CONCEPT DESIGN OF TELESCOPIC COLUMN AND BOOM

Lappeenranta–Lahti University of Technology LUT

Master's Programme in Mechanical Engineering, Master's thesis

2025

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Examiners: Adjunct Professor Antti Ahola

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ABSTRACT

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Concept design of telescopic column and boom

Master's thesis

2025

57 pages, 35 figures

Examiners: Adjunct Professor Antti Ahola and D.S.c. (Tech.) Kalle Lipiäinen

Keywords: concept design, product development, welding tower, telescopic boom

This thesis deals with the conceptual design of a telescopic welding tower. While modern day manufacturing industry is growing and developing, manufacturing machines must develop alongside to enable more efficient working. The aim was to develop a machine that has an excellent horizontal reach to workpiece and while the boom is packed it would require less machine footprint than conventional fixed boom. This thesis is focusing on column and boom structural design as well as cable and welding consumables handling.

Based on the technical specification agreed on beginning there is calculated optimal cross sections for the booms. For the optimal boom there is done FE-study, which confirms the calculations. Based on calculation there is done two different options for boom with different style of movement. One with linear guideways and one with sliding rollers. For the column and handling cables is shown options that are based on existing structures. Calculations are based on using steel but also using lighter material is studied.

Options and designs for structures that are shown in this thesis are evaluated in the end and also needs for follow-up actions and final design are gone through. Based on the figures in the end there are achieved space saving and reach.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUTin energiajärjestelmien tiedekunta

Konetekniikka

Elmeri Kouri

Teleskooppisen hitsaustornin konseptisuunnittelu

Konetekniikan diplomityö

2025

57 sivua, 35 kuvaa

Tarkastajat: Dosentti Antti Ahola ja TkT Kalle Lipiäinen

Avainsanat: konseptisuunnittelu, tuotekehitys, hitsaustorni, teleskooppipuomi

Tämä tutkielma käsittelee teleskooppisen hitsaustornin konseptisuunnittelua. Nykyajan valmistava teollisuus kehittyy ja valmistuslaitteiden pitää kehittyä mukana, jotta valmistus olisi mahdollisimman tehokasta. Tässä työssä konseptoidaan tähän tarkoitukseen tehokasta hitsauslaitetta. Tavoitteena oli saavuttaa laite, jolla on erinomainen ulottuvuus työkappaleelle vaakasuunnassa sekä puomi sisään ajettuna se veisi vähemmän tilaa kuin perinteinen kiinteäpuominen hitsaustorni. Työssä keskitytään vaakapuomiin, pystypuomiin sekä kaapeleiden ja hitsauslisäaineiden hallintaan.

Lähtötietojen pohjalta lasketaan optimaaliset koot eri vaiheiden puomien poikkileikkauksille. Optimaalisesta puomista tehdään myös FE-tutkimus, joka vahvistaa laskujen oikeellisuuden. Laskennan perusteella tehdään kaksi eri variaatiota puomeista johteilla ja liukurullilla toimivana. Pystypuomin ja kaapelien hallintaan esitetään vaihtoehdot, jotka pohjautuvat olemassa oleviin toteutuksiin. Laskennat pohjautuvat teräksen käyttöön vaakapuomissa, mutta myös kevyemmän materiaalin käyttöä on tarkasteltu.

Työssä esitetyt vaihtoehdot ja suunnitelmat rakenteille ovat lopuksi arvioitu sekä tarpeet jatkotoimenpiteisiin ja lopullisen tuotteen suunnittelemiseen ovat käyty läpi. Lopussa esitettyjen kuvien perusteella tilasäästöä ja ulottuvuutta on saavutettu.

SYMBOLS AND ABBREVIATIONS

Roman characters

B	width of beam	mm
f	deflection	mm
f_{SL}	static support stability	[-]
H	height of beam	mm
I	second moment of area	mm^4
M	moment	Nm
P	load	N
t	thickness	mm

Abbreviations

C&B	Column&Boom
CAD	Computer Aided Design
FE	Finite Element
HS	High Strength
SAW	Submerged Arc Welding

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1 Introduction

Modern day steel fabrication industry needs advanced solutions from equipment manufacturers. In the same proportion as the workpieces increases in size also the equipment must grow to meet demand. Especially the wind turbine industry is growing, and bigger wind turbines are designed which need larger tower and foundations. Equipment to manufacture these structures need to be developed and designed. Need created by demand to design new solutions have influenced the topic choice of this thesis which is concept design of telescopic welding tower

This thesis is made for Finnish welding automation company Pemamek oy which is developing and manufacturing machines and production lines for industry. One of the main product categories is welding and material handling equipment for on- and offshore wind turbine frame production. The aim of this thesis is to concept design a welding tower especially for offshore wind tower foundations, monopiles. Monopiles are large cylindrical foundations that are placed to the bottom of the sea. Monopiles can be over 11 meters in diameter and over 100 meters long. Material thicknesses can be over 100 millimetres. In the figure 1 is presented monopile foundation with diameter of 9,6 meter. There could be seen the welding seams that are done with the welding tower. Monopiles are welded from individual cylindrical pieces and welding these parts generates a demand for new innovations.

Figure 1. Monopile foundation with visible welding seams (Electrek 2023).

1.1 Objectives for thesis

As the monopiles are growing the individual pieces are also bigger. This requires more reach from welding tower which means that the boom (figure 2) needs to be longer. With conventional fixed boom that would enlarge the whole structure due to a heavier boom. Another matter is the space that the welding tower is requiring. With fixed boom the rear-end zone needs to be as long as the boom is. Figure 3 presents the length that the boom is requiring. With telescopic boom these features could be decreased. The biggest advantages with a telescopic boom could be achieved from the space saving when the boom is back while the reach of the boom is same or even higher than before. This leads to the research problem, which is what kind of options are available for implementing the telescopic welding tower. There can be many implementation methods and the most suitable for the intended use need to be selected.

The goal is to achieve a concept model of a telescopic welding tower that could be used in the future with less designing and development. The concept model concentrates mainly on the telescopic boom, column, cable and welding consumables handling. As a result, there should be preliminary models which would help the future design process and reduce the time used for design. Also, the results should be applicable for cost estimation of the welding tower and based on this, make a quotation. Accurate cost estimation increases competitiveness which is needed in highly competitive business sectors.

1.2 Implementation

Most of the work on this thesis is done with CAD-design software as there is need for a 3d-model of the welding tower. Also, structural calculations have an important role as preliminary calculations were done for the booms, column and other critical components. Boom sections are analytically optimized. An fe-study will also be conducted for the booms to get a comparison and verifying the calculations.

Telescopic booms have been manufactured and used for decades, and proven mechanisms are utilized. Inspiration and new perspectives are researched from similar applications and those are assessed for usable solutions to utilize in this case.

1.3 Content of the thesis

This thesis will introduce the background of welding towers, telescopic booms in general and the meaning and process of conceptual design. After the background phase, there is shown the design part which consist of how the outcome is achieved and all the models that were designed. Different options for boom mechanism and material selection are evaluated to get most suitable structure for this case. For the cable and welding consumables handling, several options have been considered. Everything that has been done is evaluated for use and different options are compared. For final design, structures are analysed and assessed what needs to be done to carry out the final design process.

1.4 Column and boom welding towers

Column and boom (C&B) type welding towers are highly common in metal fabrication industries such as heavy machinery, pipeline construction and wind turbine frames where the work pieces are cylindrical. Typically, the welding method that is used for column and boom is submerged arc welding (SAW) but also welding towers can be equipped with MIG/MAG and TIG welding equipment. Common welding positions are longitudinal and circumferential welding inside and outside of cylindrical workpiece. Typical configuration of C&B can be seen in figure 2 where both horizontal and vertical movements are seven meters. Boom is equipped with SAW-welding equipment in front and welding wire reels in the back. Welding power sources are located on the platform at the bottom of the column. The column sits on top of a rail carriage, that allows the welding tower to move along rails.

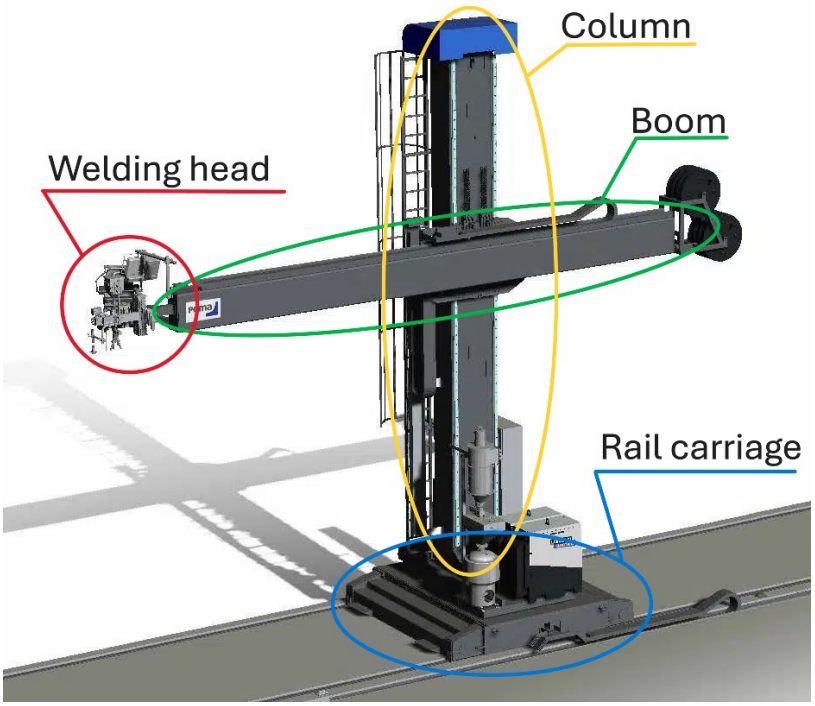

Figure 2. Pema EHD 7x7 welding tower (Pemamek Oy 2025).

