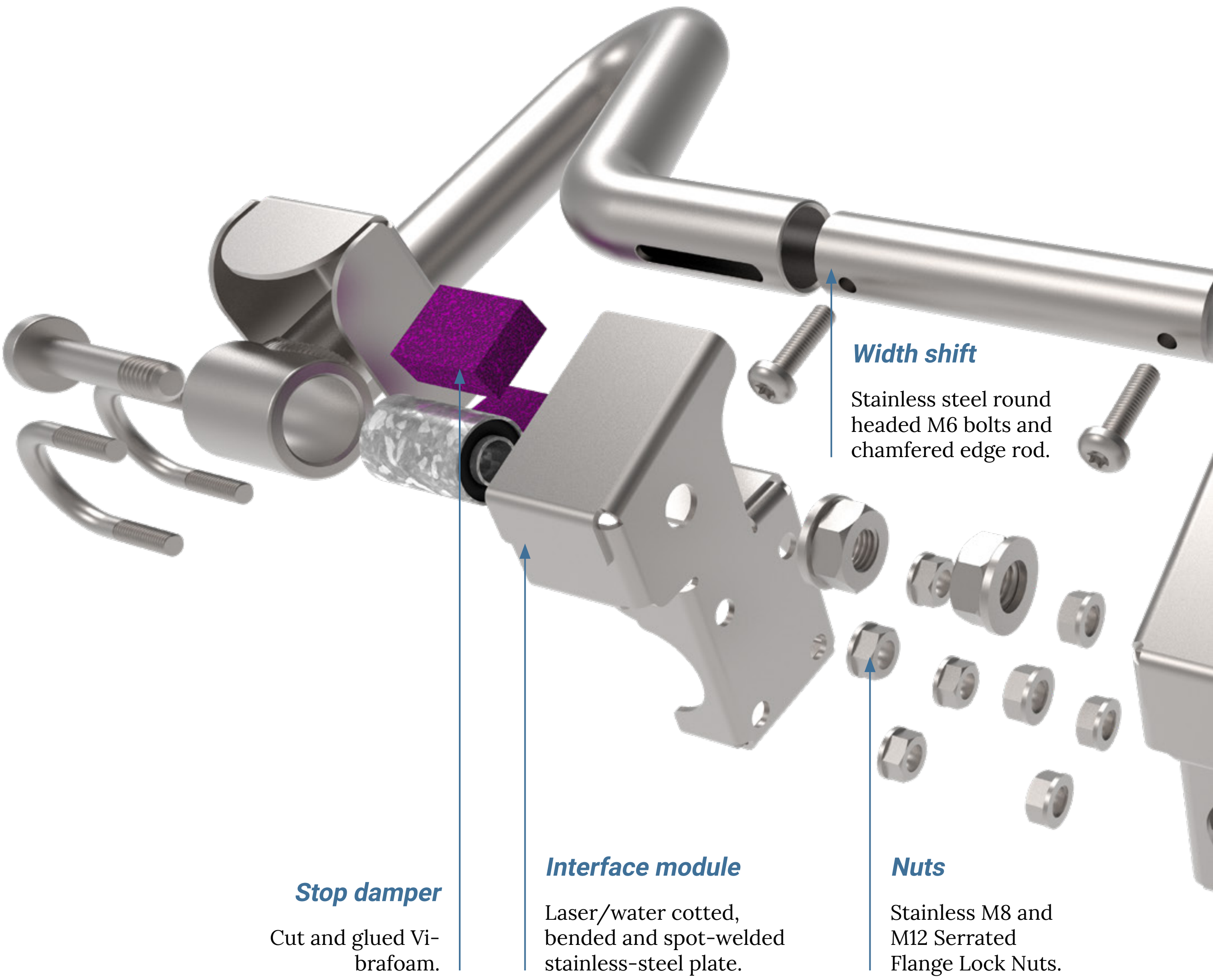
Adjustable and rigid

To fit every machine, the width of the handle is adjustable. Loosening a bolt allows it to slide within a slot in the handle. The bolt is also what prevents the parts of handle from rotating in relation to each other.

Fixation

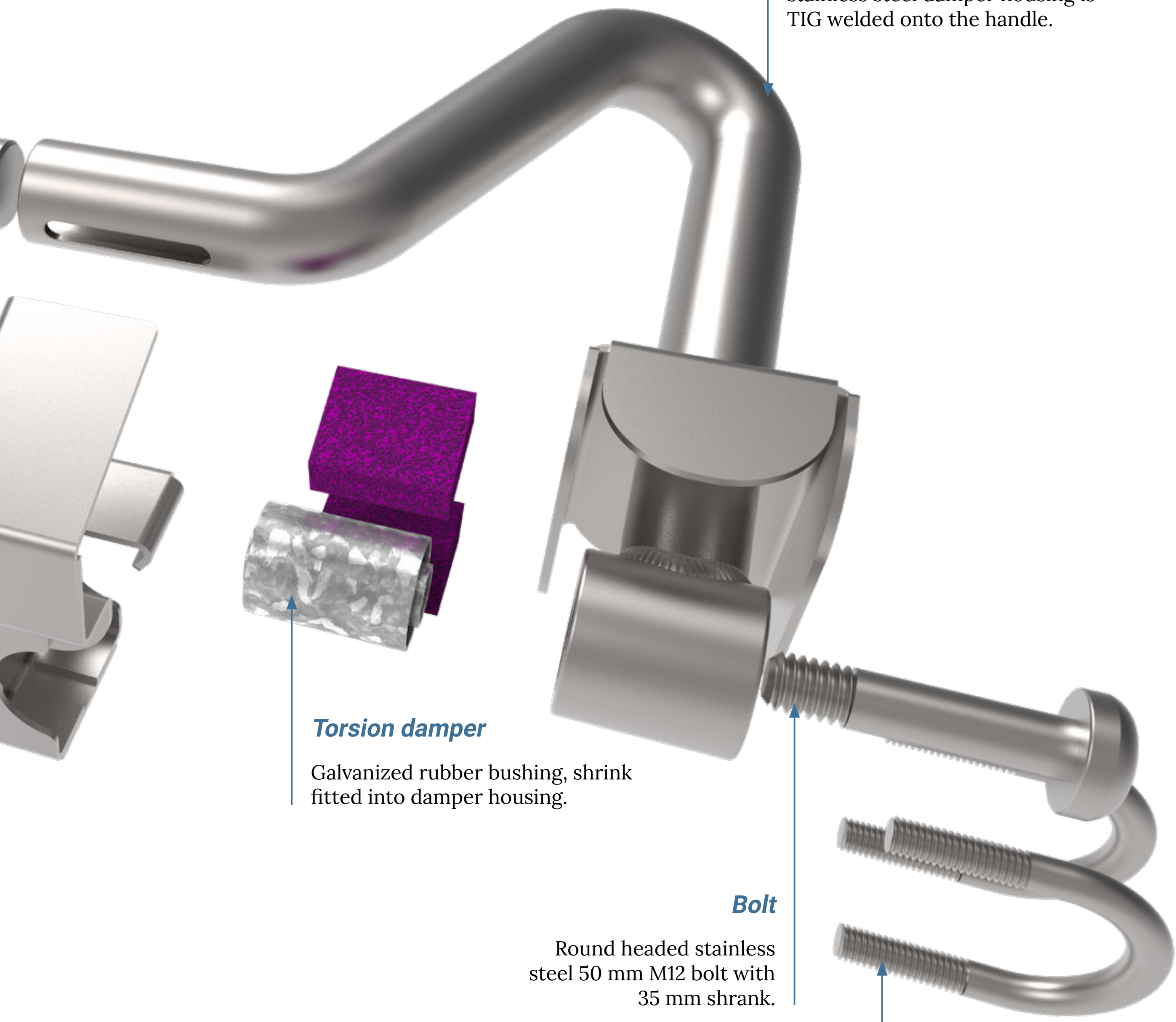
The sliding rod inside the handle has a thread. Tightening the bolt fixates it in the handle tube, because it slightly deforms the wall, plus the friction between the rod and tube increases greatly.

COMPONENTS


Width shift
Stainless steel round headed M6 bolts and chamfered edge rod.
Stop damper
Cut and glued Vi-brafoam.
Interface module
Laser/water cotted, bended and spot-welded stainless-steel plate.
Nuts
Stainless M8 and M12 Serrated Flange Lock Nuts.

Handle for VTR

Mandrel tool bended 1” stainless steel pipe, Laser/water cut, bended and spot-welded stainless steel plate safety bracket. Grooved stainless steel damper housing is TIG welded onto the handle.



Torsion damper

Galvanized rubber bushing, shrink fitted into damper housing.

Bolt

Round headed stainless steel 50 mm M12 bolt with 35 mm shrank.

Diameter shift

Stainless steel 32mm M8 U-bolt

IMPLEMENTATION

PRODUCT LAUNCH(ES)

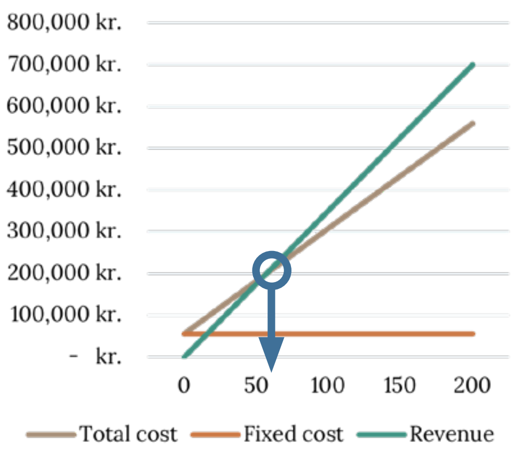
At the first product launch, the plan is to do pre-production, i.e., produce a small batch to test the market. If Vibrashifter gains traction, the production can continue. This is possible because of the currently chosen production methods that require low investment.

The retailer, Stemas, is interested in purchasing 100 units to test their customers' demand. They require a quantify discount of 40% off the consumer price.

Pre-production break-even

With a consumer price at 3500 DKK (retailer price: 2100 DKK) and estimations of cost, the break-even point of the pre-production should be at about 60 units sold.

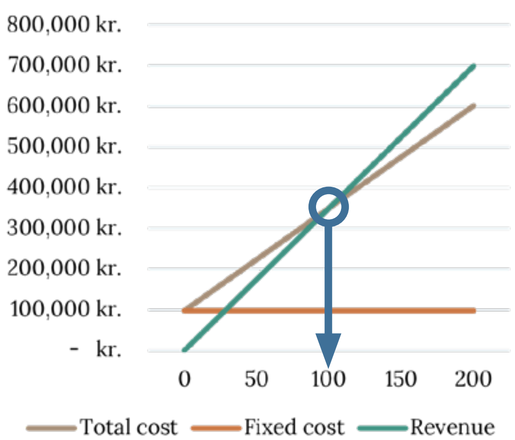
Consumer price: ***3500 DKK***
Retailer price: ***2100 DKK***
Break-even: ***60 units sold***



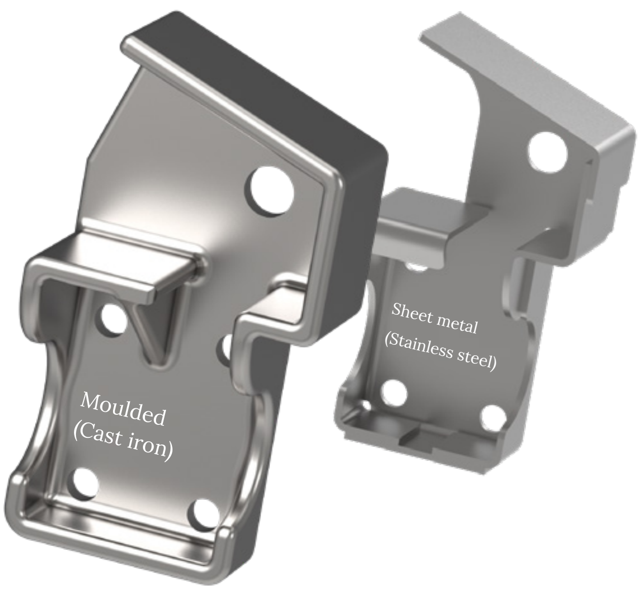
Meeting the Total Addressable Market

If Vibrashifter to meet Total Addressable Market, the production method of the interface module should be replaced with shell moulding.

This entails a higher risk because of the investment in shell moulds. The break-even point will not be reached until 100 units. So, if the pre-production run was to utilize this method, potentially needed design changes to the interface module would require further investment in new moulds pushing break-even to 200 units.



If the product gains traction, supplying the market demand would be more beneficial to produce shell moulded interface modules once above 700 units. This is realistic as the TAM for VTRs in Denmark is estimated to be 28.000. The TAM for the targeted hand operated machines might be 70.000.



SCALING PLAN

1. Test machine markets with low volume production on the Vibratory Tamping Rammer. If the VTR market shows a promising demand, initiate production of moulded interface modules to lower the variable cost.

2. Next step is to test the markets of other machines. Since the interface module is a carryover component, this merely requires another handle shape and the ordering of new torsion and stop dampers.

3. After this, implementing additional features such as a heat insolating rubber wrap should be considered to increase the perceived value of Vibrashifter with low production cost increases.

AALBORG UNIVERSITY

STUDENT REPORT

Industrial Design
Spring 2023
MA4-ID8

TECHNICAL DRAWINGS

Sheet:	Description:
1	Isometric view of all components
2	Exploded view and BOM of VTR variant
3	Range of motion and adjustability of VTR variant
4	Detail drawing of press fitting in housing

VIBRASHIFTER

HAND-ARM VIBRATION DAMPING EQUIPMENT

DESIGNED BY ALEXANDER THYRRESTRUP OLSEN
& JENS HENRIK THORDAL SLOTH

Aalborg University
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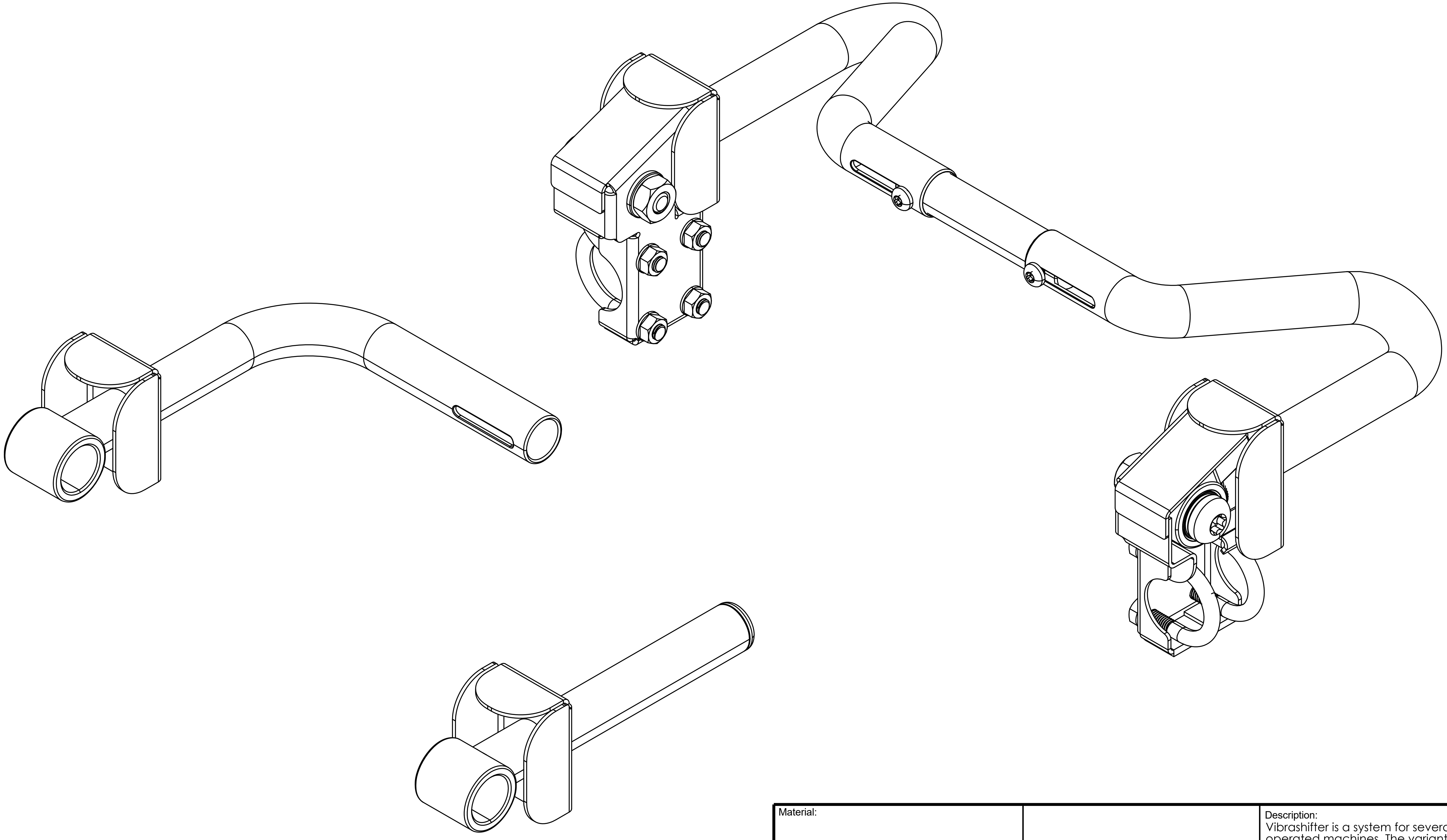
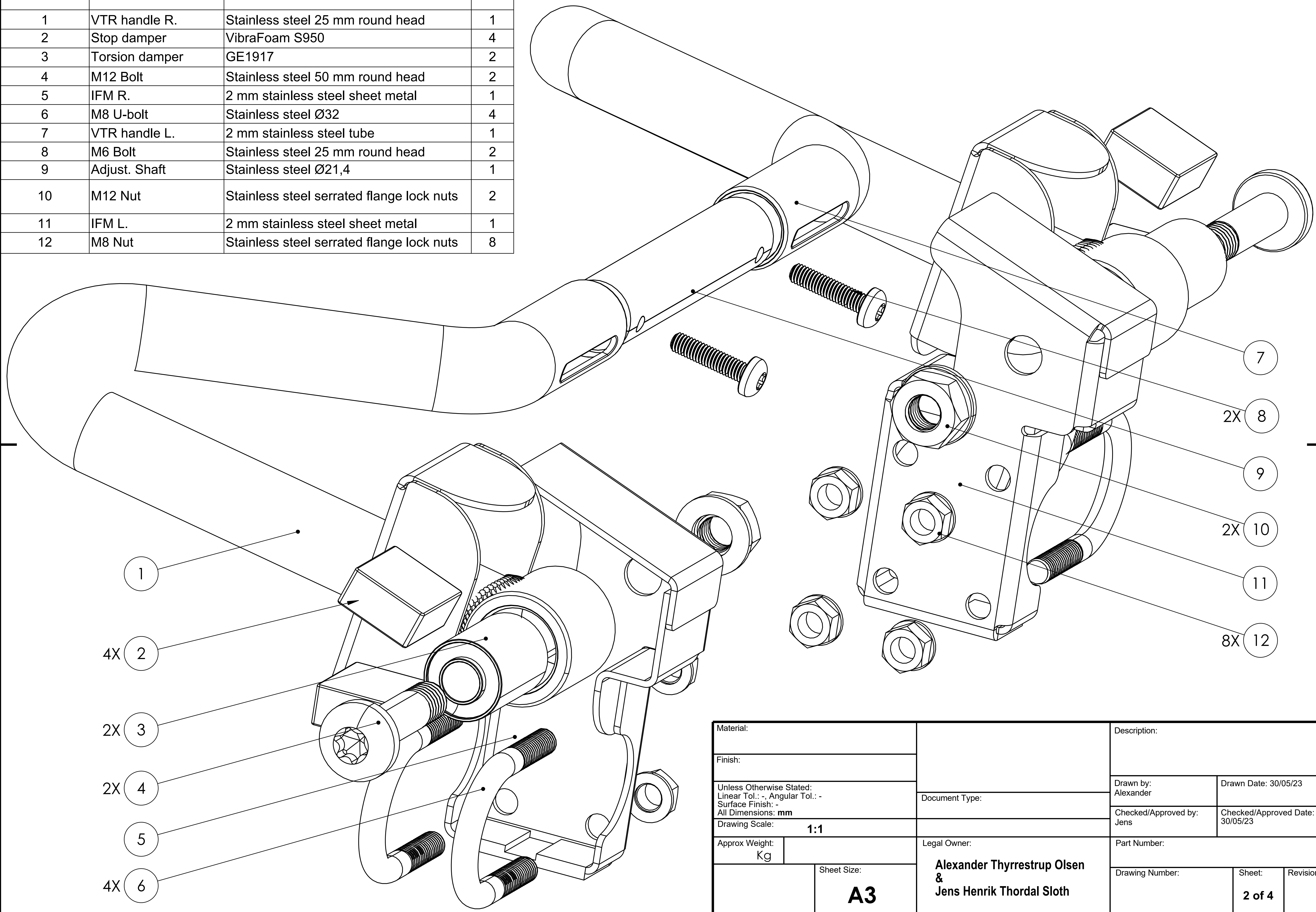


Material:		Description: Vibrashifter is a system for several hand operated machines. The variant that fits the Vibratory Tamping Rammer (VTR) is the focus of the project
Finish:		Drawn by: Alexander — Drawn Date: 30/05/23
Unless Otherwise Stated: Linear Tol.: -, Angular Tol.: - Surface Finish: - All Dimensions: **mm**	Document Type:	Checked/Approved by: Jens Henrik — Checked/Approved Date: Jens Henrik
Drawing Scale: **1:2**		
Approx Weight: Kg	Legal Owners: **Alexander Thyrrestrup Olsen & Jens Henrik Thordal Sloth**	Part Number:
Sheet Size: **A3**		Drawing Number: — Sheet: **1 of 4** — Revision:

PART NO.	PART NAME	DESCRIPTION	QTY.
1	VTR handle R.	Stainless steel 25 mm round head	1
2	Stop damper	VibraFoam S950	4
3	Torsion damper	GE1917	2
4	M12 Bolt	Stainless steel 50 mm round head	2
5	IFM R.	2 mm stainless steel sheet metal	1
6	M8 U-bolt	Stainless steel Ø32	4
7	VTR handle L.	2 mm stainless steel tube	1
8	M6 Bolt	Stainless steel 25 mm round head	2
9	Adjust. Shaft	Stainless steel Ø21,4	1
10	M12 Nut	Stainless steel serrated flange lock nuts	2
11	IFM L.	2 mm stainless steel sheet metal	1
12	M8 Nut	Stainless steel serrated flange lock nuts	8



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Surface Finish: -
All Dimensions: **mm**

Drawing Scale: 1:1

Approx Weight: Kg

Sheet Size: **A3**

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Description:

Drawn by: Alexander

Drawn Date: 30/05/23

Checked/Approved by: Jens

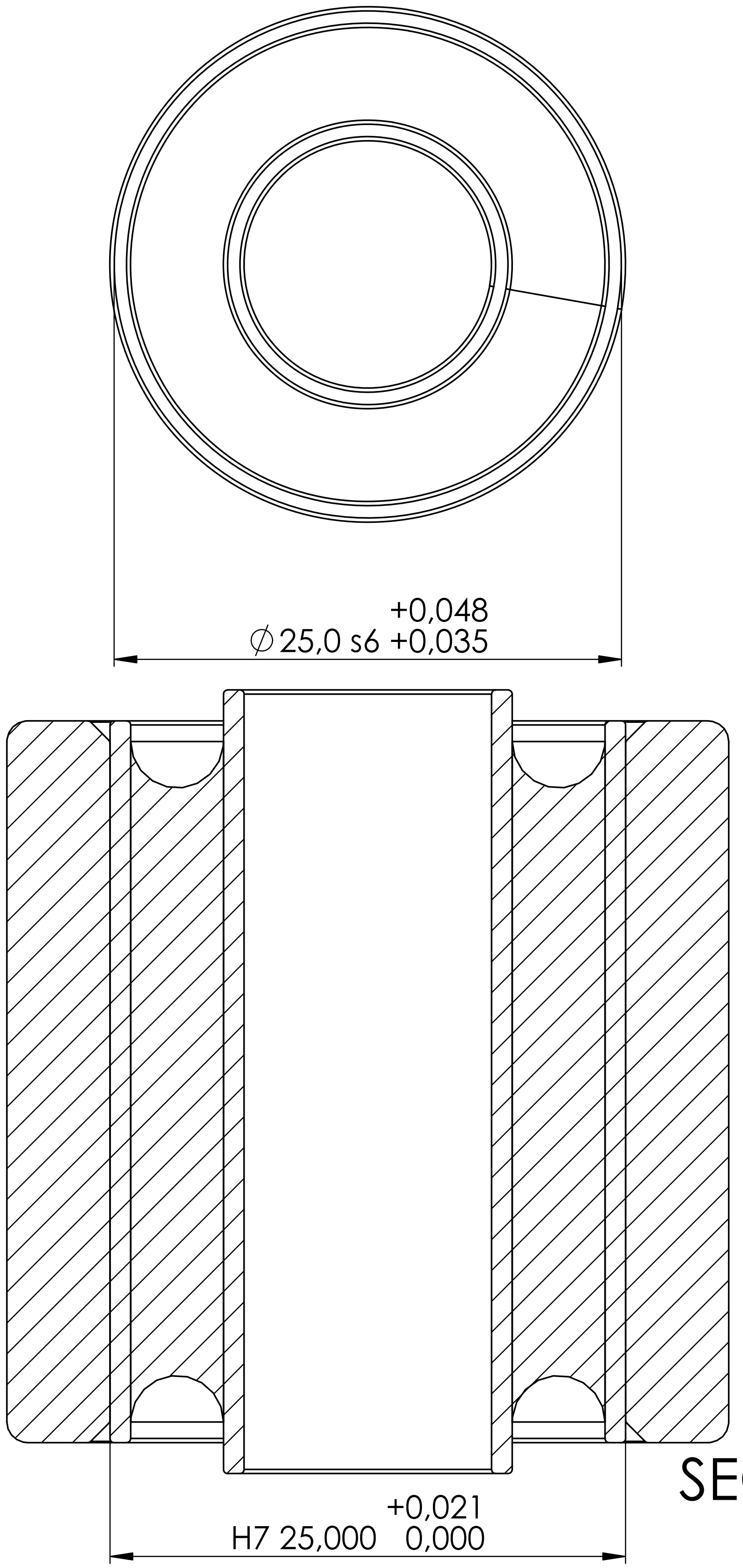
Checked/Approved Date: 30/05/23

Part Number:

Drawing Number:

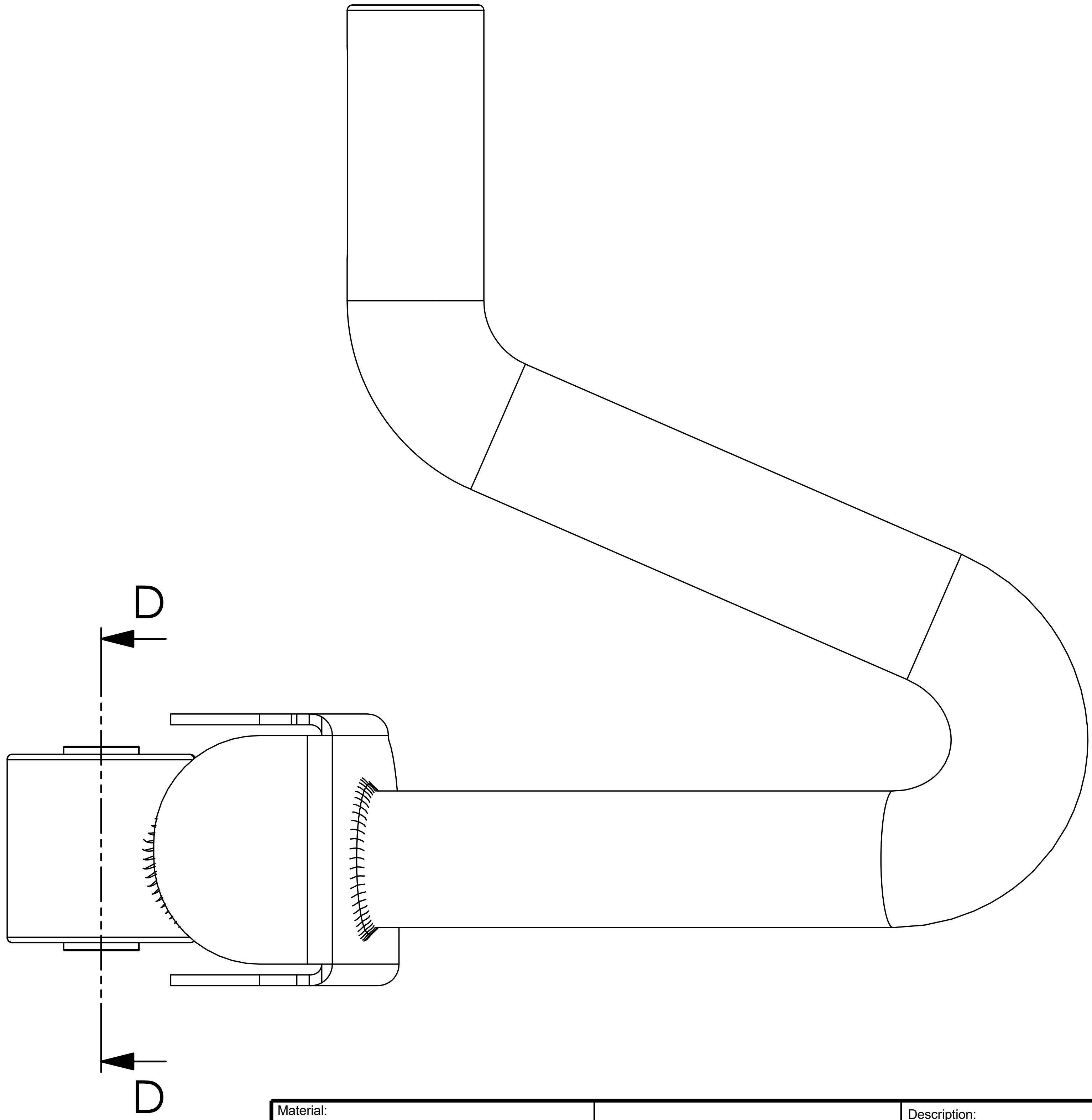
Sheet: 2 of 4

Revision:



SECTION D-D

SCALE 3 : 1



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All Dimensions: **mm**

Drawing Scale: **1:1**

Sheet Size: **A3**

Document Type:

Legal Owners:

Alexander Thyrrestrup Olsen
&
Jens Henrik Thordal Sloth

Description:
Press fitting assembly of the VTR handle and the torsion damper.

Drawn by: Alexander

Drawn Date: 30/05/23

Checked/Approved by: Jens

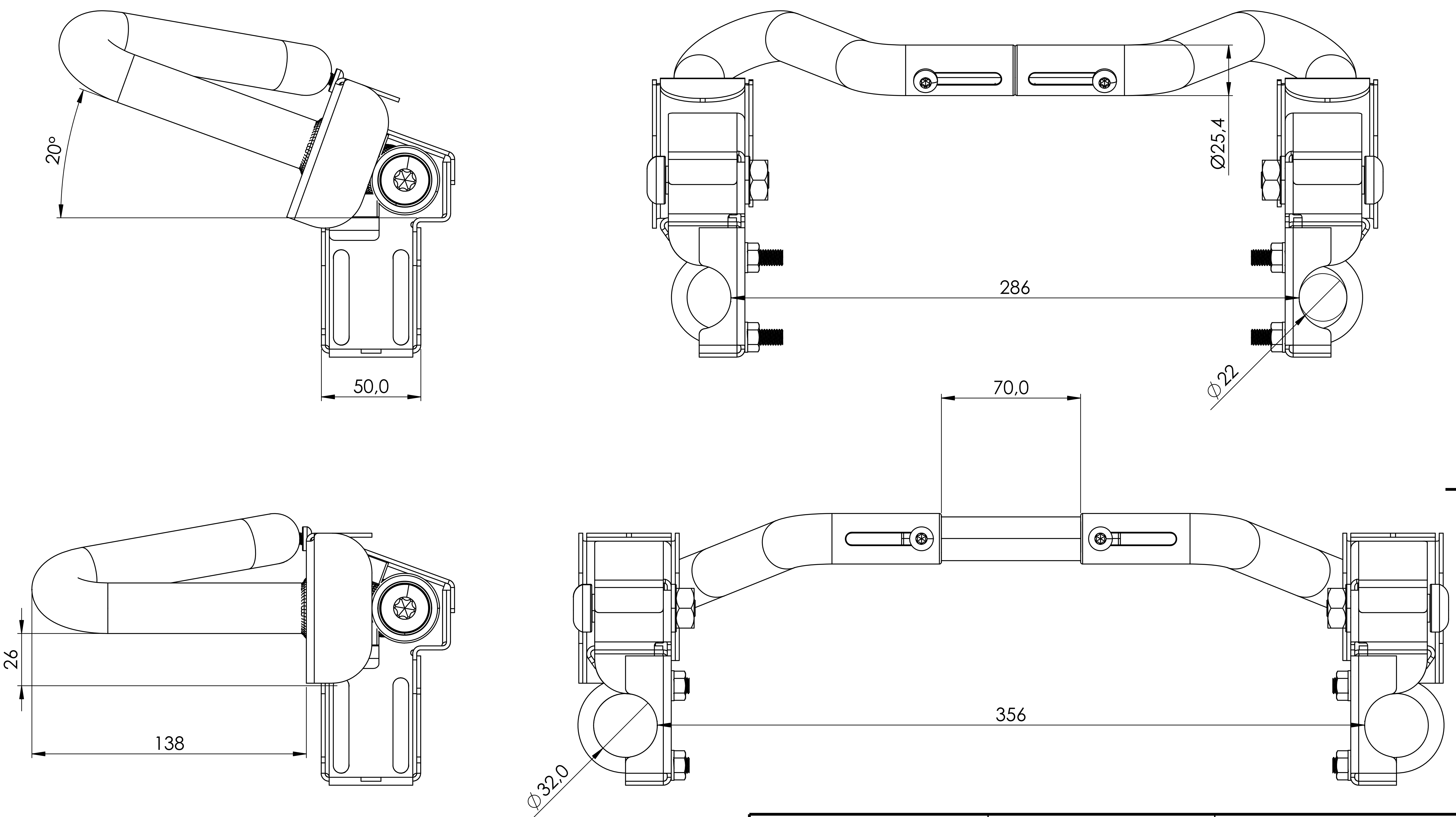
Checked/Approved Date: 30/05/23

Part Number: 3 & 7

Drawing Number:

Sheet: **3 of 4**

Revision:



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All Dimensions: **mm**

Drawing Scale: **1:2**

Approx Weight: Kg

Sheet Size: **A3**

Document Type:

Legal Owners:
Alexander Thyrrestrup Olsen
&
Jens Henrik Thordal Sloth

Description:
The adjustability and range of motion of the VTR variant.

Drawn by: Alexander

Drawn Date: 30/05/23

Checked/Approved by: Jens

Checked/Approved Date: 30/05/23

Part Number:

Drawing Number:

Sheet: **4 of 4**

Revision:

MASTER THESIS / PROCESS REPORT

VIBRASHIFTER

HAND-ARM VIBRATION DAMPING EQUIPMENT

DESIGNED BY ALEXANDER THYRRESTRUP OLSEN
& JENS HENRIK THORDAL SLOTH

Aalborg University
June 2023
MA4-ID8

DESIGN TEAM

1: Alexander and Jens (the industrial design team)

Title:	Vibrashifter
Theme:	Hand-arm vibration
Project team:	01.02.2023 - 31.05.2023
Project period:	MA4-ID8
Main supervisor:	Christian Tollestrup
Co-supervisor:	Erik Lund
Issues:	5
Pages:	100
Appendices:	23

READING GUIDE

At start of each section, a brief, blue text (like the one you are reading in this very moment) will introduce the activities and methods that the content of the section is based upon. For instance, "This section is a guide that explains the purpose of the graphic elements and choice of language". Occasionally, a disclaimer will be included here to explain why the activities did not turn out as intended.

Reading order

The documentation of this project should be read in the following order:

- Product report (Presentation of the design proposal)
- Technical drawings (Component overview and dimensions)
- Process report (Summarization of the design process and learnings)
- Worksheets (All activities that have been summarized)

Language and terms

- When we write 'we', we refer to the design team behind the product.
- When we refer to 'the product', it means the design proposal of this project.
- The frequent appearance of the word prototype/prototyping (opposed to model and mock-up) might seem inordinate. This is a deliberate choice to emphasize the high quality of what was built during prototyping.

Formatting

Anything written with *italic* is quotation from a source (book, web etc.), stakeholder, or user.

Text with a light blue/grey background is not more important than something else. These backgrounds merely act as a guide to read the page in the intended order, by grouping or separating elements.

ABSTRACT

Dette speciale i industrielt design omhandler udviklingen af Vibrashifter, et alsidigt, eftermonterbart, vibrationsdæmpende håndtag der bevarer kontrol af en række vibrerende, håndstyrede maskiner i blandt andet byggeri- og anlægsbranchen.

Projektets udgangspunkt var identifikationen af Hånd-arm Vibrations Syndrom (HAVS) som et sundheds- og samfundsmæssigt problem, der kan opstå ved blandt andet brugen af vibrerende maskiner, afhængig af styrke og udsættelsestid. Dette kan give operatøren arbejdsskader, der belaster dem, deres arbejdsgiver og samfundet på grund af erstatningskrav, bøder, behandlinger og tidlig pension.

HAVS omfatter mange lidelser, men muskelskeletsygdommen karpaltunnelsyndrom og Raynauds syndrom har den hyppigste forekomst. Disse kan medføre generer som fingersmerter, kramper, spasme, tab af førlighed, motorisk kontrol og styrke. Karpaltunnelsyndrom kan kirurgisk behandles, men kræver ofte 3 måneders efterfølgende sygemelding, og arbejdsformen bør ændres for at undgå følgegener. Raynauds syndrom er uhelbredelig og meget udbredt. Det viser sig som anfald udløst af kuldepåvirkning, hvilket jævnligt er del af udendørs arbejde.

Sygdommene udbredes da byggelederne ofte stilles i et svært dilemma, hvor de skal vælge mellem at overholde lovgivningen ved at beskytte medarbejdere mod udvikling af HAVS eller at afslutte projektet inden for den altafgørende tidsramme. Konkurrenceevnen er afhængig af tidsramme og pris. Dette betyder, at brugen af især ældre, men funktionelle maskiner nemt overskrider grænseværdierne for vibrations udsættelse. Blandt andet af økonomiske årsager udskiftes de ældre maskiner dog sjældent til nyere modeller for at mindske vibrationer, men benyttes indtil de ikke længere er funktions dygtige. Her er Vibrashifter et alternativ, der kan hjælpe byggelederne med at beskytte deres medarbejdere uden at gå på kompromis med effektivitet.

These symbols appear close to something that is rejected or accepted.

✓ Hook or solution ✗ Objection or problem

At the end of each section this may appear:

X.X (Section #)

The blue text is a summary of the section, highlighting what drives progress.

! The blue box marks an important takeaway that was considered relevant at the time of the activity that the current section describes. It may contain a problem insight or a new requirement.

The brown text is a brief reflection <u>on</u> the actions or output of the section. It is written in retrospect.

ACKNOWLEDGEMENTS

This section is an acknowledgement of the individuals that have impacted the projected positively.

Thank you, Christian Tollestrup. Numerous educational, honest supervisions and continuous support has made a difference throughout this and earlier projects.

Thank you, Erik Lund. Engaged involvement and short response time during confusing, busy weeks eased the end of the project.

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Thank you, Kristen Holst Outzen (Stemas). Product-related, professional guidance and respect during several phone calls have provided with motivation and self-confidence.

To the following individuals, thank you for taking time out of a tight schedule to give feedback and access to interview employees:

- Jesper Pinstrup (Jorton)
- Henrik Todberg (Poul Erik Nielsen)
- Brian Barslev and Jacob Rye (Aabybro Entreprenør)

INTRODUCTION

The purpose of the section is to provide with context to understand the extent of the problem and the motivation behind choosing it.