C&B is a welding tower where the boom can be moved in X- and Y-axis back and forth. Typically, there is also slewing ring on bottom of the column so the column can be rotated. With rail carriage the C&B can be moved along the rails. Over the time welding towers have grown bigger along with the workpieces and modern-day C&B movements can be from one meter to over ten meters. Welding towers can also be equipped with operator seat so the operator can be near and monitor the welding process when working with high workpieces. Adding of the operator seat sets strict requires for steel structures load capacity and fatigue as the welding tower is then classified as personal lift.

Welding automation is highly competitive sector, and many manufacturers offers C&B-type welding towers. Most of the selection is conventional fixed boom welding towers. Biggest difference come from welding equipment and software and of these one have to choose the most suitable. Some of manufacturers have already welding towers with telescopic boom in their product range. One of the telescopic welding towers can be seen on figure 3. There is shown solution from Esab where the boom is constructed from three phases.

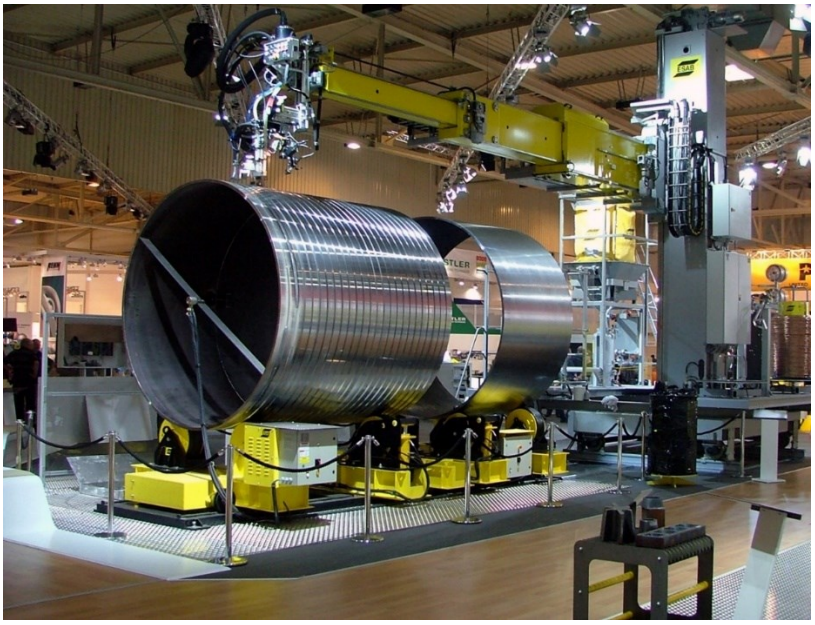

Figure 3. Esab TELBO telescopic welding tower (Disprosol 2025).

In figure 4, the size range of Pema welding towers is shown from smallest to biggest. The smallest series is called MD (medium) where movements are from 3 to 5 meters. Middle size series is called HD (heavy) where movements are from 3 to 8 meters. Biggest series is EHD (extra heavy duty) where movements are from 5 to 10 meters. (Pemamek Oy 2025.)

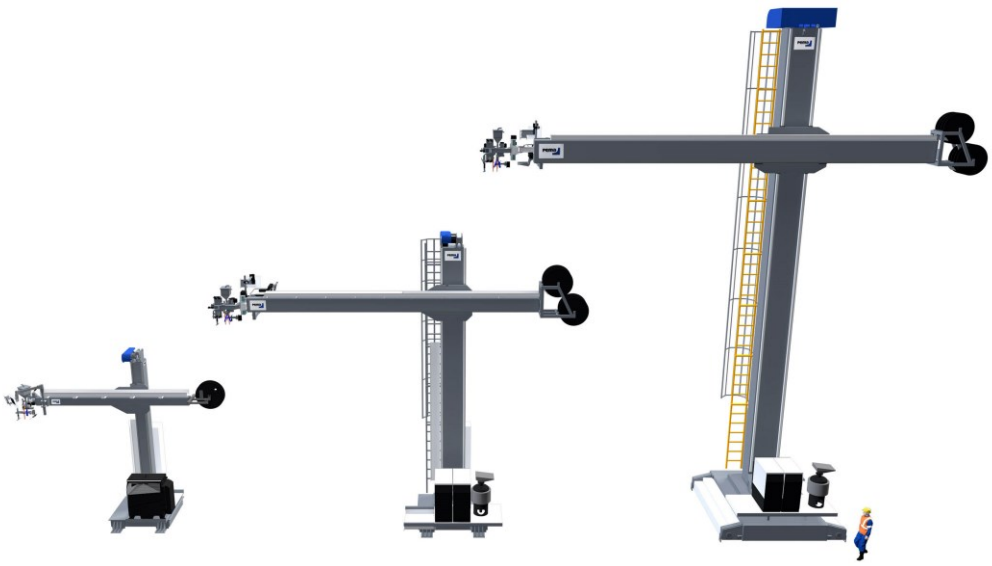

Figure 4. Size range of Pema C&B's (Pemamek 2025).

2 Basics of concept designing

This chapter focuses on concept designing and what are the main step on it toward the successful completion of designing process. In this case the concept design has great impact to the final design process when you don't have to begin from scratch.

2.1 Steps of process

After the task has clarified, concept design phase determines the principle solution. The part of the design process is conceptual design where the primary solution outlines the fundamental approach to solving the problem. This is achieved by addressing problems by abstracting them, developing functional frameworks, identifying appropriate working principles, and integrating these into a cohesive system. (Pahl, Beitz, Feldhusen & Grote 2007, p. 159.)

The individual steps for the concept design can be seen in figure 5. With these steps the concept design phase is carried out to fulfil the phase.

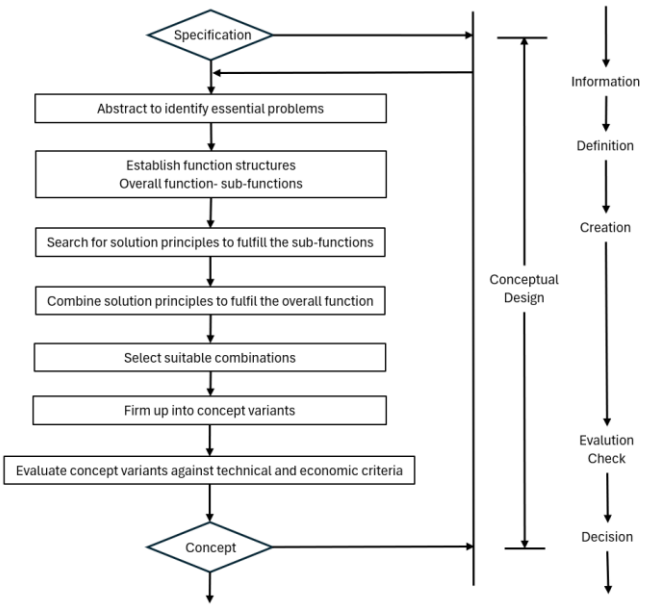

Figure 5. Steps of conceptual design.

2.2 Abstract to identifying the essential problems

Solution ideas or designs build from usual methods are unlikely to yield optimal results when breakthroughs in solutions, technologies, material, methods, and academic research hold the key to move more advanced outcomes. Each industry and design office possesses a rich repository of experience. These, combined with a desire to minimize risks, can hinder the adoption of more innovative and cost-effective solutions. The client, customer, or product planning team may have included specific suggestions in the requirements list. Additionally, during discussions about individual requirements, ideas and suggestions for solutions may arise. Some solutions might exist subconsciously, and there may already be concrete ideas, however, they might be affected by entrenched belief and unfounded restrictions. Searching for the best resolutions, engineers, -detached from the influence of rigid or traditional concepts-, have to for that reason examine with care whether novel and more acceptable ways are available for them. (Pahl et al. 2007, p. 161.)

When improving something that already exist with set of requirements, the job is thoroughly detailed through list of needs and the creation of the goal to be reached. In an abstract approach, the core focus shifts away from the existing object itself. The improvement can be such as improving technical functions, decrease weight or room, noticeably lower the expenses, significantly reduce delivery times or simply enhance production methods. All of these must be satisfied on the whole solution, but the importance of individual point may vary from case to case. (Pahl et al. 2007, p. 161.)

2.3 Establishing the function

The needs and requirements rules the function that characterizes the intended relationship between a system's inputs and outputs. When the heart of the overall problem is put together it's achievable to specify an overall function. As the complexity of a problem increases, so does the complexity of the resulting function. A technical system, for example, may be decomposed into subsystems and elements to manage this complexity, so the complexity or overall function could be managed as subfunctions. All of the subfunctions are result for function structure that represents the overall function. Goal for the splitting the overall functions are to:

- Identify subfunctions that aid in the subsequent search for a solution.
- Integrate these subfunctions into a clear and straightforward function structure.

When setting up function structures it's good to keep up on mind these points: First obtain a coarse function structure with couple subfunctions from the functional relationship that can be identified from the requirement list and after that split that rough structure down by solving complex subfunctions. If there is no direct relationship between subfunctions that can be recognized, the first solution principle could be based on simple list of identified subfunctions with no logical relationship. From a coarse structure it's possible to obtain onward variants and thus optimise the solution by splitting down or integrating single subfunctions and change the organization of single subfunctions. (Pahl et al. 2007, p. 164.)

2.4 Searching for working principles

The development of working principles for individual subfunctions is essential, followed by their integration into a coherent system. Each principle must embody the functional effect it is intended to produce, including relevant material and geometric parameters. Often, the primary issue lies in the form design, making it unnecessary to seek new physical effects. Additionally, when seeking a solution, it is often challenging to clearly differentiate between the intended physical outcome and the implemented design attributes. Therefore, designers typically identify working principles that align with the relevant physical mechanism and satisfy the required geometric and material specifications, integrating them into a functional whole. (Pahl et al. 2007, p. 181.)

2.5 Combine working principles

Achieving the overall function requires synthesizing a complete solution by combining individual working principles into a unified system. This system synthesis is grounded in the function structure, which defines feasible and beneficial interrelations among the subfunctions. The foremost challenge in system integration is achieving physical and geometric compatibility among the selected working principles to ensure seamless material, energy, and signal flow. Subsequently, the focus turns to evaluating and selecting

combinations that offer the greatest technical and economic benefits from the broader set of theoretical options. (Pahl et al. 2007, p. 184.)

Mathematical methods can only be used to combine solutions for working principles with quantifiable properties. Nonetheless, achieving this at an early phase is rarely practical. Exceptions include scenarios like variant design or control system that utilize electronic or hydraulic elements. In overall to combining working principles, it's good to keep up mind that combine only subfunctions that are compatible, focus solely on solutions that satisfy the requirements list and appear to fit within the proposed budget and focus on the most promising combinations and determine why they should be prioritized over the others. (Pahl, et al. 2007, p. 185.)

2.6 Select working combinations

As the working structures are not quite concrete and also the properties are known only qualitative, selection procedure that suits most likely is systematic selection. This method is defined by the process of identifying and selecting preferences. It utilizes a schematic selection chart that provides a clear overview and allows for easy verification. example of the selection chart can be seen in figure 6. As a result of systematic selection chart there is a combination of most suitable subfunctions. (Pahl et al. 2007, p. 186.)

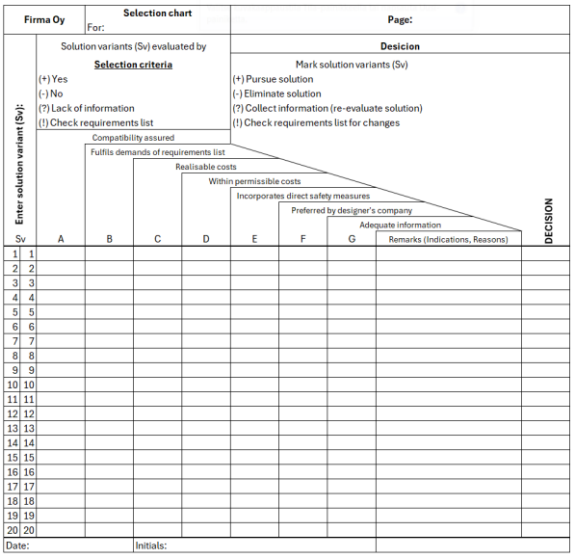

Figure 6. Example of systematic selection chart.

An alternative method for making a quick selection is to make a two-dimensional classification scheme. That kind of selecting table can be seen in figure 7. In this chart the different combinations are evaluated against the requirement list and variants that are unsuitable are discarded for several immediately apparent reasons. (Pahl et al. 2007, p. 187.)

Subfunctions \ Solutions		1	2	...	j	...	m
1	F_1	S_{11}	S_{12}		S_{1j}		S_{1m}
2	F_2	S_{21}	S_{22}		S_{2j}		S_{2m}
...		...	...		...		...
i	F_1	S_{i1}	S_{i2}		S_{ij}		S_{im}
...		...	...		...		...
n	F_n	S_{n1}	S_{n2}		S_{nj}		S_{nm}

Figure 7. Example of systematic combination selection matrix.

2.7 Firm up into principle solutions

The previously mentioned principles are often too abstract to result in the adoption of a specific concept. This is because the search for a solution is primarily focused on fulfilling a technical function, based on the function structure. Before concept variants can be assessed, they need to be clearly defined. Experience indicates that this process almost always requires substantial effort. During the selection process, a lack of information regarding key properties may become apparent. Therefore, the main characteristics of the proposed combination of principles must first be defined more concretely-qualitatively, and often also in a rough quantitative manner. (Pahl et al. 2007, p. 190.)

For the working principle the important characteristics and at a minimum, key task-specific constraints should be known, even if only in rough terms. Detailed information should be gathered only for the most promising combinations. The essential data are primarily gathered using proven methods like (Pahl et al. 2007, p. 190):

- rough calculation based on simple presumption.

- Coarse sketches or coarse scale drawings of potential layouts, space requirements or forms.
- Model tests or initial experiments to define main properties and to receive approximative quantitative statements around the performance and potential for improvement.
- Building models to support analysis and visualization.
- Analog modelling and system simulation, frequently utilizing computers: such as loss and stability analysis of hydraulic system.
- Conducting more targeted searches of patents and literature.
- Market analysis of suggested technologies, materials, and purchased components, etc.

With the newly acquired data, the most promising combinations of principles can be further refined to a level where meaningful evaluation becomes possible. The variants should demonstrate both technical and economic characteristics, enabling the most precise evaluation possible. (Pahl et al. 2007, p. 190.)

2.8 Evaluate principal solutions

What comes to evaluating principal solution variants, there is several steps that are suggested to use. First one is to identify evaluation criteria. This is based on the requirements list. During a selection process unmet demands might have resulted in the removal of variants deemed fundamentally unsuitable. Therefore, it's recommended to verify, with the newly practiced information, whether each proposal being evaluated continues to satisfy the defined requirements. In the conceptual phase, key considerations include both technical and economic characteristics as early as possible for evaluation. (Pahl et al. 2007, p. 192.)

Second step is to weight the evaluation criteria. The importance of evaluation criteria can vary significantly. During the conceptual phase, where information is limited due to the lack of detailed embodiment, it is generally not advisable to apply weighting. Instead, it is more beneficial to aim for an approximate balance in selecting evaluation criteria, temporarily disregarding those with lower importance. (Pahl et al. 2007, p. 192.)

In the third phase, parameters are complied. Experience shows that organizing evaluation criteria under checklist categories and aligning variant parameters accordingly enhances clarity. Quantitative data should be included where possible, while qualitative parameters- common in early design stages- should be expressed in descriptive terms and associated with a value scale. (Pahl et al. 2007, p. 194.)

Fourth step is determining the overall value. Determining the overall value is straightforward once points are applied to both the evaluation criteria and the proposed variants. If the evaluation uncertainty permits only a point range for individual variants, or if directional indicators are used, the potential minimum and maximum overall value points can be calculated to determine the likely overall value range. (Pahl et al. 2007, p. 195.)

Fifth step is comparing the concept variants. For comparison the absolute value scale is usually more suitable for this purpose. It can tell if particular variants are comparatively far or close from the target. Variants that are like 60% under the target aren't worth to development further. With rating over 80% the variants can be moved to the next design phase without onward improvements. It's very common that two or more variants are equivalent so in this case weak spots and the value profile should be looked more specifically. (Pahl et al. 2007, p. 197.)

Sixth step is to search for weak spots. In the conceptual phase there is a important role for the value profile. High rating variants with clear weak spots may become very tricky during later development. If there is some unidentified evaluation uncertainty the whole concept could be in doubt and the work that has been done may be useless because some weak spot appears later. Cases like this it's more certain to choose a variant with lower rating but better-balanced value profile. (Pahl et al. 2007, p. 198.)

3 Telescopic booms in general

The telescopic structures are highly utilized in applications in engineering world. Most common applications are mobile cranes, telescoping boom lifts and loader cranes. Cranes and lifts are used widely in field of construction machinery because of their strong flexibility and large extension range. Lifting height in use can reach from tens to hundred meters. Extended structure of telescopic boom is usually a slender structure with effect of nonlinearity. (Zhao, Qi & Wang 2024.)

Telescopic boom lifts are constructed with multiple different booms. For example, boom lift with three different sections, there is base boom which is typically fixed and then there is two different section booms as it can be seen from figure 8.

Figure 8. JLG 860SJ Telescopic boom lift (JLG 2025).

Loader cranes and mobile cranes are typically constructed with multiple sections as it can be seen in figure 9. Booms are different sizes with smaller booms fitting inside bigger ones.

Figure 9. Hiab iX.158 loader crane (Hiab 2025).

Usually, telescopic movement is achieved with hydraulic cylinder, rope or chain and pulleys. With movement of the hydraulic cylinder the inner sections are extended relatively to base section as it can be seen in figure 10. Retracting the booms is achieved in turn with moving the hydraulic cylinder to inwards. (Lindores mobile cranes 2025.)

To achieve smooth movement booms are typically equipped with sliding pads or supports rollers. Sliding pads can be seen in figure 10 as there is pads in top and bottom and in both sides of the boom. The needed mechanism for movement can be seen in figure 10. There is a hydraulic cylinder inside which moves the middle boom. Chain or rope is connected to mother boom and through the pulley to inner boom. The pulley is connected middle boom and while the middle boom moves is achieved also movement for the inner boom.

What makes the telescopic system a great option to different applications is the compact structure when packed and on the other hand it can achieve great reach when deployed. With three section booms when the other sections go inside the base section the total length of boom decreases almost three times. Limited areas in buildings, the ability to fit in traffic and gaining much more larger working area are usually reasons to choose telescopic structure.

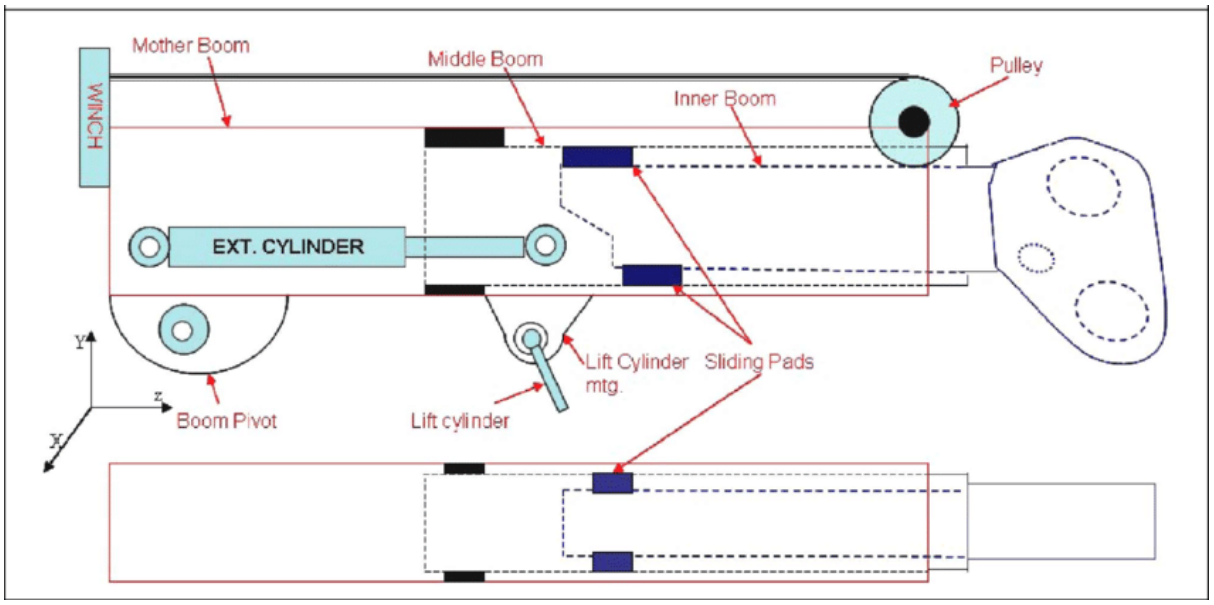

Figure 10. Construction of telescopic boom (Kumar 2012).