The extent of HAV

In Denmark, 5% of the employed, manual workers are subjected Hand-Arm Vibrations (HAV). HAV exposure accounts for 7% of all reported work-related illnesses. These illnesses are commonly referred to as Hand-Arm vibration Syndrome (HAVS). The most frequently reported HAVS are Raynaud's Phenomenon (RP) and Carpal Tunnel syndrome (CTS) (Borup & Petersen 2020). As for muscle skeleton illnesses like CTS, the report incidence of the construction industry as well as the wood and furniture industry are twice the average (at.dk 2015).

CTS is 2,9 times more likely vibration exposure is a part of daily work (Nilsson, Wahlström & Burström 2017). In 2014, there were about 550 reported incidents of work-related neurological diseases like CTS in Denmark. HAV was related to 330 cases (at.dk 2015; bm.dk 2018).

HAV also increases the risk of vascular diseases like RP. The risk of developing RP is 6,9 times higher than if individuals were not exposed to HAV (Nilsson, Wahlström, & Burström 2017). On average from 2009 to 2013, 67 Raynaud's phenomenon cases per year were recognized as vibration-induced by the Danish National Board of Industrial Injuries (Sundhed.dk 2020; Rasmussen & Petersen 2016).

International issue

Few Danes experience that their job regularly involves vibrations compared to other EU countries, and the reason is that Danish companies are good at investing in innovative technology with a focus at reducing risk factors involved with work (Jakobsen, K.N. et al. 2019).

In the US, CTS is one of the most common repetitive stress injuries. The US Centers for Disease Control and Prevention reports an average of about 900.000 new cases annually. In cases where HAVS can be attributed to working conditions, it allows employees to make compensation claims. A business may be held responsible for compensating their workers if it is found that their normal duties or working conditions led to the illness. Workers in sectors with higher rates of HAVS tend to be more successful in their claims (Briotix 2019).

General regulations

Legally in Denmark, health risks related to vibrations must be reduced as much as possible. Employers should pay attention to recent technology to minimise the vibration exposure magnitude, type, or duration (at.dk 2005).

If the daily vibration exposure exceeds recommendations, the employer must ensure the exposure is reduced accordingly. This could be a choice of suitable technical aids with a good ergonomic design and the lowest possible vibration level such as equipment that lowers the risk of HAVS. Those who violate or do not comply with the current regulations will be held responsible and punished with a fine (at.dk 2005).

Project motivation

Since HAVS is a significant problem that impacts many different sectors worldwide, a new solution would make a difference for many lives. There is potential to improve the safety in the work environment for manual workers. The attention to the problem in Denmark is advantageous during the design process as well if a product is to enter the market. However, there is a risk that many already have attempted to solve the problem.

WORD EXPLANATION

Word/Abbreviation	Explanation
Accelerometer	A device that measures the vibration, or acceleration of motion of a structure
Add-on	Added feature or component to enhance the thing it is added to
BAM-Bus	Byggeriets Arbejdsmiljøbus
Bend radius	The distance from the center of a bend to the center of the medium
CAD	Computer-Aided Design
CTS	Carpal Tunnel Syndrome
D	Outer Diameter
Damping	A reduction in the amplitude of an oscillation as a result of energy being drained from the system to overcome frictional or other resistive forces
DWEA	Danish Working Environment Authority
EAV	Exposure Action Value, a daily vibration magnitude of 2,5 m/s^2, indicates when to act in relation to the vibration exposure.
ELV	The Exposure Limit Value, a daily vibration magnitude of 5,0 m/s^2 and must under no circumstances be exceeded.
Frequency	The number of oscillations with significant magnitude per second [Hz]
HAV	Hand-Arm Vibration
HAVS	Hand-Arm Vibration Syndrome
HSE	Health and Safety Executive in the United Kingdom
HVM	High Vibration Magnitude
Magnitude	Value of acceleration [m/s^2]
Milestone	A feedback project status presentation for the entire semester and all supervisors
OHD	Occupational Health Department
Pre-production	The first small batch of products produced aimed at discovering potential pitfalls
Retrofit	New or modified parts or equipment not available or considered necessary at the time of manufacture
RP	Raynaud's Phenomenon
TAM	Total Addressable Market
VWF	Vibration-induced White Fingers

TABLE OF CONTENTS

At the end of phase 1, 2, 3, and 4, there is a design brief, milestone and reflection. The design briefs sum up key takeaways that influence the design process. The milestone sections summarize the presented material and the supervisors' feedback. The reflection sections contain reflections on the actions of the phase it appears in and the ones prior to it.

INITIAL RESEARCH

MACHINE SCOPING

RAPID PROTOTYPING

VALUE PROPOSITION

PRODUCT SCALABILITY

EPILOGUE

1 INITIAL RESEARCH

The first phase of the project revolves around the project foundation. Initially, the problem is unfolded through desk research. Market research helps navigate the scope and interviews with retailers and end users reveal the first insights into the problems related to vibration.

2: Recording slow motion video of jackhammer

1.1 VIBRATION-INDUCED ILLNESSES

Method: Desk Research

This section confirms that power tool vibrations cause severe health issues. The illnesses, the related treatments, and coping strategies are explained.

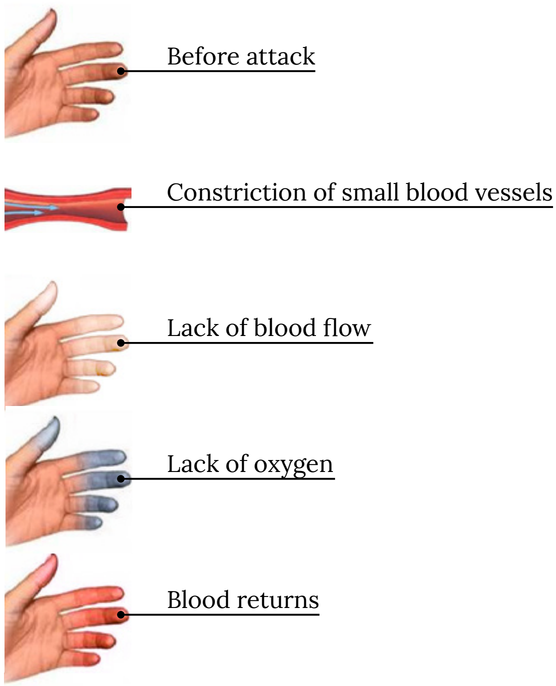
Hand-Arm Vibration Syndrome (HAVS)

According to several authorities in Denmark and the UK, vibrations created by some handheld power tools or hand-operated machines are harmful. Long-term use of tools that expose the operator to HAV are the cause of several illnesses. That is why the illnesses fall under the category of HAVS. HAVS are injuries on blood vessels, nerves, and the musculoskeletal system. The most common illnesses are Raynaud's Syndrome, also known as Vibration-induced White Fingers, and Carpal Tunnel Syndrome (CTS). Patients can suffer from one or several of these illnesses simultaneously (at.dk 2006; hse.gov.uk 2005; Borup & Petersen 2020).

Raynaud's Syndrome

Raynaud's syndrome is an excessive version of the vasomotor response (a normal body process). Blood vessels open and tighten to help the body respond to its environment. In a cold environment, blood vessels near the skin's surface restrict blood flow so the blood stays near vital organs. The blood vessels do the same doing a stressful situation to help the body save oxygen. Raynaud's disrupts this normal body process which causes the blood vessels to restrict the blood flow more than they should and limits the oxygen available in the fingers (clevelandclinic.org 2022).

During attacks (ill. 3), the skin colour of the fingers change to white and blue. Depending on the severity of the illness, a part of a finger, or multiple fingers will be affected. The attacks are episodic spasms (vasospastic attacks) that limit blood flow and cause numbness and a reduced sense of touch. As the blood vessels relax and open again the skin may look red and feel tingly. These attacks usually last about 15 minutes (clevelandclinic.org 2022).



3: An attack of Raynaud's Phenomenon

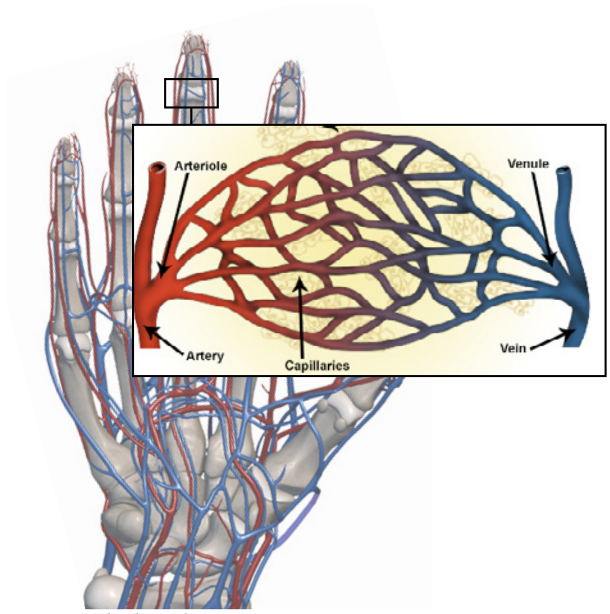
Raynaud's Disease

Raynaud's disease, also known as Primary Raynaud's Syndrome, is typically inherited. Since it is not related to work, it is excluded from the project scope. Besides, it is less severe and does not damage blood vessels (clevelandclinic.org 2022).

Raynaud's Phenomenon

The Secondary Raynaud's Syndrome, also known as Raynaud's Phenomenon (RP), is more common. It is work-related and called Vibration-induced White Finger (VWF). Vibrations damage the small blood vessels (the arterioles and capillaries) in the hands and fingers (gigtforeningen.dk 2023). Even after RP has been diagnosed, continuous work in a cold environment, holding onto cold handles, or use of vibrating tools or machines can increase the severity of attacks (Bispebjerghospital.dk 2010).

Generally, Raynaud's phenomenon induces more severe symptoms than Raynaud's disease. Conditions associated with RP may in extreme cases affect the heart. Other rare side effects of lack of oxygen are gangrene (tissue death) and skin ulcers (clevelandclinic.org 2022).



4: Blood vessel types

1.1

Carpal Tunnel Syndrome (CTS)

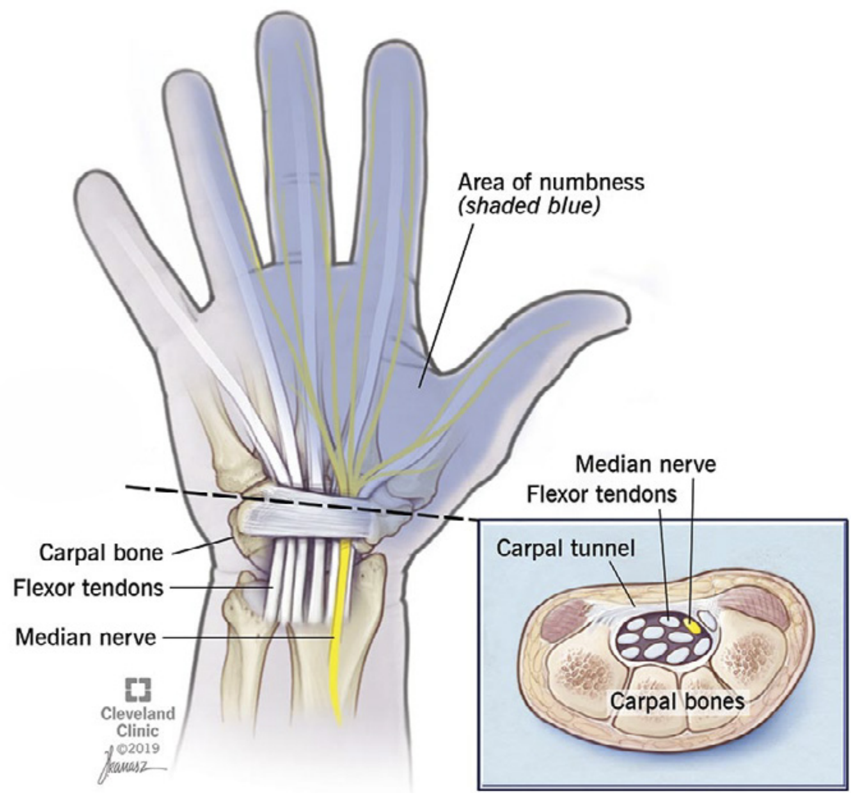
The carpal tunnel runs from the forearm into the palm of the hand. It is a narrow and rigid passageway through bones and ligaments. It contains the median nerve and the tendons that bends the fingers. As ill. 3 shows, the median nerve is connected to the thumb, index finger, middle finger and a part of the ring finger (Thomsen & Haahr 2017).

Causes

When tendons are irritated, their swelling narrows the tunnel and compresses the median nerve. Compression of the carpal tunnel near the wrist cause this irritation. Compressing it on a regular basis can cause CTS (Thomsen & Haahr 2017). It is often the result of a combination of factors that increase pressure on the median nerve and tendons in the carpal tunnel and not a problem with the nerve itself. Repeated use of vibrating hand tools is a contributing factor (Ninds.nih.go. 2023). According to (Lawson 2020),

> *"occupational risk factors include forceful gripping, repetitive flexion and extension at the wrist and vibration exposure".*

How and why vibration contributes is still unknown, because the vibration exposure usually comes with compressions and impact of the carpal tunnel (Thomsen & Haahr 2017).



5: Carpal Tunnel Syndrom explanation

Effects

The symptoms start gradually, in the form of numbness, tingling in the thumb, the index and middle finger, a feeling of weak fingers, swollen fingers, or pain. This often appears at night and the dominant hand is usually affected first. As symptoms worsen, the affected person might begin to feel the same doing the day. They will experience loss of hand movement and hand weakness that will make it difficult to grasp small objects or perform manual tasks. In chronic or untreated cases, the muscles of the base of the hand can shrink and waste away. In even worse cases, the affected cannot distinguish between hot and cold touch and may burn their fingers without knowing (Ninds.nih.go. 2023).

Treatment

It is important to get it treated as early as possible to avoid permanent damage to the median nerve.

The carpal tunnel can be treated through operation. Carpal tunnel release in one of the most common surgical procedures. This can be recommended when the non-surgical treatments are ineffective, or the subject's condition has worsened. The surgery involves cutting the ligament pressuring the median nerve to release the pressure on it. Often surgery is required on both hands. Less than half of people undergoing surgery say their hands are feel completely normal after surgery. Some numbness or weakness is common and permanent. (Ninds.nih.go. 2023).

The condition can in some cases disappear when the subject can avoid exposure. After an operation, a normalisation of the nerve fibres can usually happen within hours or days. A normalisation of the muscular strength usually comes within 10 to 20 weeks. Soreness due to the sharp edges left behind after the thick layer of ligament has been cut can take many weeks to disappear after the operation (Thomsen & Haahr 2017).

Coping strategies of HAVS

Raynaud’s Phenomenon (RP)

RP is uncurable, but there are treatment measures and coping strategies to reduce the number and severity of the attack (Barry 2022) The triggers are often associated with exposure to cold such as air-conditioned rooms, cold spaces, anxiety, emotional stress or excitement, chilly weather, holding something cold, or moisture that cools the skin (clevelandclinic.org 2022).

Carpal Tunnel Syndrome (CTS)

To cope with CTS, it is recommended to get redesigned workstations, tools, and handles so that the wrist maintains a natural position during work. Besides, wearing gloves should keep the hands warm and flexible. At work, the workers can also perform stretching exercises, take frequent breaks, and stay aware of their posture and wrist position (Ninds.nih.go 2023).

If CTS is sought to be caused by work-related circumstances, it should be considered change of job functions or work task rotations. Therefore, further education may be necessary so that more tasks become available. A reduction in work hours or tempo can also be necessary in a returning period after notification of illness. Changes in workflow and use of assistive aid, observation of trigger time of the HAV tools, and exchange from old to newer tools has a significant impact on the vibration exposure. These measures may allow the affected to continue their line of work.

CTS is covered by the occupational disease record. It is recognized when dealing with a long-term combination doing hours of powerful and repetitive work, exposure to HAV, or because of tenosynovitis or direct pressure against the median nerve (Thomsen & Haahr 2017).

1.1

HAV contributes to the development of multiple long-term diseases that are generically referred to as HAVS. RP is uncurable, and CTS requires operation. However, reducing exposure to vibration can reduce attack severity of RP and cure CTS. So, there are many reasons to reduce HAV exposure. That might be why several coping strategies are currently recommended (underlying desk research available in app. 1):

- ! **Long-term exposure to vibration increases risk of long-term diseases**
- ! **Force and frequency of compressions and impacts on the wrist should be reduced**
- ! **Keeping hands warm reduces risk of illness and severity of attacks**

1.2 REGULATIONS

Method: Desk Research

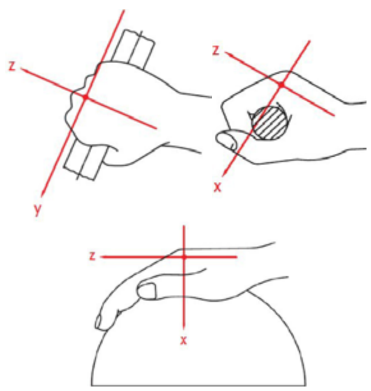
This section explains the most relevant regulations found on the website of the Danish Working Environment Authority (DWEA) found during phase 1 and 2. This is the source (at.dk 2006), if no other reference occurs. Appendix 3 contains additional information.

Magnitude

Vibrations are calculated and rated by their magnitude of acceleration (m/s^2). Measurements are conducted by attaching an accelerometer to the machine where the vibrating surface is in contact with the hand. The result contains accelerations in three mutually perpendicular directions (a_{hwx}, a_{hwy}, and a_{hwz}) as shown on ill. 6.

This formula defines the vibration magnitude:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2}$$



6: Directions of acceleration

Acceleration is proportional to energy, which is alleged to be decisive for the risk of illnesses. Vibrations are also characterized by frequency measured in hertz (Hz). Hand-transmitted vibrations range from 5-1200 Hz. The main risk factor is the magnitude of the acceleration. Descriptions of tool handling should include type of grip, grip strength, and contact with vibrating parts, if any. Duration in years and number of effective hours per day should be described, too (Rasmussen & Petersen 2016).

Risk assessment

The diagram on ill. 7 indicates risk by showing the relationship between vibration exposure and duration of exposure. It shows that even small acceleration magnitudes can cause health risks, if the exposure lasts multiple years. High acceleration magnitudes increase the health risks.

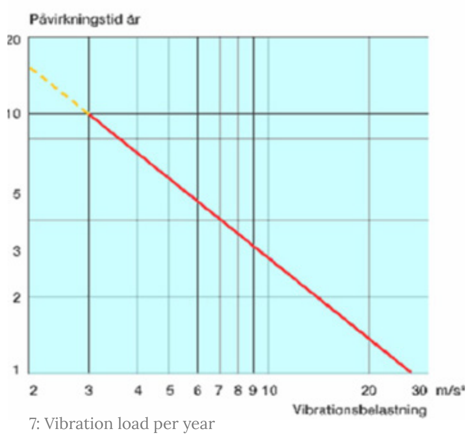
In Denmark, there are regulations to follow. They assess if employees are at health risk. Assessment of vibrations include magnitude, type, exposure time.

This also applies to the load from repeated shocks or repeated uniform periods of vibration interrupted by intervals at which the vibrations cease or change clearly in magnitude or type. Especially for striking tools such as jackhammers and impact wrenches, the risk can be underestimated. Special attention should therefore be paid to symptoms of vibration damage and always limit this type of vibration as much as possible.

The vibration exposure on a person is calculated over an 8-hour working day. It is based on the acceleration magnitude and duration of exposure.

The vibration exposure can be calculated based on information from the supplier about the vibration magnitude of the technical aid compared to the duration of the specific work operations. However, it is a prerequisite that the work operation is comparable to that on which the supplier's information is based.

Therefore, it should be taking into consideration whether the operating conditions are comparable to the intended (rpm, speed, workpiece, working position, etc.). But also, which measuring points have been used and whether measurements have been made in all three directions.



7: Vibration load per year

The vibration exposure over a working day is the time-weighted average of vibration magnitude and duration over a working day of 8 hours. The Vibration Order contains an exposure action value and an exposure limit value for the daily vibration exposure (8 hours). Both values should be understood as "averages" over a working day. Short periods of strong vibration are therefore allowed.

Exposure action value

The Exposure Action Value (EAV) is a daily vibration magnitude of 2,5 m/s^2. It indicates when to act in relation to the vibration exposure. If the value is exceeded, the cause should be investigated, and technical and organisational measures should be planned and implemented to minimise the load.

Exposure limit value

The Exposure Limit Value (ELV) is a daily vibration magnitude of 5,0 m/s^2 and must under no circumstances be exceeded. If the value is exceeded, immediate action must be taken to bring the exposure below the limit value. The cause of reason must be identified, and organizational and technical measures must be taken to avoid repeating the incidence.

Calculating vibration exposure

The vibration magnitude is used as the input in the table column, and the associated exposure time is found in the table row.

Then, read the number of "vibration points". Here it becomes clear, if the points are below the EAV (green area), above EAV (yellow area) or above the ELV (red area).

The daily exposure value is identified by locating the vibration points in the 8-hour column. Then, read the vibration magnitude in the far-left column.

If several machines are used on the same working day, the vibration points are read for each machine. The sum of all the vibration point is used as the input in the 8-hour column, and the vibration value in the column on the far left.

Vibration magnitude [m/s^2]	00:01*	00:05	00:15	00:30	01:00	02:00	03:00	04:00	05:00	06:00	08:00	10:00
40	*53*	267	800	1600	3200	6400	9600	12800	16000	19200	25600	32000
30	*30*	150	450	900	1800	3600	5400	7200	9000	10800	14400	18000
25	*21*	104	313	625	1250	2500	3750	5000	6250	7500	10000	12500
20	*13*	67	200	400	800	1600	2400	3200	4000	4800	6400	8000
19	*12*	60	181	361	722	1444	2166	2888	3610	4332	5776	7220
18	*11*	54	162	324	648	1296	1944	2592	3240	3888	5184	6480
17	*10*	48	145	289	578	1156	1734	2312	2890	3468	4624	5780
16	*9*	43	128	256	512	1024	1536	2048	2560	3072	4096	5120
15	*8*	38	113	225	450	900	1350	1800	2250	2700	3600	4500
14	*7*	33	98	196	392	784	1176	1568	1960	2352	3136	3920
13	*6*	28	85	169	338	676	1014	1352	1690	2028	2704	3380
12	*4,8*	24	72	144	288	576	864	1152	1440	1728	2304	2880
11	*4*	20	61	121	242	484	726	968	1210	1452	1936	2420
10	*3,3*	17	50	100	200	400	600	800	1000	1200	1600	2000
9,5	*3*	15	45	90	181	361	542	722	903	1083	1444	1805
9	*2,7*	14	41	81	162	324	486	648	810	972	1296	1620
8,5	*2,4*	12	36	72	145	289	434	578	723	867	1156	1445
8	*2,1*	11	32	64	128	256	384	512	640	768	1024	1280
7,5	*1,9*	9	28	56	113	225	338	450	563	675	900	1125
7	*1,6*	8	25	49	98	196	294	392	490	588	784	980
6,5	*1,4*	7	21	42	85	169	254	338	423	507	676	845
6	*1,2*	6	18	36	72	144	216	288	360	432	576	720
5,5	*1*	5	15	30	61	121	182	242	303	363	484	605
5	*0,83*	4,2	13	25	50	100	150	200	250	300	400	500
4,5	*0,68*	3,4	10	20	41	81	122	162	203	243	280	405
4	*0,53*	2,7	8	16	32	64	96	128	160	192		320
3,5	*0,41*	2	6	12	25	49	74	98	123	147	196	245
3	*0,3*	1,5	4,5	9	18	36	54	72	90	108	144	180
2,5	*0,21*	1	3,1	6	13	25	38	50	63	75	100	125
2	*0,13*	0,67	2	4	8	16	24	32	40	48	64	80

Daily exposure duration [hh:mm]

8: Example is marked with white in table for calculating daily vibration load, A(8)

Example

An employee at a foundry cleans castings. He uses 3 tools during a working day:

Angle grinder (4 m/s^2)
for 2 hours

Polishing machine (6 m/s^2)
for 1 hour

Jackhammer (12 m/s^2)
for 0,5 hours

The vibration exposure is calculated using the table:

Angle grinder: 64 points

Polishing machine: 72 points

Jackhammer: 144 points

When the total value of 280 points is used as the input in the column for 8 hours, it indicates that the vibration exposure is between 4 and 4.5 m/s^2, it is in the yellow area and above the action value and action should be taken to minimize exposure.

Notice that the high vibration magnitude (HVM) of the jackhammer makes it the most influential tool even though it is used for the shortest period.

1.2

The vibration exposure is calculated including the daily exposure time and vibration magnitude of every operated machine. Since the vibration magnitude influences points the most, this is the critical property of the machines. Frequency is not regarded as relevant.

- ! **Vibration exposure is calculated as magnitude over time becoming a daily average**
- ! **Every period of vibration exposure from any tool is in included in the daily exposure.**

1.3 PRODUCTS IN THE MARKET

Method: Desk research

To our knowledge, there only exist two product categories on the market which can reduce exposure to HAV.

Antivibration gloves

The first category is shown on ill. 9. Antivibration gloves come with a layer of a rubber. Gloves may have some protective effect when exposed to HAV with frequencies above 150 Hz (9000 rpm). But the vibration-reducing effect of the gloves is too uncertain to be considered when assessing the operator's daily vibration load (at.dk 2006).

According to Washington State Department of Labor & Industries (2023), many gloves fail to protect their user against low frequency vibrations though they are more hazardous.

The Health and Safety Executive in the United Kingdom (HSE) (2023) claims that the gloves do not protect the fingers as well as the palms. The material in some gloves increases the vibration transferred to the fingers. Besides, wearing thicker gloves increase the need to apply grip force to the handle, increasing the risk of CTS. Gripping more tightly also increases the vibration transferred to the hands and arms.

9: Antivibration gloves

Integrated antivibration

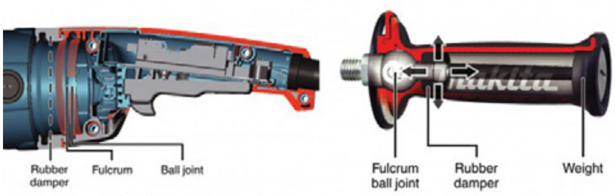
The second category includes all elements that act as a part of the power tool. As ill. 10 shows, manufacturers integrate anti-vibration features in power tools. In recent years, many companies have increased their focus on vibration (Kelvin 2023). Since 2005, it has been standard for all Metabo's angle grinders to be equipped with an anti-vibration handle. Like Metabo, ill. 11 shows that Makita included technology in the handles and the body of their angle grinder.

Though it seems like the manufacturers are contributing to reducing HAV, HSE (2005) states:

For powered hand-tools, regular and frequent use of modern, well-designed, well-maintained tools is likely to result in exposure at or above the EAV [Exposure Action Value] after:

- *the use of a hammer action tool for about 15 minutes; or*
- *the use of non-hammer action tools for about one hour.*

10: Integrated damping in hammer drills and angle grinder



11: X-ray xiew of Makita angle grinder

1.3

Some of the information above is based on sources that were quickly found on the web. The claims need to be validated through experts. Nevertheless, from now on, the focus will be hammer action tools since they harm their operator the most.

! Modern power tools should be used less than one hour a day

! The personal protective equipment in the market does not reduce low frequency vibrations

1.4 FIRST USER VISITS

Several retailers and a building contractor (appendix 2) were visited in two sequential days.

The purpose of these visits was to unfold the problem space with different power tool users' viewpoints on vibration. The plan was to record statements with notes, to enable quick data processing and decision-making afterwards.

Retailer visits

Method: Ready-fire-aim (Sarasvathy 2005)

Some of the visited retailers had more expertise and will to share their knowledge than others. This section only shows the information that was rendered relevant after the visits.

Carl Ras

12: Logo

No expertise available.

13: Hammer drill

14: Reciprocating saw

Some tools contain anti-vibration while other do not. In this case, it might be because the saw is used for shorter periods than the hammer drill.

Scandinova

15: Logo

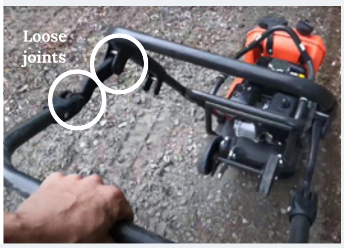
Stark udlejning

16: Logo

Erenfred Pedersen

17: Logo

18: Brian, Salesman



19: Husqvarna LF 20 L vibratory plate

The loose handle of the Husqvarna LF 80 (ill. 19) isolates the operator from the vibration of the machine. Atlas Copco invented it, but they wanted to focus on other types of machinery.

Erenfred Pedersen

20: Logo

21: Bent, Salesman

22: Bent shows an electric jackhammer

Most vibrating tools contain damping features. However, that is not the most important in contractors' purchasing decision. They care more about:

- Low purchase price
- Low maintenance and operation cost
- Previous customer relations

They prefer the electric jackhammer rather than gas or pneumatic alternatives (ill. 23), though the electric ones vibrate the most. The salesman Bent, thinks that it depends on what energy supply that is accessible on the construction site.

If operators apply pressure to tools, they have acquired tools that are not suited for their current task. Ideally, the operator of a power tool is only supposed to hold it to maintain balance.

23: Pneumatic jackhammer

Jydsk Værktøj

24: Logo

Nordjysk lift (rental company)

25: Logo

26: Lasse, Head of Department

If a Husqvarna LF80 L is used along something like a wall, the operator needs to grab somewhere else than the loose handle to control it. Besides, the buttons of the user interface should be within reach.

Some of Nordjysk Lift's tools are up to 14 years old, but it varies depending on the treatment by the renters.

Many companies supply their employees with personal protective equipment that they are responsible for. Gloves are usually not a part of this package.

End user visit #1

Methods: Situated interview, Acting out
(Sperschneider & Bagger 2003)

Building contractors use various hammer action tools. One of TL Byg's renovation projects, a private property in Aabybro, was visited to interview and observe a site manager and two masons. Prior to the visit, they had spent 6 hours a day for 5 workdays to remove herringbone tiles from the floor.

27: TL Byg's renovation project (From the left: Site manager, mason 1)

Tools on site

They alternately used two tools (ill. 28):

Property	Hammer drill	Jackhammer
Weight:	Lightest	Heaviest
Damping?	No	Yes
Hammer action:	Least	Most
Application:	Corners	Large areas

28: Hammer drill and jackhammer

The masons choose tool based on the working area.

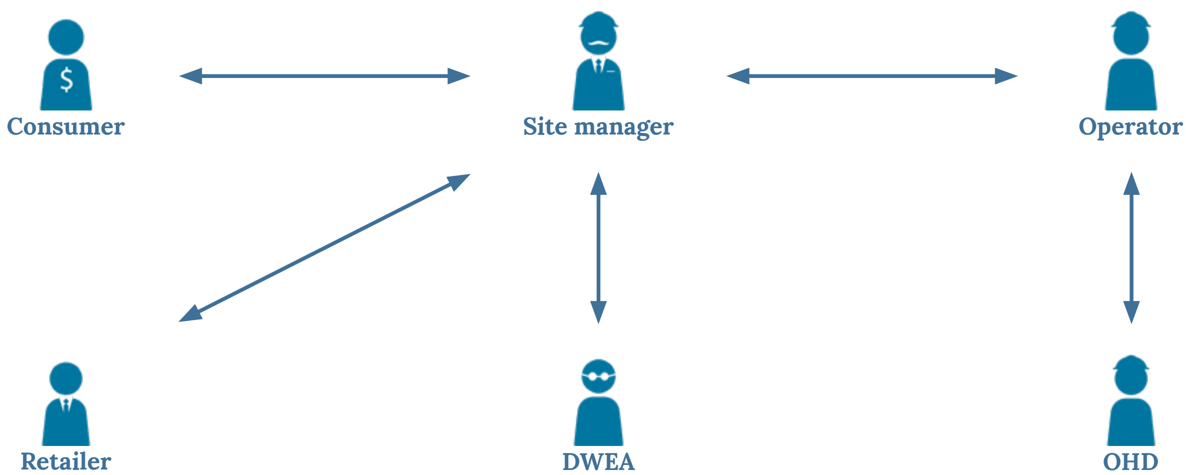
Mason 1: So, *the small one* [hammer drill] *is good near corners, where you need to be careful to avoid damaging anything near the wall. It is not as heavy, and it does not jump as much as the other one* [jackhammer].

Across the entire company, Bosch is the brand they use. According to the site manager, they stick with this brand because of battery compatibility and an agreement (probably involving some sort of quantity discount). Besides, high-end professional power tools are very similar.

Since they are masons, they don't use the demolition tools very often. That is also why they do not know the age or condition of the tool. They *replace the tools when they break* (full interview in appendix 2)

Stakeholder mapping

During the retailer visits and end user visit #1, the following stakeholders have been identified. The arrows between the stakeholders indicate the direct interactions. The next page presents two dilemmas. The stakeholder icons appear on the side of the dilemma that they support. So far, no statements from the Occupational Health Department (OHD) or the consumer has been retrieved.



DILEMMA

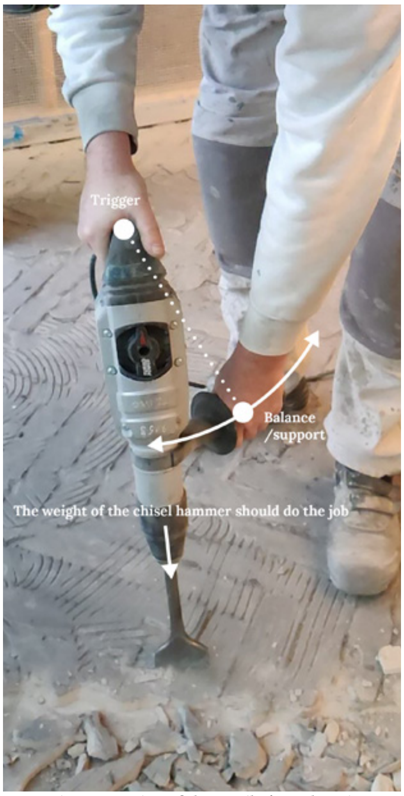
Experience of control vs. Avoid vibration

Erenfred Pedersen and the masons seem to have different opinions on how power tools are supposed to be handled. As ill. 30 shows, the mason applies pressure to the jackhammer to control it.

The masons do not wear gloves because they think that *then you do not have that feeling of the tool.*

29: Mason 2 with hammer drill

30: Mason 2's comments on use of the jackhammer



31: Our interpretation of the retailer's explanation

DILEMMA

Regulations vs. Customer expectations

According to Lasse (Nordjysk Lift) as well as the TL Byg site manager there is a misalignment between the DWEA regulations and the expectations of the contractor's customers. If the regulations were followed, the customer would not understand, since they expect the work to finish as soon as possible.

For instance, if a tool has a recommended limit of one hour a day, what are you going to do after that? Stand and stare? - Site manager

Nevertheless, removing the herringbone tiles is hard work. The masons take up to 6 breaks a day and they are grateful that the manager usually delegates demolition work sub-contractors with Polish workers.

The masons say that they use the power tool until they feel fatigue. That is comparable to applying sunscreen after getting a sunburn.

1.4

Taking notes during the interview is stressful and relevant details might be missed. However, it is less time consuming to process and evaluate afterwards, which was beneficial in this stage of the process. To gather more in-depth information on next visit, interviews will be recorded on video, if the interviewee consents.

During every visit, the DWEA was mentioned. To confirm that a power tool add-on will extend the allowed working period, the DWEA should be contacted.

- ! **Power tool customers prefer setup convenience over low vibration tools**
- ! **Control of demolition tools is only important when there is a risk damaging property**
- ! **Operators stop the use after they feel the fatigue**
- ! **Dilemma: Apply pressure to control (operator) >< Let it work by itself (retailer)**
- ! **Dilemma: Following the DWEA regulations >< Contractors' ability to compete on price**

1.5 DESIGN BRIEF

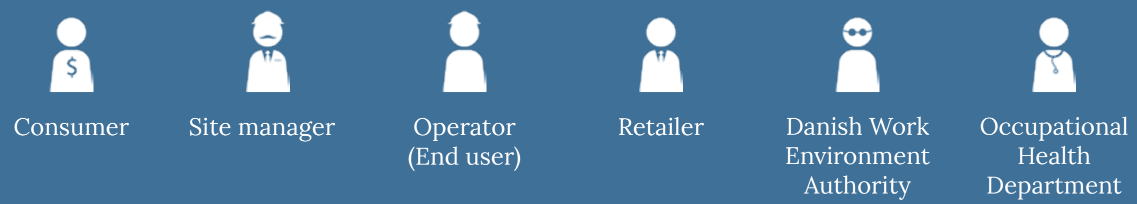
Vision

Safe and effective work environment

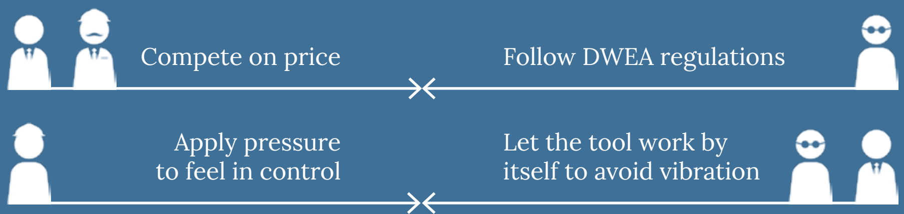
Problem statement

How can a physical product reduce the risk of developing Raynaud's Phenomenon and Carpal Tunnel Syndrome during operators' use of power tools every day?

Stakeholders



Dilemmas



Key takeaways

1.1	Long-term exposure to vibration increases risk of long-term diseases. Force and frequency of compressions and impacts on the wrist should be reduced. Keeping hands warm reduces risk of illness and severity of attacks.
1.2	Vibration exposure is magnitude over time All vibrating tools should be added in daily exposure. Frequency is not important for the calculations. And is just understood as impacts per minute.
1.3	Modern power tools should be used less than one hour a day. The personal protective equipment in the market does not reduce low frequency vibrations
1.4	Power tool customers prefer setup convenience over low vibration tools Control of demolition tools is only important when there is a risk damaging property Operators stop the use after they feel the fatigue

1.6 MILESTONE

Problem fly-in

Using power tools that hammer, vibrate or rotate on a regular basis for as little as 5 minutes at a time affects anyone. In recent years, most power tool manufacturers have been integrating antivibration technology, and many companies communicate it as unique selling point.

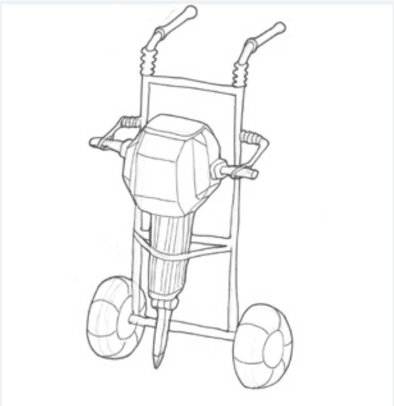
The risk of disease varies depending on the frequency and magnitude of the vibration. Despite magnitude being the critical parameter, the only existing protective equipment reduces the vibrations with high frequency and low magnitude.

Most common diseases are RP, also known as Vibration-induced White Fingers, and CTS.

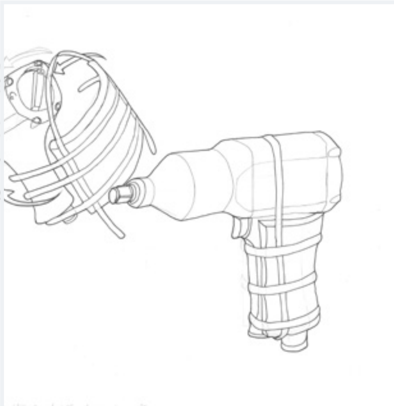
Three concepts

During this phase, multiple ideas were sketched. They marked the three current solution directions:

1) Mount on heavy tool



2) Small retro fit add-on



3) Self-surveillance in the breaks.

32: Sketch concepts presented on milestone

Key supervisor feedback: *Each concept has a trade-off, and it is usually the trade-offs that users reject.*

1.7 REFLECTION

The purpose of this phase was to pressure test the project foundation. Numerous insights into the problem were found, but at the end of the phase there was no explicit overview of the problem, besides the fact that it was a valid problem.

Why is the market blue?

As of now, it seems like the market is blue. It is still uncertain why this is the case. It is likely that a major challenge will emerge in the upcoming phases.

Our brief desk research showed that modern hammer action tools should only be used 15 minutes a day. This number might be obsolete, since many power tool manufacturers have introduced new integrated damping element in recent years. These upgrades may have reduced the vibration magnitude to an acceptable level. In the future, there might not be problems related to vibration, because all tools have been upgraded.

Ready-fire-aim

The key challenge of this phase was to find information to take decisions from. Initially, we did not know who to address, what tools to observe. Instead of searching on the web without what information was important, we decided to get out of the building and talk to people with power tool experience and opinions.

Our mindset was comparable to how a subject of Sarasvathy's (2005) study put it, "*I always live by the motto of Ready-fire-aim. I think if you if you spend too much time doing ready-aim-aim-aim-aim, you're never gonna see all the good things that would happen if you actually start doing it and then aim. And find out where your target is.*"

However, since we were not *ready* with prepared questions or explicit assumptions before visiting the retailers, it was not clear what information was surprising and why. It was difficult to prioritise and *aim* after the retailer visits.

2 MACHINE SCOPING

In this phase, it becomes clear that variations in the power tool category complicate scalability. To choose an appropriate direction, more experts are contacted, and valuable partnerships are initiated. After another visit at a potential end user the project scope is limited to hand operated machines.

33: Situated Interview at a Jorton construction site

2.1 MACHINE MAPPING

During the first phase, more tools and potential users were continuously discovered. So, it was deemed necessary to gather more information on these to consider who the target user is and what the scope of tools is. Doing the first milestone, it was also suggested to have a focus on the worst use case. In this problem scope, it is the machine that creates the highest daily vibration exposures, but also who the users are in this scenario.

Mapping 1: Motion type

The first plan to locate the worst use case scenario was to find some similarities between equipment such as handle shape, vibration action or vibration magnitude. Lastly it must also be considered which types of tools make the highest impact/influence depending on the length of working periods and frequency of use.

According to the Canadian Centre for Occupational Health and Safety handling vibrating equipment such as tools the tools represented in this mapping, should cause operators a general concern for developing Raynaud's phenomenon (ccohs.ca 2023)

The tools are categorised depending on their operation action to see if there is a coherence with tool shape and operation. Ill. 34 shows Tool mapping 1 that maps what kinds of tools and equipment than can cause HAVS.

There are also tools not on the list that we think are relevant such as. 1) Gas driven tamper, 2) Plate compactor, 3) Reciprocating saw. (Mainly hand operated machines)

From the tools that are mapped it shows that rotation action is the main type of machine operation, but they come in vastly different sizes and shapes. Hammer action tools are the second most represented and these tools also come in many different shapes and sizes. With this mapping method it could only be concluded that there is no apparent link between the different tool types and their operation action, different ways to categorize the tools and define the solutions scope must be defined. The current table does not allow to increase flexibility of the mapping.

Type of motion that touches the processed medium	There are hundreds of different types of hand-held power tools and equipment which can cause ill health from vibration. Some of the more common ones are:		
Rotation:	Chainsaws 	Hand-held grinders 	Pedestal grinders 
	Cut-off saws (for stone etc) 	Polishers 	Powered sanders 
	Strimmers/brush cutters 	Powered lawn mowers 	
Rotation & hammer action:	Hammer drills 	Impact wrenches 	
Sawing?	Jigsaws 		
Hammer:	Needle scalers 	Scabblers 	Power hammers and chisels 
	Concrete breakers/Road breakers 		

34: Tool mapping 1

Mapping 2: Handle shape

This second attempt will include different ways of categorisation to uncover where the tools are similar. The solution was a second map that divides the tool types depending on their handle shapes. Secondly it is distinguished by a trigger handle and a support handle.

Trigger handle shape

The trigger handles are divided into five categories. 1) continuous cylinder, 2) varying cylinder, 3) open organic, 4) closed organic and 5) an integrated one.

Supporting handle shape

The support handle is divided into four categories 1) continuous cylinder, 2) varying cylinder, 3) open organic, 4) integrated. It clearly shows that most tools utilise a cylindrical shaped handle as support but not as a trigger handle. The trigger handles differ more in shape.

35: Trigger handle mapping

36: Supporting handle mapping

2.1

Their handle shape and design did not provide any reasonable way to conduct a product scoping based on this factor with such a wide range of product categories.

It might be easier to investigate just one category rather than across multiple categories. More information regarding each category could be used to decide what tools to tackle instead.

! Handles vary in shape, size and orientation

We unknowingly chose to make a product for tools without a trigger handle. Just a support handle/control handle. This means that they are simpler to adapt to because they differ less across machine model and type, this problem insight was first discovered here.

2.2 USER MAPPING

After failing to narrow the project scope through tool mapping, the strategy becomes to look directly for the users of the tools. Firstly, the DWEA is contact to uncover if they have statistics concerning what industries are the most exposed in general. Secondly, a public counselling organisation is reached, and they provide multiple valuable insights.

DWEA's user knowledge

The DWEA could not provide further information beyond what is available online. Instead, they referred to Byggeriets Arbejdsmiljøbus (BAM-Bus) who are responsible for workspace safety guidance and counselling the entire construction industry. They have a lot of contacts and are responsible for testing and improve development of new safety gear and equipment for the workspace, before it becomes recommended to the DWEA and the construction industry in general.

BAM-Bus' insights

BAM-Bus does not gather specific data to backup claims concerning HAV hazardous related sectors or tools. But they have a lot of experience and useful insights and a hunch as to which sectors are especially exposed either in the terms of exposure time and limit. They might be able to help gain contact with users and help making realistic testing of the prototypes that would be created in the future. Appendix 5 contains notes from an informative phone call.

37: BAM-Bus guidance at an end user visit that will be presented in section 3.5

Construction workers

According to BAM-Bus, construction workers are by far the most exposed due to the type of machinery and duration of use. Most of their work involves some sort of machinery that impact the work medium. These tools often have a significant HVM, meaning the daily vibration exposure tends to be very high. They stated that often workers suffer from RP without notifying the DWEA nor their employer, fearing they might lose their career.

High vibration exposing tools in construction

BAM-Bus state the most vibration exposing tools in this field are, cultivators, floor strippers, scarifiers, grinders, vibratory rammers, vibratory plate compactor, concrete vibrators, bayonet saw, jigsaw, etc. This list is comprehensive, and the tools differ a lot in both size, operation, function, and their work context.

Suggested directions

Firstly, they confirmed that a universal solution for handheld power tools could be difficult to implement because they tend to have very different shaped handles. However, they did recommend keeping an open mind in the start and cut down to a smaller product category, as it would make it easier to solve the problem.

Secondly, regarding vibration exposure, they specified that the duration of use is just as important as vibration magnitude, if not more. Very short use periods will not have as significant an impact as a tool with lower vibration magnitude used for much longer periods or more frequently.

Thirdly, construction firms do not replace all their tools right away just because newer tools are developed with lower vibration exposure. So, an alternative to do so would be appreciated.

Nonetheless, reducing vibration expose must not compromise the efficiency or quality of work.

2.2

Construction workers might be the most exposed users, and because of their silence the extent of HAVS might be underrated in their industry. The product scope should be narrowed down to a smaller product category to optimise the development process. Should it become an alternative to replacing products to minimize HAV exposure, it would be appreciated. Nonetheless, it shall not reduce operation efficiency.

2.3 END USER VISIT #2

To discover more barriers from implementing an add-on on power tool, another potential end user was visited. Through our network, Jorton was reached, a contractor that was building a new indoor water park for Skallerup Seaside Resort A/S. The aim was to talk to users of power tools with high vibration magnitude (HVM).

Jorton is a nationwide construction company with almost 100 years of experience in concrete work, earthmoving, and bricklaying. Lately, they have expanded to sewage work. For demolition and carpentry, they hire subcontractors. On the day of the visit, none of these tasks were observed, since none of the HVM tools were used. Instead, the real use case was simulated with **Acting out** (Sperschneider & Bagger 2003). Appendix 4 contains extracts from transcribed interviews.

38: Jorton's construction site in Skallerup

Observed tools:

- Power drill
- Impact wrench
- Vibratory plate compactor
- Floor scarifying machine
- Small jackhammer
- Big jackhammer (not available during visit)

After the visit, the tools were categorised into:

- Hand-held tools (carried by the operator)
- Hand operated machines (not carried)

Interviewees:

Several of the interviewees preferred to stay anonymous, so no images or names of these individuals are included. These professions participated:

- Project manager
- Masons
- Construction workers
- Carpenters

39: Mason wearing knee pads

40: Mason with Carpal Tunnel Syndrome

Current safety equipment

During the interview, the workers showcased and compared their current equipment.

Knee pads

The masons like the knee pad that is attached with a Velcro strap because it allows them to move around without interacting with it. However, it is difficult to check the condition of integrated knee pads.

41: Wearable velcro knee pad

42: Seperate knee pad

43: Integrated knee pad

Anti-vibration gloves

Gloves are not worn because they seem unnecessary, if the task of using the power tool is brief. During summertime, they are not worn because it is too hot.

44: Antivibration gloves

Safety helmet

Since the helmet is comfortable, it is worn all day. Sometimes they forget to take it off before they go home.

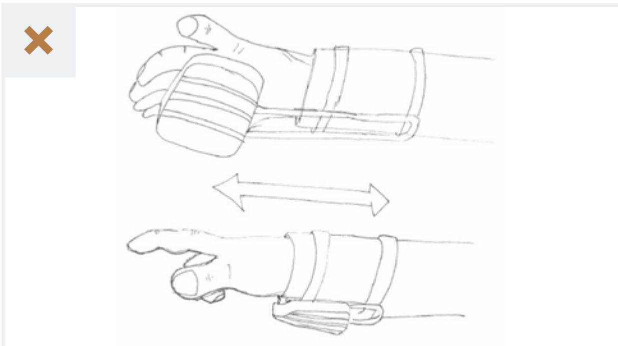
45: Helmet on an interviewee's head

The workers wear numerous types of equipment, and every time they change task or take a break, they interact with it. They prefer to dismount the least comfortable equipment as soon as it does is not seem necessary to wear. The least favourite equipment are the goggles, mask, and earmuffs. Especially when they need to wear it at the same time.

- ! **Minimize preparation time**
- ! **Comfortable to use for extended periods**
- ! **Visible condition**

To avoid overcrowding the worker's body, the product should not be wearable. The objection of the sketch on ill. 46 supports this.

It should be as small as a watch if I am wearing it.



46: Extensible pad

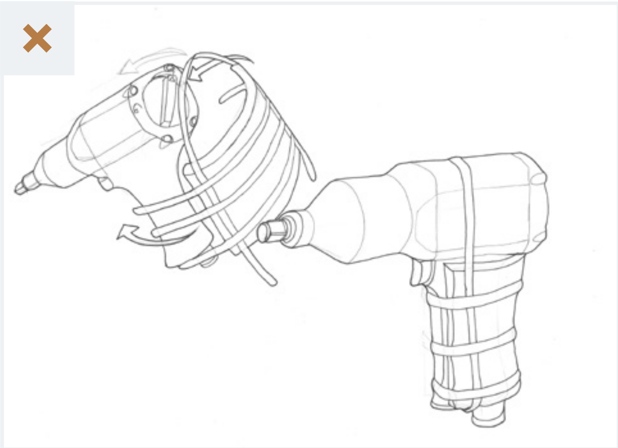
2.3

Handheld tools

Most power tools are meant to be light to carry and small to access corners. On the construction site, the carpenters use an impact wrench for extended periods of time every day. Showing them the sketch on ill. 47 trigger objections like:

I do not like fat grips, because they are harder to hold.

It should not increase the weight of the tool.



47: Handle wrap on impact wrench

48: Carpenter and impact wrench

Grabbing elsewhere than handle

In a situation such as the one shown on ill. 49, it can be necessary to hold the power drill in a specific way to maintain control.

Here, it is hassle to access, and then I usually need to put two hands on it.

49: Two hands on power drill

Carrying large jackhammer

The fact that handheld tools are liftable provide the operator with flexibility. For instance, if a large jackhammer is supported on the floor like on the sketch on ill. 50, the areas that the tool can operate in will be limited, because:

It removes what it stands on

50: Jackhammer mounted on sack trolley

Hand operated machines

These machines are typically heavy, large, powerful and do not topple if the operator lets go of it. This means that the operator does not have to hold on very tightly. Though this might be the case, the operator is still exposed to vibration. The construction worker, Christian, simulated how to use multiple machines:

Floor scarifying machine

It is supposed to run by itself, but I hold it back because it goes too fast sometimes. I cannot feel any vibration in it.

51: Christian and the floor scarifying machine

When Alexander grabs the handle, he instantly notices how much his hand is affected, but Christian continues:

[I am] *Not even* [affected] *when I walk with it, no, it is mostly when I work with the* [large] *jackhammer, because it makes that 'duk-duk-duk'.*

52: Alexander grabbing the floor scarifying machine

Vibratory plate compactor

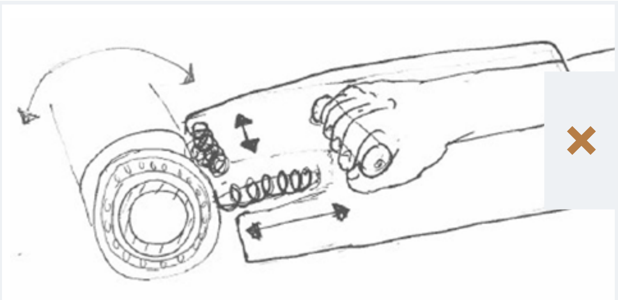
Christian describes his experience in a similarly way, but Jens feels the vibration affecting his hands after 30 second of use, even while borrowing Christian's antivibration gloves. To showcase this, a video was made for Milestone 2.

53: Jens learns how to operate the VPC

54: Christian shows how to operate the VPC

55: In the video, a white line highlights the movement of Christian's hand in slow motion

! The workers are not aware of the vibration



56: Glove mounted on machine

Sharing unhygienic equipment

Some sketches were shown with concepts that decrease the necessity of gripping force.

✕ *They will become disgusting to put your hands in if someone has been rooting in the ground after rain, or if someone has peed.* - Christian

! Appear hygienic

Time and budget management

Like TL Byg, the Jorton's workers do not keep track of their trigger time and do take breaks regularly.

The Jorton site manager also explains that it is well-known that people get operated in their hands because of tendons that are worn down or broken, so there is no doubt that you have found a subject with potential.

However, if a new product compromises the worker's efficiency, it is a deal breaker. Efficiency is any contractor's competitive performance. It is all about delivering a result with the best quality in the shortest possible time.

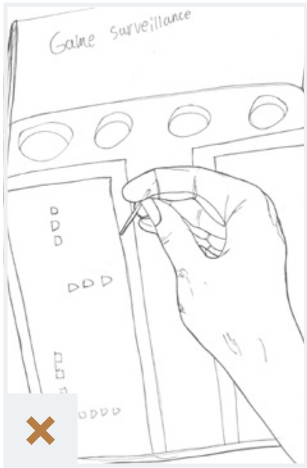
Health surveillance feedback

This concept will tell its users if they have any CTS tendencies. They are supposed to spend a minute during their small breaks to use it.

During their breaks they prefer to merely drink, eat and talk. So, it would not make sense to introduce monitoring in the everyday. On the contrary, an operator stated:

We have a safety coordinator in the company that we can call if we are not sure what is allowed safety-wise. When we have personal conversation with this person, this thing could be used.

Selling such a device to this coordinator only would not make up a market demand with enough units. Therefore, the production cost would become very high.



57: Health surveillance game

Machine lifetime and acquisition

The hand operated machines are typically a larger investment than the hand-held tools. Though they have a long lifetime, Jorton only acquires the machine that they use on a regular basis. For instance, their vibratory plate compactor is 17 years old (ill. 59). If a machine is needed for a short period, they rent it from companies like Nordjysk lift (mentioned in section 1.4), otherwise they hire one of the regular subcontractors. Jorton is very aware of what areas of construction they specialise within. To maintain long-term agreements with their subcontractors, they avoid competing with e.g., the carpentry and demolition companies.


58: The vibratory plate compactor is worn

59: The year of production is 2006

Machine scoping

Hereinafter, the project focus is to deal with the Hand Operated Machines (HOMs). This decision is based on the following reasons:

HOMs are heavy, but self-supporting, so the operator does not need to lift but merely steer (push, pull, and turn).

HOMs expose the operator to higher vibration magnitude than handheld tools.

HOMs are long-lasting and expensive. A retrofit will be valuable, because it postpones the next large investment. There will be a large market because many machines are old and worn but not ready to be replaced.

HOMs have a simple handle shape. Whatever add-on we develop, it will probably trade-off some control to dampen the vibration. Handheld tools require more precision and fine motor control to operate efficiently. This is consistent with the handle mapping in section 2.1. The shape of handles on handheld tool is more complex than the ones on HOMs. This is also a reason why HOMs might allow more scalability.

Even though it has been determined that the product should not be worn by the user. The insights from the analysis of current equipment remains relevant.

The table shows a comparison of the project potential, i.e., what category seems least challenging to a retro fit with a new product.

Parameter	Hand Operated Machines	Handheld tools
Vibration magnitude:	High	Low
Puchase price:	High	Low
Space requirements:	Low	High
Weight requirements:	Low	High

Hand operated machine examples

Lawn mower

Vibratory plate compactor

Cultivator

Floor grinding machine

Smoothing machine

Asphalt cutter

Floor stripper

Vibratory tamping rammer

60: Hand operated machines within the project scope

2.4 CHIEF PHYSICIAN INTERVIEW


61: Photo of Jacob

Semi-structured interview with Jakob Hjort Bønløkke
Chief physician, Occupational Health Department
(Danish: Overlæge, Arbejds- og Miljømedicinsk Afdeling)
Aalborg Universitetshospital (Appendix 6)

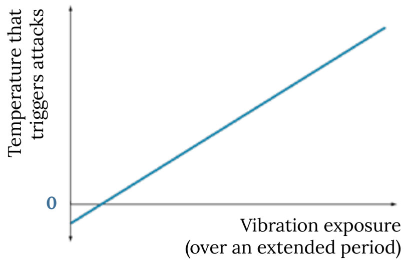
The vibration magnitude is the critical parameter. However, increased time and frequency does, obviously, increase the effect of the magnitude.

Raynaud's Phenomenon (RP)

Jacob confirms all the information gathered so far, except that cold temperatures contribute to risk of Raynaud's Phenomenon. Low temperatures do not cause RP, but they trigger the attacks.

If a patient is never affected by cold, RP will never occur. In that sense, white fingers are like cat asthma. When the patient is exposed to cats, the symptoms will manifest.

However, as ill. 62 shows, RP cannot be cured, and the temperature sensitivity of the hands will increase with continuous vibration exposure. The diagram does not contain numbers, because it is unknown what temperature the sensitivity reaches. Its purpose is to explain a correlation.



62: RP patients' hands become increasingly sensitive to temperature if they do not stop work that involves vibration exposure.

Carpal Tunnel Syndrome (CTS)

Jacob does not know how vibration influences the risk of developing CTS. But the loads are a direct cause of the CTS. It all comes down to the amount of time and magnitude of force that the carpal tunnel is compressed. Ill. 63-65 shows positions in which the carpal tunnel is stressed. Ill. 64 is the most common load position, but ill. 63 is the position that constricts the carpal tunnel the most, regardless of the load.


63: Bent wrist


65: Jacob's gesticulation of a twisted wrist


64: Most commonly loaded position

Distribution to forearm

At the end of the interview, Jacob was excited about an idea:

It could be a good idea to distribute force from hand to the forearm. It makes sense to move or spread the vibrations to the arm rather than to the many fragile bones, muscle structure in the hands.

66: Jacob touches his forearm,explaining the forearm idea

Severity components

As BAM-Bus mentioned, the severity of the vibration depends on trigger time, frequency and magnitude. In other words, the vibration is not severe if either one of these components are very low. Jacob agrees, and he is worried that operators will extend the trigger time, once they are aware of the reduced vibration.

Hand-arm vibration components		
Trigger time	Vibration magnitude	Frequency

Wear and tear extend trigger time

Many of Jacobs patients tell him, that their employers encourage use of tools until they are worn down. This amplifies, because it means that the tools become less effective and that extends the trigger time needed to execute a task. If a product could indicate that the tool is worn by measuring if its vibration has exceeded a certain level, then Jacob believes that it will enable workers to convince their employers to substitute the tools.

Attachment

The add-on should be attached to the machine rather than the operator. Jacob claims that companies either forget to purchase the product, to instruct their employees in the use, or the workers do not want to wear it.

2.4

- ! **Attach the product to the machine**
- ! **Hands are more fragile than the forearm**
- ! **Hands are vulnerable to vibrations regardless of their temperature**
- ! **Cold handles trigger attacks of Raynaud's Phenomenon**

2.5 DESIGN BRIEF

Vision

Safe and effective work environment

Problem statement

How can an add-on retrofit the large hand-operated machines to reduce the operator's risk of developing RP and CTS?

Stakeholders

Consumer

Employer

Operator (End user)

Retailer

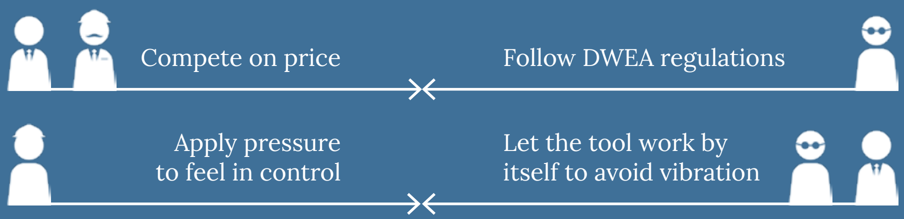
DWEA

BAM-Bus

BFA

OHD

Dilemmas



Key takeaways

At the time of Milestone 2, an overview of the insights and requirements was missing.

Based on the memory of latest activities; End user visit #3 and chief physician interview, five criteria were formulated.

The product should...
Decrease vibration exposure to hands
Appear hygienic
Not delay turning the machine
Allow to push and pull the machine
Be comfortable to hold

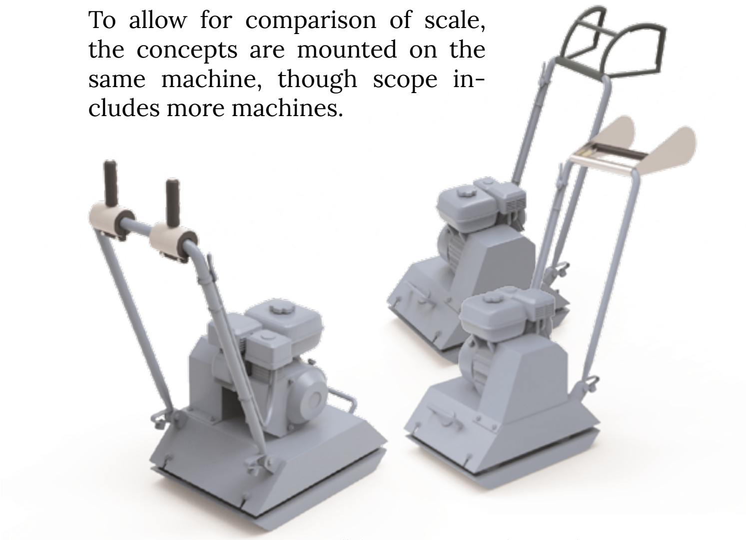
Later, during the documentation of the process report, more important takeaways were included.

2.1	Handles vary in shape, size and orientation
2.3	Visible condition The workers are not aware of the vibration
2.4	Attach the product to the machine Hands are more fragile than the forearm Hands are vulnerable to vibrations regardless of their temperature Cold handles trigger attacks of Raynaud's Phenomenon

2.6 MILESTONE

Three new concepts

To allow for comparison of scale, the concepts are mounted on the same machine, though scope includes more machines.



70: All three concepts on vibratory plate compactors

The Harness

- Distributes vibrations onto the body instead of hands and arms
- No need for grabbing with hands
- Wear the machine, it is easy to take on and off
- Padding reduces the vibration magnitude

67: The Harnees, operator view

Problem fly-in

Contractors and project managers compete on price. To minimise time-consumption, they choose the most efficient and powerful tools to do the job.

However, many of the efficient hand-held tools and machines expose their operator to a lot of vibration. Therefore, it is not healthy to operate for very long. DWEA regulations describe the permitted daily working period. According to the companies that we have talked to, obeying these regulations hinders their ability to compete.

For the small, handheld tools we notice that:

- The handle diameter should not increase
- Low weight and small size are also essential values of these tools
- The smaller they are the more convenient they are to work with

On the other hand, the heavy hand operated machines are

- More powerful and has a higher vibration level
- Since they are expensive to substitute to there is more incentive to do maintenance
- No space requirements
- No weight requirements

Gloves are...

- Expensive (600-1200 DKK), and the construction workers do not like to share
- Too warm to wear in the summer
- Not supported by any evidence that they dampen vibrations

And that is just one of our competitors. The second one is buying a new machine with integrated damping. The third (but unofficial) one is the subcontractor with foreign workers

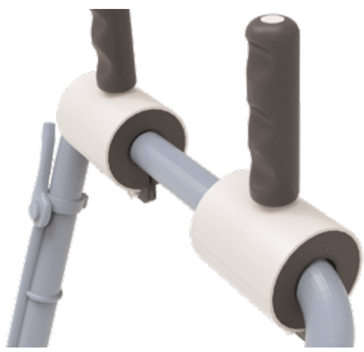
The Forearm Distributor

- Distributes vibrations to the arms and minimizes exposure to the hands
- Shock absorbers reduce the vibration magnitude
- Push the machine around with your forearms or elbows.

68: The Forearm Distributor (The concept will explored in section 3.1)

Ergo-grips

- Insulates vibrations from the hands
- Move the machine around with your hands
- Reduces vibration exposure with better grip
- Reduces vibration magnitude with vibration damping material insulator

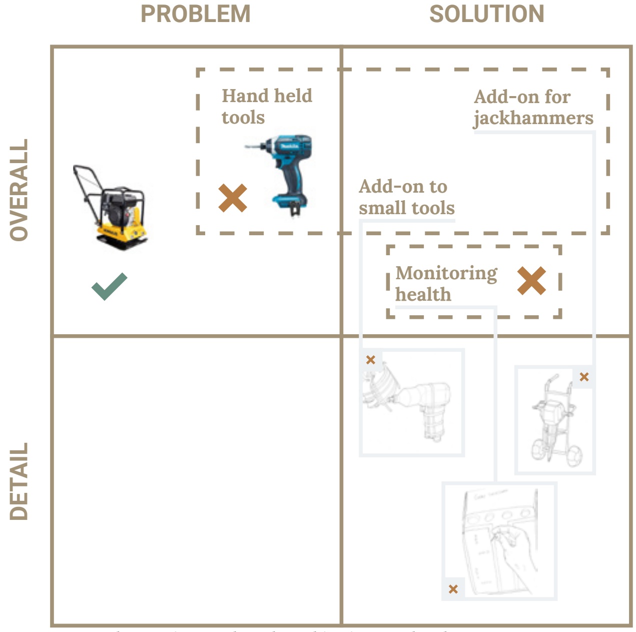


69: Ergo-grips, zoom-in (More views in section 3.1)

2.7 REFLECTION

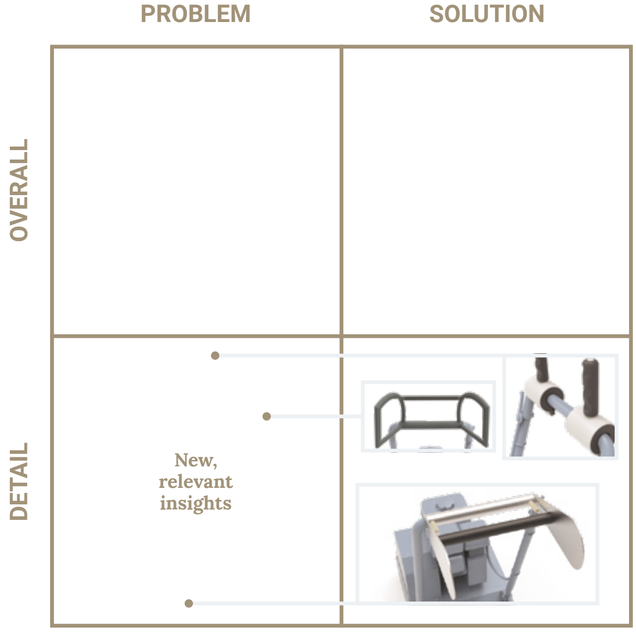
Machine scoping reasoning

According to (Haase & Laursen 2023) hooks and objections are always based on details. Accepting this premise entails that when the Jorton employees reacted to sketches (section 2.3), they utilised their imagination to interpret the sketch into a real product. Despite our awareness of this, we chose to discard overall solutions and narrow down the problem space from all vibrating machine to hand operated ones (ill. 71). However, it is important to keep the faint basis of the scoping in mind, in case the rejected project direction shows potential at some future point.



71: How the scoping was based on objections to sketches

The intend with the scoping was to approach relevant details of the problem faster. As ill. 72 shows, three concept for hand operated machines were ready at milestone 2. Since then, the project direction has showed potential, and thanks to this scoping the next uncovered details of the problem were more relevant to the project.



72: Next problem insights are relevant and detailed

3 RAPID PROTOTYPING

In this phase, progress depends on efficiency of prototyping. While experience of control and consistency of vibration measurements is unfolded, it becomes clear that the vibratory tamping rammer should be the focus of the project.

73: Testing measurement options on Vibratory Tamping Rammer

3.1 PROTOTYPING #1

Current challenge

Prototype quality

The main function of the prototypes to be built is their ability to dampen the vibration. However, if the damping entails a tradeoff of control, the user might reject it. This means that the prototype must be loose enough to disconnect the operator from the vibration but remain sturdy enough to maintain the operator's control.

Measurement method

To compare the damping of the prototypes, a consistent measurement method is essential.

Pressure of time and budget

Though it is obvious that time and money is of the essence, it is worth mentioning that these factors complicate the prototyping. It is likely that the rigidity of the prototypes cannot be simulated with cheap materials such as cardboard or 3D printed plastic.

Body vibrations

Due to information found through brief desk research, The Harness is immediately discarded. According to (BFA 2022), the Expose Action Value of full body vibrations is 0,5 m/s². This is a fifth of the HAV EAV (2,5 m/s²). This means that transferring vibrations to the torso, like The Harness does, only makes conditions worse.

74: The Harness concept

Preparations

Material sourcing

Aalborg Gummivarefabrik provided free rubber samples for the Ergo-grips.

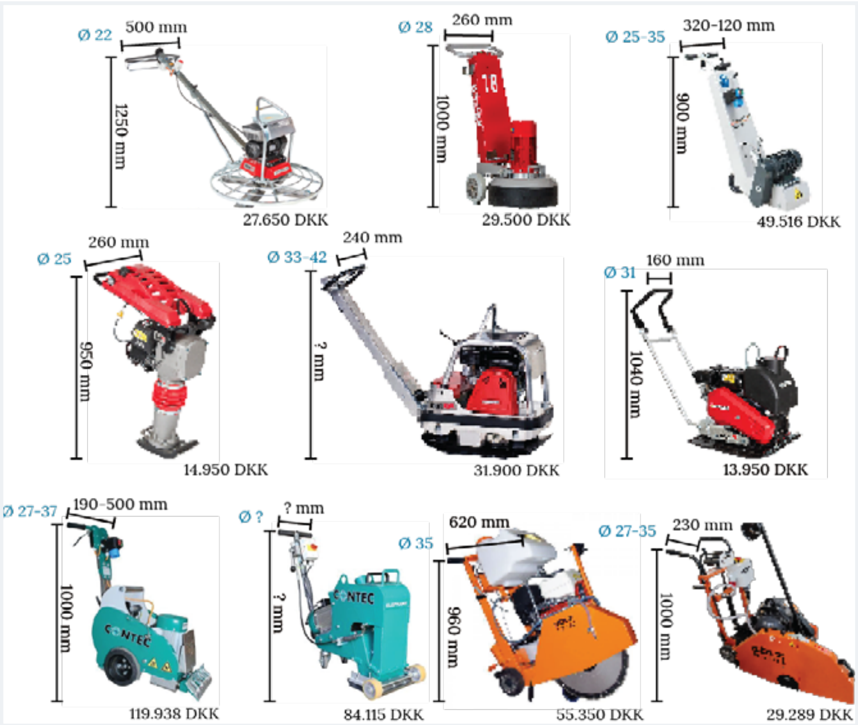
The local junkyard team leader provided dampers through a children's mountain bike and an office chair. The office chair was not used since it seemed too stiff.

75: Disassembly in workshop

76: Mountain bike front fork

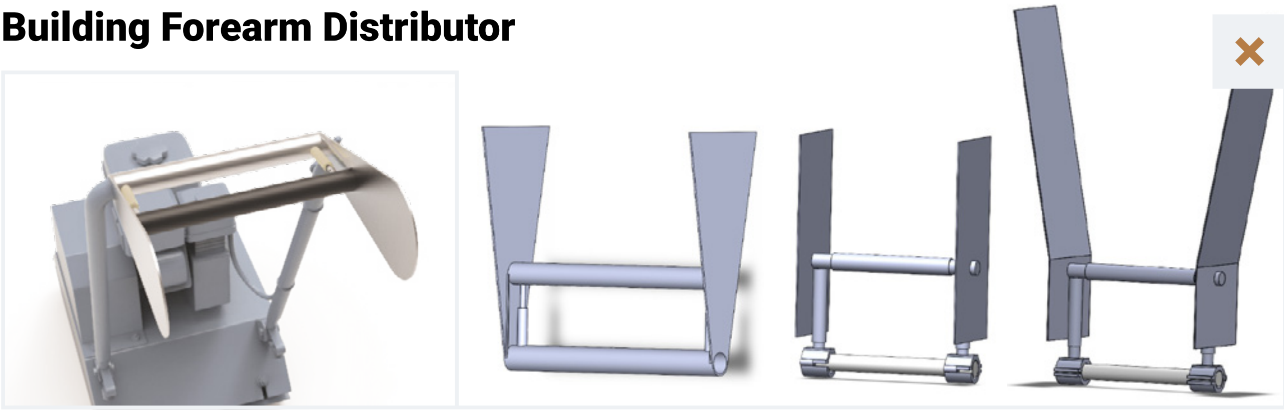
Dimension measurements

At Erenfred Pedersen, numerous hand operated machines were available to measure. Ill. 77 shows images found on the web representing the measured machine types. A salesman stated that the vibratory tamping rammer is the worst to operate.



77: Dimensions of hand operated machines

Building Forearm Distributor

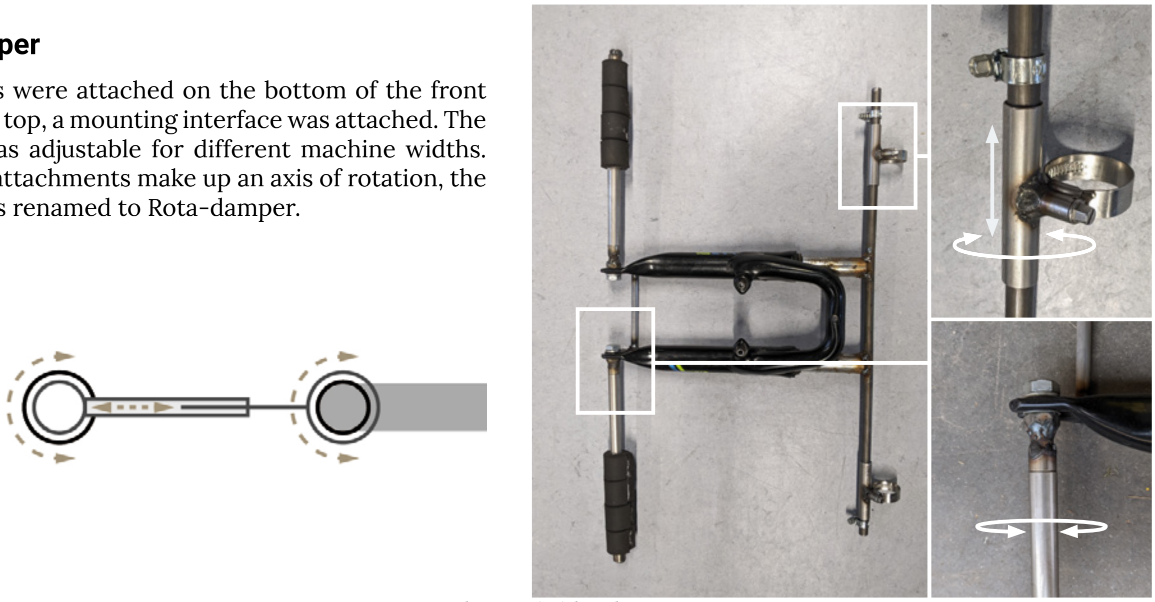


78: The Forearm Distributor concept and CAD iteration

The forearm distributor was complicated to build. Most decisions depended on whether skills, equipment, and materials were available. Although, the forearm distribution part of the concept included in CAD iterations, it was opted out in the workshop because it did not fit the damper found in the junkyard. More descriptions of the proto-type development are in appendix 7.

Rota-damper

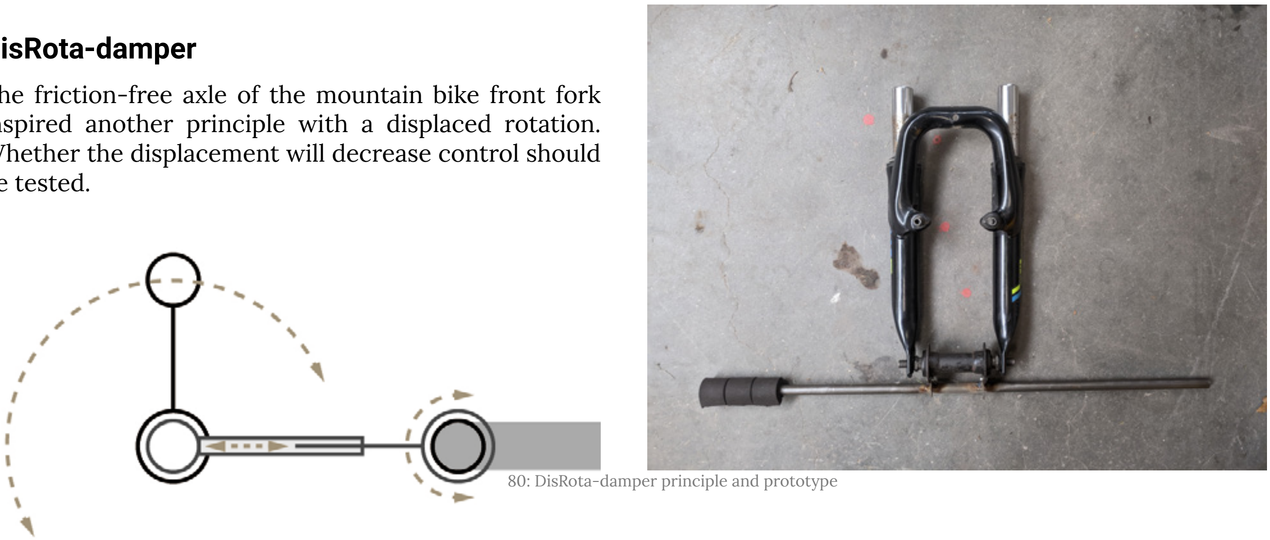
The handles were attached on the bottom of the front fork. On the top, a mounting interface was attached. The interface was adjustable for different machine widths. Since both attachments make up an axis of rotation, the concept was renamed to Rota-damper.



79: Rota-damper principle and prototype

DisRota-damper

The friction-free axle of the mountain bike front fork inspired another principle with a displaced rotation. Whether the displacement will decrease control should be tested.

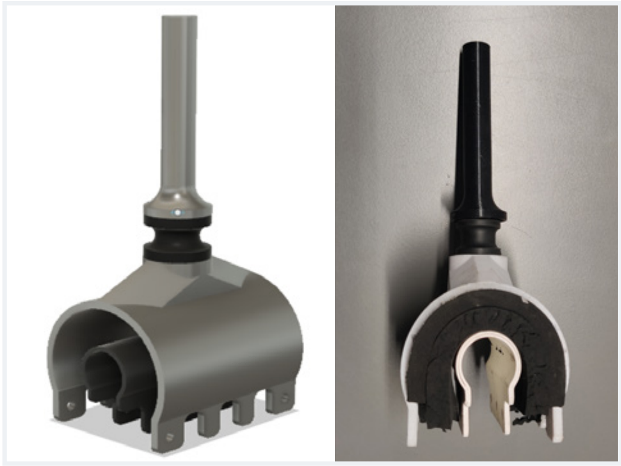


80: DisRota-damper principle and prototype

Building Ergo-grips

This concept works by engulfing the original handle of the machine with a thick layer of foam and rubber. This way all the forces are mainly squeezing of the foam. On the outside sits a handle that the operator uses to hold onto the machine.