Nowadays when high strength steels have become common, and the usage is general also the telescopic booms utilize high strength steels. Cranes and booms can be exposed to very high deflection when the bending resistance is setting limits as there is allowed to be deflection. This feature allows to utilize the full potential of high-strength steels (HSS). Example Kesla is utilizing Strenx 960MC-steel on their telescopic cranes (Kesla Oyj, 2025). HS-steels allows structures to become lighter and yet still strong compared to normal structural steel. When there is matter if the structure is light, example in transportation when you need full potential to cargo, the advantage of HS-steels light structure is valuable.

4 Design of the telescopic boom structure

This chapter focuses on to conceptual design of the structure. Main focus is on the design and optimization of the telescopic boom. Also, the Column is reviewed based on the effects that comes from the boom. Two different options for telescopic boom and column are presented based on the calculations that are done. The specifications on which the design is based on are examined in the next chapter.

4.1 Studied parts and specification

Main parts of the Column and boom were introduced earlier, and they were column, boom, welding head and rail carriage. As in this case the focus is on the telescopic boom and column, the other parts that were introduced is not studied.

The technical specification which gives frames to concept design was agreed in the beginning of the case so that the result would be desired. Also, these are used as parameters and base for calculations. These specifications are:

- Travel length of boom.
- Boom to be constructed from three different sections.
- Boom movement handled with one power unit.
- External loads that come from welding head and cables.
- External load in the back of boom.
- Restrictions to displacement of the boom when movement is deployed.

Because specifications are agreed upon in advance the concept design process should go straightforwardly. On the other hand, there always shows up surprises that took more time than planned.

4.2 Requirements for the telescopic boom

At the beginning of conceptual design there were considered the requirements for the telescopic boom that need to be fulfilled with right solutions. First there was thought about boom and what are the functions that affects the operation of machine. First of all, the boom needs to travel back and forth with one electric motor so there need to be used e.g. roller chains to connect booms to each other. Boom travel doesn't need to be very precise because there is no need to weld with boom movement in this case. The boom end needs to be constructed the way that there could be attached the welding head. And then as for the structural requirements, travel for the boom was desired to be 13 meters, boom wanted to be constructed from 3 different sections. Deflection wanted to be suitable for welding use and desired deflection was 10 mm to each section. For the material there wasn't chosen any specific to use, but few options would need to be considered. As starting point for the boom type was box beam.

Requirements for the column were that boom needs to be moved in vertical direction along the column, so there need to be linear guideways on column. Also, column needs to be rotated around vertical axis, and this is achieved with slewing ring. And in addition to these the column must be stiff enough so that it doesn't sway.

4.3 Optimization of the boom

Box beam shaped structure was chosen for optimization. This kind of structure is suitable in this case because of its manufacturability and considering linear guides, the structure needs tall side wall to attach the linear guides. Cross-section of box beam can be seen in figure 11. where H is total height, B is total width and t is material thickness. Material for the boom are expected to be normal structural steel S355. Using of HS-steels don't add any value in this case because restrictive factor is deflection. Full potential of HS-steel cannot be utilized as steels have same Youngs module which means when the deflection is restrictive factor the HS-steel beam would weigh as much as beam that is made of S355. In terms of costs the HS-steel beam would cost more than S355 beam which increases the overall cost. In addition, the use of S355 steel is supported by its availability and suitability for fabrication such as bending and welding.

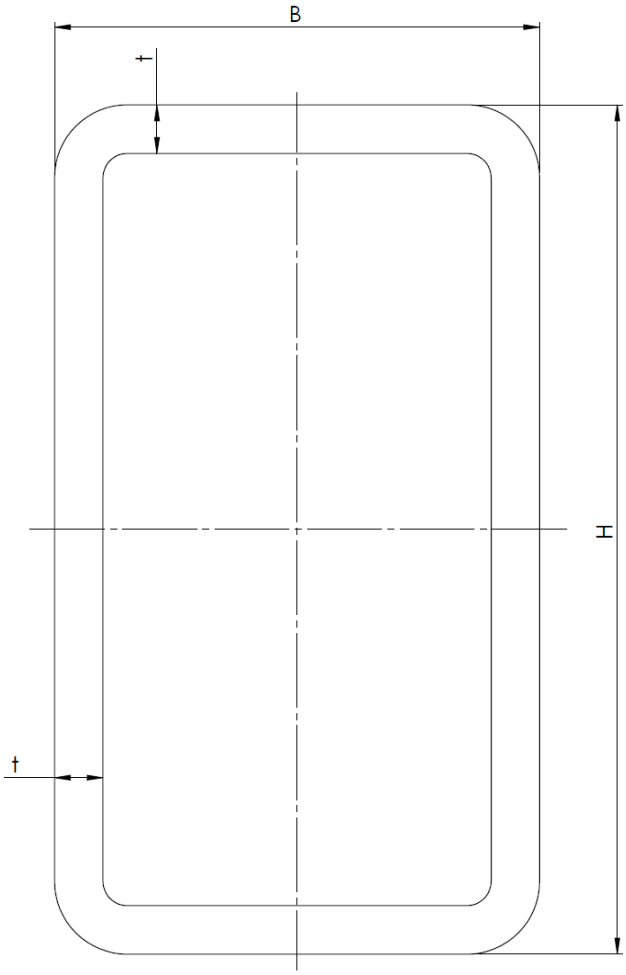

Figure 11. Cross-section of box beam.

In this case rough first calculations are calculated based on cantilever beam-type situation with single load at the end. For these types of beams there are ready formulas to calculate with. First thing to optimization was to calculate second moment of area (*I*) for the phase 3 boom. When the external force, length and permissible deflection is known the second moment of area can be calculated from derived formula of deflection (Valtanen, E. 2016, p. 321):

$$f = \frac{FL^3}{3EI} \quad (1)$$

which is now derived to

$$I = \frac{FL^3}{3Ef} \tag{2}$$

Where I is second moment of area, F is external force, L is length of boom, E is Young's modulus and f is deflection. Next thing to calculate optimal cross-section is to solve some of the unknown dimensions that can be seen in figure 10. For these dimensions there is ready equations which can be found from book Levyrakenteiden suunnittelu (E. Niemi, 2003, 55):

$$I_x = \frac{\beta*(\eta+2)^3-(\beta-2)*\eta^3}{12} * t^4 \tag{3}$$

Which calculates the second moment of area with respect to the x-axis. From where we can solve the only unknown

$$t = \sqrt[4]{\frac{I_x*12}{\beta*(\eta+2)^3-(\beta-2)*\eta^3}} \tag{4}$$

Where t is the thickness of material and η and β are ratios of c/t according to the cross-section class PL3 from Eurocode 3. PL3 is suitable for welded beams as it's semi compact sheet where compressive stress can reach the value of yield stress according to elasticity theory. As in this case the box beams are calculated as cantilever beams with point load in the free end, η and β values are read from the c/t table accordingly with that. After the thickness is calculated there can be calculated other unknows from the cross-section with (E. Niemi, 2003, p. 55):

$$H = \eta \times t \tag{5}$$

And (E. Niemi, 2003, p. 55):

$$B = \beta \times t \tag{6}$$

Where *H* is the height and *B* is the width of the beam. After that we have cross-section dimension for phase 3 boom and the mass of boom can be calculated. When the mass is known the calculations can be continued for phases 2 and 1.

For phase 2 and 1 boom there has been considered moment caused by phase 3 boom and force from boom end. Phase 3 boom is supposed to be rigid which causes moment to earlier phases. Equation for second moment of area is now

$$I_{2,1} = \frac{l^2\left(\frac{Fl}{3} + \frac{M}{2}\right)}{Ef} \tag{7}$$

Where *F* is point load in the end of phase, *M* is moment caused by phase 3 and 2. Moment can be calculated from (Valtanen, E. 2016, p. 298):

$$M = F \times l \tag{8}$$

For the deflection *f* there is used value 10 mm. Each boom is calculated separately with that deflection value due to simplification and making it easier to get going with design process. Once above-mentioned equations are calculated, there is optimal cross section for each phase. Results can be seen from table 1.

Table 1. Results for optimal cross sections

	Phase 3	Phase 2	Phase 1
I_x	69444444 mm^4	169587964 mm^4	399660714 mm^4
t	3,85 mm	4,81 mm	5,96 mm
~t	4 mm	5 mm	6 mm
H	396 mm	495 mm	593 mm
B	125 mm	156 mm	187 mm
m	193 kg	328 kg	472 kg

Above mentioned formulas may give too accurate results as example for the thickness t, so these must be rounded up to next available plate or beam thickness. Also, the way the booms are made affects how useful the results are. Tall and narrow u-shapes are more complex to manufacture than tall and wide. Using the optimal results are more or less case specific.

4.3.1 Simulation for booms

Simulation study was also carried out to get a support and validation for calculations. For the finite element simulation, SolidWorks static simulation-tool was used. Each boom was simulated separately. Dimensions for the booms are shown in the table 1. The models are made as simple as possible so that the simulation is not computationally heavy. This means that there are no other components or any machining in the models.