The damping can be further enhanced by the rubber mounts that can be screwed in between the handle and the engulfing foam and rubber.

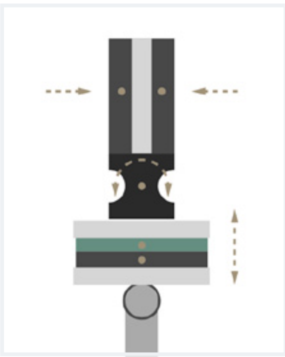


81: Ergo-grips CAD and prototype

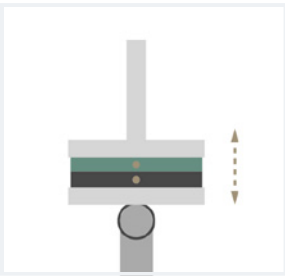
Plate-damper

This concept is a simplification and material reduction of the Ergo-grips. The Plate-damper isolates the handle with layers of foam.

Here, the operator's handle sits on the other side of the insulated part and the handle can be further dampened by attaching a rubber mount damper in between the two. All forces are translated through the foam; pulling, squeezing, twisting.



82: Principle (with rubber mount and soft handle)



83: Principle (stripped down)

84: Plate-damper CAD and prototype

3.1

- ! **Transferring vibrations to the torso is worse than the hands**
- ! **Machine handlebars have different thickness, width and length**

It was deliberately decided that the choice of concepts to build were chosen based on simplicity and availability of the principles used. Therefore, foam and rubber joints are so present in these models as they were available and simple to implement into the different concepts. The main reason for building the models is to test them out in the real context just to get more insights and discover the unknown unknowns. Which principles are used to do this is less relevant than what can be discovered.

It is easier to evaluate simple concepts as there are fewer variables that can intervene in the outcome. Complexity is mostly increasing as more demands are discovered.

3.2 MEASUREMENT METHODS

Parallelly with the activities of the other sections in phase 3, the activities of this section occurred. It explains what measurement methods were explored, employed and chosen.

Explored methods

Visual inspection

One way to quantify the vibrations could be to visually gather data on the difference of the vibrations and compare them. With a coloured fluid in a transparent container placed on the contact point and a level indication near it could be used to exemplify the magnitude of the vibrations.

85: Visual inspection

Professional tool

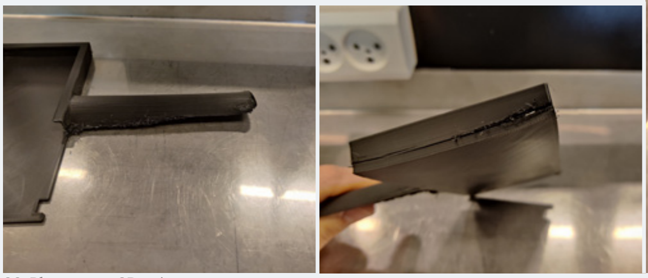
Getting help from an organisation like BAM-Bus is another way to get accurate readings on our models. They agreed to help once we have functioning prototypes that can be performed tests on, and we have it set up with users.

Acquiring a measurement tool

In order to get our hands on some relatively precise and more convenient equipment another option is to buy a tree axis vibrations datalogger but in order to cut cost a mail is formulated to AAU suggesting they acquire this equipment so that this and other projects may lend it in the future as it is a very useful piece of measurement equipment to have on hand.

Phone application

Using an app and the phones integrated 3-akse accelerometer could help to give some respective data. However, the consistency and accuracy of this system was unknown. So, it was decided to test out the consistency by making a phone holder which would allow vibrations between the hand and grip surface to be transferred to the phone more consistently. The phone holder was 3D printed. The first model failed, and the strength of the phone holder was too weak so the flex between the handle and phone case is too large and might introduce irregularities and higher vibration readings.



86: Phone case 3D prints

87: Phone application

3.2

Eventually the final decision is to use the phone's accelerometer app in conjunction with the reinforced 3D printed phone holder for the initial tests of new concepts and those first proven will then secondly be tested with BAM-Bus and their equipment to verify the results. The other solutions are disregarded because there is so far no response from the University to acquire the equipment. And using the visual principle could prove to be a more complicated setup and this would be inappropriate as multiple tests will require reorganising it and lastly this principle will have to be created from scratch.


88: Mounted on VTR(section 3.4)


89: Mounted on DisRota-damper (section 3.4)


90: Mounted on VTR (section 3.5)

During the activities described in section 3.4 and 3.5, the phone case was used to measure vibration. The phone was equipped with a measurement app. Unfortunately, despite the substantial time and effort that was spent on designing the case and understanding the app, attempts to process the data were without success.

Therefore, the measurement tool that was supplied by BAM-Bus during end user visit #3 gave the only tangible vibration data. This influenced the project a lot because the price and fragility of the measurement tool entailed that BAM-Bus would only lend it with if BAM-Bus representative conducted the measurements.

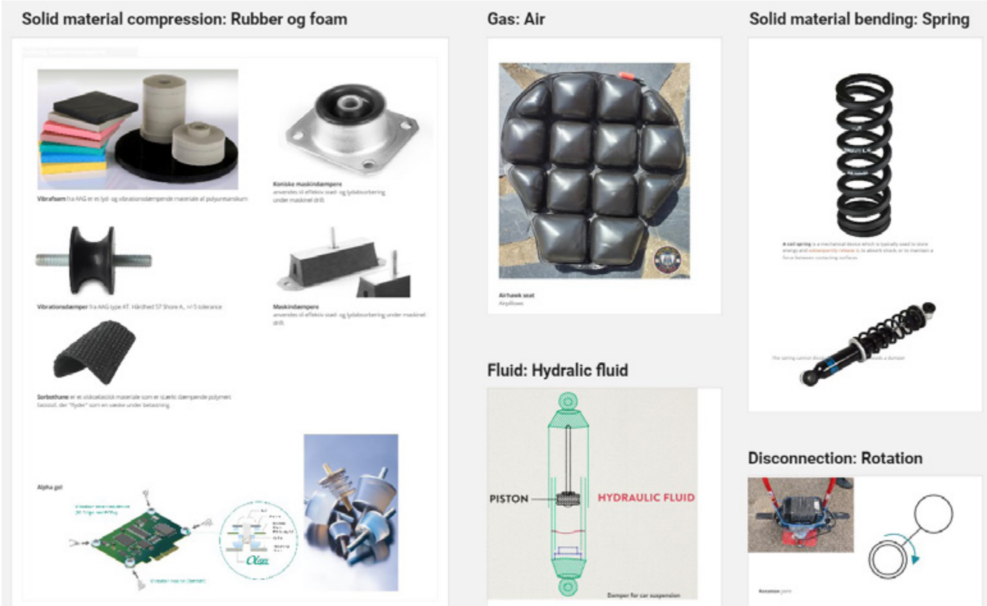
Since it complicated the planning to bring a BAM-Bus representative to every end user visit, visual inspection in the form of slow-motion video and operator comments were used to compare the damping performance of prototypes in end user visit #4 and #5 (section 4.2 and 4.4). This was sufficient as basis for choices.

3.3 ANTIVIBRATION PRINCIPLES

This section presents an overview of every antivibration principle that has been explored until this point of the project. Principles have identified during desk research, on machines during retailer visits, and during supervision. This overview was important to clarify how much solution space had been explored.

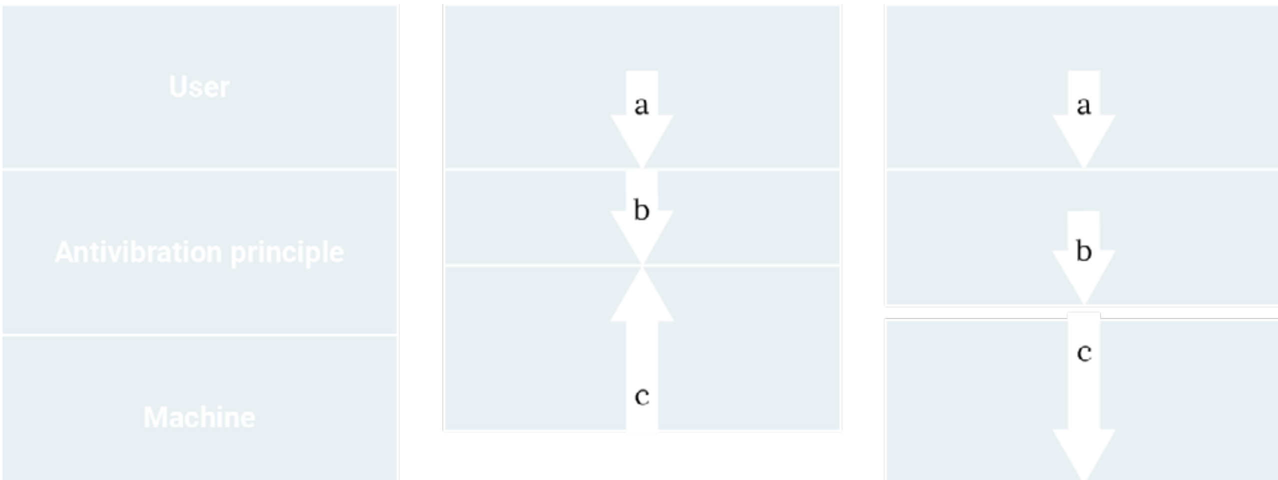
Principle overview

Most of the principles were compression of solid materials such as rubber and foam. It indicates that this kind of principles is most suited for damping. To understand what properties the damping principle should contain, it is described how it should react during a single vibration cycle:



91: Screenshot of principle overview from Miro.com

Slow motion description of principle basics



92: Simplified boxes representing the elements of the context

1) Initial/stable state:

Machine is turned off. Nothing moves.

The user holds on to the antivibration principle and it is attached to the machine.

2) Vibration cycle starts:

a) The user applies some force to hold the handle.
b) The principle is compressed. To avoid transferring force to the user, the resistance should be <u>low enough</u> to absorb energy <u>and high enough</u> to avoid collapse and allow the user to experience control.
c) Machine moves upwards.

3) Preparing for next cycle:

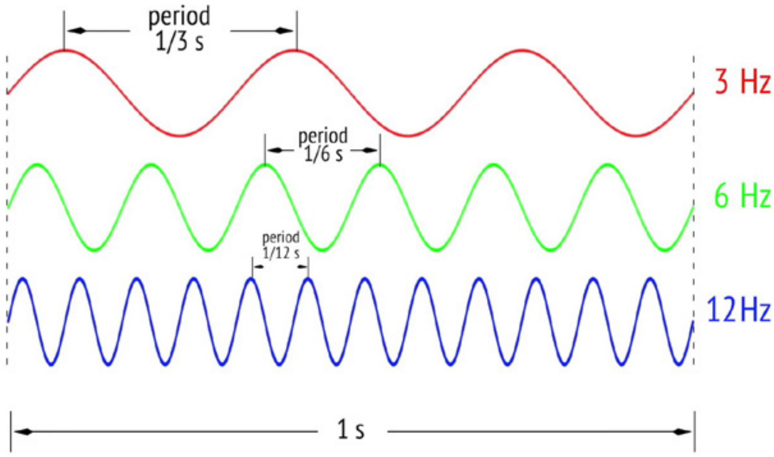
a) The user still holds on.
b) The principle must reset to initial state (1) as quickly as the machine moves.
c) The machine moves back down.

Step **(2)** and **(3)** repeat numerous times until the machine is turned off.

3.3

Vibration theory and vocabulary

Until this point in the project, the meaning of the different vibration terms had been unclear. To align internal and external communication, the terms where defined. Illustrations and images are from Adash (2020).



Frequency:

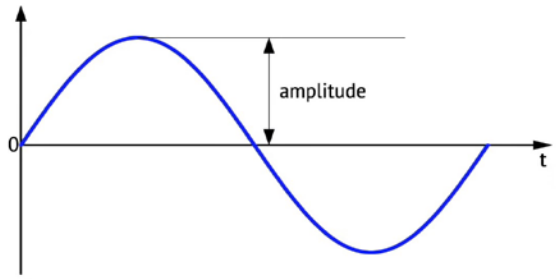
A number of occurrences of a repeating event in a second

Period:

The duration of one cycle of repeating vocabu events. So, it is the reciprocal of frequency.

Amplitude:

The maximum extend of a repeating event



Displacement: Distance between the stable and the exceed position

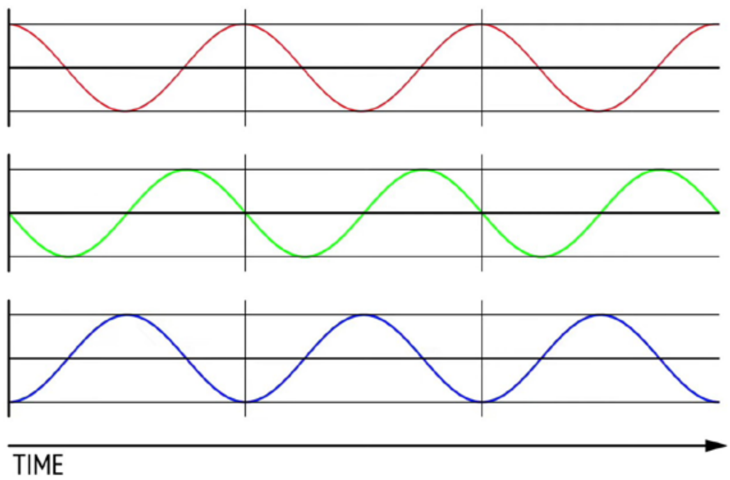
mm

Velocity: The rate of change of a distance

mm/s

Acceleration: The maximum acceleration is at the point where the movement changes direction

mm/s^2



3.3

It has been clarified what the terms mean and describe. Vibration magnitude is acceleration.

Any vibration basically has a frequency and an amplitude. The requirements to the anti-vibration principle depend on these two factors. It must be able to "keep up" with the frequency and resist the amplitude appropriately.

These models and descriptions are simplifications, and in the real scenario numerous additional factors influence how a vibrating element act. Therefore, the VTR should be observed closely.

3.4 MACHINE APPRENTICESHIP

This section presents our first time trying a VTR. Prior to end user visit #3, Jens Thyrrestrup Olsen (JTO) was visited to refine the prototypes. He is a self-employed contractor with a Vibratory Plate Compactor (VPC) and a Vibratory Tamping Rammer (VTR). JTO was not available to demonstrate operation. VTR was operated on top of compact ground and soft ground. An interview with JTO is available in appendix 8.

VTR operation is complicated

The VTR is not easy to control. When it is operated on soft ground, it digs down, preventing Jens from continuing forward.

When Jens attempted to lift it from the ground, the displacement of the VTR vibrations increased.

93: VTR digs into the ground

94: Vibrations displacement increases

Ergo-grips

As Jens tried to turn (ill. 96), the VTR started to tilt, forcing him to move his hands from the ergo-grips to the handlebar to regain control. This may be caused by:

The high flexibility of the damper or the low stiffness of the 3D-print bracket. It rotates around the handlebar. Mounting it on the corner of the handlebar prevent rotation.

95: The damper bends easily

96: Jens attempts to regain control

Rota-damper

Due to weather conditions and lack of time, neither the Rota-damper nor the DisRota-Damper was tried on soft ground. On compact ground, the damper did not move, not even when Alexander applied force, and it seemed more difficult to control than the Ergo-grips. However, since the understanding of the VTR was limited, both prototypes were brought to end user visit #3.

97: Alexander pushes towards the VTR handlebar

3.4

The bike suspension from the junkyard is too stiff to absorb any vibration, but the rotation principle might provide enough damping. During the test, the following unknowns were identified.

Can a new handle offer the same control and dampen the vibrations?

How does the professional operator control the VTR?

How are the machines transported?

Focus on the VTR

According to JTO, the VPC is not difficult and straining to operate, in relation to the VTR. Because of this statement and the fact that focusing on a single machine will simplify the prototyping process, the project scope temporarily only includes the VTR.

Comment during technical supervision after Milestone 3: The viscosity of the fluid within a damper like this is too high. It is not compatible with the frequency of a vibratory tamping rammer.

3.5 END USER VISIT #3

Situated interview & Acting out (Sperschneider & Bagger 2003)

There were several objectives for the third end user visit. The first was to observe a real use case including transport and preparation. However, the circumstances only allowed observation of the VTR operation and test of prototypes with a single operator. Since PE-Nielsen had a time schedule to obey, they had to level the ground with an excavator and prepare the VTR. The second objective what to quantify the control, and the third was to measure how much the prototypes could reduce the vibration. Appendix 9 contains additional quotes from feedback.

98: Poul Erik Nielsen's road construction site in Hjallerup

Atlas Copco LT 6005 ST

The following information describe the VTR model on site (iSPREZET 2023):

- Weight: 70 kg
- Tamper amplitude: 65-75 mm
- Tamper width: 280 mm
- Frequency: 12 Hz
- Vibration magnitude: 6,5 m/s^2

According to RC Holm (2023), rammers are used in all conditions on granular and cohesive ground.

> ! The VTR weighs up to 80 kg
>
> ! The VTR is used year-round in all weather

Measurement uncertainties

To measure the vibration reduction, the results of measurements were noted before and after the prototype is mounted. The reduction results were inconsistent because they varied depending on these parameters:

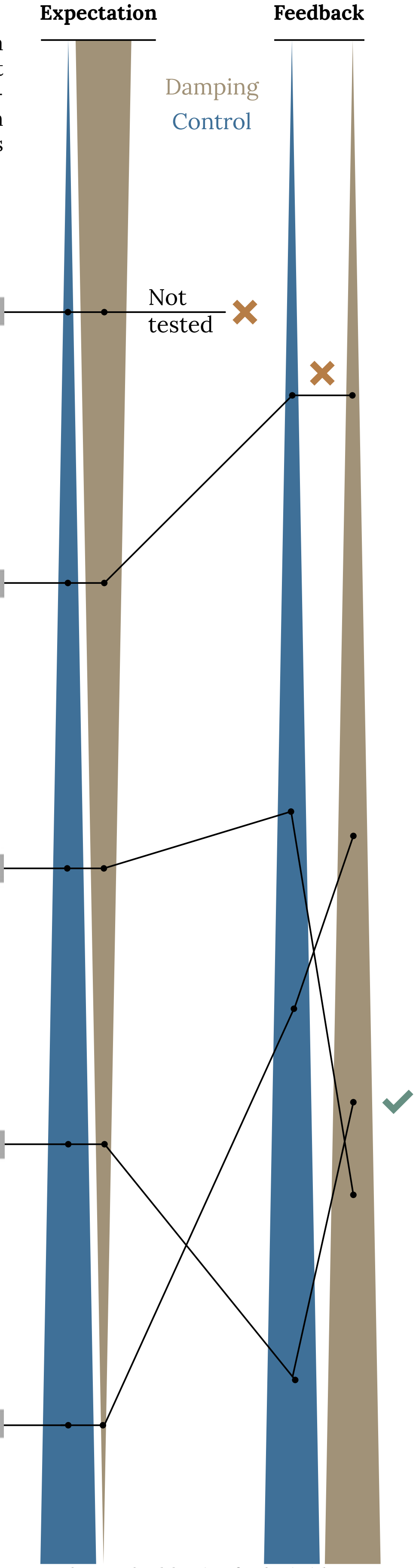
- How compact the ground is. It increases as soon as the VTR rams it.
- How tight the operator holds on to the handle.
- How much the operator pushes down the handle.

These parameters also indicate that the VTR does not only vibrate with one magnitude. It was measured up to 13.80 m/s^2. Appendix 11 contains all measurement results

> ! **The VTR vibration magnitude is 6,5-13 m/s^2**
>
> ! **The VTR vibration increase as the ground compaction increases**

Overview of principles

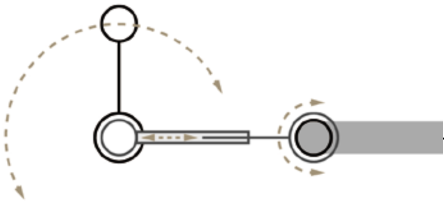
The prototypes contain several different principles, and they were built in a modular way to offer additional options, if the test subject were to a different level of damping or control. The principles on this page were the configurations that was planned to be tested. They are ordered to fit the diagram on the right side that indicates what level of control and damping that was expected and what the feedback indicated.



99: The control and damping of each principle

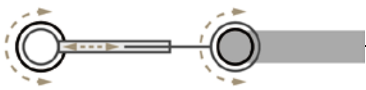
DisRota-damper

This principle was expected to be the best damper. However, since the tested prototype was not sufficiently controllable, the operator rendered the DisRota-damper as useless.



Rota-damper

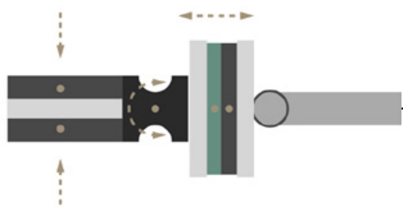
This principle rotates around the current handle, isolating the operator from the upward vibration with high amplitude.



Flexible Ergo-grips

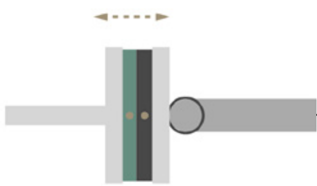
The steering of it, it's more difficult, you should not go out and ram something that is too loose with these ... Then I think it would be a problem to control with them.

There is a lot of comfort in this.... Both with the vibrations and that they are so good that there is that extra [foam on the handle] *on here, it becomes much milder on the hands, you can also more easily hold on to it*



Rigid Ergo-grips

It was more difficult when it would dig in, and you had to tilt it down [squeeze the handle down to get it up], *it was difficult, if it was going to dive in.*



Grinding Boards

You can usually feel a lot of small impacts up in the hand and elbow, which I think this is a tad milder to walk with.

Appendix 10 contains the set of questions that the operator was asked to clarify his experience of control. These questions were only used once because the output was not significant.

Handle position

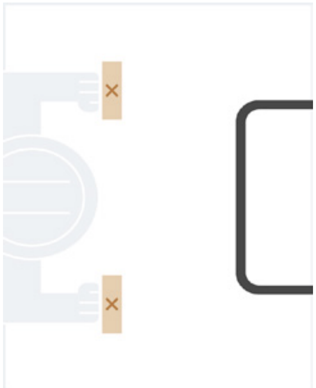
The operator was not told where to place the prototypes. He experimented with different positions until he found the most appropriate one that the design of each prototype allowed.

Top view **Side view**

Rota-damper

You can't push it when it's tilting down like that, if there had been a stop on it then I think it would have been good... You can't press it down and push it forward.


100: The only way to mount the Rota-damper

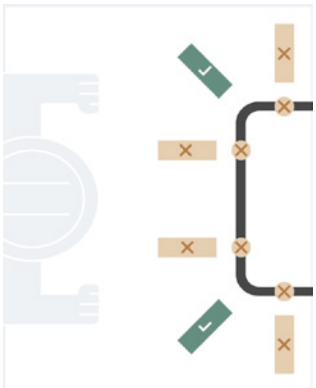

101: One Rota-damper position

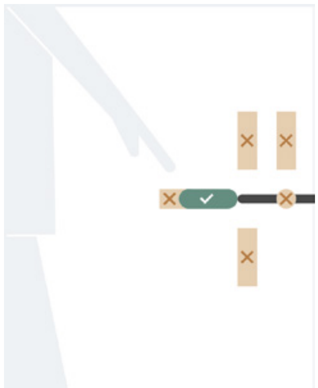
102: The Rota-damper is moveable

Ergo-grips:

I'd rather have them here, it feels more natural. Ergonomically, it feels more correct. Here, there was a little more control in it


103: Preferred Ergo-grips position


104: Ergo-grips position

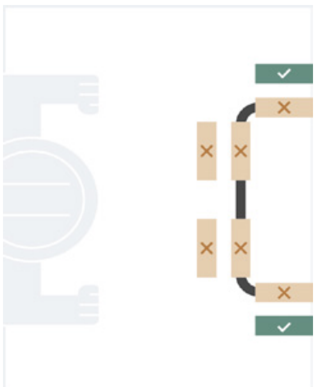

105: Ergo-grips positions

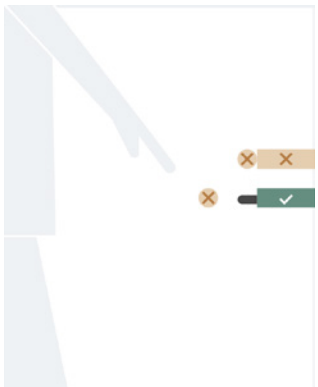
Grinding Boards

I'd rather grab it on the sides, I think it's awkward to grab it like this (red. Hands closely together)

I think it's a bit awkward to work with them when they get this far out here [on the side]


106: Preferred Grinding Boards position

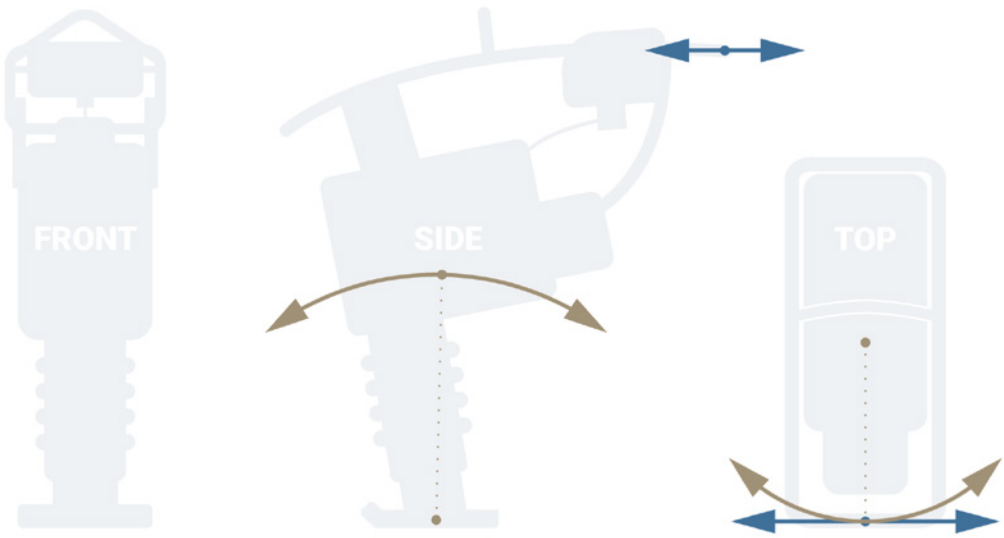

107: Grinding Boards positions


108: Grinding Boards positions

How to operate VTR

Assumptions before visit:

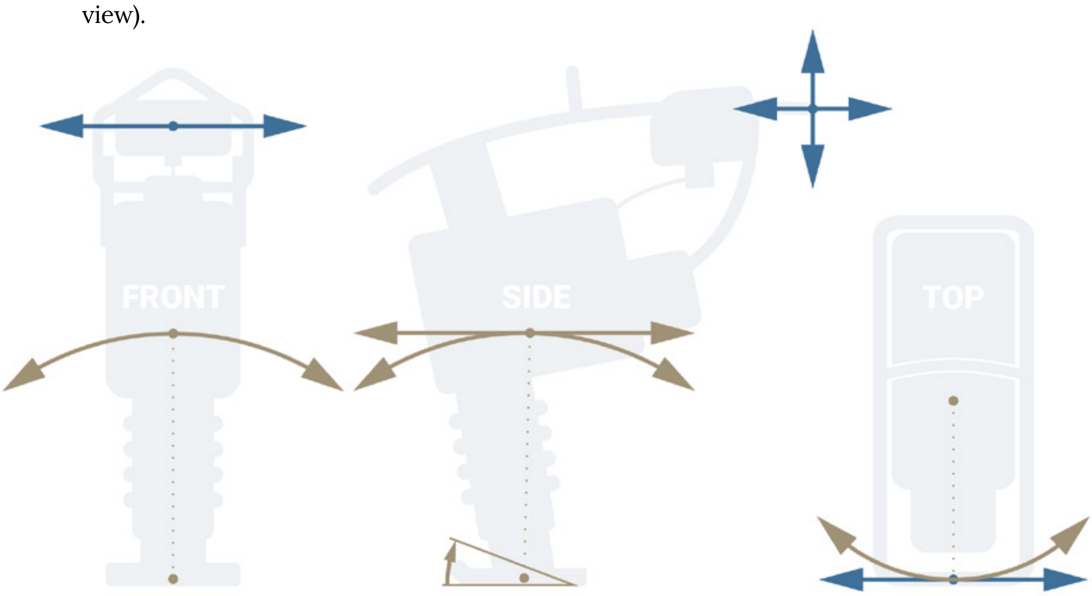
The VTR moves forward by itself, when it is tilted forward to the current angle. To turn the machine, it should be pushed from side to side.



109: Blue indicates interaction and brown is the reaction of machine

Understanding after visit:

Pushing down and forwards is essential to control the VTR. It lets the front of the foot raise to stay on top of soft soil. Often, the VTR also tilts sideways (front view).



110: One blue and two brown arrows are added to side view and one of each color on front view

! VTR control contains tilting, turning and most importantly, pushing down and forward

3.5

Coping strategies

Pulling in another handle

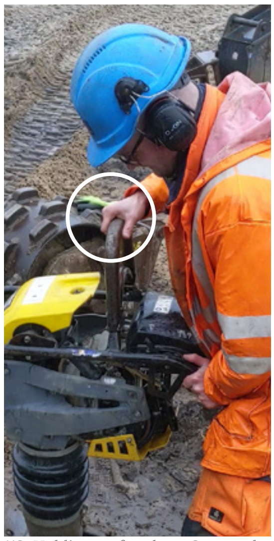
When the operator feels like he is about to lose control of the VTR, he grabs the top handle temporarily, though it exposes him to more vibration. Despite his statement;

> *It is really hard to operate these in the start, also that you learn to keep the balance on it... and this where I have found out, that if it* [the VTR] *starts* [tilting] *then I can quickly just grab loosely on the top, so I can steer it,*

video clearly indicates that he grabs firmly enough to expose himself to substantially more vibration.

111: Body language while explaining

112: Holding on for about 2 seconds



113: Holding on for about 2 seconds

! The VTR is difficult to control on uneven ground

Pushing with the hip

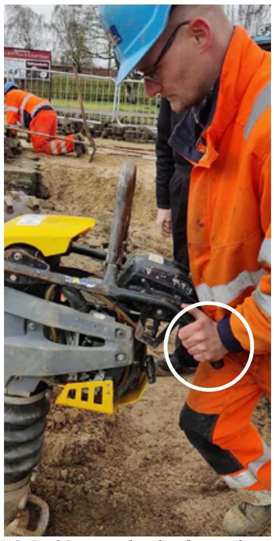
To save his energy, the operator pushes the VTR with his hip. This is especially necessary to move through soft and inclined areas.

> *You are probably a bit taller than I am, so I have a lower centre of gravity, so for me it fits to push with the hip here.*

According to the research of section 3.1, pushing with the body is worse than with the arms and hands. The next prototypes should enable the user to use only their hands.

114: Body language while explaining

115: Pushing uphill



116: Pushing w. other leg forward

! The VTR operators' height varies

! The VTR is difficult to move forward on soft ground

Unknown trigger time

After the visit but prior to the milestone, the Poul Erik Nielsen site manager was called to clarify the extent of the operators' trigger time. His answer was unclear, but this was the essence:

We don't know how much time we use it for. And we don't know how long we want to use it per day - just as much as we need it for the task, but that is probably not more than 5 min.

This was another reason to look for a new end user to observe.

3.5

This end user visit was the culmination of weeks of preparations. Testing several principles and interviewing an experienced VTR operator generated multiple insights into the problem and the solution space. These insights have been highlighted through the section. Since it was not possible to observe the transportation of the VTR, this is important to arrange for the next end user visit.

3.6 DESIGN BRIEF

Vision

Safe and effective work environment

Problem statement

How can an add-on product retrofit a Vibratory Tamping Rammer (VTR) to reduce the operator's risk of developing RP and CTS?

Stakeholders

Consumer

Employer

Operator (End user)

Retailer

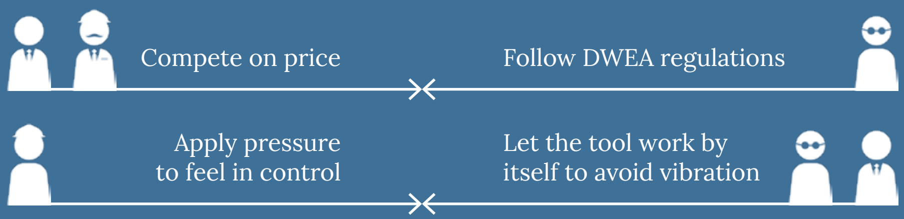
DWEA

BAM-Bus

BFA

OHD

Dilemmas



Design variables

To maintain overview of the current information, the takeaways are divided into prioritised categories.

Priority	Category	Key takeaways	
1st	Control	3.5	The VTR is difficult to control on uneven ground
		3.5	The VTR is difficult to move forward on soft ground
		3.5	VTR control contains tilting, turning and most importantly, pushing down and forward
1st	Damping	3.1	Transferring vibrations to the torso is worse than the hands
		3.5	The VTR vibration increase as the ground compaction increases
		3.5	The VTR frequency is 12 Hz
		3.5	The VTR vibration magnitude is 6,5-13 m/s^2
2nd	Transportation	3.4	No significant insights yet ...
3rd	Adjustability	3.5	The VTR operators' height varies
		3.1	VTR handlebars have different thickness, width and length
4th	Durability	3.5	The VTR weighs up to 80 kg
		3.5	The VTR is used year-round in all weather
5th	Other categories	2.4	The product should be permanently mounted
		2.3	Hygiene

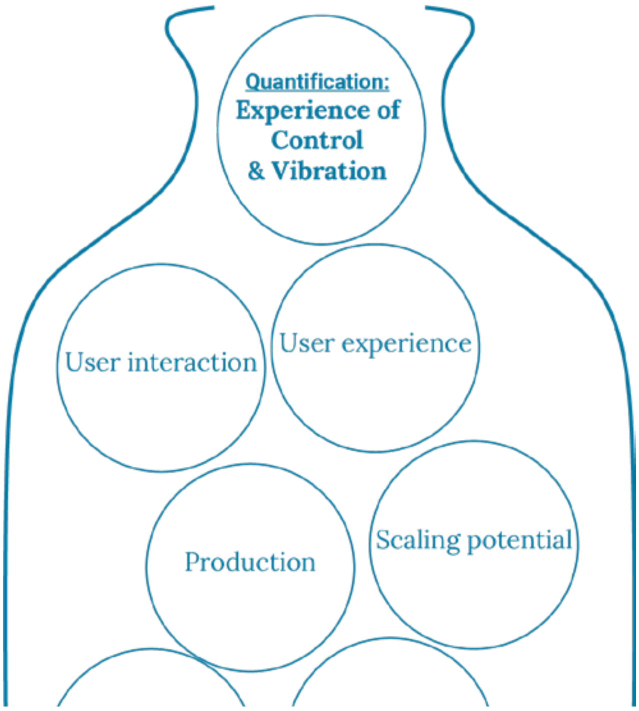
3.7 MILESTONE

The focus of this milestone was to showcase that the control and damping had been quantified.

Since the current VTR trigger time was unknown, the allowed trigger time with 13 m/s^2 vibration magnitude was presented. According to the conducted measurements, the Flexible Ergo-grips reduces the magnitude by 25%. This doubles the allowable trigger time to 2 hours.

14	7	33	98	196	392	784	1176	1568	1960	2352	3136	3920
13	6	28	85	169	338	676	1014	1352	1690	2028	2704	3380
	,8	24	72	144	288	576	864	1152	1440	1728	2304	2880
11	4	20	61	121	242	484	726	968	1210	1452	1936	2420
10	3,3	17	50	100	200	400	600	800	1000	1200	1600	2000
9,5	3	15	45	90	181	361	542	722	903	1083	1444	1805
	,7	14	41	81	162	324	486	648	810	972	1296	1620
8,5	2,4	12	36	72	145	289	434	578	723	867	1156	1445
8	2,1	11	32	64	128	256	384	512	640	768	1024	1280
7,5	1,9	9	28	56	113	225	338	450	563	675	900	1125
7	1,6	8	25	49	98	196	294	392	490	588	784	980
6,5	1,4	7	21	42	85	169	254	338	423	507	676	845
6	1,2	6	18	36	72	144	216	288	360	432	576	720
5,5	1	5	15	30	61	121	182	242	303	363	484	605
5	0,83	4,2	13	25	50	100	150	200	250	300	400	500
4,5	0,68	3,4	10	20	41	81	122	162	203	243	324	405
4	0,53	2,7	8	16	32	64	96	128	160	192	256	320
3,5	0,41	2	6	12	25	49	74	98	123	147	196	245
3	0,3	1,5	4,5	9	18	36	54	72	90	108	144	180
2,5	0,21	1	3,1	6	13	25	38	50	63	75	100	125
2	0,13	0,67	2	[illegible]	[illegible]	[illegible]	[illegible]	32	40	48	64	80
	00:01*	00:05	00:15	00:	01:00	02:00	00	04:00	05:00	06:00	08:00	10:00

117: Reading of the DWEA vibration exposure diagram



118: Bottleneck metaphor was utilized to limit supervisor feedback

3.8 REFLECTION

Order of activities

A significant amount of time was spent building the prototypes that were tested on Jens Thyrrestrup Olsen's VTR. Several of the insights that emerged during the activities of section 3.4 seemed obvious when they emerged. It was clear that it was the prototypes where not designed based on any prior experience with VTR operation.

It begs the question if the activities of phase 3 should have been done in the opposite order.

Conducted order of activities

1) Build prototyping

2) Jens Thyrrestrup Olsen (JTO) visit:
   Machine apprenticeship
   Test prototypes on machine without end user

3) Refine prototypes

4) End user visit #3:
   Observe end user's VTR operation
   End user simulates use of prototype
   Situated interview

Reasoning behind choosing this order: When an end user agrees to spend their time helping, it should be utilized. Otherwise, it constitutes a risk of losing their goodwill. Besides, the transportation and data processing connected to each visit consumes substantial amounts of project time.

Alternative order of activities

1) VTR apprenticeship with JTO

2) Situated interview with professional VTR operator

3) Build prototypes with VTR available to do quick tests

4) End user simulates use of prototype

Why this order was not chosen: Prior to JTO visit the VTR was not yet the focus, despite the knowledge of its HVM had been acquired. However, the experience of machine apprenticeship at End User Visit #2 (section 2.3) pointed towards keeping the Vibratory Plate Compactor and the Floor Scarifying Machine within the project scope. Unfortunately, the reality is that one does not know, what one does not know.

4 VALUE PROPOSITION

Prior to this phase, the focus has been on determining what the users need. In this phase the focus shifts to the exploration of what the users want and are willing to pay for. Through additional prototyping, end user visits, and video meetings with employers a value proposition is formulated.

119: VTR operator giving feedback during end user visit #4

4.1 PROTOTYPING #2

The apprenticeship and end user test (section 3.4 & 3.5) uncovered new insights to the dilemma between control and damping and more aspects related to the context of the product:

Transport, Setup, use (in real context), dig out (rescue)

Does it provide the necessary levels of control?

Does it hinder the operation? (Is it obtaining critical space, make certain tasks difficult/impossible)

Does it fit into their context besides the operation (Transport, Setup, dig out (rescue), storage)

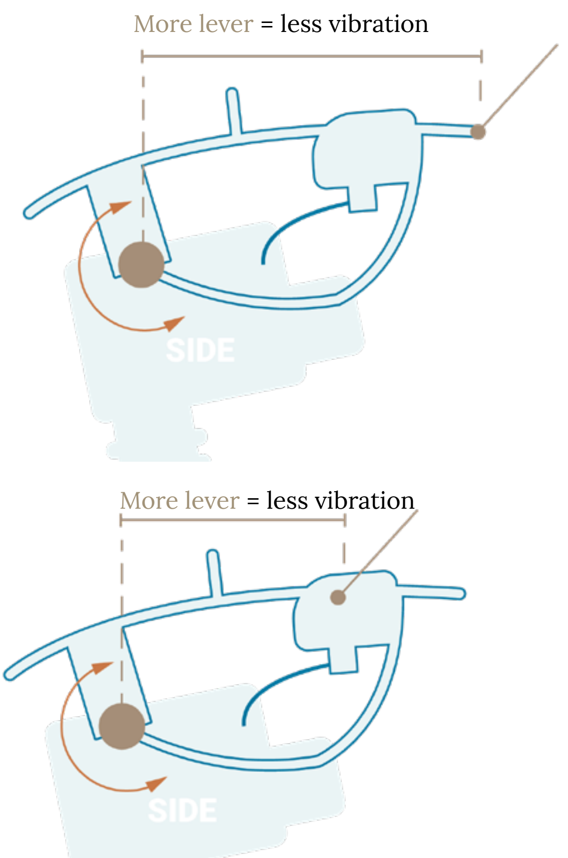
How many units would they need?

To unfold these points, the plan is to showcase 3 concepts with reasonably extreme variance of features that is believed to be favourable. These concepts will not propose solutions to all the points. On the contrary, they will include selected features to test what the users value. Hopefully, this will enable a converging into one concept after secondary stakeholders (the buyers), have approved them. Afterward, accumulating this into a value proposition can guide future detailing and design choices.

Understanding VTR damping principle

The VTR already have a dampening principle that reduces the displacement handle to a controllable level.

The damping principle is a rubber hinge joint the entire handlebar is attached to. The damping occurs by twisting of the rubber hinge with the control force applied by the operator through the handlebar. The horizontal distance between the hinge and the control point affects the damping efficiency as seen below.

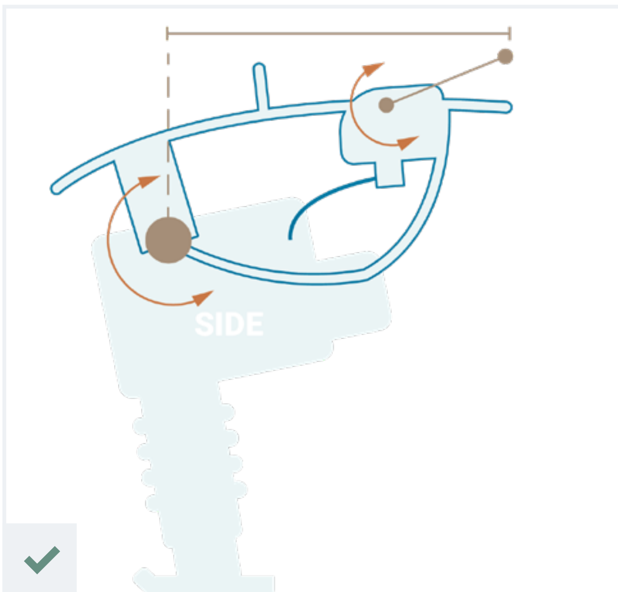


120: Analysis of VTR damping

It is believed that torque magnitude affects how much the hinge flexes and directly changes the damping effect. So, if the operator's control point is the furthest away from the hinge point, the damping will be highest, and it will have the opposite effect if the control point is closer to the hinge.

If a solution were to utilize the existing damping most efficiently, it would make sense to mount the add-on far from the rubber hinge.

However, if the add-on were to be mounted at the furthest point, it would in some cases increase the overall length of the machine, and the assumption is that it might become too long and acquire space that is not available in the real context. The same concern relates to the width of the handles. If a solution is wider than the original handle, it might be too wide.



121: Choice of add-on position

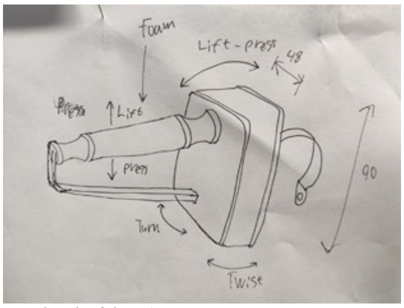
Flexi-handles

The first concept was aiming a dampening effect of around 25% on three specified machines. Furthermore, it was meant to be:

- A flexible system that could be adapted to three different machine types
- Allowing the user to place the handles individually in desirable spots that retain their control needs.
- Produced in higher numbers so the purchase price would be the lowest of the three concepts created in this prototyping round.

Minimizing flexibility

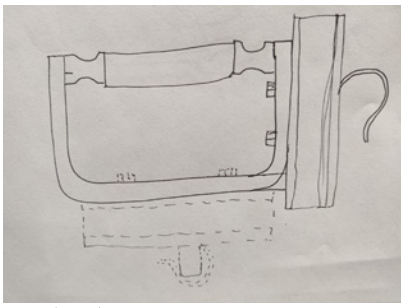
Using tested principles form the ergo grips. But enhancing the rubber mount with a second rubber mount on the back minimize flexing and increasing control. Secondly only one mounting point needed to make positioning more flexible.



122: Sketch of damping

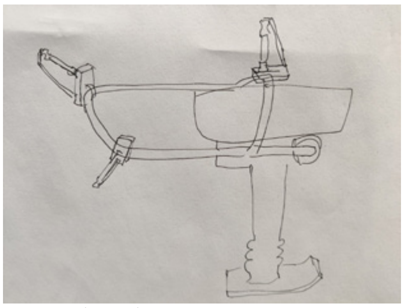
Adjustable mounting

The mounting plate can be moved 90 degrees to change the handles position.


123: Orientations

Extra control opportunities

The Handles can be used in uneven amounts and more gives the operator extra control opportunities.


124: Mounting options

Increases comfort

It had a foam wrapped handle for increased comfort, heat insulation and a little vibration damping.


125: Rubber wrap on handle

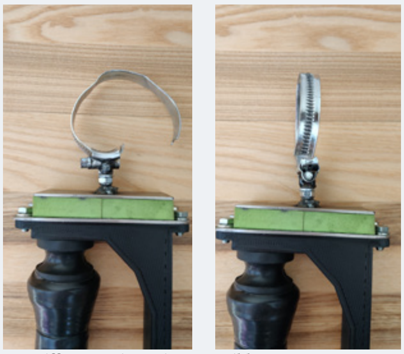
Single tool mounting

Four screws on the mounting bracket can be removed to mount it parallel with the handle.


126: Mounting adjustablity

Custom adjustment

The large diameter adjustable mounting bracket can be rotated 360 to suit any desired angle and locked in that position.


127: Different orientations possible

! The VTR handle diameter varies between brands

Push Down Bar

This concept was aiming for a significant dampening effect of around 50% because it would only suite the VTR:

- Retaining the exact same level of control and shouldn't reduce control options.
- A permanently mounted solution but had to allow for transportation.
- A lower volume production and would be medium to high priced.
- Using existing damping principle already on VTRs to reduce most of the remaining vibrations.

Redesign of VTR damping principle

A handlebar shaped like the existing VTR handle with a torsion damper at the attachment point.

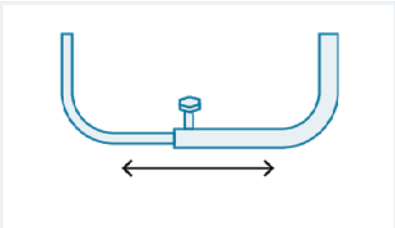
Adjustment to the VTR by changing width of the handle with a sliding principle that can be locked in the desired position with a bolt. The adjustment to the handlebar diameter happened with a steel band principle.

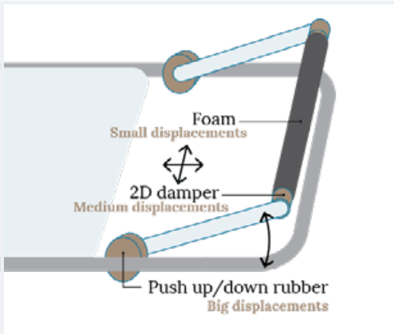
Pushing down on the add-on would rotate a rubber torsion damper under load. It was also believed that radial vibrations had to be absorbed by a separate rubber damper on the handle end.

The add-on sat closer to the VTRs own damper even though it's not optimal it is a simple way to avoid it extruding out beyond the machine.

Also, it was supposed to sit right above the org. VTR handle.

The prototype was very basic and used the previous rubber dampers from the Flexi-handles to cut costs.


128: Top view of adjustment principle



129: Dampers absorb to different displacements


130: Position of concept on the VTR (isometric view)

It introduced the principle of a rod sliding inside two other pipes that were also handles and two bolts locking the position when the width has been adjusted.

The necessity of a feature damping sideways vibrations was discarded in the prototype as they are believed to be much lower than the main vertical vibration direction. The additional damper shown above would also minimize hand positions and add complexity.

The final prototype is placed on the outside of the VTR because it was too wide to be right above the current handle.


131: Width adjustment principle


132: Damping principle included in prototype


133: Position of prototype in relation VTR handle

! The VTR handle width varies between brands

Increased Control

This concept will provide new and more different hand positions. The end user (section 3.5) desired other hand positions that are allowed by the current VTR handle. This means that this could create some hooks the users would prefer.

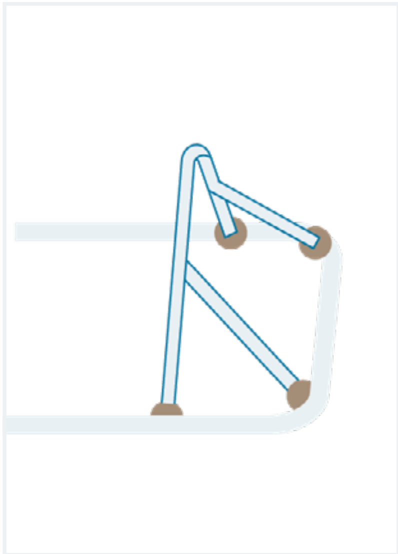
The user said that this type of hand position increased his ability to control its sideways tilt.

134: Operator grab a second handle

The user said that this position increased his ability to turn the VTR and had a more ergonomic feel, though he wanted to be a bit closer to the machine.

135: The operator shows his preference

An idea is brought to light that includes both more hand positions and higher control points to ease tilting control. While being closer to the machine and remaining within its footprint.



136: The Increased control concept

For this prototype building round the Increased Control concept was not built due to a lack of time. Besides, it did not directly focus on creating better damping or a better business case in terms of cheaper production.

4.1

The two concepts provide quite different value sets. The Flexi-handles try to be very adaptable to many different use cases, with different handle positions at a more affordable price. The Push Down Bar is only adaptable to VTRs. It strives to reduce the vibrations magnitudes the most while retaining the current control level, but since it is more specialized and complex, it will be more expensive. Unfortunately, the Increase Control was not able to be created in this round. It is unknown how much value this concept could provide since it was an idea made on observations not recommendations.

These concepts were primarily built on previous experience from the last model test and created on the base of simple principles and sketches related to the insights. It was decided not to spend unnecessary time on 3D modelling and sketching since the model itself gave a much more in depth understanding and communication of the concept and problem in the context. Furthermore, the main dilemma is related control and dampening effect, and these are near impossible to verify in other ways than functional models in realistic tests.

4.2 END USER VISIT #4

Through BAM-Bus' network, Aabybro Entreprenør was contacted. They used the VTR more than Poul Erik Nielsen (section 3.5), because they were working with digging and filling district heating trenches south of Aalborg in Storvorde. 800 house owners had requested to be connected to the district heating system. The driveway of houses is exemplary at showing what the job consisted of. This section describes what the workers who perform this job think of the prototypes presented in section 4.1. Additional feedback is noted in appendix 12.

At the time of the visit the workers had almost finished filling the trench and thereby also most of the VTR operation. However, there was a pile of sand, that could be used to simulate operation on the soft ground.

137: The operators and the district heating trench in a driveway

A part of purpose of the visit was to test value propositions with the buyer, but he was not available at the time. A week later (section 4.6), the director and buyer of Aabybro Entreprenør was reached.

Transportation

Aabybro Entreprenør drives to each of the houses in a van. Ill. 138 shows how the VTR is stored inside the van.

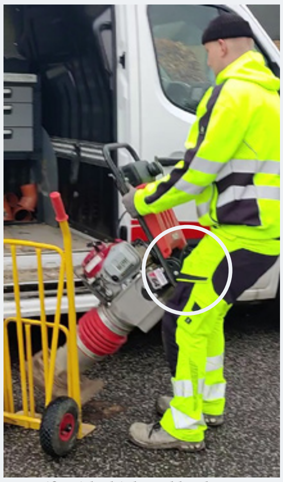
138: The VTR is fastened with a strap

We are probably the only ones who have to put it down in the car. Then we put this around the handle. Then it is locked. The others have it upright. In [VW] Transits there is a little more space, and then they have a board screwed to the bottom to control it.

Moving between van and sack truck

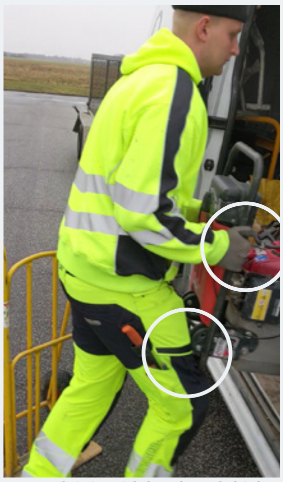
The operator lifts the VTR manually between sack truck and van.

139: Keep the balance of the VTR with the hand on top



140: Lift with thigh and back

141: Keep it on the thighs and bend knees to lift the foot onto the van floor



142: Push it in with hands and thighs on the handlebar

Moving between van and trench

143: Support gently after putting in on the ground, while grabbing sack cart

144: Tip with hand, push the sack cart with foot

145: Tip sack cart, grab handle bar

146: Hold on top while tilting sack cart down and tip

- ! The VTR sometimes lies down during transportation
- ! The VTR is transported on a sack truck

Current operation

147: Tall operators are hunched over

148: Operators change hand position while driving depending on conditions

149: Another hand position

150: Operators turn the machine by circulating and controlling sideways

- ! The VTR operators' height varies
- ! The VTR operators' physique varies

4.2

Push down bar

Operation on even, compact ground

The operator seems to remain in control.

It is actually pleasant

151: Operation on even ground

Operation on uneven, soft ground

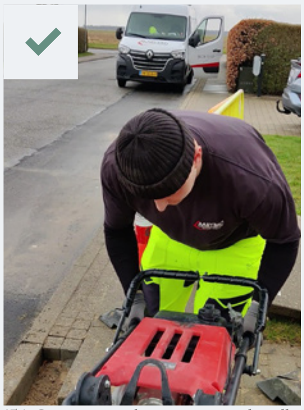
The operator tries to lift it up and push, but the push down bar is too flexible

152: Operation on uneven ground

Different levels of control and damping

You could hold on here (ill. 153), *when it goes straight ahead. And then* [when it is uneven], *you could do like this* (ill. 154). *It is not for very long that you need to uphill.*

153: Operator shows where he holds



154: Operator pushes on current handle

The operator implies that he could settle for damping while the ground is even and the VTR is easy to control. He also explained that: *It would take a lot of the vibration when I drive downhill because here you need to pull. And when you pull, the vibrations are a lot worse.*

Flexi-handles

Operation on even, compact ground

There is no reduction compared to the other one

155: Operation on even ground

Operation on uneven, soft ground

The operator hunches to reach the handles that are further down than the current handle.

156: Operation on uneven ground

Protecting fingers

There is actually built-in protection. Here you have protection in front of your fingers. When you drive along walls, you always get your fingers.

157: Operator points at protecting part

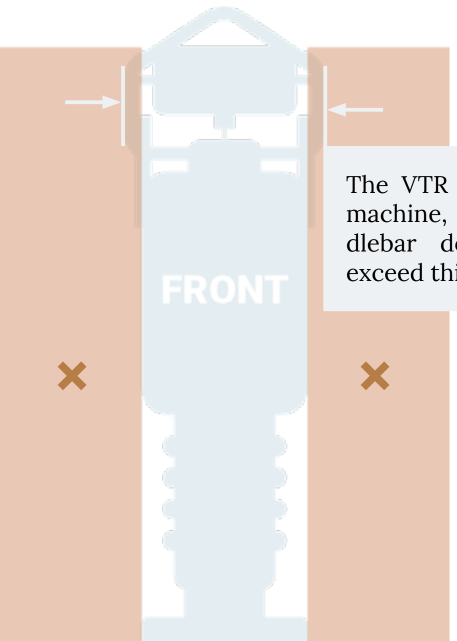
Effects of increasing dimensions

If the handlebar length is extended, more space will be required to turn the VTR.

Often, when we turn in a trench, we turn it around like this.

158: The handle intersects with where the operator usually moves

The foot actually sets the limit of how wide the handle should be. You need to be able to operate along walls



The VTR is a narrow machine, but its handlebar does already exceed this limit.

159: Forbidden area according to operator

Soft handle surface

The rubber on the handle of the prototype might not endure handling when the VTR lies down or when it is exposed to substances that the operators' gloves contain.

> ! **The operators often have sand, acidic and alkaline substances on their hands**

Measuring the applied force

The push down bar seemed to be too flexible. To determine how flexible it should be, the applied force was measured. The force could not be measured during operation because of the frequency of the VTR. The alternative was to measure the static load required to push down the handlebar completely.

160: A suitcase weight is mounted underneath the VTR handle

> ! **The operator applies 17 kg to push down the VTR**

Stakeholder perception

Doing the visit, the employees expressed their doubts about the success of a product in this health risk reduction category. In their view, the employer only cares about profit. If a product does not increase the workers efficiency or it is a legal requirement, they do not believe that their employer would invest in it. As they put it, comfort and health of the employees is a small concern, as they can just hire new workers when they are worn down. That is why the employees had acquired antivibration gloves themselves.

> ! **Workers think employers only care about efficiency not their comfort or health**

Damping-wise, the push down bar was by far the best prototype. However, there are issues with control in soft ground. Besides, it is unclear how much time is spent ramming soft ground. To observe this, another visit is planned.

4.3 PROTOTYPING #3

After End-user visit 4, another concept was built that should dampen the vibration and allow control as it is. It is an evolution of the Push down bar but introduces a control increase variant, for increased efficiency, and dampening increase variant for higher health risk reduction. The purpose here is to verify the importance of these features from both the operators' and employers' perspective.

Key insights

After the end user visit #4 SW 22 it was clear that the concept providing the best damping was the Push down bar. However, it struggled to provide the existing level of control especially when dealing with the tilting of the machine and being able to control on soft ground. One of the main control features when operating the VTR in loose soil is the ability to press down and lift in the machine.

As seen here, the Push down bar tilts way too much backwards to a point where the operator must use his knee to stop it and press it upright and forward again.

161: Damping elasticity during test

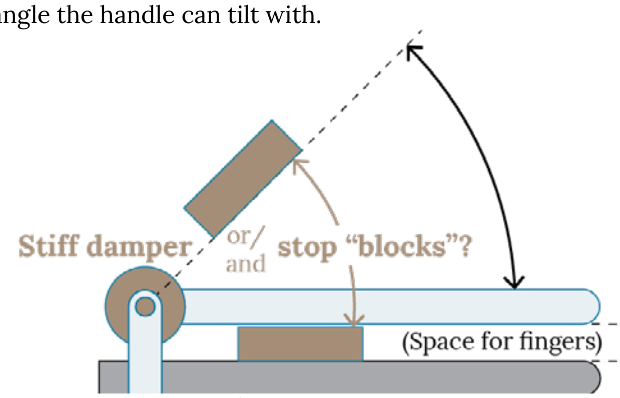
The Push down bar was clearly way too soft as it went down past the VTR handle and the operator cannot change the angle of the VTR accordingly.

162: Damper elasticity during test

As a conclusion, the movement of the handle must be controlled and that there should be a limit to how much it can tilt forwards and backwards. Furthermore, it should also be stiffer in general to make the operator's input more direct.

Variable damping and control

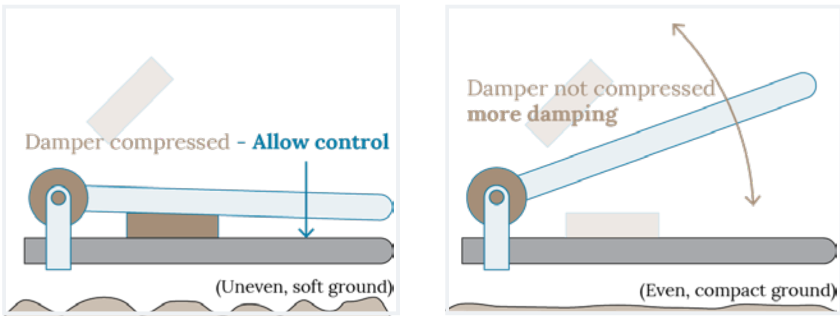
It was apparent that the Push down bar was easy to control on ground that had already been compacted. However, it struggled on soft ground. Here, the movement of the handle should be constrained. The initial idea is to limit the angle the handle can tilt with.



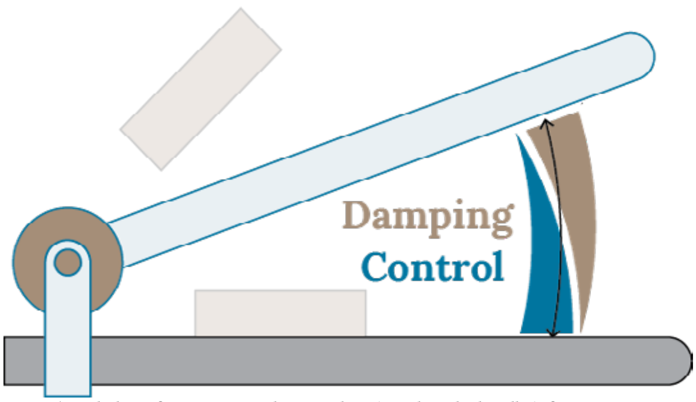
163: Damper options

The lower limit is essential because the operator pushes down when he needs additional control. Here, a stop just above the original handle with a rubber or foam damper in-between makes damping progressively harder, and it enables damping when the torsion damper is overloaded. The upper limit is when the VTR tilts towards the operator or the operator lifts in the VTR.

The rotation damper should probably not be stiff enough to resist the full control force, so it will be overloaded in the situations that the operator wants to feel in full control situations.



164: Option to have most control or damping based on ground conditions



165: Push down for most control - most damping when the handle is free to move

Rotation damper

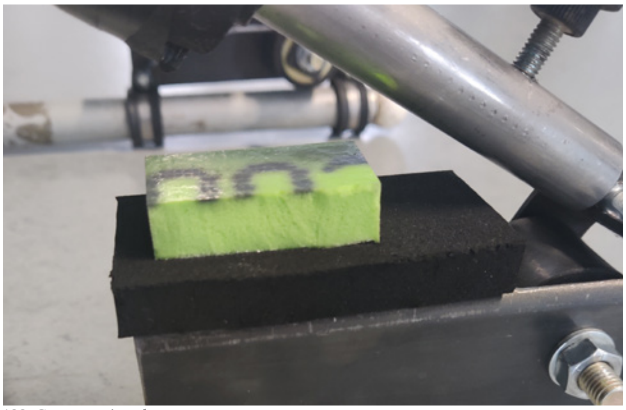
The main damping principle of the two concepts is the torsion of a rubber damper. The more the rubber is rotated the more resistance it creates. The exact same principle is already used on the VTRs meaning it has a damping effect in both directions around the rotating axes.


166: Damper pushed down


167: Damper pulled up

Material compression damper

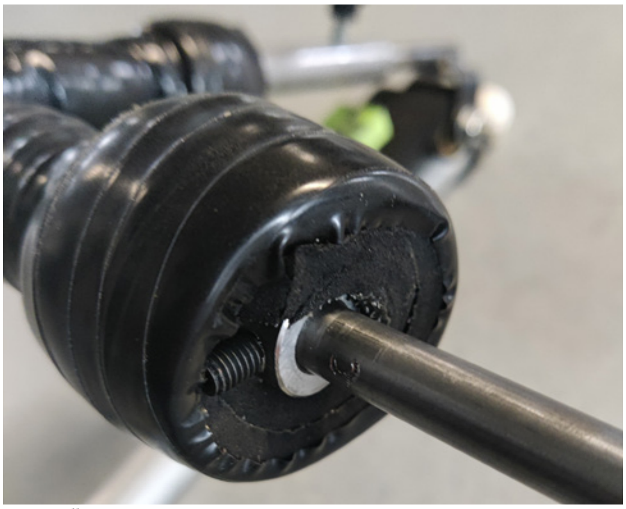
The second damping principle is material compression of a foam and a cellular rubber. This works as a cushion when the handle is pressed all the way down this gradually increases the damping resistance even more and means the rotation damper can be softer while avoiding the handle being pressed too far down.


168: Compression damper

Soft dampening handle wrap

The handle itself is wrapped in cell rubber to give an extra damping effect to minimise pressure on the carpal tunnel and reduce the vibration magnitude further. It also works as an extra feature of comfort since it is soft and heat insulating against the cold to avoid triggering Raynaud's syndrome symptoms.

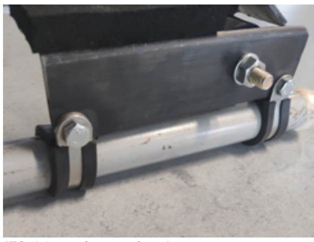
The outer layer is wrapped in a thin elastic plastic that is ware resilient and makes it easier to keep the handle clean.


169: Handle wrap

Mounting principles

It is assumed that the VTRs are relatively the same diameter so a simple steel band could be sufficient to hold the handle in place, these do not however have a huge flexibility in fitment and not fit well on some machines.

The hose clamp can still be attached just as a precautionary measure, these can vary a lot in handle diameter. But they are bigger and not as strong as a simple steel band.


170: Mounting option 1


171: Backup mounting option from earlier test

Width adjustment

The main need of adjustability is the width of the add on to insure it sits just above the org. VTR handle and isn't too wide or narrow.

This is done by a steel rod gliding inside the two handle tubes. The rod is then locked in its position by a screw in the end of each pipe. By having adjustability in both handle pieces, the maximum amount of adjustability can be achieved.


172: Shortened


173: Extended

4.3

More control or more damping

Two concepts, Adjustable Damper and Additional Control, were created based on the principles above but focused on verifying the assumptions that the employer would only have Increased efficiency and the employees would desire dampening increase variant for better health risk reduction.

174: Adjustable Damper (shortened and extended)

Adjustable Damper

The Adaptive Damper copies the shape of the original VTR handles as this concept just strives to maintain the level of control but provides adjustable damping so the operator can tailor it to suit the scenario. Appendix 13 shows a load test of the shortened and extended handle.

Adjusting the length of the handle alters the torque on the rotation damper and its resistance therefore creating double the damping effect at double the length. This feature that could be used when the top and hardest layers would be tampered by the VTR. The control needs are then lower, but the vibrations are higher.

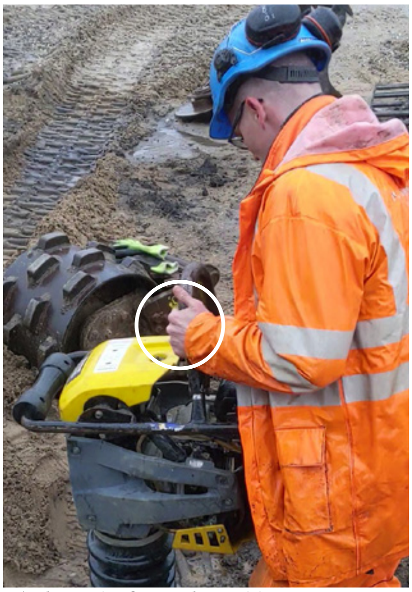
Additional Control

At end user visit #3, it was observed that hand and arm positioning greatly influenced the operators feel of control. An idea emerged to increase the control to optimize the operator's efficiency with the VTR.

The users said that this position increased their ability to turn the VTR and had a more ergonomic feel, however they wanted to be a bit closer to the machine.

The concept focuses on increasing control points and minimising the flexing and over stressing of the wrist when the operator applies pressure down on the handle while getting the control points closer to the machine.

It introduced more bends to allow the operator more handle position potions. The bends create a second handle position that is inclined and slanted giving a more ergonomic angle for the wrist when pressing on the handle. The sides of the handle are just parallel with the original handle retaining the ability for them to control it like they are used to.



175: Observation from end user visit #3

176: Additional Control handle (sideview)

177: Additional Control handle (topview)

4.4 END USER VISIT #5

Like the other visits this one has multiple purposes. First, observe the entire sand filling part of Aabybro Entreprenør's district heating jobs. Due to unclear communication, the first layer of sand had been rammed before observation was possible. Instead, interviews were conducted to retrieve information regarding the process that was not observed.

Second, test the variable damping prototype with each of the two handles that gives its user additional control or the option to adapt the level of damping. Operation without add-on was observed, too. This is explained in Section 4.5. Appendix 14 contains all feedback and observation.

Ground preparation

Contrary to end user visit #4, this operation site had an excavator. It was utilized because extra filling is needed when the trench goes through the road. The crane is used anywhere it can reach. Outside of its reach a wheelbarrow is used. Once they have placed piles of sand in the trench, they distribute the sand with shovels to ensure that the ground is evenly compacted.

178: Access to the main line of the district heating

179: Excavator and wheelbarrow in the background

Variable damping

The operator liked the damping principle in general, if he has it pushed down. If he pulls it up, the vibration expose feels enhanced. He disliked that the add-on increased the height of the handle.

180: The operator is forced to raise his elbow while applying pressure

181: Pulling the handle up causes a sudden stop (as steel hits steel)

! The product should dampen vibration during lifting and pushing down

Adaptable Damper

The extended handle requires less force push down, and that convinced the operator to think that the height is low enough.

182: The operator has pushed the add-on closer to the handlebar of the VTR

The extended handle also allowed operation from a distance, so the operator avoided tripping over the edge of the tiles.

183: The operator avoids the edge of the tiles

During transport, the operator thought that it could become a part of routine to shorten the handle. They are used to packing handles away on other machines like a vibratory plate compactor.

Additional Control

Extra hand positioning options

The operator was excited about the option to change hand position multiple times during a short operation.

I really like this handle shape. It is a lot easier to steer and control. I would choose this handle because I have more angles to grab from, so I am in control no matter what.

✔ *I have two control points I can use to steer depending on what is the best in the situation. When I need to turn, I have the option to grab in here and push.*

184: 'Turn right' hand position

185: 'Turn left' hand position

✔ *It's the same when I need to push it forward, then I have this position.*

186: Hand position while pushing frontward

Feedback after an entire day with Additional Control

At the end of the visit, the operator preferred to keep Additional Control. He agreed to use it during every trench filling job the next 24 hours and give feedback afterwards. The intention behind this agreement was to test if any problems during transportation, storage and other handling scenarios had not been discovered. The additional interaction time would also allow the operator to get used to the new way of operating, enabling him to access whether the new level control is sufficient.

The problems highlighted on this page and the subsequent were the only ones that the operator noticed.

No extension used

Though the operator was contempt with the extension feature after first use, he did not utilize it to adjust damping the entire day. If the product extends beyond the handlebar, it hits surroundings during operation and transport.

I noticed that we were often bumping into these that are sticking out beyond the original handle when we were lifting it. So, for a final version it should be designed so that nothing is sticking out beyond the frame.

187: Top view of size requirements

No additional control

Addition Control did not provide additional control, but it did increase the operators control options and ergonomics in certain situations.

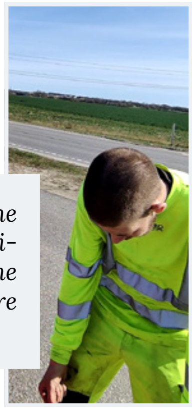
It is more universal when I need to turn in a tight space. With the different handle positions, I have more options to hold onto it in different positions. I no longer have to twist in the entire body to hold onto it.

188: The operator gesticulates in parking space next to the highway where the product was returned

Comfort

The operator liked that the handle was softer and a bit thicker than the current VTR which is made of iron. Besides, he saw potential in height adjustment.

I would like the ability to adjust the height. It would also make it more universal because we are not all the same height. Some are 2 metres tall others are 1,5 metres. It is just nice it fits us all.



189: Tall people would hunch their back (exaggerated)

190: Low people would have a hard time applying pressure (exaggerated)

- ! **The product should not exceed the handlebar perimeter**
- ! **The product should afford new ways to hold the VTR**
- ! **The product handle should be soft**
- ! **The product should be fit different operator heights**

Mounting

As ill. 192 shows, the Addition Control handle was too wide. The shape of this handle allows less adjustability than the Adaptable Damper handle. Ill. 193 shows that the mounting interface was also too wide. It intersected with the gas tank of the VTR.

192: The handle width causes the mounting interface to tilt (it cannot adjust to become more narrow)

193: The bolts of the mounting interface intersects with the gas tank

To solve these problems, it was mounted on the side of the handlebar (ill. 194). However, after 10 additional minutes of use, it was clear that the hose clamp had rotated around the handlebar.

194: The hose clamp is not tight enough to withstand operation

Lack of rigidity

As ill. 183 showed on page 64, the prototype was not rigid enough, when the operator applied unevenly distributed pressure. The hose clamps and the width adjustment are the weak points.

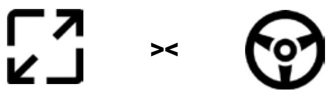
If you tighten the middle [width adjustment] *it would be nice.*

191: The operator points at the width adjustment

After about a workday of use, the operator had to remove the prototype because it had become too flexible to control.

Dilemma

Building a prototype with enough rigidity (to maintain control) contradicts with the level of adjustability (to mount on different machines)

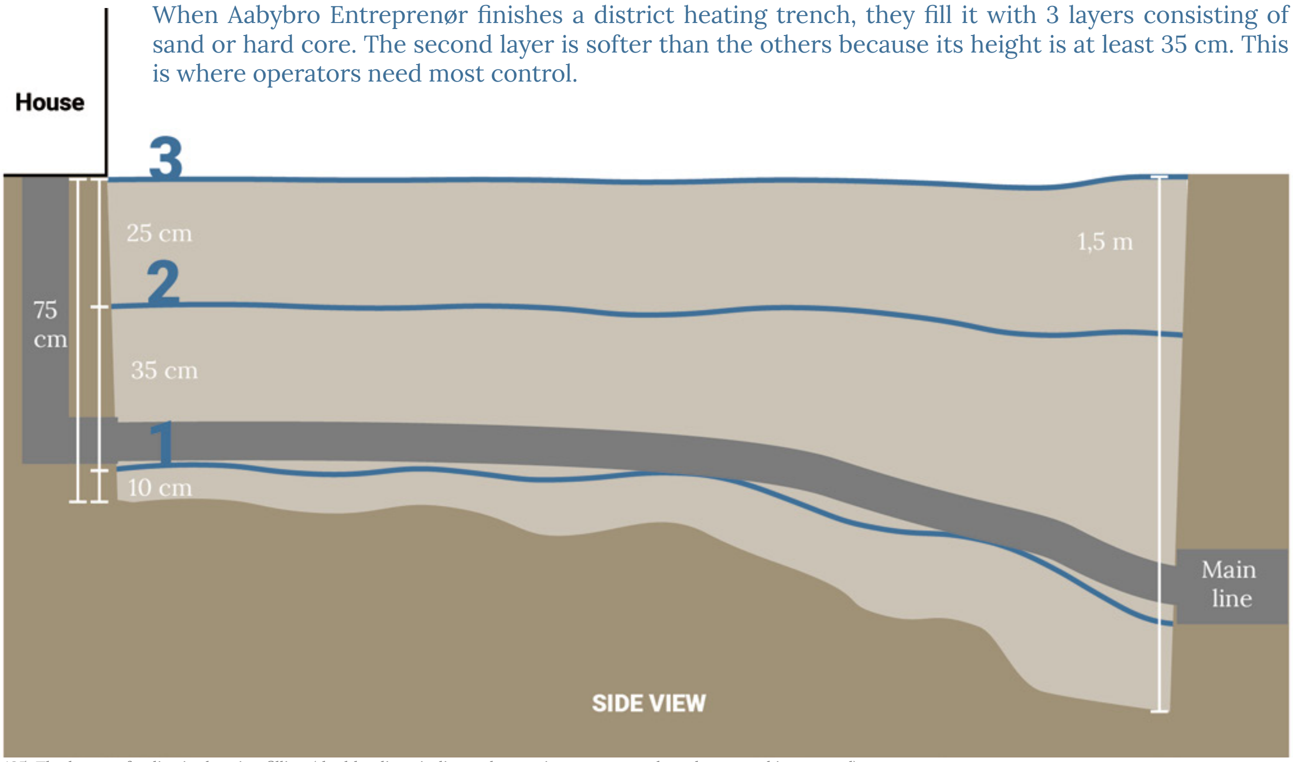


! Dilemma: Rigidity >< Adjustability

As mentioned, the sand is distributed with a shovel prior to VTR operation to ensure that the ground becomes evenly compacted. The next page explains why it is sufficient if the product merely dampens the vibration on even ground.

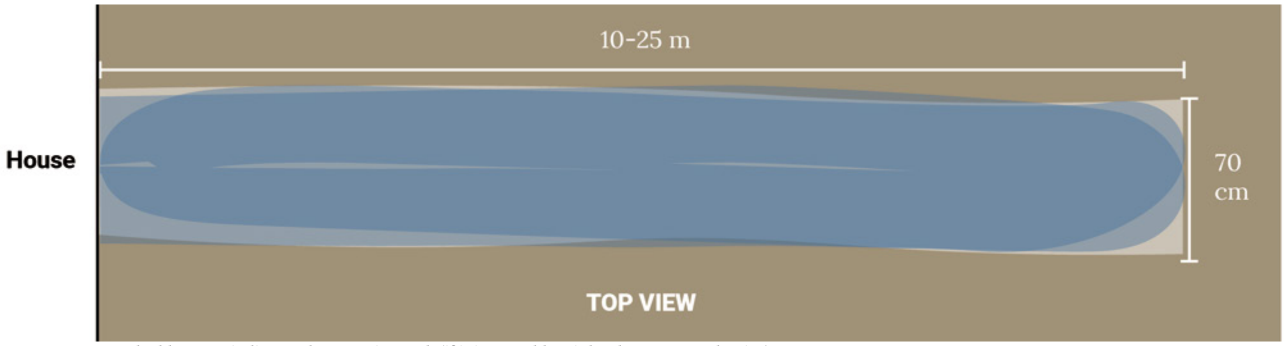
Ground evenness and compaction

When Aabybro Entreprenør finishes a district heating trench, they fill it with 3 layers consisting of sand or hard core. The second layer is softer than the others because its height is at least 35 cm. This is where operators need most control.



195: The layers of a district heating filling (the blue lines indicate the varying evenness when the ground is rammed)

On top of each layer, they drive back and forth at least twice, and after the first round the ground is more even and compact. In the second round, the VTR vibrates more, but less control is needed. The other layers are more even and compact in the first round because less sand is filled in.

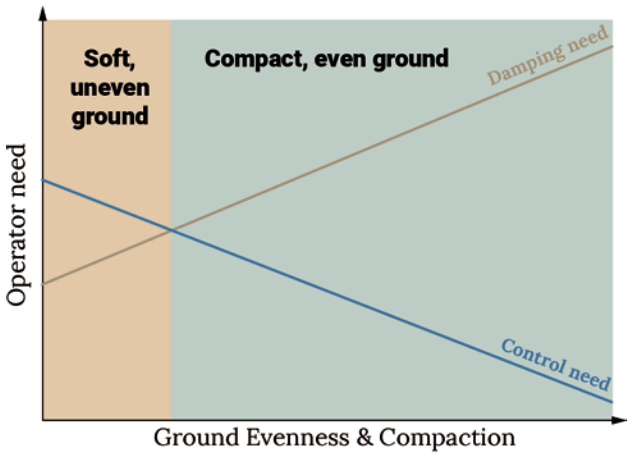


196: The blue area indicates the ramming path (if it is more blue, it has been rammed twice)

The variation of needs depending on ground

The mapping indicates that most of the operation time is spent ramming compact and even ground. Here, the operator has a low need of control but high damping. In the soft, uneven ground, there is a high need of control, but the damping need is lower.

> ! The VTR is mostly operated on compact, even ground



197: The operator's need of control and damping depends on the ground

4.5 AS IS SCENARIO

Based on the observations, and interviews conducted, and prototypes tested during end user visit #4 and #5, an understanding has been developed of what problems the current VTR operation contains. This section shows a an as-is scenario to clarify these problems and how they relate in time. Some of the points that will be highlighted have already been mentioned with more detail in section 4.2 and 4.4. The purpose of this section is to provide with overview and underline what the focus of the project is.

198: As is scenario

01

The VTR is stored and transported in a van.

02

Upon arrival to operation site, move the VTR from the van to trench with a sack truck.

03

Prior to ramming, distribute sand or hard core in the trench.