Booms are modelled as solid box beams and booms are assumed to be rigid. For the element type there is used solid mesh with uniform mesh size which is shown in figure 12. Analysis type is static. All three booms are fixed from the rear side which restricts the translations to all directions and allows booms to bend. The same loads have been used for the booms as in the calculations. Loads are placed as distributed vertical load to front of boom. Also, for the phase 1 and 2, moment caused by previous phase is applied to front of boom.

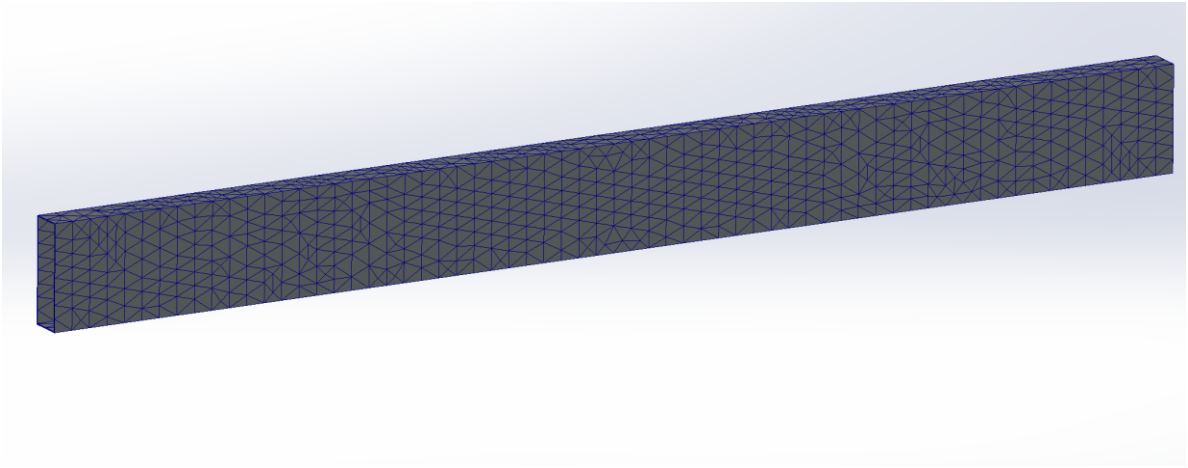

Figure 12. Mesh on the phase 3 boom for the FE-study.

Results from the simulations are presented in table 2. Maximum stresses are low as it might be expected when the design criteria was displacement. With restricted displacement there should be a lot of load capacity left. Highest stress was 67,9 MPa which was on the phase 1 boom. The stress distributed evenly on top and bottom corners where was the fixing points. In figure 13 is presented the stress distribution and there can be seen where maximum stresses are. As it can be seen from table 2, displacements are very close to analytical results where the target was 10 mm. In figure 14 can be seen the displacement result from phase 2 boom FE-study. With these FE-studies, results from analytical calculations can be ensured as the results are very close to each other.

Table 2. FE-study results for each boom phase.

	Max stress (Mpa)	Displacement (mm)
Phase 1	67,9	10,4
Phase 2	62,9	9,1
Phase 3	55,2	8,7

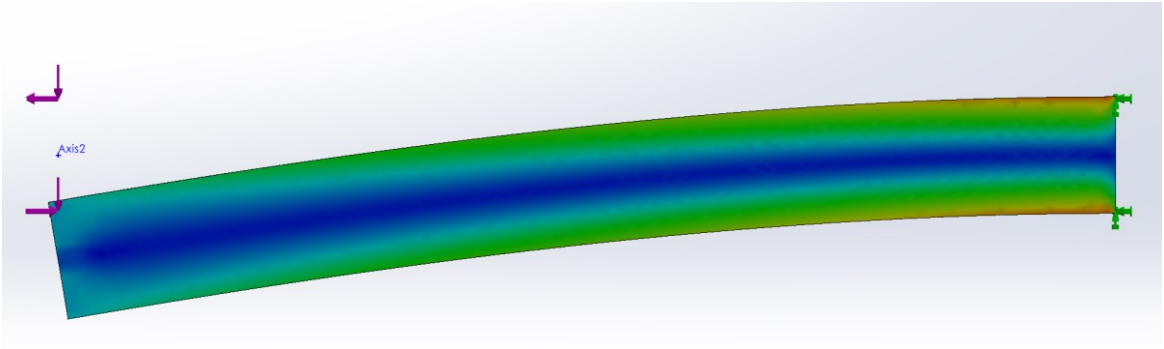

Figure 13. Stress result of phase 2 boom FE-study.

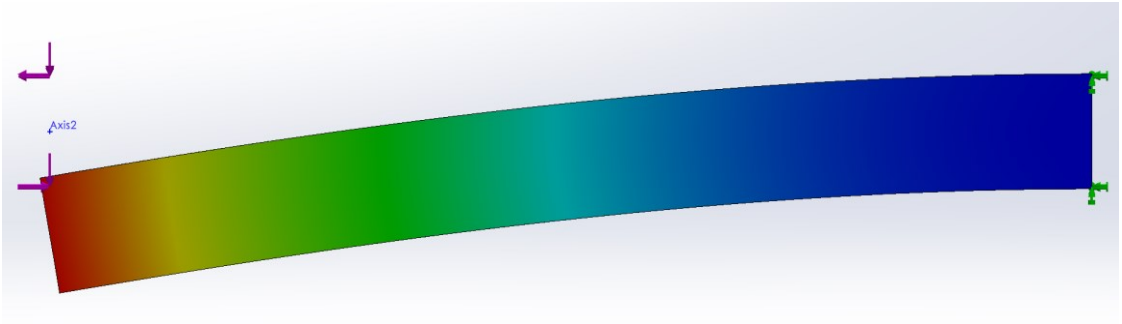

Figure 14. Displacement result of phase 2 boom FE-study.

After separate FE-studies for the booms, FE-study was also conducted for the assembled version of booms. Assembly version was also modelled as a solid box beam and meshed with solid mesh. Same static analysis was also used. Phase 1 boom was fixed from linear saddles which are on the side of boom. Translations were prevented to all directions from fixing points which describes the real situation.

Results from FE-simulation are showing that the maximum stress was 45 MPa and it's located near one of the linear saddles. Otherwise, the stresses are very evenly distributed. Stress distribution can be seen in figure 15. Maximum displacement for was 25mm. In figure 16 is showed the displacement of the boom where can be seen how the booms are bending more from the connection points.

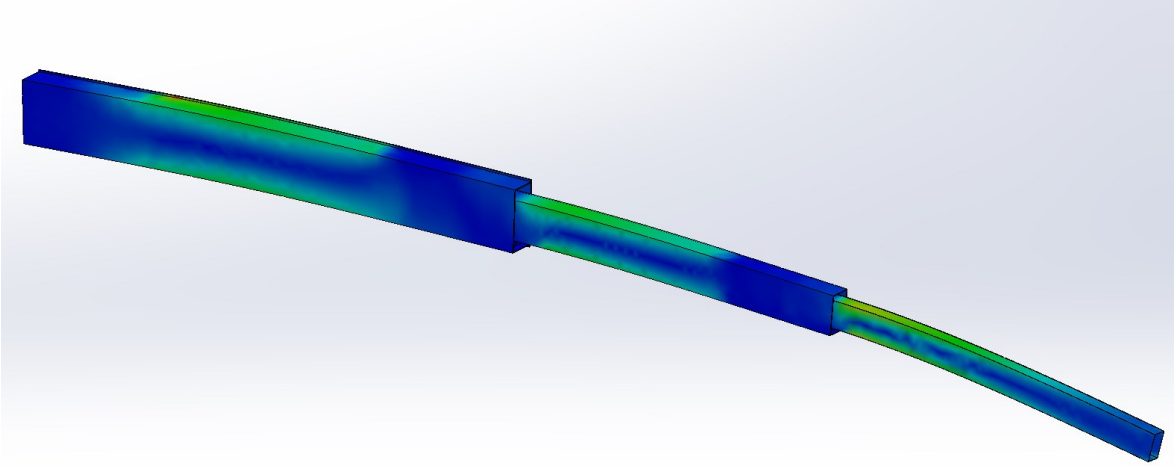

Figure 15. Stress distribution from FEM-model.

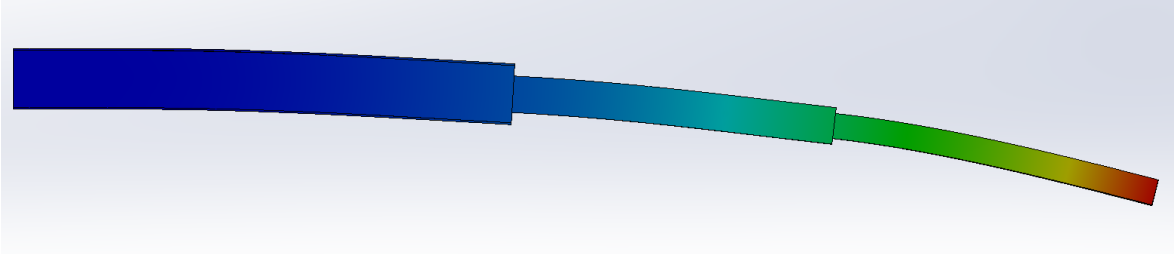

Figure 16. Displacement of telescopic boom.

Results from the simulation study corresponds very precisely to the calculated results. On analytical calculations the target deflection was 10 mm and FE-studies ensures that the calculations are on the beam. This simulation was only initial and should be continued with finer studies and more concentrated parts. Stress distribution due to rolling sliders would be higher than the simulation is showing so these areas would need more studying and more concentrated simulation.

4.3.2 Different material option

There was also considered possibility to use different material for phase 3 boom than steel. For this study aluminium profile was chosen to be investigated. As there are great range of ready-made aluminium profiles available in markets, it was easy choice to look up.