11

Return to the VTR to the van and continue to next district heating trench.

Repeat step
03-10
three times per
district heating
trench filling.

10

Once the ground is sufficiently compact, remove the VTR from the trench.

Project focus: Control & damping

Step **05-08** occur multiple times in random order. During these steps, the VTR exposes the operator to vibration. Though the product should also take the other steps into consideration, solving these steps of the problem is the exemplary dive that the remaining pages of the report will describe.

- ! **The VTR is lifted minimum 8 times manually per trench filling**
- ! **The VTR is lifted into and out of the trench by hand**
- ! **The operator pulls the handle to move the VTR in every direction**

04

Pull the VTR into the trench by grabbing the front of the handlebar.

05

Once operation is initiated, apply pressure to the VTR to control it on the soft, uneven ground.

06

As the ground becomes more compact and even, less pressure is needed to control the VTR.

09

Take a break to avoid exhaustion.

08

Twist body to turn the VTR.

07

While ramming near property, avoid causing damage by pulling the VTR quickly backwards.

4.6 BUSINESS PITCHES

It was known the concept functionally works. However, it was still unknown if anyone were willing to pay for it and how much. It was necessary to find out if the buyers see any value in this as a real product to determine if there is a viable business case.

The plan is to contact differently sized contractor companies to see if their needs and demands differ. A large company like Jorton (visit 2), a medium like PE-Nielsen (visit 4) or Aabybro Entreprenør (visit 4), and small one like Jens Thyrrestrup Olsen.

Unfortunately, it was not possible to set up a meeting with a large company like Jorton. But both PE-Nielsen, Aabybro Entreprenør, and Jens Thyrrestrup participated.

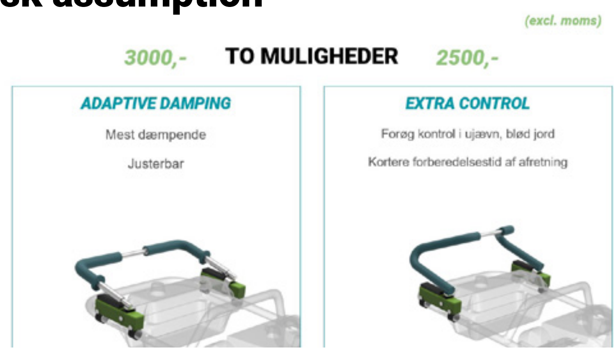
A sales pitch was then conducted to the three companies, and afterwards they would be interviewed to get their hooks and rejections. The result should culminate into a value proposition for the buyer.

The plan was to convince the businesses that the two concepts were real, by creating a quick CAD model and renders presented in a streamed PowerPoint presentation. It would display the materials, features, durability, comforts and price of the products. Some of the features and functions would be displayed on the functional model.

Verifying the efficiency over health risk assumption

This business pitch also created the opportunity to verify if the employers only care about the workers efficiency and not their long-term wellbeing. Again, the two concepts Adjustable Damping and Addition Control were representing health risk reduction and increased efficiency respectively. This would give the employers a chance to hook or reject on what features they find the most important

The concepts varied in the following features:



	Adjustable Damping	Additional Control	Reason for variance
Value proposition:	Less vibration gives more allowable work hours.	Shorter prep time because it provides more control in uneven terrain	Do they value safety or efficiency?
Vibration reduction and increase in total allowable work time: (compared to the current measured vibration magnitude; 13 m/s²)	Up to 50% reduction increases allowable trigger time to 4 hours	Up to 25% reduction increases allowable trigger time to 2 hours	If they feel they are sacrificing something we know they are willing to pay for it and see its value. If they don't feel like losing something we should only provide just enough damping to fit a certain use case and not the optimal damping effect.
Suggested by:	BAM-Bus, OHD and DWEA for its comfort and damping effect.	Workers and site managers for its increase in control and prep time reduction	Do they value organisations health advice or their workers word for efficiency
Control level:	Retains	Increases	More control gives the workers the ability to operate in worse conditions, ie. save more time
Main feature:	Adjustable damping and handle length	Better hand positioning, stability and turning	To discover if they find the highest value in the increase in health and safety or efficiency and output.

199: Plan and slides of the business pitch

Pricing the product

The employers were pitched to individually on separate occasions, and the suggested price was increased accordingly doing each pitch to find their rejections. The employers represented multiple roles, as both directors, buyers and site managers.

The employers said the prices presented seemed reasonable and no pricing rejections were observed. With the highest asking reaching 3000 DKK. They would buy a product like this for both old and new machines if it were used on a regular basis.

1500 ✔ Jens Thyrrestrup Olsen (Self-employed)

2000 ✔ Henrik Todberg (Site manager, Poul Erik Nielsen)

3000 ✔ Brian Østergaard Barslev (Director, Aabybro Entreprenør)

Employers feedback

This is the collective feedback the employers gave after the product pitch and their perceived value of the two concepts presented.

- Generally, it was difficult for them to act on which concept they would prefer the most. It relied on which one their employees liked the most when using it.
- They would have to try out both concepts to know which one to buy.
    - The extra control was not seen as necessary because the ground needs to be levelled nicely before using the VTR - This gives the most even compaction of the soil.
    - The primary purchase barrier is the uncertainty about if the workers will use it - they bought an 8000 DKK semi-automatic pipe cutter for the power drill, but the workers did not use it, because it was slower than cutting the pipes manually.
    - If they are satisfied and actively uses it, they would implement it on all their VTRs.
- They had the perception that these were good products placed correctly on the machines and had the right features for control, operational use, transportation, comfort and storage.
    - They acknowledged that vibrations from VTRs and vibratory plate compactors was a problem.
    - They would always prefer keeping their employees and the prices suggested for the products would not cause them to reject this claim.
- They saw the greatest value of the products was its vibration reduction and enabling them to keep their employees for longer.

Choice of Additional Control

Though the employers do not think that the operator needs additional control, their statements point towards choosing the Additional Control concept.

The manager prioritises the well-being of their employees. It is expensive to replace a good worker. However, the decision to purchase a new product depends on the operators' willingness to use it. Though the Additional Control handle does not provide most damping, it is the one that operators prefer to use (according to section 4.5).

Value proposition

As it is expensive and difficult to find or make new good and reliable employees it is better to take care of the ones they already have.

The vibratory tamping rammer is disliked among workers because of its high vibration magnitude. The operator is exposed to most of this vibration during tasks that require low control. The product is a flexible protective equipment that is permanently mounted. It almost isolates the operator from vibration during low control operation and offers new ways to ease the high control situations while also reducing the vibration.

This can be acquired for 3000 DKK and provides:

25% reduced vibration exposure => from 1 to 2 extra permitted hour of trigger time

Workers will use less energy on VTR operation and work faster during other tasks

Same level of control and more ergonomic body postures in situations with limited space.

If the price is reasonable compared to the machines, the workers desire to use it, and its damping feature is significant, the Additional Control concept is worth the 3000 DKK (a higher price has not been tested). This pricing can help guide future design choices regarding production methods and features that will affect the operating cost and profit.

4.7 PRODUCT FEATURES

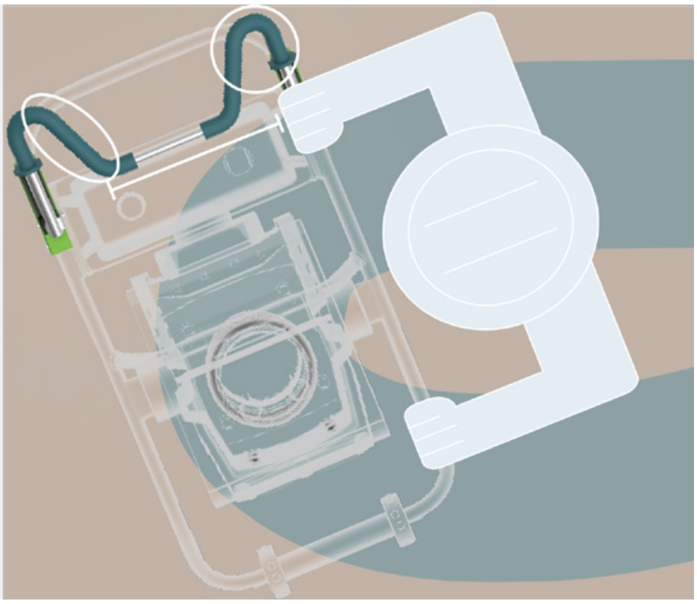
This section presents an overview of the key features of the product to be - Vibrashifter. The concept of Vibrashifter is to “shift” vibration “mode”. Situations from section 4.5 (As is scenario) will clarify what part of the problem each feature solves. Renders of the Additional Control concept made for the business pitches (prior to obtaining insights from the last visit) act as visuals of Vibrashifter.

Control options

In narrow spaces

08

Vibrashifter offers several ways to hold the handle, allowing the operator to control with ergonomic body postures.

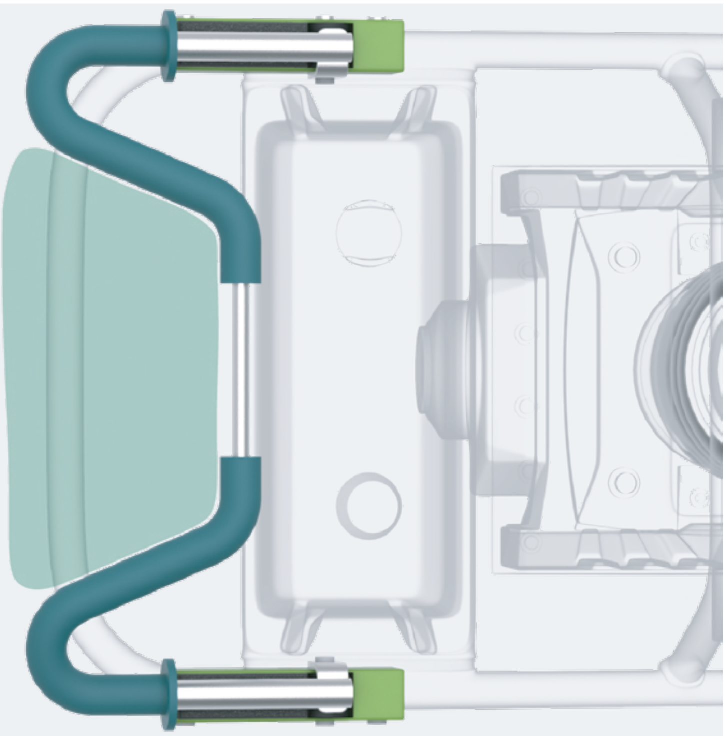


200: For instance in a trench, the operator has a shorter reach while turning it around

On soft ground

05

During operation on soft ground, the operator leans over the current handlebar to push with the hip. The shape of the handle allows this.



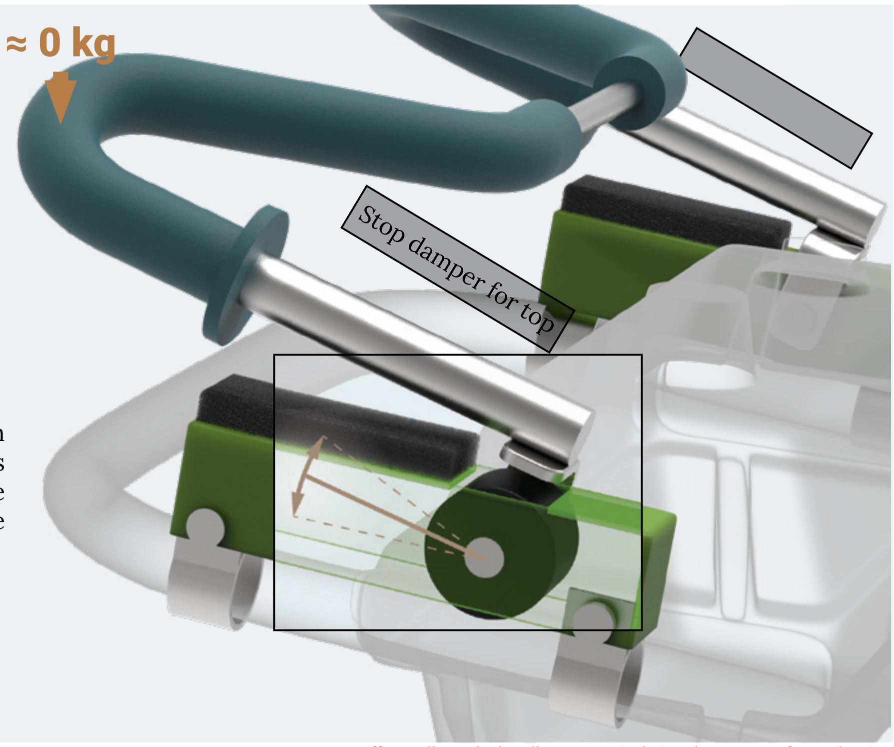
201: Room for the torso

Progressive damping

On compact ground

06

During most of the operation time, the torsion damper deals with the vibration by allowing the VTR to rotate isolated from the operator.

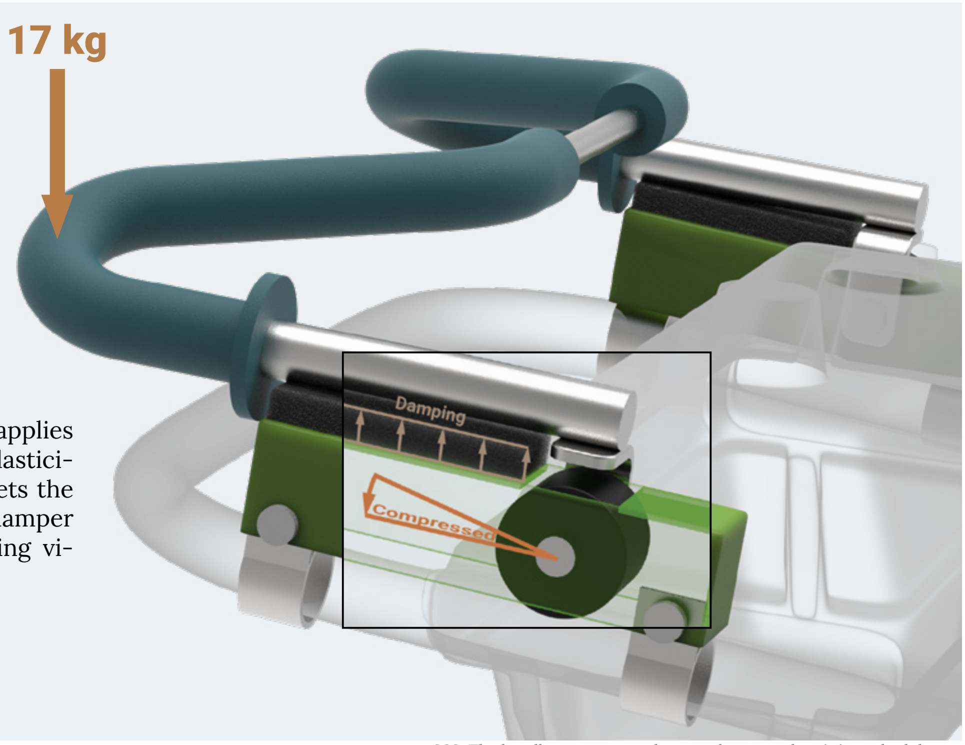


202: Damper stiffness allows the handle to move, isolating the operator from vibration

On soft ground

05

Whenever the operator applies additional pressure, the elasticity of the torsion damper lets the handle to touch the stop damper that dampens the remaining vibration.



203: The handle compresses the stop damper, when it is pushed down

4.8 DESIGN BRIEF

Vision

Safe and effective work environment

Problem statement

How can we retrofit a Vibratory Tamping Rammer (VTR) to reduce the operator's risk of developing Hand-Arm Vibration Syndrome (HAVS)?

Stakeholders

Consumer

Site manager
Buyer
Director

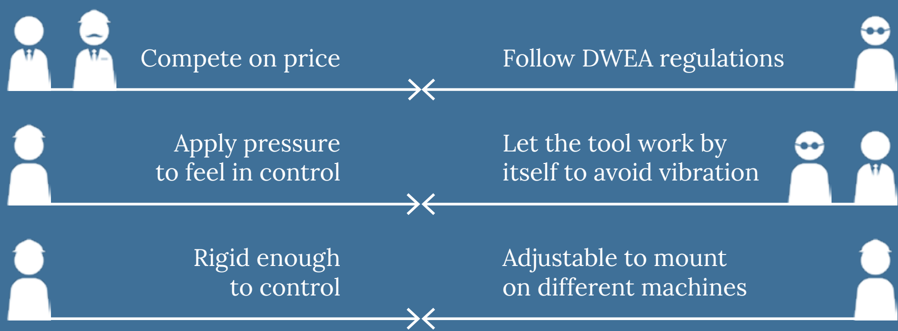
Operator
(End user)

Retailer

DWEA
BAM-Bus
BFA

OHD

Dilemmas



Design variables

To maintain overview of the current information, the takeaways are divided into prioritised categories.

Priority	Category	Key takeaways	
1st	Control	3.5	The VTR is difficult to control on uneven ground
		3.5	The VTR is difficult to move forward on soft ground
		4.4	The VTR is mostly operated on compact, even ground
		4.5	The VTR operator pulls the handle to move the VTR in every direction
		4.2	The VTR operator applies 17 kg to push down the VTR
		4.4	The product should afford new ways to hold the VTR
1st	Damping	3.5	The VTR vibrates more the harder the ground becomes
		3.5	The VTR frequency is 12 Hz
		3.5	The VTR vibration magnitude is 6,5-13 m/s^2
		4.4	The product should dampen vibration during lifting and pushing down
1st	Mounting	4.2	The VTR handle width varies between brands
		4.2	The VTR handle diameter varies between brands
2nd	Transportation	4.2	The VTR sometimes lies down during transportation
		4.4	The product should not exceed the handlebar perimeter
		4.5	The VTR is lifted into and out of the trench by hand
		4.2	The VTR is transported on a sack truck
		4.5	The VTR is lifted 8 times manually per trench filling
3rd	Durability	4.2	The operators often have sand, acidic and alkaline substances on their hands
		3.5	The VTR is used year-round in all weather
4th	Operator fit	4.4	The product should be fit different operator heights
		4.2	The VTR operators' physique varies
5th	Comfort	2.4	Cold handles trigger attacks of Raynaud's Phenomenon
		4.4	The product handle should be soft
6th	Other categories	2.3	Hygiene

4.9 MILESTONE

The presentation included an introduction to each parameter and how features Vibrashifter reflected that it had been considered. The supervisors requested a clarification of the prioritisation afterwards:

Priority

1st **Control** is the prerequisite of the product. If too much on control is compromised, they are not going to adopt the product.

1st **Damping** is the reason why the product exists.

1st **Mounting**: The product must be fixed to the machine to allow the operator to control the machine.

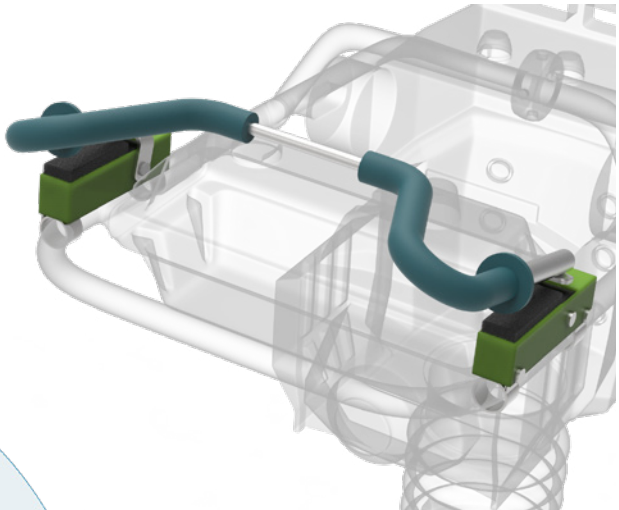
2nd **Transportation:** To operate the machine it must be moved to the operation site. This should be convenient, but they can cope with minor inconvenience.

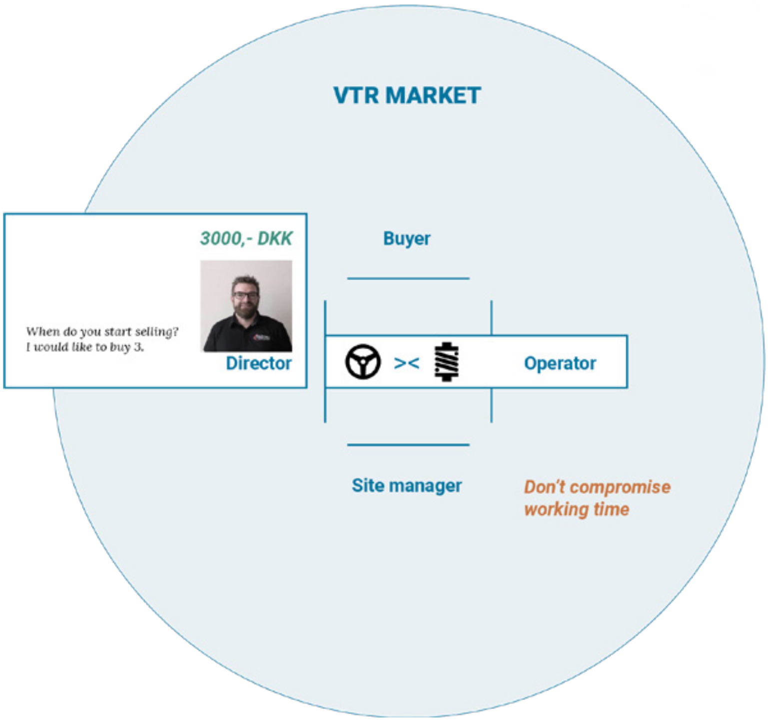
3rd **Operator fit:** The existing machine fits operators differently. They mention the related inconvenience during interview.

4th **Comfort:** The operator is more likely to want to work with the machine, if the operation is comfortable

As ill. 206 shows, the recent project focus had been on the VTR market. The plans for phase 5 were also presented, but the supervisors had no comments on these.


204: Presented use context image


205: Concept heroshot mounted on VTR with x-ray effect



206: Stakeholders of the VTR market overview (part of animation from powerpoint)

4.10 REFLECTION

Difference between planning, executing, and communicating activities

The order of the sections presented in this phase is not the same as chronological order of the executed activities nor the planned order. The planned order was to carry out the business pitches (section 4.6) as the first thing to ensure that least development effort was wasted. But since the director of the Aabybro Entreprenør was not available before end user visit #4 (section 4.2), the business pitches were conducted as the next thing. According to the feedback from both Poul Erik Nielsen and Aabybro Entreprenør, a purchase decision predominantly depends on whether the operator will use the new equipment. Unfolding what factors are included in the operator's willingness to adopt the product became a part of purpose of end user visit #5 (section 4.6.)

Planned order	Executed order	Communicated order
Business pitches	End user visit #4	4.2 End user visit #4
End user visit #4	Business pitches	4.4 End user visit #5
(Maybe) End user visit #5	End user visit #5	4.6 Business pitches

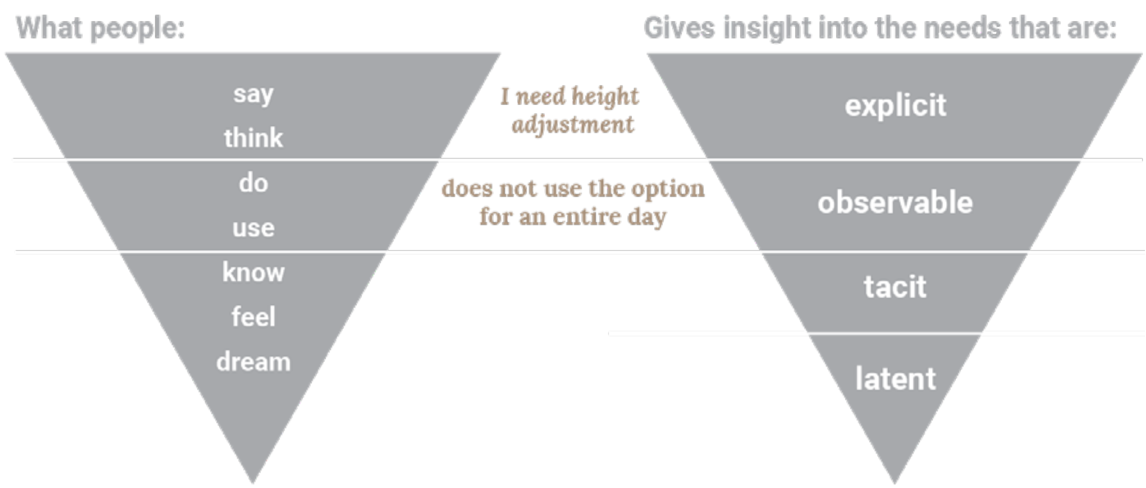
Minimal Viable Product

The business pitches were presented to company buyers because they are the customer, though the operator is the end user. The pitch was a Minimal Viable Product (Ries 2011) that tested what the customers valued. To our knowledge, it was the fastest viable way to acquire the feedback and reason for improving one of the concepts (Additional Control or Adaptable Damper) or to pivot (Ries 2011).

Contradiction between levels of needs

Sometimes there is a difference between users' explicit and observable needs (Sanders 2002). As section 4.4 describes, the operator liked the idea of damping adjustment, but when he was allowed to use the prototype for a day by himself, he did not utilize it. On the next day, he suggested height adjustment as feature, even though he knew that it was already implemented. There is a risk that the implemented adjustment feature had an unacceptable trade-off.

So, adding features based only on a user's explicit desires may not add the intended value. For example, the soft, wrapped handles, which has been a feature included in every prototype. The users express their delight, but to our knowledge, no machines have soft handles. The wrapping might lack the reliability and rigid feel of the control, or it might not withstand the abuse of the environment. A wrapped handle may eventually cause them to stop using the product. And so far, it is still unknown what impact it has on their desires, since no handles with a hard surface have been tested.

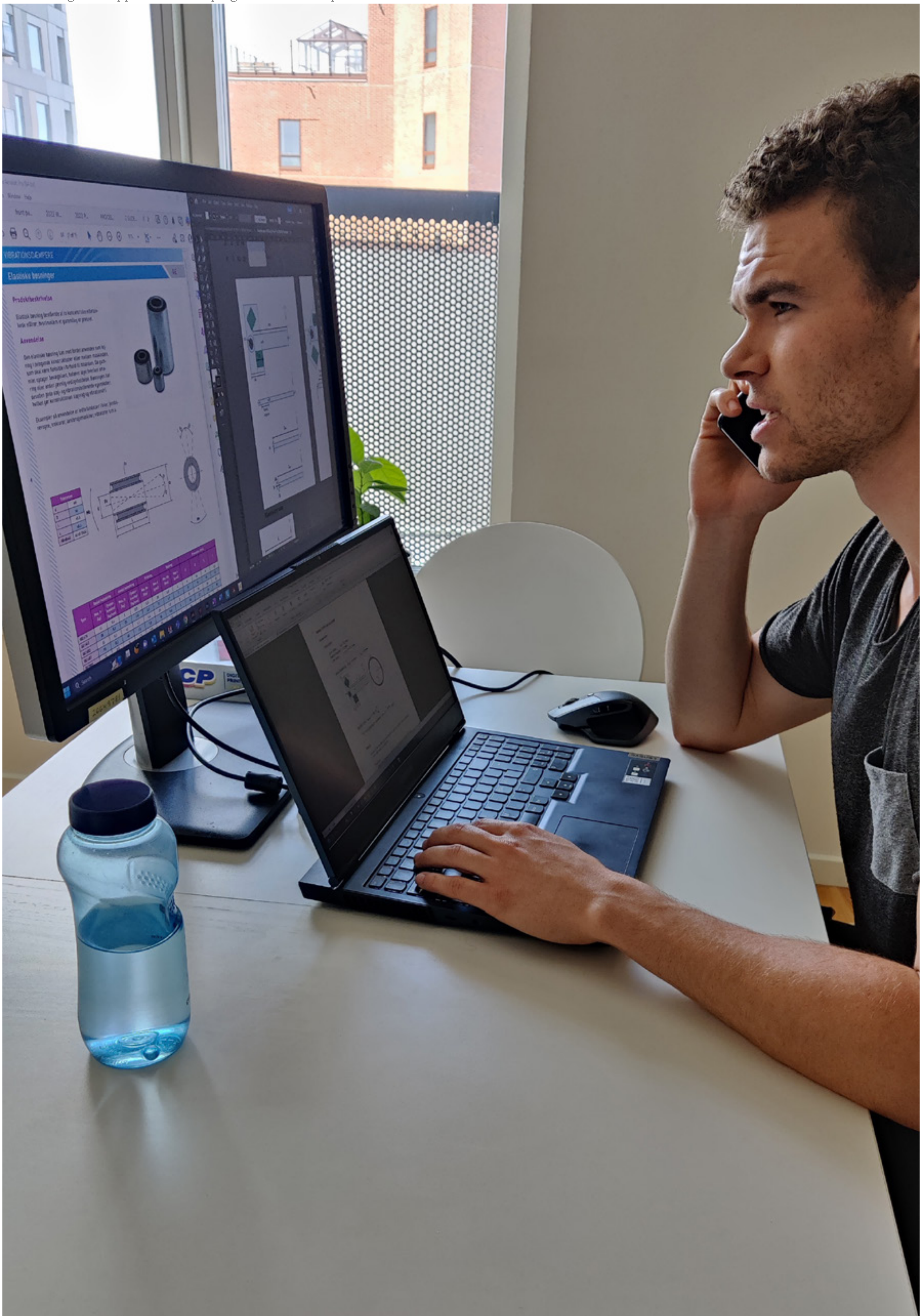


207: Sanders' (2022) pyramids of needs (recolored and commented)

5 PRODUCT SCALABILITY

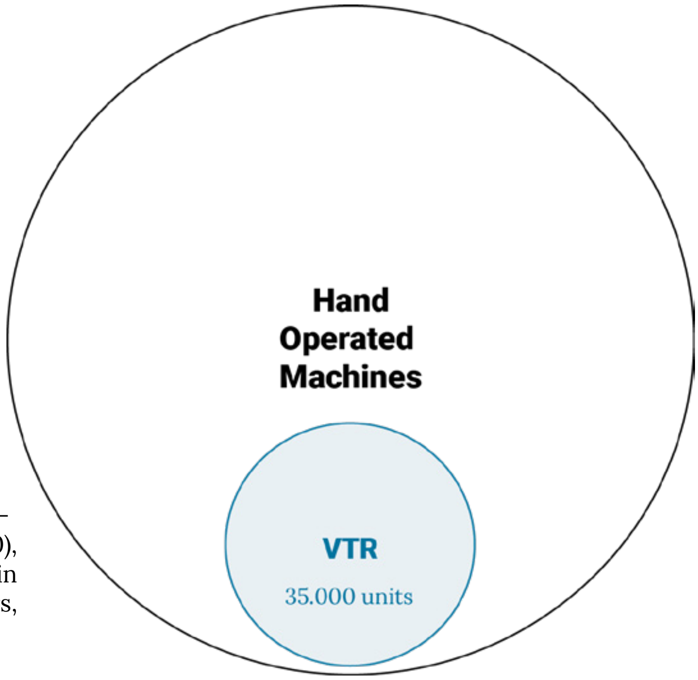
In this phase, the current design turns into industrial design. Considering the topics of mounting, manufacturing, product architecture, and construction, the concept of Vibrashifter becomes what is presented in the product report.

208: Talking to a supplier while keeping count of assumptions related to calculations



5.1 SCALABILITY

This section unfolds the content of phase 5 to provide an overview. It is described how and why the activities have occurred parallelly, though the upcoming sections of the report are thematic descriptions. An attempt at planning the activities of phase 5 is in appendix 15.



209: The TAM of VTRs is a minority of the TAM of Hand Operated Machines

Total Addressable Market

TAM of VTR

Use of VTRs is widespread across the construction industry. According to Danmarks Statistik (dst.dk 2020), 34756 construction companies existed in Denmark in 2020. Based on the numbers from the visited end users, it is estimated that the average company own 1 VTR.

Company	# of employees	# of VTRs
Aabybro Entreprenør:	35	15
Poul Erik Nielsen:	30	2
Jorton:	500	10
Jens Thyrrestrup Olsen:	1	1

Addressing a large market lowers risk

Considering the Total Addressable Market (TAM) of the VTR in Denmark, it is concluded that Vibrashifter should be compatible with other machines. This conclusion will lower risk, if a smaller market share is sufficient to become a profitable business.

Scalability breakdown

Determining the number of units of Vibrashifter is complicated. It does not only depend on the market demand but also on whether Vibrashifter can evolve into a system that meets the needs of other vibrating machines as well as the identified needs of the VTR.

To tackle this, it has been necessary to take the topics of section 5.2, 5.4, and 5.5 into consideration several times. The tasks related to these topics are introduced briefly below.

5.2 Machine variables

Choose machines similar to the VTR in respect to:

- Dimensions
- Vibration
- Control

5.3 Product architecture

Redesign the current product into a modular product architecture that fulfil VTR needs and new machines.

5.4 Manufacturing methods

Considering risks and rewards, and how the product features may change depending on chosen manufacturing methods.

5.2 MACHINE VARIABLES

To increase the TAM, (i.e., potential revenue), by designing product architecture with carry-over components, it is vital to know the variables across machine types. The number of variables included in the product architecture will determine the necessary variance and thereby the cost. The first step is to identify the remaining variables within the VTR category. Next, it will be considered what other variables Vibrashifter should accommodate to enable scalability. Appendix 16 shows the entire process of mapping the variables.

VTR compatibility

Three large VTR manufacturers, Wacker-Neuson, Ammann and MasterPac, were investigated to identify how big a variance the machines have in both handle width and diameter. With 28 different models, all the VTRs varied in handle width between 340-410 mm. Meaning a width adjustment of 70 mm within the spectrum would be sufficient to fit most VTRs.

Model	A	B	C	D	E
PMR40R	1120/44	345/14	705/28	100/4	270/11
PMR60H	1063/42	345/14	703/28	265/10	340/13
PMR60R	1063/42	345/14	703/28	265/10	340/13
PMR68H	1028/40	345/14	703/28	285/11	340/13
PMR70H	1028/40	345/14	703/28	285/11	340/13
PMR70R	1060/42	410/16	692/27	285/11	340/13
PMR75R	1060/42	410/16	692/27	285/11	340/13
PMR85D	1040/41	410/16	703/28	285/11	340/13

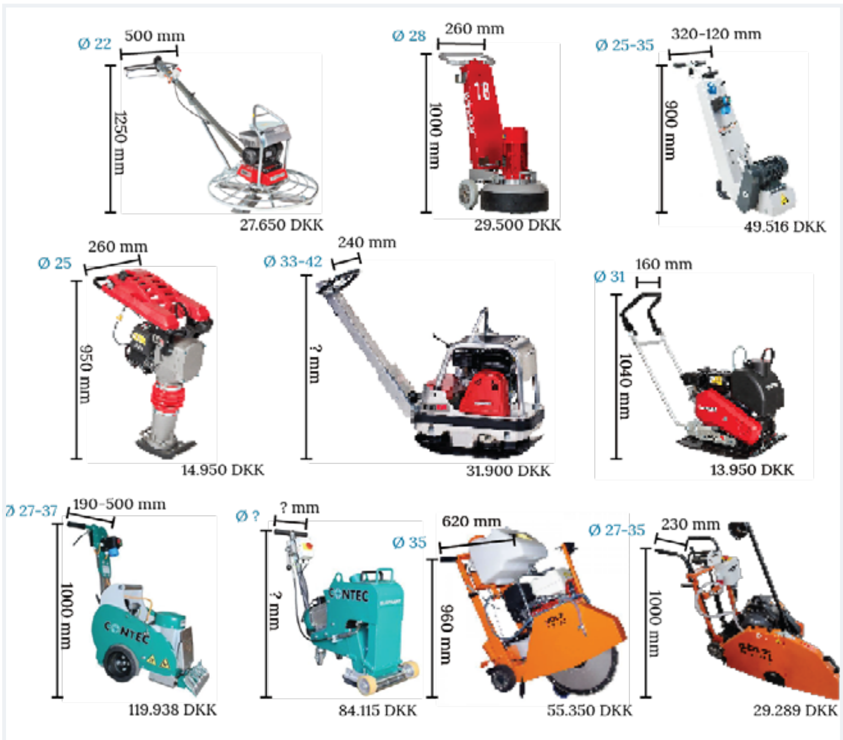
210: VTR models and dimensions

Revisiting measurement

In section 3.1, the measurements of hand operated machines showed that the steel part of the handles was all within the range of Ø22-32 mm. The rubber on the handle is often wrapped around, so it can easily be removed. Here, a variance of Ø10 within the range would be sufficient. While looking through the images a second time, the short handle length (ill. 211) of Swepac's (another large manufacturer) VTR model is unexpected. As ill. 216 in section 5.3 shows, the current design does not fit.

New driving dimension:

211: Swepac VTR zoom



212: Hand operated machines dimensions and prices

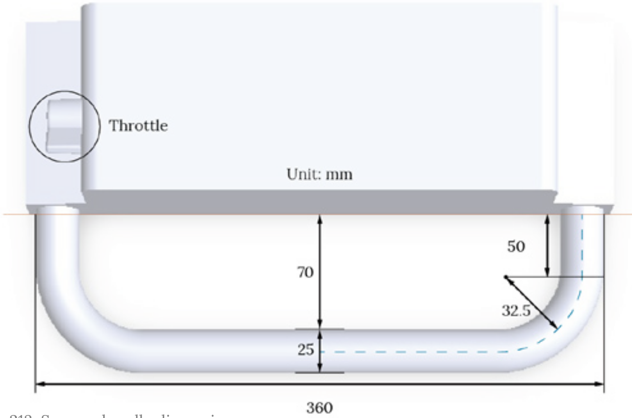
Straight handle length

The short handle length may be limiting. A critical part of the mounting in the current design is this parallel part. The handle is mere 50 mm long (excluding the curve of the corner). The fuel tank of this Swepac VTR (ill. 211) has a plastic cover that overlaps the handle.

Thus, the attachment should strive for being as close to 50 mm is attachment length as possible while maintaining a rigidity to an acceptable level.

Vibration differences

Most VTRs are within the same frequency range of 11-13 Hz, but the vibration magnitude varies more, depending on model and manufacture. However, as mentioned, the magnitude varies a lot depending on ground compaction.



213: Swepac handle dimensions

Suitable machine types

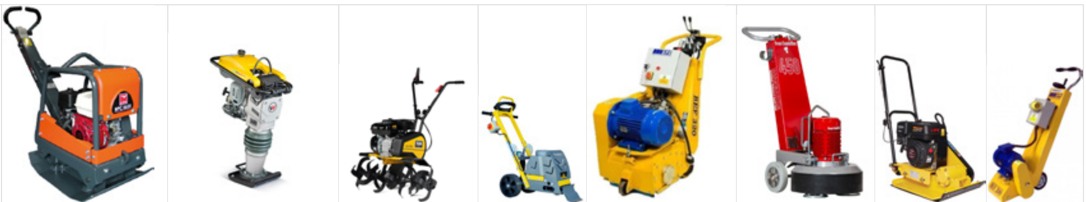
The initial scope for a larger category of machines is set to be closely related to the VTR and its operation, this would be machines that:

- an operator controls by walking behind it
- moved forward by the operator pushing it
- carrying their own weight and primary balance
- perform a task on the ground surface it is moving on
- causes HVM exposure
- use a circular handle profile at a given straight length
- are used regularly by workers

Machine selection

A machine matrix previously made is revised.

Of these the Vibratory plate compactor and the Floor scarifying machine represent quite large versions of those machines and they are quite often self-pushing/driven and very heavy meaning the vibration exposure is also lower than their smaller versions. Therefor the machine categories are adjusted to smaller versions of those machines that require the operator to push it.



English name	Vibratory plate compactor	Vibratory tamping rammer	Cultivator	Floor stripper	Floor scarifying machine	Floor grinding machine	Small VPC	Small FSM
Danish name	Pladevibrator	Jordlop	Jordfræser	Gulvstripper	Gulvfræser/betonfræser	Betonsliber		
Weight (kg)	161-174	72	52	67	310-339	90	78	68
Dimensions x*y*z (mm)	500 * 1265 * 657	673 * 342 * 965	1210 * 620-850 * 1240	965 * 606 * 1066	1230 * 590 * 1220	810 * 460 * 1030	1030 x 400 x 920	900 x 900 x 350
Handle height (mm)	1265	965	1240	1066	1220	1030	1030	900
Handle dimensions								
Maximum controle force								
Main controle force direction								
Motor vibration magnitude (m/s^2)			4,7					
Motor speed (rpm)	3000-3400	4200	3600	1725		950-1200	5600	
Opperation frequency (Hz)	95	11	2,7	83	15,5 - 22	12,5	98	
Vibration maginitude (m/s^2)							10,98	6,6

214: Machine overview (work in progress)

5.2

Handle orientation

The machines also vary a not only in size but also handle orientation.

The handle orientation typically varies between parallel, co-linear and some are slanted

215: Sketch (without proportion) of handle shape of each new machine type

Handle diameter

Since all the machines selected only have a circular handle profile the fitment only relates to the diameter and the length of the straight profile.

It has previously been established that the diameter adjustment must vary between **22-32 millimetres** to fit most machine types meaning the adjustment of **10 mm** still holds true for the selection of machines.

Handle width

These machine types tend to vary a lot in width even within the same machine category from **260 to 500 mm.** A function of all the handles except the VTR handle could be that they should be able to be as narrow as 260 mm meaning **one handle part is 130 mm wide** and the **adjustment is 80 mm** this can be done by having three lengths of rods allows the handle to reach within the interval.

Alternatively, it is possible to separate the handles for the other machines thus eliminating the need for an adjustment rod in between.

Control variation

Only the VTR requires pressure downwards to control it. The other machines mainly require a pushing force followed by a steering and pulling force.

The main **control of the VTR is pushing down**

The main **control of the scarifying machine and floor stripper is pushing forward**

The main **control of the vibratory plate compactor and floor grinding machine is turning**

Some customized handle shapes could be created to fulfil these five machines' main control needs.

> **! Other machine types vary more in handle width than VTRs**

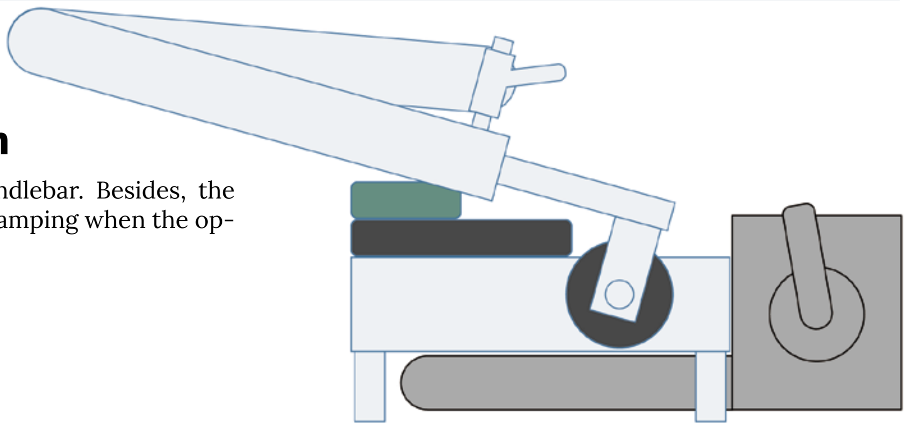
5.3 PRODUCT ARCHITECTURE

As explained in section 5.2 a new driving dimension was discovered. This section explains how the components of Vibrashifter are reorganised to fit the Swepac VTR and the floor stripper with collinear handles. Appendix 18 shows an unpolished version of the redesign process. At the end, the product architecture is presented.

1

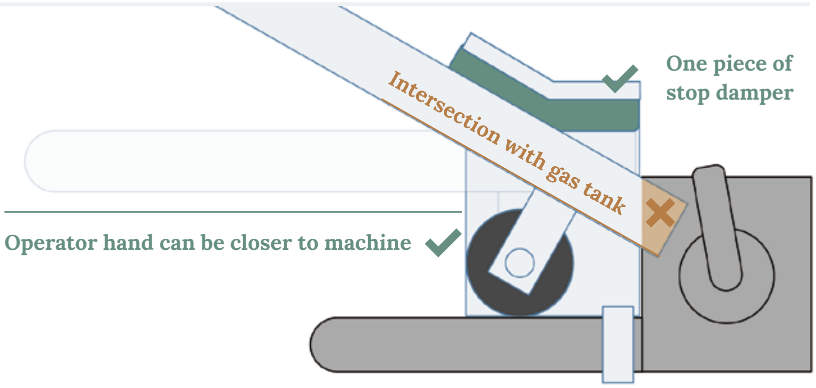
Architecture redesign

Design 1 extends beyond the handlebar. Besides, the stop damper only contributes to damping when the operator pushes down.



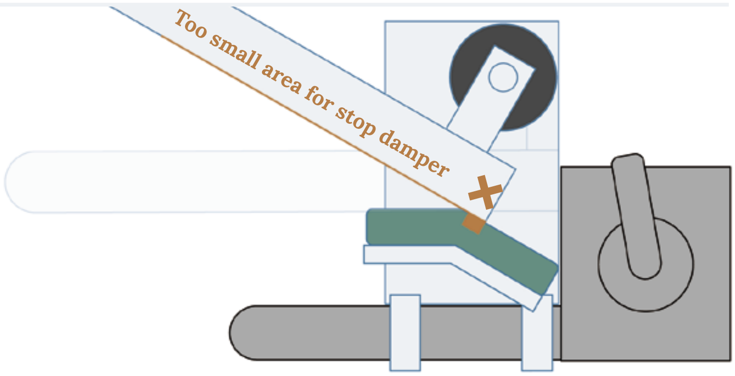
2

The gas tank (of the Swepac VTR identified in section 5.2) will intersect with the handle when it is in the upper position.



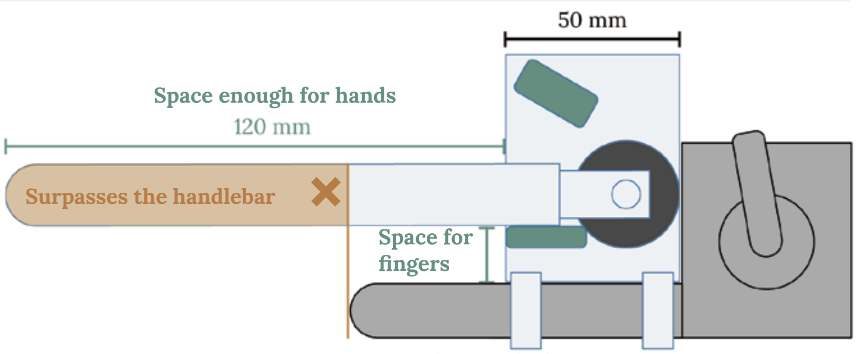
3

As section 5.4 will explain, a small area will require a stop damper with a high stiffness, and that will feel like an abrupt stop instead of soft damping.



4

It does not seem possible to make space for hands and avoid exceeding the handlebar perimeter and enable mounting Vibrashifter on a Swepac VTR. Since control has been assessed a higher priority than transportation, this operator wish is redefined into:



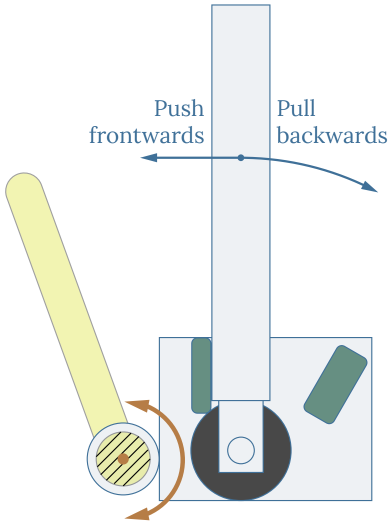
216: Two-dimensional redesign process

! The product should not increase the width of the VTR

5.3

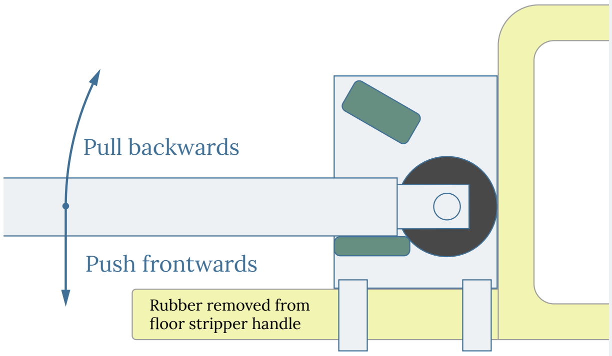
Product orientation on collinear handle

While considering mounting Vibrashifter on collinear handle, new problems emerge.



219: Mounted across handle (Side view of machine)

218: Floor stripper handle



217: Mounted paralelly to handle (Top view of machine)

✗ **The attachment must be adjustable to fit both 0-degree and 90-degree orientation.**

✗ **The product will rotate around the handle when the operator pushes or pulls.**

✗ **Current handle does not fit.**

✓ **Solution: Divide handle into two parts**

! **Separated handles do not need width adjustment**

Torsion test

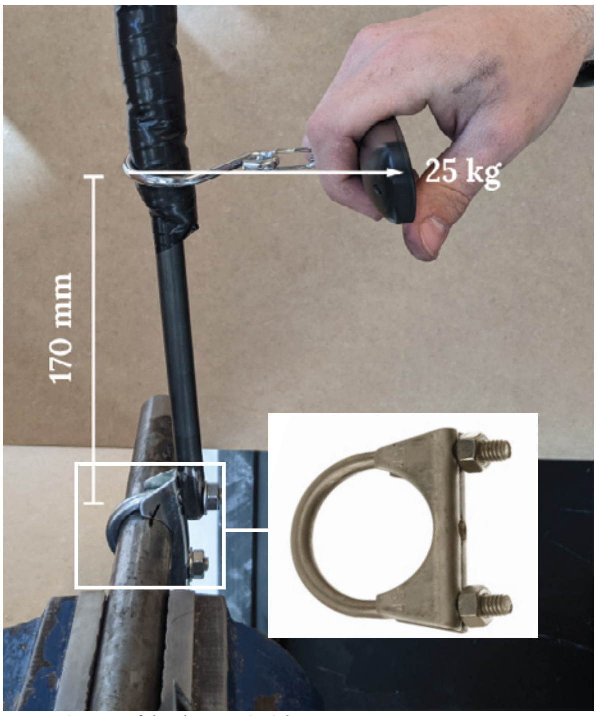
A torsion test was conducted to confirm that separated handles mounted on a floor stripper would be sufficiently stable.

Out of the six principles tested, the clamp on ill. 221 was best. It could withstand 25 kg pulled 170 mm from the surface of the 27 mm pipe before moving. This is approximately a torque of 42 Nm. All the other principles failed before 10 kg was applied.

This principle was the one that deformed the least. The other principles deformed when they were tightened.

✓ The pipe clamp fit the Swepac handle

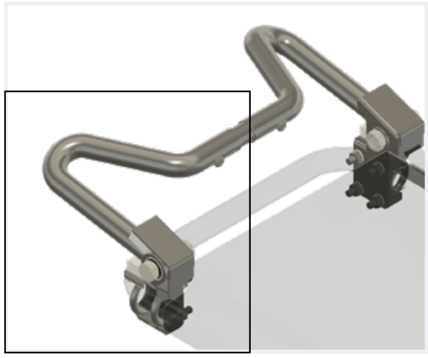
220: The pipe clamp mounted on the Swepac handle

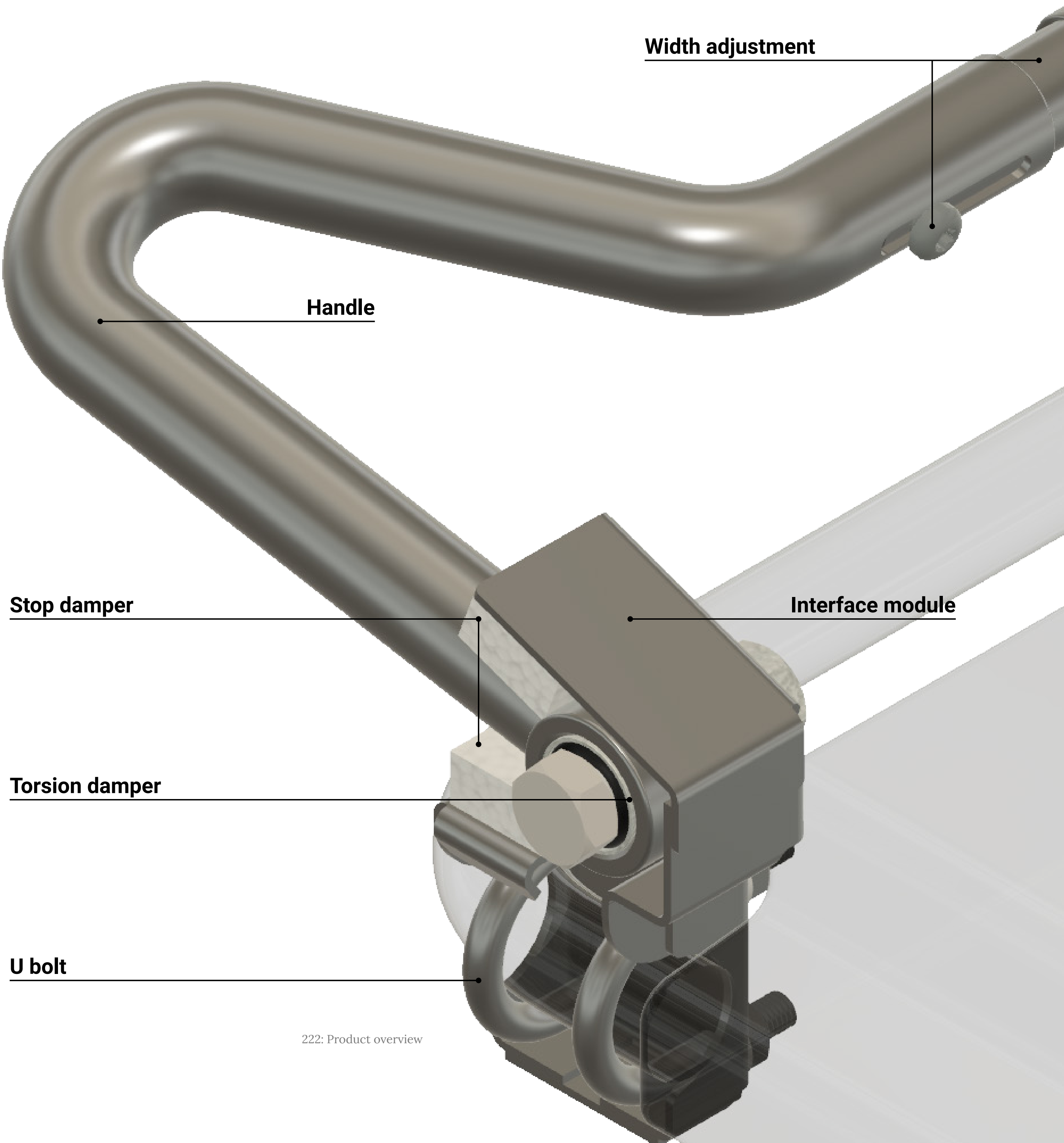


221: Torsion test of the chosen principle

Product overview

On upcoming pages, the following names will be used to refer to components of Vibrashifter. The part of the product shown on this page can be mirrored to the other side.



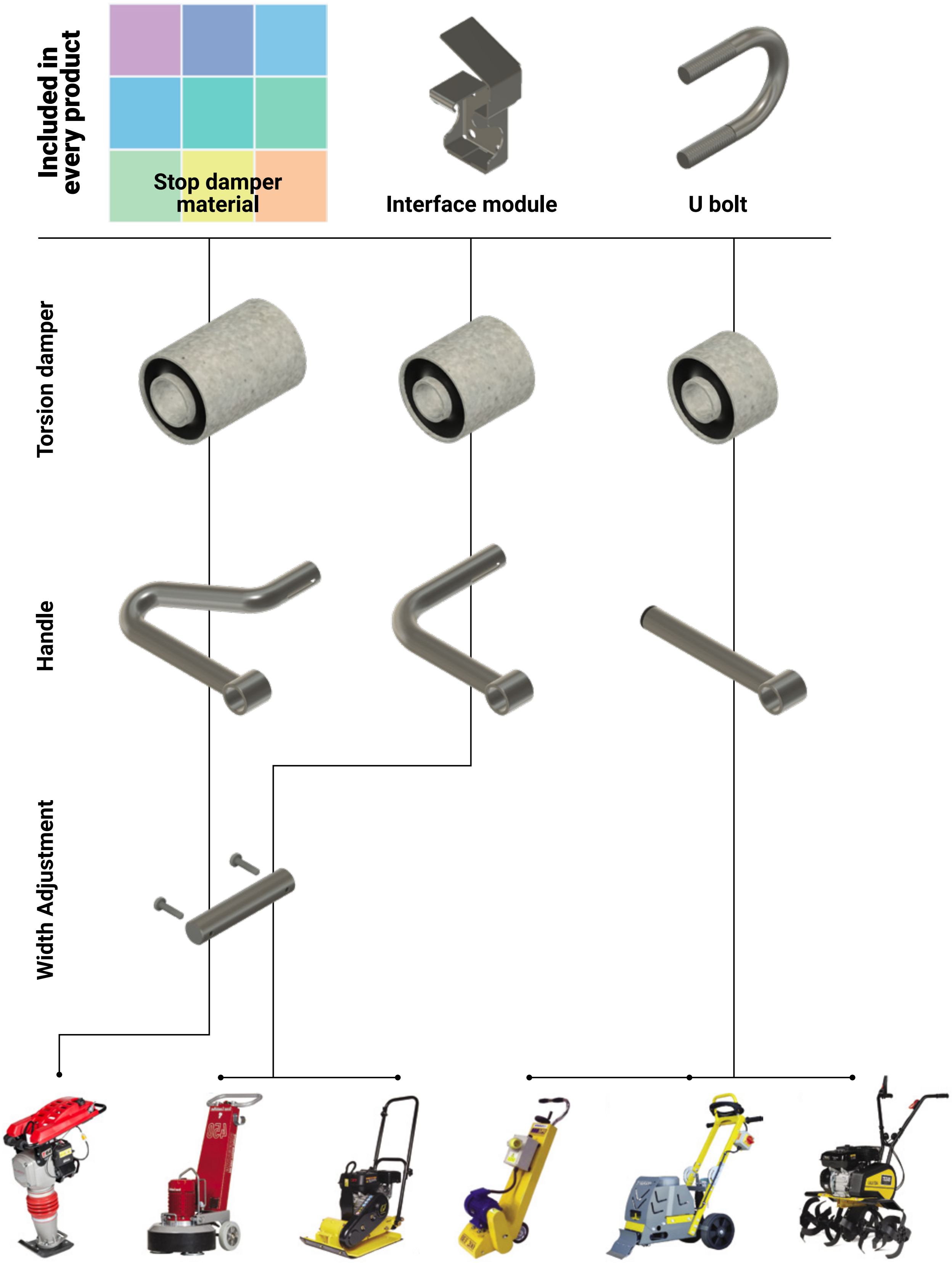


222: Product overview

5.3

Product architecture

To fit every machine type within the selected scope, the product architecture consists of different modules with interchangeable components. The machines that Handle 3 suits do not need a Width Adjustment because the handles are not connected. Appendix 17 presents the prior iterations.



223: Overview of how the components fit to the machine types

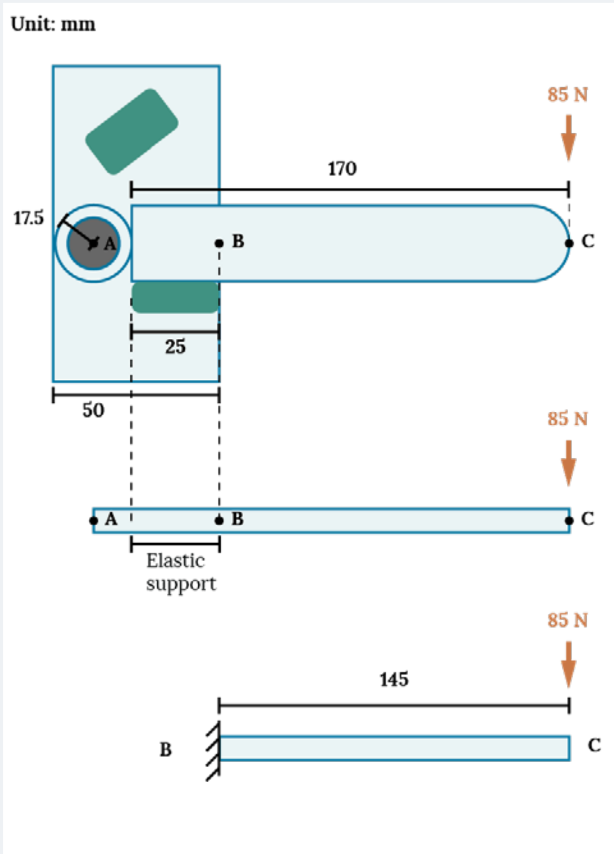
5.4 MANUFACTURING METHODS

This section presents the key considerations related to the choices of manufacturing methods.

Free body diagram

Several of the manufacturing choices come down to what is assumed to be the load conditions. The following sketches and Free Body Diagram (FBD) explain the reasoning behind the calculation assumptions. Calculations related to defining the handle cross section is available in appendix 19.

As ill. 224 shows, the handle of Vibrashifter is regarded as a beam. Since the support of the (green) stop damper is elastic, it is complicated to account for in calculations. Though the critical point of the beam would be near point A, the FBD cuts the beam at point B to approximate the maximum torque in the beam.



224: Breakdown of how the handle pipe is regarded as beam (The proportions do not align with reality)

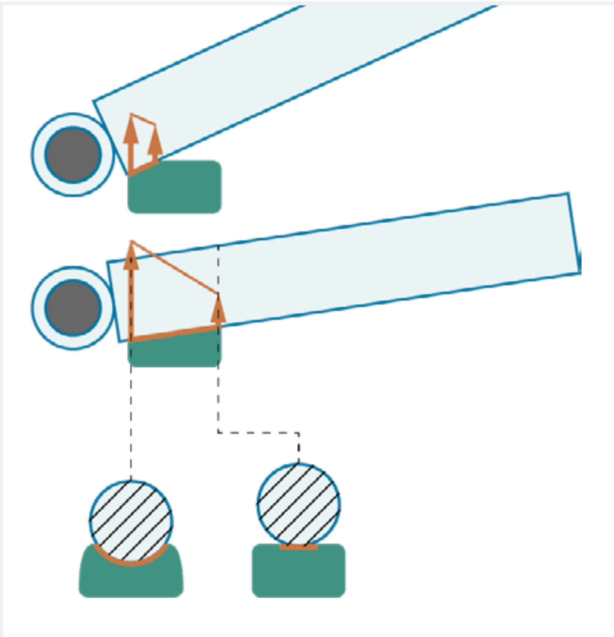
Elasticity of stop damper

Once the handle has been pushed down to the lowest position, it deforms the stop damper. The position in relation to the handle pipe and the elasticity of the stop damper provides slow deceleration (i.e., a comfortable stop for the user). The calculations are nonlinear for these reasons:

- The resistance of the stop damper increases, at it is compressed.
- Due to the circular cross section of the handle, the contact surface increases as the stop damper is compressed.

This is why the calculations are simplified to regard the handle pipe to be supported by the stop damper horizontally.

Both reasons also entail a slow deceleration in case a stiff stop damper is chosen. The laws of pressure dictate that less area requires less force to compress. This means that the required force gradually increases when the stop damper is compressed.



225: As the stop damper is compressed, the elasticity varies because the resistance of the material and the contact surface area increases

5.4

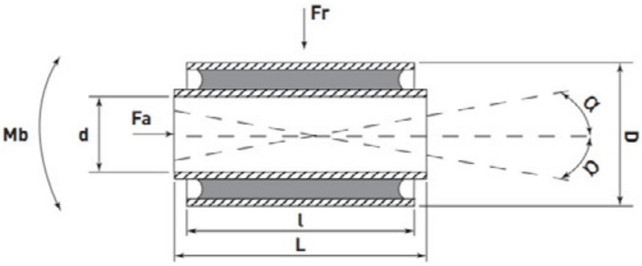
Torsion damper

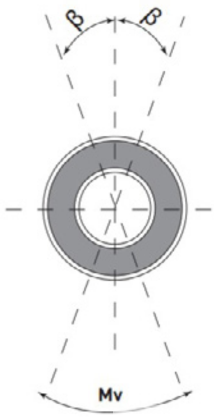
According to IAC Nordic (damping component retailer), the current rubber damper is meant for compressing in the coaxial direction and not torsion in the axial direction. They said that the most reasonable damper for Vibrashifter's application is an elastic bushing existing of two concentric galvanised steel tubes in between which a rubber layer is squeezed.

It has good vibration dampening features and is meant for axial torsion. They supply a data sheet with tolerances that defines what tolerance pairs are suitable for mounting through press fitting. Appendix 20 presents the identification of the tolerance pairs.

226: Bushing

Tolerances	
d	H9
D	s6
l	±0.5
L	±0.1
Hårdhed	60 ±5 Sh(A)





227: Tolerances and explanatory graphics shown in the data sheet

Unfortunately, they cannot find any data about what frequencies the bushing suits, so for now it is decided to identify its suitability with testing on the machines. Alternatively, more time in the future can be spent uncovering a damper with more thorough specifications.

Either way, the data sheet specifies how much axial reaction torque it provides under a maximum torsion angle. So far, the deciding factor is the reaction torque. Which is identified as the operator's maximum applied static load, 17 kg, at 170 mm from the damper centre to the far edge of the handle. It is estimated as follows: According to the data sheet the GE1917 is the most suitable with a maximum reaction torque of 16.7Nm, above the minimum required to resist the applied torque at static load.

Type	Vridning		Dimension (mm)			
	Max Mv (Nm)	Max ß (grad)	d	D	L	l
GE1676	1.0	28	6	16	14	12
GE1462	3.5	21	8	16	20	18
GE1652	4.4	21	8	16	28	25
GE1457	9.8	18	10	22	33	30
GE2000	2.9	28	10	25	18	15
GE2104	9.8	22	10	25	28	25
GE1751	9.8	20	12	25	23	20
GE1917	16.7	20	12	25	38	35

VTR choice

229: Clipping of bushing options

Dampers with lower Max Mv have same outer diameter

Operator load

Measured static load to push down VTR	170 N	17 kg
Distance from center of Torsion Dampers	0,17 m	170 mm
Torque applied to Torsion Dampers	28,9 Nm	
Torque applied to each Torsion Damper (TD)	14,45 Nm	

Choice of damper

Mv	16,7 Nm
Max beta	20 degree
Spring constant	0,835 Nm/degree
Loaded deflection angle	17 degree

> 20 deg (Max beta)

228: Torsion damper calculations

Whether the damper is functional within the frequency of the machines remains unknown. However, judging from the description of the data sheet, it applies the correct amount of a critical reaction torque and at an acceptable angle of 17 degrees. Besides, the dampers with lower stiffness have the same outer diameter. They are probably suitable for the other machines within the project scope. This is beneficial when they are mounted on the same spot on the interface module.

Stop damper

The conclusion after a meeting with the technical supervisor is that the stop damper calculations should be supported by test. As mentioned, several assumptions are related to the damper. The elasticity of the chosen Vibrafoam (a suiting material with many variants) should be soft enough to let the operator feel a soft stop rather than an abrupt one.

Calculation

If the total load of the operator is regarded as dynamic, i.e., two times the static load (2 x 170N = 340N), the torsion dampers merely withstand half of the load, leaving 170 N for the two stop dampers.

Since the rotation damper is sufficient to withstand the operator load if is considered static the Vibrafoam will withstand the dynamic of 1=static load as an elastic support. With the same torque applied to the small area of VibraFoam close to the centre of rotation it is going to be a high surface pressure.

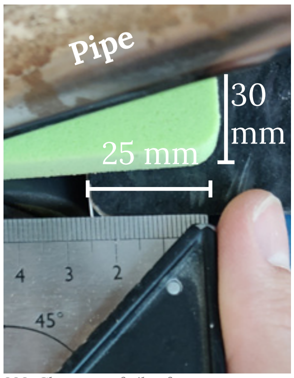
Operator load				
If the load is dynamic, this damper will be affected by 1 times the measured static load too.				
Remaining dynamic torque from operator:	170N * 0,17m =	14,45	Nm	
Distance from TD		0,025	m	25 mm
Load to be carried by Vibrafoam		578	N	
Choice of Vibrafoam				
Pipe circumference: 25*pi =		79	mm	30mm
Contact area between handle and Vibrafoam		750	mm^2	=30mm*25mm
Pressure on Vibrafoam		0,771	N/mm^2	

230: Stop damper calculations

The calculation point towards Vibrafoam SD650. The properties of this type be sufficient. Its static load property is lower than the calculated and its dynamic load higher.

Testing Vibrafoam for suitable reaction force

231: Vibrafoam samples from AAU



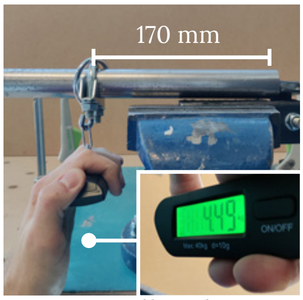
232: Close-up of vibrafoam support

9 different stiffnesses of Vibrafoam are tested. Bright green (SD65, on the left) has been used for the prototypes. During the redesign, the foam was moved closer to the rotation axis, so the new choice of foam should be stiffer.

The surface area of the Vibrafoam that is tested is 25x30 mm.

If the premise is that two pieces of Vibrafoam should withstand the 17 kg, a base value of the currently mounted torsion damper should be subtracted from each Vibrafoam value.

17 kg = 2 x (Torsion damper resistance + Vibrafoam resistance)



233: Test setup and base value

To determine the base value, the handle is pulled down to horizontal level (until there is a narrow gap between pipe and bracket). Here, the resistance force of the torsion damper is 4,5 kg.

Pulling the pipe to same position with the dark violet (SD950) underneath shows a value of 13,4 kg. This should be an appropriately progressive damping because (13,4 kg - 4,5 kg) x 2 = 17,8 kg.

More information regarding test setup and sources of error is available in appendix 20.

Since the test and the calculations show similar results, the test result (SD 950) is chosen. To validate this choice, the damper should be tested on the next prototype that is mounted on a VTR.

										Calculated	Tested		
Properties	SD 10	SD 16	SD 26	SD 40	SD 65	SD 110	SD 170	SD 260	SD 400	SD 650	SD 950	SD 1300	SD 1900
Colour	red	pink	orange	yellow	bright green	green	dark green	petrol	blue	dark blue	dark violet	violet	bordeaux red
Static loads [N/mm²] (1)	0.010	0.016	0.026	0.040	0.065	0.110	0.170	0.260	0.400	0.650	0.950	1.300	1.900
Dynamic loads [N/mm²] (1)	0.016	0.026	0.040	0.065	0.110	0.170	0.260	0.400	0.650	0.950	1.450	2.000	2.800
Load peaks [N/mm²] (1)	0.5	0.7	1.0	2.0	2.5	3.0	3.5	4.0	4.5	5.5	6.0	6.5	7.0
Mechanical loss factor (2)	0.25	0.24	0.22	0.15	0.18	0.12	0.13	0.11	0.10	0.10	0.10	0.09	0.09
Static E-modulus [N/mm²] (2)	0.048	0.111	0.129	0.316	0.453	0.861	0.931	1.64	2.72	4.57	8.16	12.0	20.4

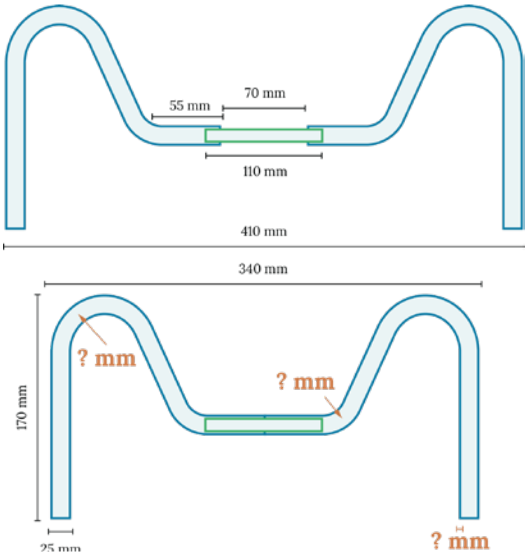
234: Screenshot of AAG Vibrafoam SD Physical properties and data

Handle

Handle specifications

Knowing the overall specification for the VTR handle makes it easier to identify a suitable geometry size.

The handle will have the following top dimensions:



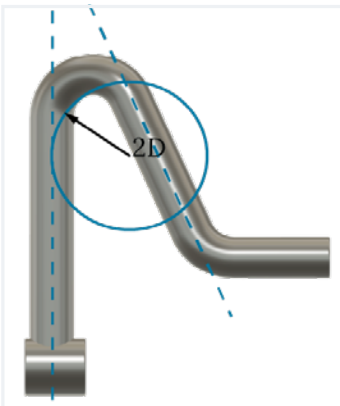
235: Defined and undefined parameters

If the handle is to be produced in steel, advantageous bending methods could be taken into consideration.

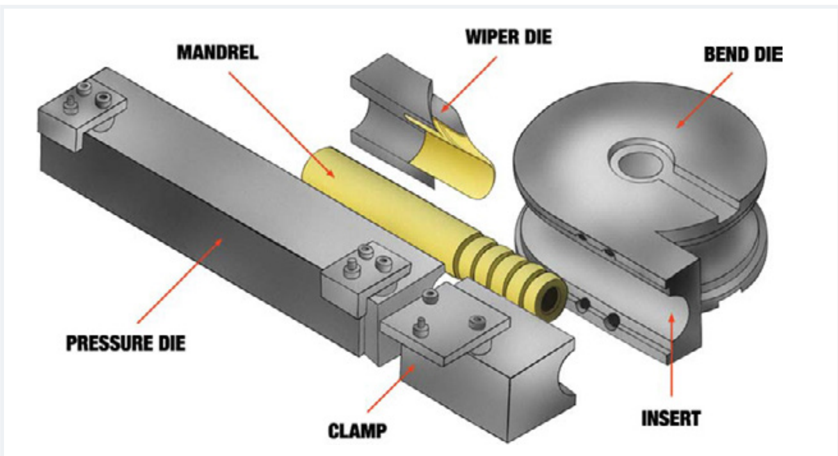
If the desired handle diameter is 25 mm, the standard tube thickness for bending a pipe of this diameter is 2 mm. This is sufficiently rigid according to appendix 19. Since bend radius typically are two times the outer Diameter (D), so the bend radius of this handle should be 50 mm. Trying out this bend radius on the current design in CAD, some certain issues appear:

The bend would simply become so big that the feature of multiple handle positioning would disappear. Other solutions will have to be made to accomplish this.

Using a mandrel bending principle it is possible to go as low as ½D, but it is a more costly manufacture method because it requires special tools.



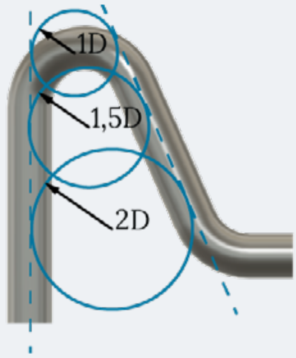
236: Double outer diameter bend radius



237: Mandrel bending tool

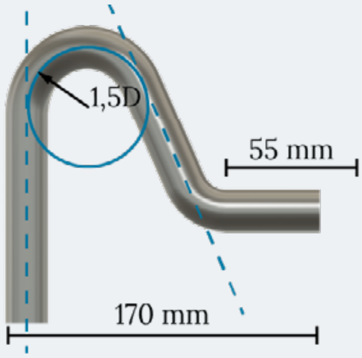
Even though mandrel bending is more expensive than regular draw pipe bending it is supposably still 50% cheaper than welding when dealing with stainless steel. Using a mandrel bending tool can help retain the handling features. By choosing standard mandrel bending tools it will help reducing cost further.

Here bends of 2 D, 1,5 D and 1 D are represented on the handle shape.



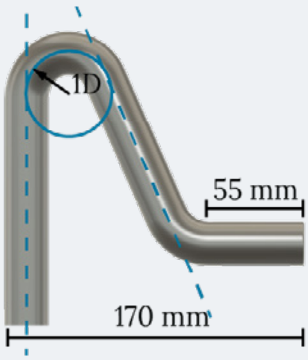
238: Comparison of bend radii

The larger bends means that the width adjustment is not sufficient with this handle shape



239: Implications on width adjustment

If both bends have a bend radius of 1 D, it will be sufficient width adjustment when the handle is altered slightly



240: Sufficient width adjustment

It seems that the design would benefit the most from bends with a 1 D (Bend radius=25,4 mm).

Defining wall thickness

Choosing a standard tube diameter has several advantages. Firstly, the pipe material is more readily available, secondly the prices are lower than a custom-made pipe material a lower to moderate quantities tube manipulator is more likely to already have the required tooling reducing startup cost to customise tools and it gives more contractors to choose from.

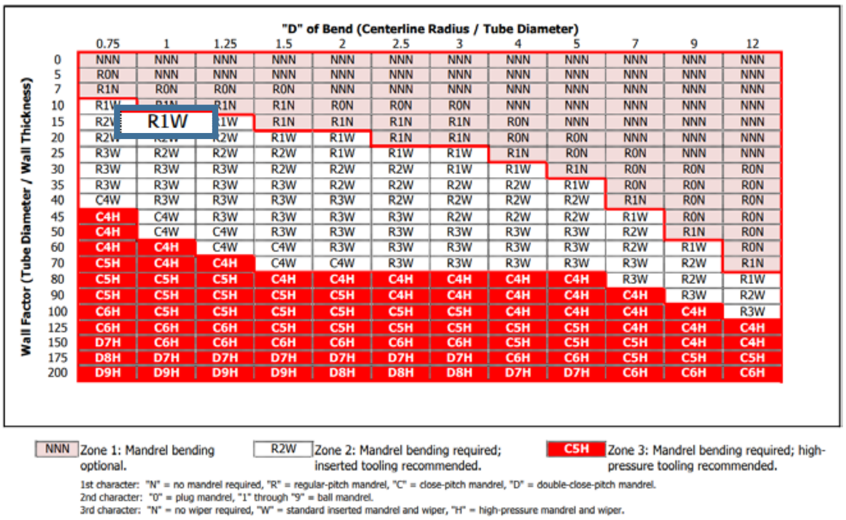
METRIC SIZES	
Outside Diameter (mm)	Wall (mm)
4	1
6	1
8	1
10	1
12	1.5
15	1.5
16	2
18	1.5
20	2
22	2
25	2
28	2

241: Wall thickness standards

From the chart a 25 mm tube is normally 2 mm in wall thickness.

Defining mandrel bending tools

A bend tooling mandrel and wiper selection chart is used to define if this is an allowable wall thickness for a 1" (25,4 mm) pipe at the bend radius of 1 D (25,4 mm) when conduction mandrel bending. The chart uses inches as a unit when calculating the wall factor and the bend radius factor which is 1 (1"/1"). The wall factor at a 2 mm wall thickness is (1"/0,0787") = 12,7.