Aluminium could be reasonable because of its lightness compared to steel but there is also downside with the strength that is lower than steel. Example of aluminium profile can be seen in figure 17 which was chosen for further study. This kind extrusion profile is widely available, and it has many potential fixing points for accessories which makes it a good option. Also, this type of extrusion profile has good strength properties due to its profile. Potential benefits are investigated next.

Figure 17. Overview of aluminium extrusion profile (Rose+Krieger 2025).

The second moment of area are calculated with equation 2, same as with steel boom. Only difference is that aluminium has 67% lower young's modulus than steel so it will increase the needed second moment of area of aluminium compared to steel. Result for the calculated I is 178571429 mm^4. So based on this the closest aluminium extrusion profile could be 320x160 mm, which is presented in figure 18.

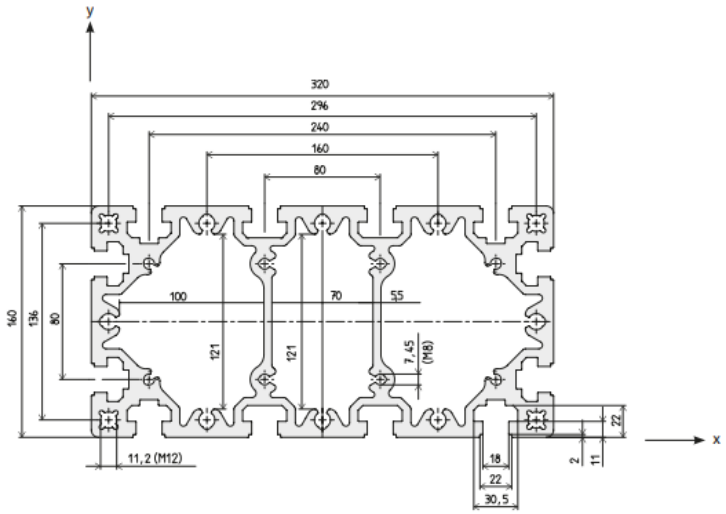

Figure 18. Cross section of aluminium extrusion profile (Rose+Krieger 2025).

In the figure 18 is the particular cross section of the aluminium profile. Manufacturers of these kind profiles provides all necessary information regarding dimensions and weight. For this profile the second moment of area is 156183000 mm^4 (Rose+krieger 2025) which is 14% lower than the required. For the desired deflection that makes 10% increase, which is acceptable. As the optimal phase 3 steel boom weighs 32 kg/m, and the aluminium profile weighs 37 kg/m which makes the aluminium heavier option to choose.

As seen in the figures 17 and 18, the aluminium profiles contain slots on all sides and ready-made holes at the end of profile. These kinds of fixing points create many possibilities to fasten parts and accessories to it. In some cases, those fixing points may make the machining unnecessary which reduces overall cost. And overall, the aluminium profiles are made very precisely which makes them uniform.

4.4 Options for boom mechanism

For the construction of moving mechanism was chosen two different configurations to study. First option is to use linear guides on each phase and second option is to use sliding rollers for phase 2 and 3 booms. For both options the movement is handled with roller chain for phase 2 and 3 and with the pinion rack for the phase 1. Next up both options have been examined in more detail.

4.4.1 Boom with linear guides

Linear guides are good choice when there is needed precise and smooth linear movement. Linear guides consist of the guide itself and linear saddles which slides along the guide. In figure 19 is shown linear guideway and two linear saddles and there can be seen the profile that guideways have. In this case there is two guides per boom and totally four saddles per boom.

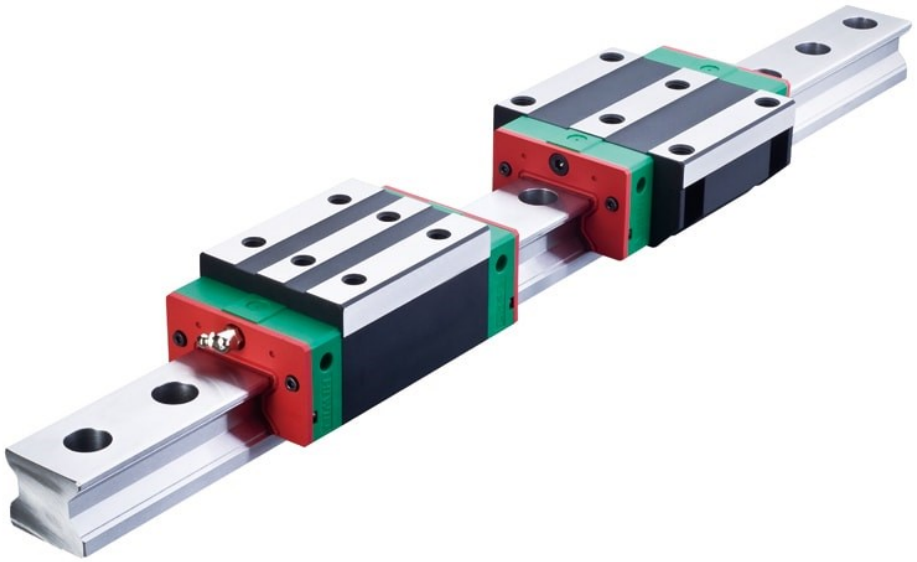

Figure 19. Example picture of linear guideway and saddles (Hiwin 2025).

Linear guides are attached to the side of booms and saddles are attached to the other boom as it can be seen on the cross section in figure 22. Roller chains and chain wheels are attached to the bottom side of booms that can be seen in figure 21.

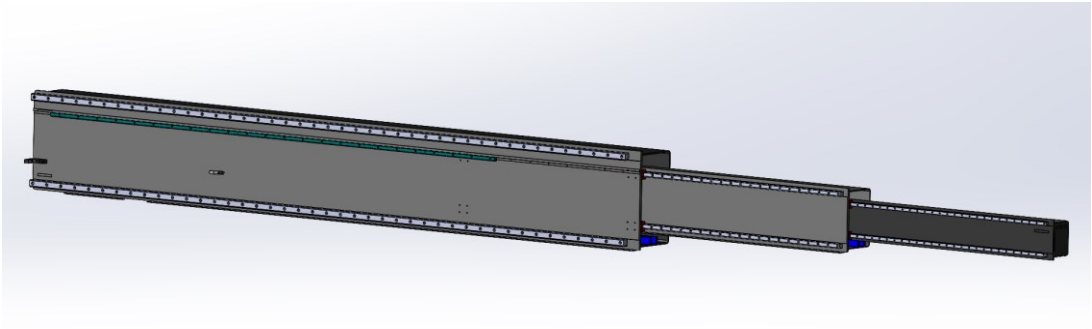

Figure 20. Telescopic boom with linear guides.

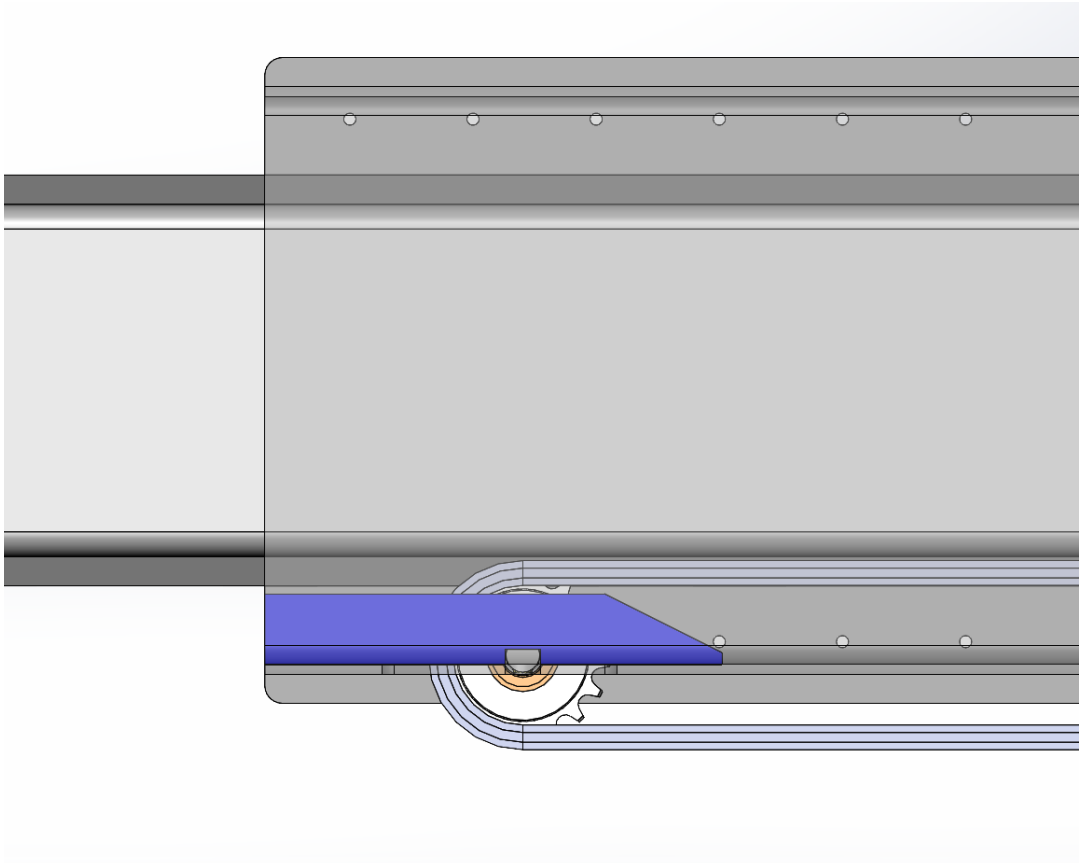

Figure 21. Construction of chain wheel and roller chain.

Construction of the booms needs to be suitable for using the linear guides. As the guides need very precise machined surface and shoulder to be attached, there needs to be surface what can be machined. Therefore, the boom construction consists of channel and thicker side plate as it can be seen in figure 22. With this kind of construction, the manufacturing is

straightforward as there is only two main components on the boom. Dimensions for this option booms are from the results of the optimal cross section calculations. There have been taken account of the manufacturing aspect so everything could be manufactured.