BEND TOOLING MANDREL AND WIPER SELECTION CHART™

Wall Factor (Tube Diameter / Wall Thickness)	"D" of Bend (Centerline Radius / Tube Diameter) 0.75	1	1.25	1.5	2	2.5	3	4	5	7	9	12
0	NNN	NNN	NNN	NNN	NNN	NNN	NNN	NNN	NNN	NNN	NNN	NNN
5	R0N	NNN	NNN	NNN	NNN	NNN	NNN	NNN	NNN	NNN	NNN	NNN
7	R1N	R0N	R0N	R0N	NNN	NNN	NNN	NNN	NNN	NNN	NNN	NNN
10	R1W	R1N	R1N	R1N	R0N	R0N	R0N	NNN	NNN	NNN	NNN	NNN
15	R2W	R1W	R1W	R1N	R1N	R1N	R1N	R0N	NNN	NNN	NNN	NNN
20	R2W	R2W	R2W	R1W	R1W	R1N	R1N	R0N	R0N	NNN	NNN	NNN
25	R3W	R2W	R2W	R2W	R1W	R1W	R1W	R1N	R0N	R0N	NNN	NNN
30	R3W	R3W	R3W	R2W	R2W	R2W	R1W	R1W	R1N	R0N	R0N	R0N
35	R3W	R3W	R3W	R3W	R2W	R2W	R2W	R2W	R1W	R0N	R0N	R0N
40	C4W	R3W	R3W	R3W	R3W	R2W	R2W	R2W	R2W	R1N	R0N	R0N
45	C4H	C4W	R3W	R3W	R3W	R3W	R2W	R2W	R2W	R1W	R0N	R0N
50	C4H	C4W	C4W	R3W	R3W	R3W	R3W	R3W	R3W	R2W	R1N	R0N
60	C4H	C4H	C4W	C4W	R3W	R3W	R3W	R3W	R3W	R2W	R1W	R0N
70	C5H	C4H	C4H	C4W	C4W	R3W	R3W	R3W	R3W	R3W	R2W	R1N
80	C5H	C5H	C5H	C4H	C4H	C4H	C4H	C4H	C4H	R3W	R2W	R1W
90	C5H	C5H	C5H	C5H	C5H	C4H	C4H	C4H	C4H	C4H	R3W	R2W
100	C6H	C5H	C5H	C5H	C5H	C5H	C5H	C4H	C4H	C4H	C4H	R3W
125	C6H	C6H	C6H	C5H	C5H	C5H	C5H	C5H	C5H	C4H	C4H	C4H
150	D7H	C6H	C6H	C6H	C6H	C6H	C6H	C5H	C5H	C5H	C4H	C4H
175	D8H	D7H	D7H	D7H	D7H	D7H	D7H	C6H	C6H	C5H	C5H	C5H
200	D9H	D9H	D9H	D9H	D8H	D8H	D8H	D7H	D7H	C6H	C6H	C6H

NNN Zone 1: Mandrel bending optional.
R2W Zone 2: Mandrel bending required; inserted tooling recommended.
C5H Zone 3: Mandrel bending required; high-pressure tooling recommended.
1st character: "N" = no mandrel required, "R" = regular-pitch mandrel, "C" = close-pitch mandrel, "D" = double-close-pitch mandrel.
2nd character: "0" = plug mandrel, "1" through "9" = ball mandrel.
3rd character: "N" = no wiper required, "W" = standard inserted mandrel and wiper, "H" = high-pressure mandrel and wiper.

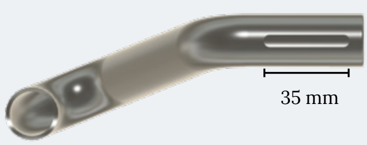
242: Bend tooling mandrel selection chart

According to the chart a regular pitch through inserted mandrel and a wiper is the bending tool required at this thickness. Using standard dimensions these tools should be available.

Handle width adjustment

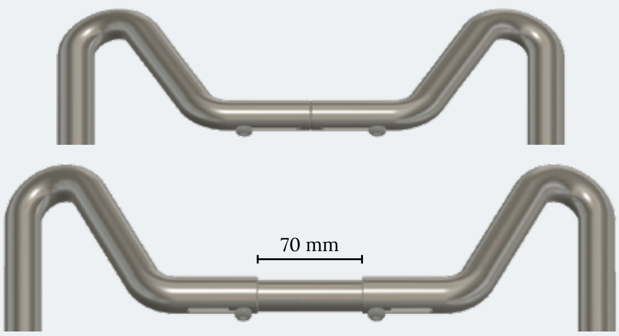
It is known that the handle must adjust 70 mm. The handles co-linear length provides 35 mm adjustment on both parts of the handle as used in the latest functioning model. However, fastening the rod against rotation was unsuccessful so a new principle is introduced where the bolt is screwed into a threaded rod sliding inside the handle tubes.

A slot in each handle piece of 35 millimetre with suitable rounded ends will allow the variance of 70 mm.



243: Slot shape and size

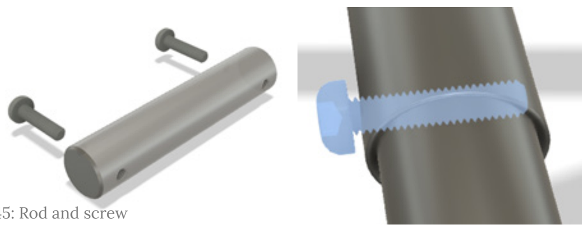
The two are joined by a rod and held in place by two round headed screws. This makes unwanted rotation impossible without material deformation.



244: Width adjustability

The rod is solid and has a long thread going all the way through in each end.

The screws are extra-long and allows material deformation of the pipe handle where the end of the screw is pressed into the tube inner wall. This will effectively lock the width adjustment unless the pipe is deformed further or the screw is released.



245: Rod and screw

Interface module

The interface module is part of Vibrashifter core; thus, it is the part that will be produced in the highest numbers. However, it is a component that has a lot of features:

- Attachment to machine
- Vibrafoam attachment
- Rotation damper attachment
- Endstops for handle rotation
- Be a carry over to other machine types

The principle of attachment to the machine has already been defined to be a 32 mm U-bolt exhaust clamp.


246: Tested U-clamp

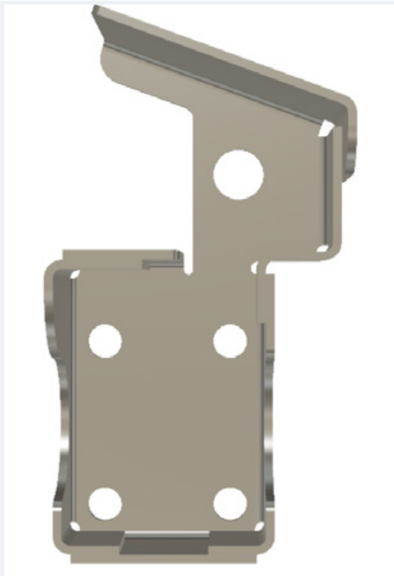
This was the principle that proved best at resisting rotation. The clap itself is made in a 2 mm bended sheet metal. This has several advantages that the interface module can benefit from.

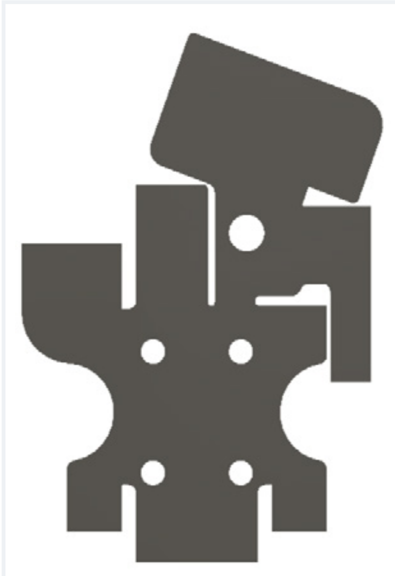
Bend sheet metal, low startup - fixed cost

Sheet metal is chosen as a cheap alternative for a low to medium volume production versus casting. Punching or laser cutting will be the most obvious choice for a production volume in the 100s to 10.000 units. The sheet metal chosen is a 2 mm thickness just as the exhaust clamp. This allows for sharper bends and more form freedom than a thicker sheet would.

A metal sheet can be laser cut, punched or a combo of the two. Then it must be bent in an according order.

To add strength and rigidity a lot of overlapping flanges has been made, here spot welds can join the overlapping material and increase the strength and minimise deformation.


247: Interface module


248: Interface module unfolded

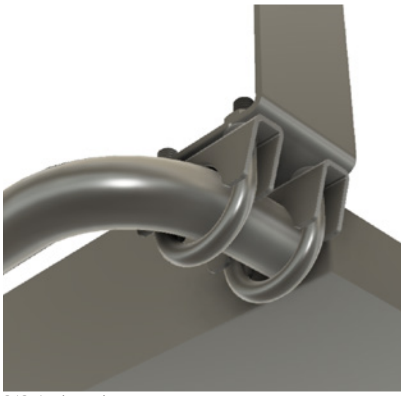
Merging features - Diameter adjustment

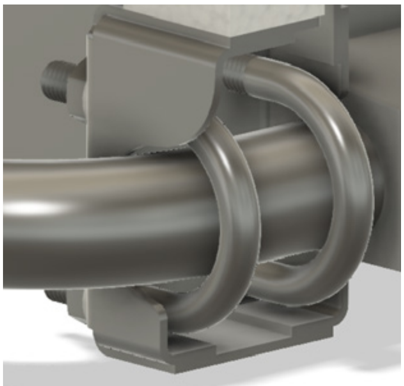
Adding two exhaust clamps makes it

- Difficult to install do to five loose parts when mounting
- Looks less complete as a product

Combining the clamp feature is easy to implement with sheet metal and makes it

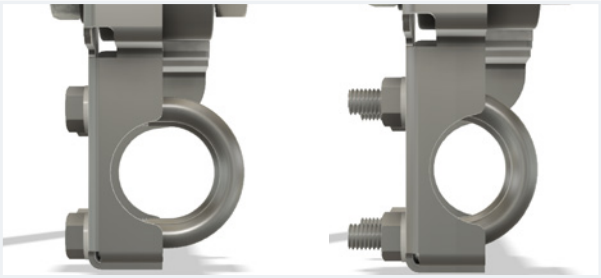
- Easier to install
- Cheaper due to less fixed cost of outsourced components
- Looks more complete as a product


249: 1st iteration


250: 2nd iteration

The u bolt used for diameter adjustment is very strong and needs a strong structure to squeeze against that is also why overlapping material has been placed near the holes.

The diameter adjustment can vary from 32 mm and below.



251: U-clamp adjustability

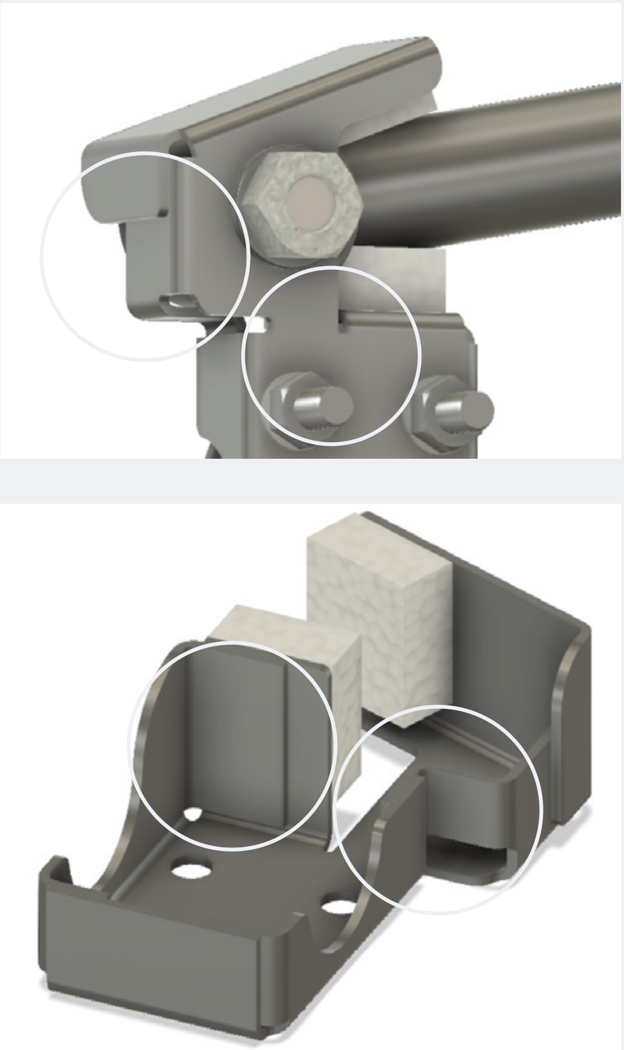
Potential weak point

Doing the sheet metal design phase some potential issues were discovered.

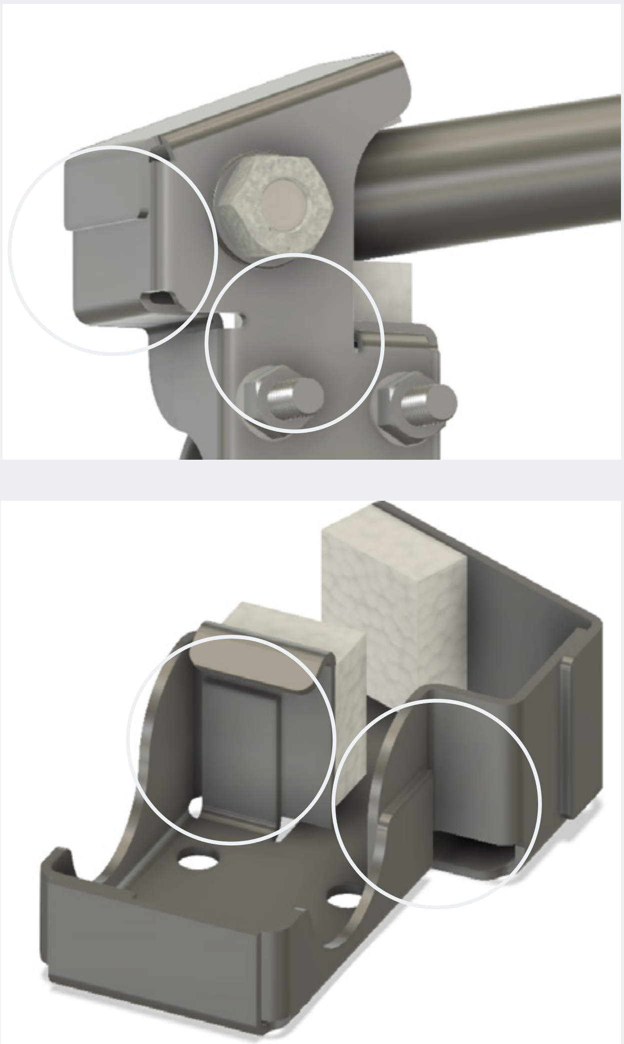
A potential weak point is spotted. With high stresses occurring when the handle is pressed against the end stops this puts extra load on this narrow part of the interface module.

It can be reinforced if it was a moulded or cast part, or the geometry can be reorganised like here.

Beneath it is reinforced as well, with an extra flange for the bottom Vibrafoam plate and a taller flange surrounding the rotation damper.



252: 1st iteration



253: 2nd iteration

5.5 BUSINESS MODELS

This section contains an example of considerations and comparisons between productions and their risk implications. The custom-made interface module is exemplary because the plan is to include it every product of the Vibrashifter system.

Risk assessment

The current suggested production method is reliant on the fact that it will be a low to medium volume production sub 10.000 units with a low-risk investment but relatively high fixed cost. But what if the market potential is bigger, when do other alternative production methods become a better business. Therefore, comparing the current production method with a higher volume alternative based on a reasonable business proposition can help decide what size of total addressable market is most beneficial for each production method. The deciding factor is the one that generates the most profit, there are a few things this business proposition will need to incorporate such as cost, profit and volume which is heavily reliant on the total addressable market.

Total Addressable Market (TAM) in Denmark

During the selection of machines to scale to, the TAM was taken into consideration. However, as mentioned, it was not the only driving factor. The product architecture proposal that has been designed indicate the TAM. It fits the following machines, and the current count of each machine type has been estimated through desk research:

Vibratory Tamping Rammers:

35.000

Vibratory Plate Compactors:

35.000

Floor Grinding Machines:

5.000

Floor Scarifying Machines:

5.000

Floor Strippers:

200

Cultivators:

5000

If Vibrashifter fits 80%, the TAM is about **70.000**.

Disclaimer

These are rough estimates based on statistics of company count and conservative guesses on number of machines for each company. It was estimated that each machine-related company has one machine, because some companies rent while others own several machines. The sources of the number are available in appendix 21.

! TAM in Denmark is roughly 70.000 potential machines

There are some big uncertainties in these estimates, but the conservative approach may have tipped these in favour of realism. To believe that there are collectively 85.200 of these six machines in Denmark seems reasonable. For a more accurate estimates, a retailer or importer could be contacted to get some firsthand insights to how many machines their customers have of each type.

Retailers' perspective

A salesman at Stemas, a Danish construction machinery retailer, was contacted to get his perspective on the Vibrashifter. According to him Denmark is one of the biggest markets here in Europe because of the work safety awareness and the extensive use of the VTR in relation to other northern countries - relying on TAM in Denmark would be relatively accurate as a starting point, Holland was also a suggestion because they have similar work safety awareness. He believed that Stemas would be able to sell a few hundred of these a year, but they would be likely to purchase 50-100 units initially, to explore the market. Furthermore, a retailer discount between 38-45% would be quite normal on this kind of product. Notes from phone call are in appendix 22

! 50-100 units' pre-production to explore the market

! Retailers expect 38-45% discount

Cost, volume and revenue

The unit volume demanded by the TAM volume influences what production methods is most beneficial.

By design the main part of Vibrashifter that will be mass-produced is the interface module. This part will be carried over to all the variants of the product. Other parts may change more, that is why they are designed to involve a simpler manufacturing process with higher variable cost. The cost of these other parts is estimated in appendix 24.

The interface module introduces some fixed cost because it involves some higher volume manufacturing methods.

Sheet metal punching and bending

Sheet metal manufacturing may involve a minimum unit volume because there can be many units on one standard sheet metal and manufactures often require a certain number of sheets to be processed to avoid startup expenses.

Shell moulding vs sheet metal production of interface module

Shell mould casting

A Danish casting company Dansk Skalform was contacted, and they suggested shell mould casting as an alternative to sheet metal. According to them this production method requires a 4-5 mm material thickness and R3 roundings to accomplish this. So understandably the design will have to be adjusted to this. The material suggested was ductile iron, EN-GJS-500-7, and a surface treatment of either zinc plating or powder coating. Of which the approximate price would be 2 DKK/pcs and 15-25 DKK/pcs respectively.

Interface production shell moulding

Shell moulds	2,0	units
Shell mould cost	32000,0	
Material and molding	35,0	
Zink plateing	2,0	
Powder coating	20,0	
Minimum units	600	
Fixed cost	**98200,0**	
Variable cost	**57,0**	

254: Cost estimation

The tool mould price is 32.000 DKK and produces 6 units at a time, the mould lasts up to 10.000 cycles with a positive mould like this without a core. The unit price at a minimum order of 300 is 35 DKK. Using a mould also means that two moulds are necessary since one is mirrored. And 300 units of each makes the fix cost roughly 98200 DKK.

It is chosen to be zinc plated and powder coated finished to justify it not being as weather resilient as stainless steel.

Sheet metal production

A price calculation sheet from the Danish sheet metal production company CAMRO is used to estimate a price based on the size, material, thickness, count of bends and welding. 2 mm stainless sheet metal is chosen.

Interface production sheet metal

Matr.vægt i kg	72,0	
Matr.kg.pris	20,0	
Matr. Pris	1440,0	
Plade spild	30%	
Pris Hel plade	1872,0	
Antal emner	50,0	
Stk.pris	37,4	
Stans tid min.	45,0	
Stans pris	10,0	
Stk.pris	9,0	
Buk Pris	2,5	
Antal buk	13,0	
Total Buk pris	32,5	
Svejs	20,0	
Opstart	2,0	
Slibning	4,0	
Tømning af palet	1,0	
Sundry	5,0	
Fixed cost	**55470,0**	Min 10 sheets
Variable cost	**110,9**	

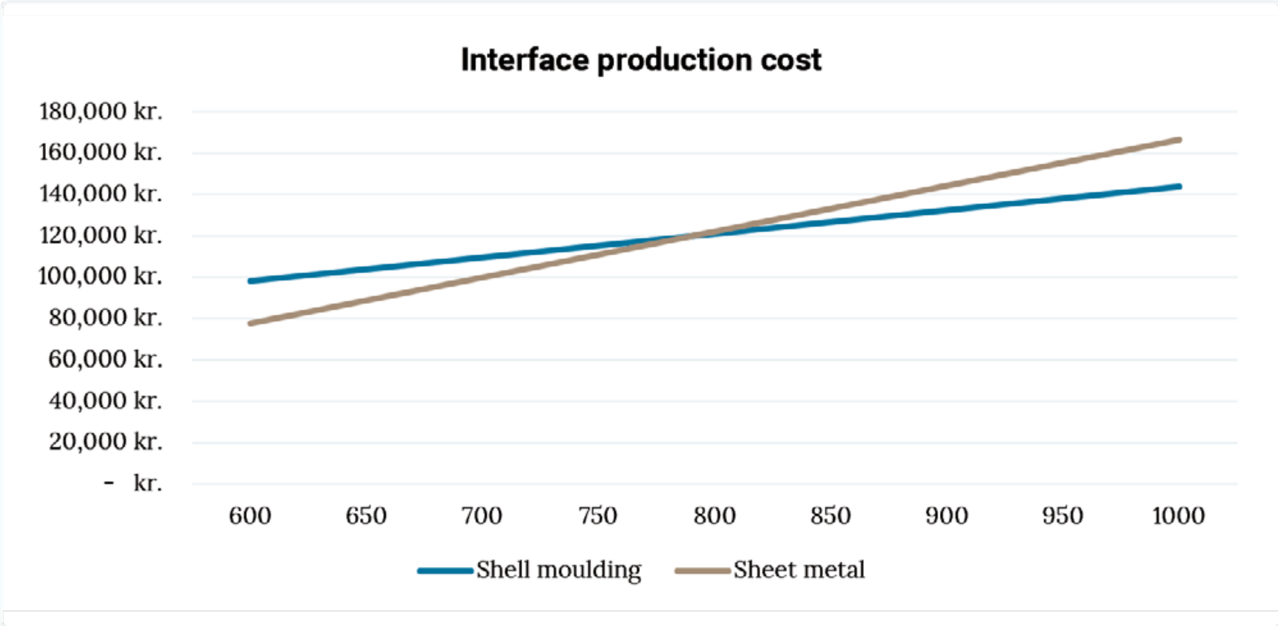
255: Cost estimation

If a minimum production requires 10 sheets the volume is 500 units and the fixed cost is roughly 55.000 dkk. and a single interface module is 110 dkk. After this the fixed cost is 220 dkk. For the interface modules. Since the interfaces are mirrored, they can be cutted equally but bent in the other direction for the mirrored one without costing more in sheet metal cutting startup.

5.5

When is either one the better option?

The start-up cost of the moulding process is the most expensive. And is roughly twice the expense of the sheet metal process. However, at volumes near 800 units it is clear that the moulding becomes more profitable by having a lower variable cost. And the shell moulds last up to 30.000 cycles so reinvestment is low.

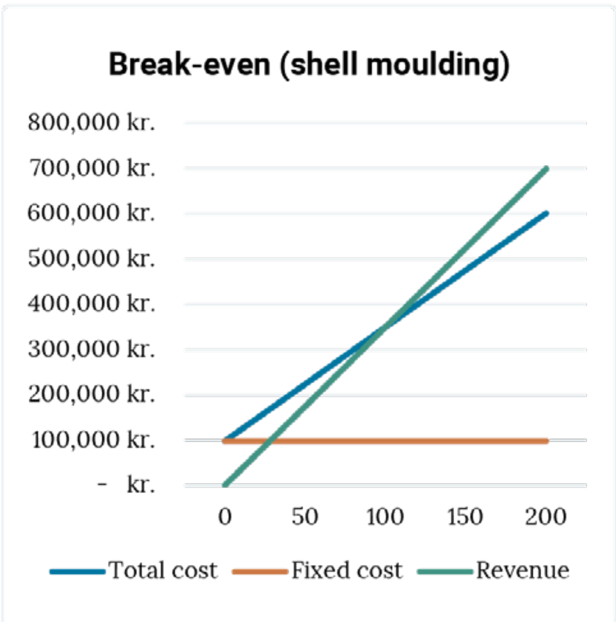


256: Interface module production method comparison

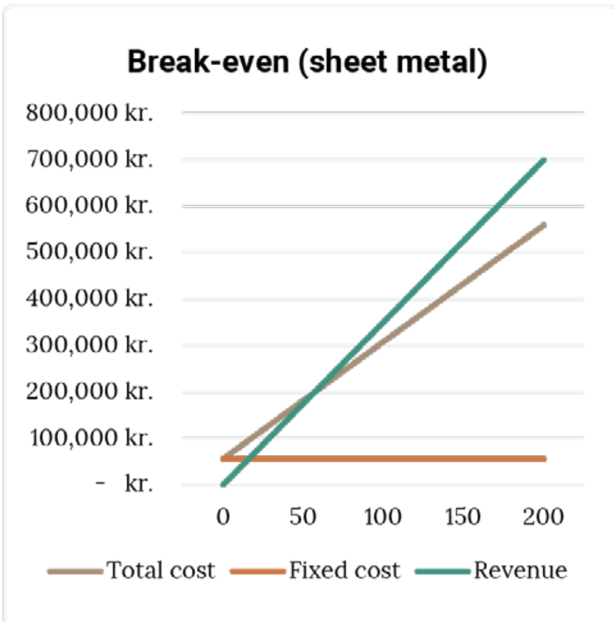
Risk assessment

To minimise loss of investment a pre-production run is a low-risk way to test out the market and Vibrashifter for any defects.

- Is only more profitable above 600 units
- Low reinvestment
- If the design wasn't mirrored and reducing the startup cost could be possible
- It could be lucrative to choose a sheet metal production simply because it can reach breakeven at 60 units, which is half the sales of a shell moulded interface.
- The fixed cost is also half that of a shell moulding production
- Design changes has a lower cost



257: Break-even at about 100 units



258: Break-even at about 60 units

Parameter comparison

Characteristic	Sheet	Mould
Visible deformation to inform user under installation before rupture	+	-
Rounded/not sharp finish	-	+
Can easily be made in stainless steel	+	-
Lightest construction with similar strength	+	-
Cheapest to make design changes	+	-
Allows a large degree of form freedom	-	+
More 'complete' look, like having better finish on corners	-	+
Beneficial with medium or high-volume production	-	+
Coloured surface treatment included	-	+

Durability vs. Safety

While focusing on optimising construction and durability, it is important to keep the trade-offs in mind. For instance, the current design might not be safe to use, because the operator risks getting a finger caught between the handle and the interface module.

This problem has been identified and neglected multiple times but never unfolded. The latest discussion dealt with whether rubber should be wrapped around the handle. The arguments presented were:

Handle	Critique	Reason
Rubber wrap	It will be worn down by sand and transport*	The comfort makes operator prefer it*
Steel-only	Fingers with get caught*	Durability*

*Requires long-term testing to validate

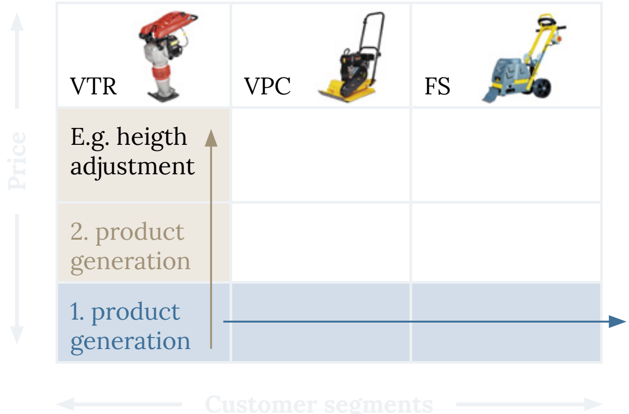
No testing has been done on the steel-only handle. Each prototype has included some sort of rubber surface on the handle. Nonetheless, due to its low cost and the fact that current VTR handles are made of steel, the steel-only handle has been implemented in the first generation of Vibrashifter.

Vertical leveraging

In entire phase 5, the focus has been horizontal leveraging (Meyer 1997). In other words, how can product variants be created with maximum carry-over components. Vertical leveraging is also relevant, since some nice to have features have been identified.

- Height/length adjustment to fit tall people and give more operation option
- Soft, isolating handle wrap
- Heated handles to avoid white finger attacks

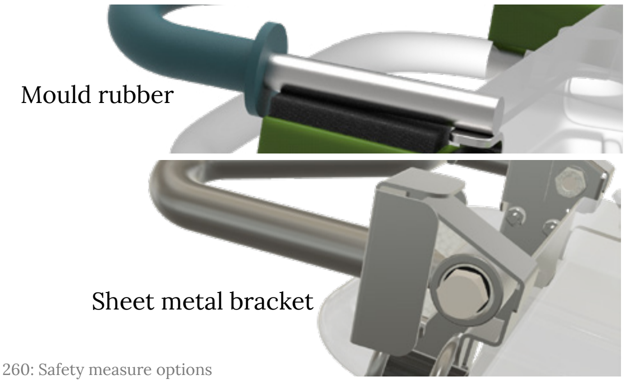
If the implementation of these feature cost less than the perceived value that they add, they should be considered, in case of further development.



259: Horizontal and vertical leveraging

Avoid catching fingers

This leaves safety issue related to the fingers unresolved. What can minimise the risk? Since the handle and the operator's hand move in relation to the interface module, redesign of seems unreasonable. The rubber handle wrap from milestone (section 4.9), could be moulded, if Vibrashifter becomes successful in the market. Until then, welding a bended plate is preferable low-risk solution.



260: Safety measure options

5.5

If the first generation of Vibrashifter is successful in the market, moulding the interface module and rubber handle is relevant for the next generation.

5.6 DESIGN BRIEF

Vision

Safe and effective work environment

Problem statement

How can a progressive damping add-on reduce the risk of developing Hand-Arm Vibration Syndrome (HAVS) during the use of hand operated machines?

Stakeholders

Consumer

Site manager
Buyer
Director

Operator
(End user)

Retailer

DWEA
BAM-Bus
BFA

OHD

Dilemmas

Compete on price ⟷ Follow DWEA regulations

Apply pressure to feel in control ⟷ Let the tool work by itself to avoid vibration

Rigid enough to control ⟷ Adjustable to mount on different machines

Requirements and wishes

The intend with this last design brief of the report is to supply you (the reader) with an overview of the driving Requirements (**R**) and Wishes (**W**) of Vibrashifter. Appendix 23 showcases the reasoning behind the choice of these parameters. It contains a comprehensive backtrack of each parameter as well an overview of what components they influence.

Quality	**R**	**W**	**Parameter**	**Section #**	**Metric**
Rigidity (control)	x		Withstand an operator pushing down	4.2	17 kg
	x		Withstand lifting	4.7	80 kg
Interaction (control)		x	Afford pushing forward	3.5	Binary
		x	Afford pushing down	3.5	Binary
		x	Afford turning	3.5	Binary
		x	Space for hands	5.3	Undefined
Damping	x		Fit different vibration magnitudes	5.2	5-13 m/s^2
	x		Fit different vibration frequencies	5.2	11-95 Hz
	x		Alternate quickly between the modes: 1) High control 2) High damping	4.3	Undefined
Mountable	x		Fit different handle diameters	5.2	22-32 mm
	x		Fit different handle widths	5.2	260-500 mm
		x	Without special tools or skills	5.3	Binary
	x		Without increasing the width of VTR	5.3	Binary
		x	Without increasing the length of the VTR	5.3	Binary
Durable	x		Withstand chemicals	4.2	Binary
	x		Non-absorbent surface	4.2	Binary
	x		Withstand sun, water, freezing	3.5	Binary
Vertical leveraging					
Comfort		x	Soft handles	4.4	Undefined
		x	Height adjustment	4.4	Undefined

6 EPILOGUE

The vision of creating a product that contributes to a safe and effective work environment has sustained throughout the thesis. The problem statement has been revised about four times, mostly to encapsulate the machine/tool scope and solution space. In other words, the problem has not been the main barrier of this project. Creating the solution, on the other hand, is and was complex, so it still has multiple loose ends. The conclusion is an evaluation of the key aspects of our proposal. The reflection discusses the details of our decisions as well as our overall approach to problem-solving.

6.1 CONCLUSION

Reduce vibration and maintain control

Stakeholders repeatedly confirmed the importance of efficiency. Compromising control (when it is needed) would decrease efficiency, and that was simply not an option. Nonetheless, we had to acknowledge that damping and control are inversely proportional to some extent after several attempts to defy the laws of physics. When the insight of the connection between control needs and ground compaction emerged, the goal became to design progressive damping with mode shift.

A single prototype with two different handles was designed to reach this goal. When the operator hooked on one of these handles, the VTR-focused design process basically ended. In phase 5, proposals for each component were introduced, but none of them has been verified. The following essential elements of the current concept have yet to be tested:

- The angles, thickness and length of handle. What shape will allow most control? What if it is only the operator from end user visit 5 that prefers this shape? Additional shapes should be tested systematically in different scenarios on at least three users with different physiques and heights.
- The most recent prototype was not rigid enough for VTR operation. Solutions for this problem have been implemented in Vibrashifter: Although the width adjustment with slots should prevent twisting, and the grip force of the implemented pipe clamps has been tested in a lab setting, it has not yet been tested whether they will remain rigid on the VTR long-term.
- No vibration measurement has been conducted since section 3.5. This means that the effect of the implemented damping components has not been verified. The entire structure of Vibrashifter revolves around these components. When the BAM-Bus consultant returns to work in June, we will be ready to test the next prototype and verify these damping assumptions.

Body vibrations

At end user visit #3 (section 3.5), we observed that the VTR operator utilises the hip to push the machine forward. This coping strategy was also present at end user visit 5 (section 4.4). Despite discarding the Harness concept in section 3.1 due to the low exposure action value of body vibrations, Vibrashifter affords this coping strategy to maintain the operator's current level of control.

The critical question is whether the operators' bodies are exposed for long enough to exceed the expose action value. Determining this will require observation of operators for consecutive days and recording of the exposure time and vibration magnitude. The difficult part of this is the vibration magnitude. The measurements will vary depending on at least ground compaction and operator's physique, clothing, and grip strength.

Whether this problem is the responsibility of Vibrashifter can be discussed. A product will never be able to solve every problem, at least not to the same extent as if a few problems are the focus. Vibrashifter is a piece of HAV damping equipment.

However, it was decided that the issue lay outside the problem scope as it has always revolved around reducing HAV exposure. With the mindset that it is always the most efficient to solve one problem well rather than every problem to a minor extent.

Scalable product architecture

The low estimation of the total addressable VTR market convinced us that it was necessary to make the product architecture scalable to other machines. Rather than risking wasting a lot of time refining the design for the VTR alone, we could expand the scope and include product scalability prior to entering the detailing phase. At this point we were not aware of the fundamental loose ends we were going to leave behind.

The goal became to develop a system that fits the control, vibration and dimensions of six machines. The goal seemed obtainable because Vibrashifter already fit the VTR, the machine that requires the most control and damping. However, it was ambitious to think that we could complete a product architecture design for 6 machine types within a week.

However, some fundamental elements of the product architecture design were clarified:

- Identification of machine variables such as handle diameter, width and orientation and vibration type became clear. The following aspects were explored:
  - Creation of possible carryover components for multiple machine types and brands.
  - Specified the potential interchangeable components.
  - Identification of which parts should be customisable to potentially suite the different machines.

Through the aspects above it has made probable that the concept of Vibrashifter can become a system that fits multiple machines.

Of course, these elements rely on several assumptions: Firstly, the measurements done at Erenfred Pedersen A/S (section 3.1) represents most of the machine geometry variation. Secondly, the damping effect remains despite the vibration variation because of the interchangeable dampening components. Thirdly, the differentiating control needed across machine types can be obtained using different handle shapes. The list could go on, but looking forward, the next actions will revolve around proving that Vibrashifter does reduce HAV transmission to the operators and maintains control of the various machines.

6.2 REFLECTION

Product

The calculation foundation

Every dimension and component of the current proposal is based on the 17 kg measurement conducted at end user visit #4 (section 4.2). This was a deliberate choice despite the knowledge of the force generated by the machine vibration. This force is simply too complex to consider. However, the force of machine weight was included in the handle calculation regarding its deflection.

Remove torsion damper

The current reason for the implementation of torsion damper is its ability to dampen vibrations along axes besides than the vertical one (radial and axial loads in respect to torsion damper). Suspecting that it is too stiff to dampen the displacements of the VTR, we have considered whether it is necessary in Vibrashifter. The Vibrafoam might be sufficiently close to the handle pipe to dampen vibrations constantly. Of course, this cannot be determined without a test.

Heat transmission

Vibrashifter's handle is made of stainless steel. When compared to painted steel, this has a high heat transmission. The operator's skin may freeze to the steel in very low temperatures, which can be dangerous/injuring to the skin. It can also more easily triggers attacks of Raynaud's phenomenon. Besides, the hard surface of the handle may also increase pressure on the carpal tunnel.

Process

Early choices with major influences

We did not investigate the demolition sector even though we have insights that point towards this being the most exposed target group. We have written that the scope should be the worst use case in Section 2.2 and 2.3 and intro to phase 2. How would the outcome have been and is the current direction the most crucial and convenient one?

Analysing over execution

Maybe we were analysing and observing the problem for too long instead of being biased for action and test our problem with prototypes that could have helped us understand and discover more of the problem and the solution earlier. Like we did at the visit at Jens Thyrrestrup. And then analyse our findings with the things we are testing. This could have been a way to crack the problem earlier on.

(Why) is the antivibration accessory market a blue ocean?

In the first week of the project, we assumed that a blue ocean market in the antivibration product category had been discovered. In 1.7 Reflection this was mentioned as a worry (As of now, it seems like the market is blue. It is still uncertain why this is the case. It is likely that a major challenge will emerge in the upcoming phases).

Besides the gloves, there were no retrofit accessories for hand operated machines nor hand-held tools. After confirming that vibration exposure cause health problems and that the gloves do not dampen low frequencies, we were convinced that the problem and market composed a solid project foundation.

The initial Leap Of Faith Assumption (LOFA) (Ries 2011) was:

We can solve the dilemma between control and damping with a physical product

This LOFA entailed the pursuit of a Minimal Viable Product (MVP) that could reveal quantifiable knowledge with “quick” build-measure-learn loops (Ries 2011). As ill. 261 shows, we thought this should be solved before anything else. During this pursuit, we also searched for a suitable end user that used a machine with a vibration of low frequency and high magnitude. We rendered the end user suitable if they used the machine to an extend that exceeded the recommendations. With the vision in mind, we were searching for the right strategy, while spending hours and days on product optimisation (Ries 2011).

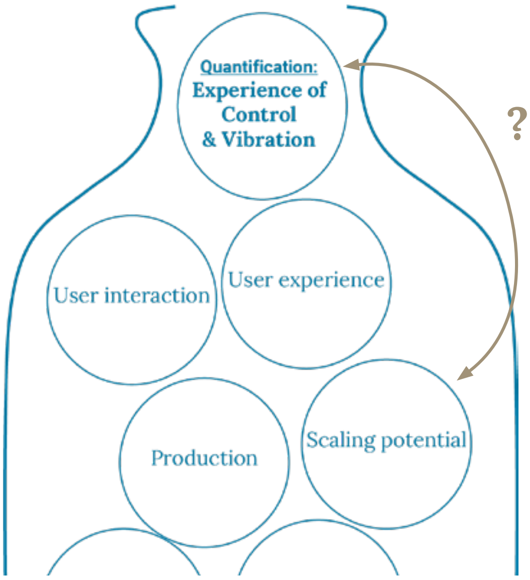
Now, in retrospect, one could argue that strategy was too narrow, or that we should have pivoted (ill. 262) because this LOFA had not been validated:

The market demands another antivibration accessory

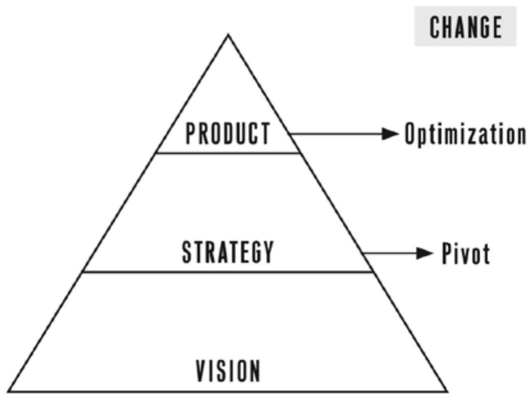
We have been risking designing something that nobody wants, because we are still not certain if there is a market for Vibrashifter. Though, the director of Aabybro Entreprenør has expressed his desire to purchase vibrashifter to all his machines if his workers are satisfied, he has not paid anything yet. In addition, we do not know whether any other customers are interested in Vibrashifter, though Kristen from Stemas has vouched for its potential and imagined that he could test the market with 50-100 units.

Here, the intriguing question is: Could the market have been tested prior to months of product optimisation? The answer to this should be an explanation of how to test. Would we be able to convince customers of the solution to the control-damping dilemma? Perhaps, we could have tested the market by announcing a product launch and start to accept preorders.

It is likely that we would never have come up with the same concept as VibrationShifter without the time-consuming product optimisation. One could also question if it is ever certain that a product is what the customers want until they buy it.



261: Should the scaling potential have been explored first?



262: Startups have a vision, strategy and a product (Ries, 2011)

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ILLUSTRATIONS

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