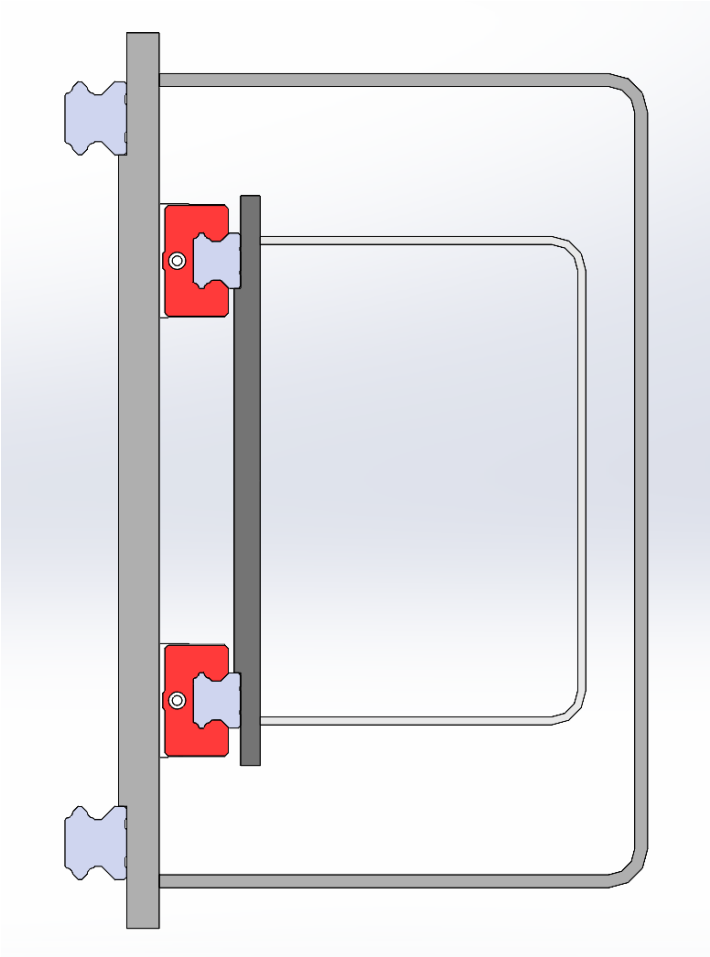

Figure 22. Cross section of booms.

Linear guideways can withstand loads in several directions at the same time which makes the use of them versatile. Manufacturers of linear movement products provides suitable formulas to calculate safety factors and nominal life of linear guideways in different load cases and combination of guides. In this case there is used equations for Hiwin products. For determine the static support stability there is equation (Hiwin 2024):

$$f_{SL} = \frac{C_0}{P_e} \tag{9}$$

where C_0 is static load rating and P_e is static equivalent load for linear saddle. For determining the loads for saddles can be used equations (Hiwin 2024):

$$P_1 \sim P_4 = \frac{W \cdot h}{2c} - \frac{F \cdot l}{2c} \tag{10}$$

$$P_{t1} = P_{t3} = \frac{W}{4} + \frac{F}{4} + \frac{F \cdot k}{2d} \tag{11}$$

$$P_{t2} = P_{t4} = \frac{W}{4} + \frac{F}{4} - \frac{F \cdot k}{2d} \tag{12}$$

where W is applied weight, h is distance from center of gravity to driver, l is distance from external force to driver, c is rail spacing, F is external force, d is block spacing and k is distance from external force to geometric center. Now P_e for equation 9 can be calculated (Hiwin 2024):

$$P_e = P_1 \sim P_4 + P_{t_{1,3}} \tag{13}$$

where P_1~P_4 is result from equation 10 and $P_{t1,3}$ is result from equation 12. Descriptive picture of loading points and distances of linear guidelines can be seen in figure 23. There is two linear guides and four saddles on corners of saddle plate. This situation is similar as this cases booms.

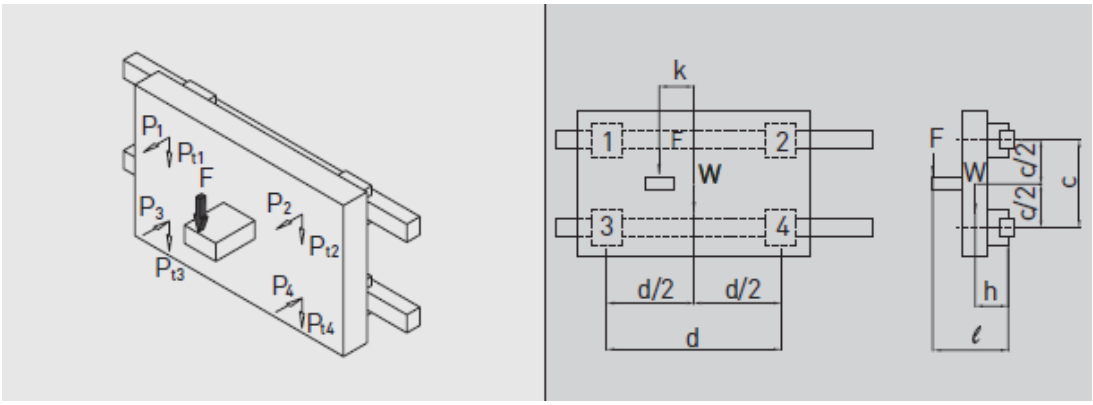

Figure 23. Load points of linear guideways (Hiwin 2025).

4.4.2 Boom with sliding rollers

Basic idea in this option is to use rollers that helps the booms to slide effortless to their maximum and minimum length. Sliding rollers on phase 2 and 3 booms is cost effective way to create linear movement. As compared to linear guideways, the sliding rollers don't need very precise machining like the guideways which reduce the manufacturing costs. Overview of the boom version 2 can be seen in figure 24.

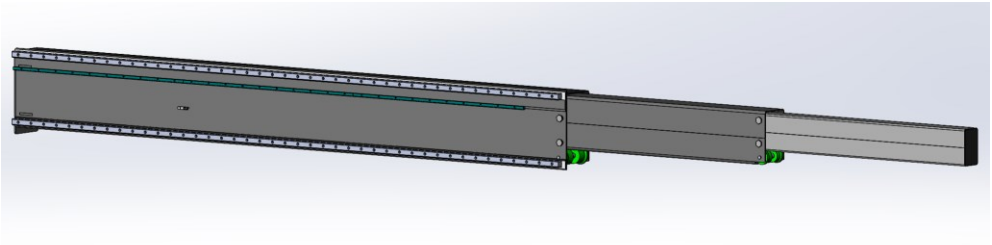

Figure 24. Telescopic boom with sliding rollers.

Phase 2 and 3 booms in this option are constructed from two symmetrical u-shapes that are welded together. In this case the welds are in the neutral axis of the box beam as the main load is vertical. Size for the beams are based on the optimal boom calculations. Construction of booms can be seen in figures 25 and 26. Fastening holes for sliding rollers would need to be machined so apart from these there would be nothing else that need machining.

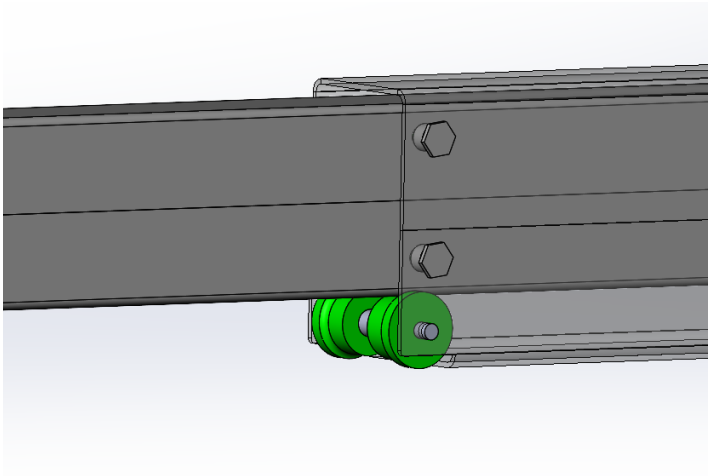

Figure 25. Example of bottom sliding roller and side supports.

Sliding rollers are under a heavy load due to long booms that causes moment. Round shape of rollers focuses loads to small area of booms. For the example rollers there is made rounding to bottom rollers for distributing the load evenly along bottom. Top rollers are thought to be as wide as can be so there the load can be also distributed evenly.

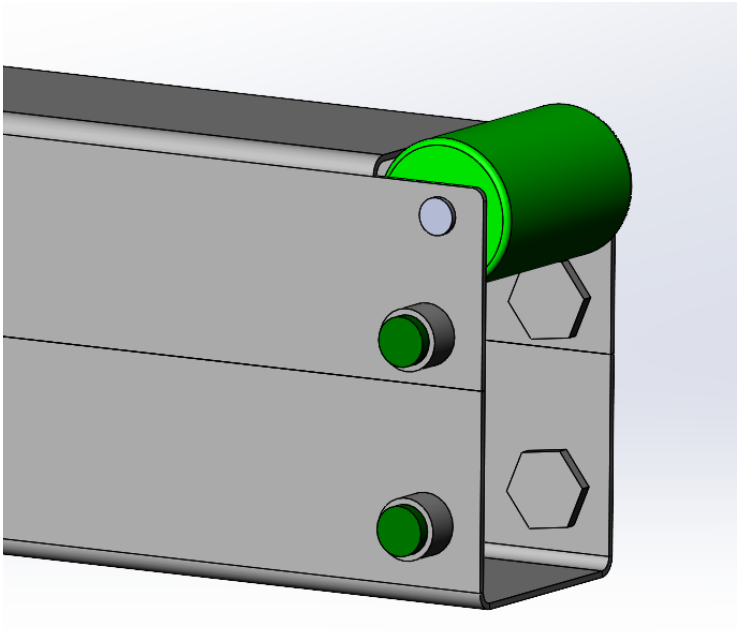

Figure 26. Example of top side sliding roller and side supports.

To define the loads acting on rollers were calculated by using the equations for simply supported beam with point load. By doing this there could be reviewed if the booms can handle the surface loads and don't yield. In figure 27 is shown the situation which describes the reaction forces in boom. Defining began with calculation of point *A* with equation (Valtanen, E. 2016, p. 320):

$$A = \frac{-Fa}{l} \tag{14}$$

Where *A* is reaction force in point A, *F* is external force, *a* is length of free end and *l* is length of supports. And for the point *B* used equation (Valtanen, E. 2016, p. 320):

$$B = \frac{F(a+l)}{l} \tag{15}$$

Where B is reaction force in point B, *F* is external force, *a* is length of free end and *l* is length of supports. On equation 14 the external force is negative due to location of supporting point.

Figure 27. Load case for sliding roller's reaction forces.

4.5 Design of the column

Column is usually constructed from bended channel and front plate that are welded together. At the base there is plate for the slewing ring and some reinforcement plates also welded together to column. Front plate contains machining that linear guides require as there are linear guides to achieve vertical movement for boom. Base plate is also machined as there is attached slewing ring which allows the C&B to rotate. In figure 28 can be seen the example of slewing ring with external gear teeth to achieve rotation.

Figure 28. Exposed view of slewing ring (Schaeffler 2025).

Model for the column is taken from similar C&B as in this case. Size class of the copied column is close, but its use needs to be clarified. For determining that the copied column is suitable there was calculated the moment and axial load caused by structure attached to slewing ring. Moment and load are limiting factors to use of slewing ring as there is defined maximum values by manufacturer. Generally slewing rings have high load carrying capacity, they support radial, axial and tilting moments. This basic equation for moment was used to determine the moment (Valtanen, E. 2016, p. 298):

$$M = F \times l \tag{16}$$

Where *M* is moment, *F* is force and *l* is lever. Required parameters were obtained from 3d-model assembly of C&B. Tilting moment for the slewing ring was 302 kNm and the axial load was 137 kN. For determining the load capacity with results of calculations there is limit load curve provided by the manufacturer of slewing ring. Limit load curve is presented in figure 29. Example of the column can be seen in figure 30. The results showed that the slewing ring are suitable and there is sufficient safety factor.

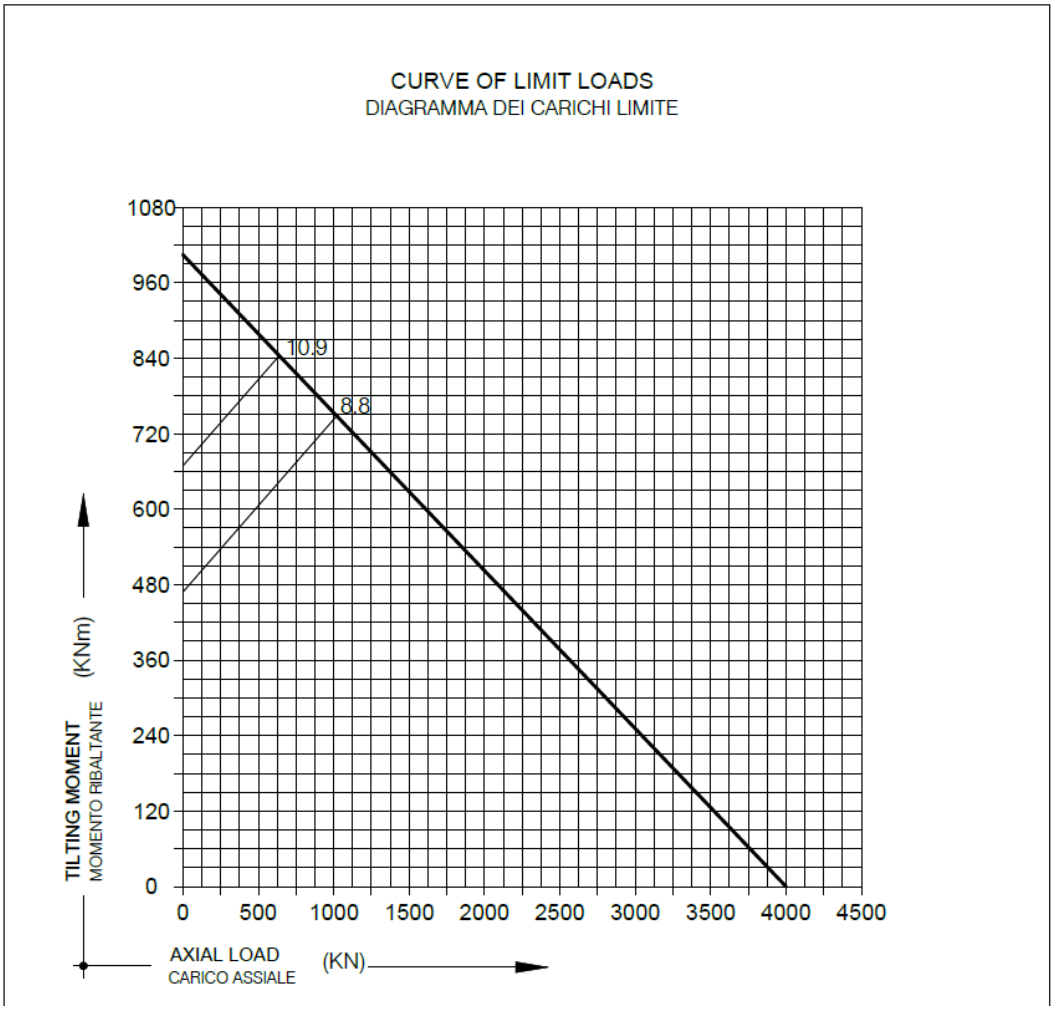

Figure 29. Limit load curve for specific slewing ring (Torriani Gianni 2001).

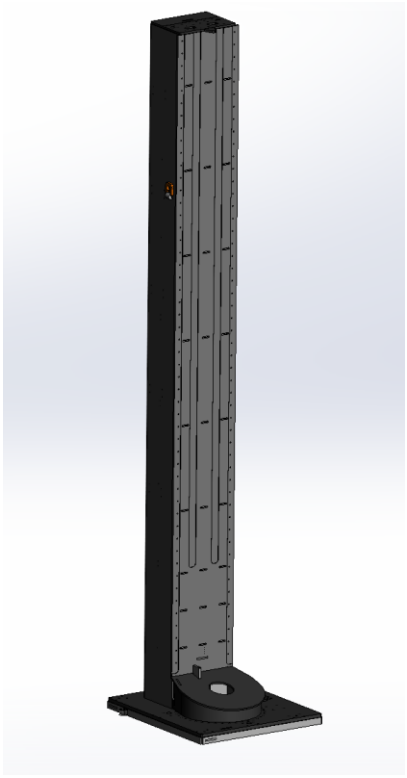

Figure 30. Picture of the column.

4.6 Effect of the operator seat and second welding head

One of the tasks was to assess how the seat for operator and second welding head would affect the structures of C&B and what would it require to use those parts. Affects are assessed from a strength perspective because in this case increasing weight affects the capacity of structure. Operator seat would be attached to the end of boom and second welding head to the middle of boom. Structure wasn't designed specifically to use these so this is only draft what needs to be done and designed for using these.

Operator seat is used by an operator when the work pieces are large and the view for welding process is blocked from ground. Example of this kind of situation is circular outside welding of large cylinder. Operator seat as seen in figure 31 are connected to side of boom end with hinged arm. The hinges allow for changing operating position as the welding position may change. So as the seat is located to the end of boom it would increase the mass which raise the moment for column and as the boom is cantilever beam the seat would affect also the

load capacity of boom. When adding the operator seat, it sets new standards to the structures as the welding tower is then used for lifting personnel and have to be designed for that.

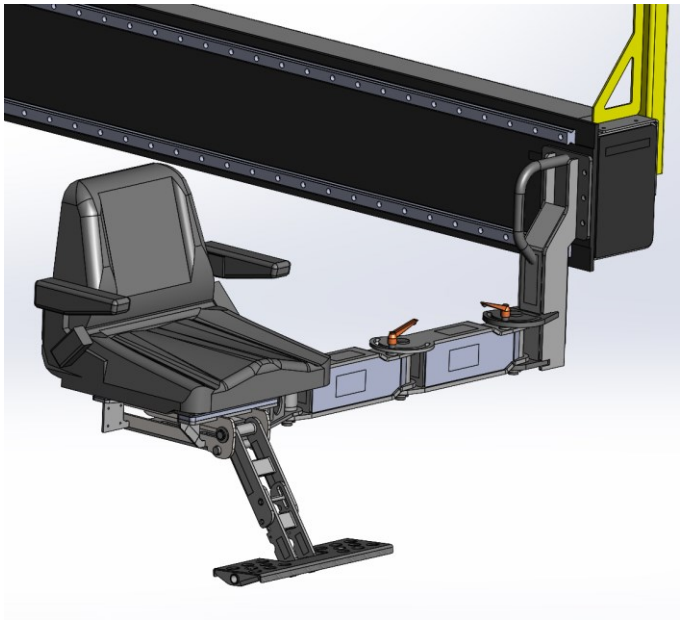

Figure 31. Operator seat.

Adding the second welding head would have bigger impact for the structure as the welding head weights couple of hundreds of kilograms itself. As mass increases, the boom bends more and the deflection is no longer within the permissible range. Also, bending stress and warping should be taken into account because second welding head would be attached to the side of boom. Cables and welding consumables that welding head needs would also increase the mass. The energy chain that is needed for the cables and consumables would require quite a space which is already limited. Movement control would have to be reevaluated as there might be a need to move different phases separately as workpieces are not always similar. This means that the phases would need own sources for movement, e.g. cylinder or electric motor with pinion and rack.

Adding both operator seat and a second welding head would affect the load capacity of the boom. Also, there should be considered the warping of boom as both operator seat and welding head would be attached to the side of the boom which makes the mass eccentric. The boom design would need updated values for calculation because these adding.

5 Cable and welding consumables management

This chapter discusses various options for handling cables and welding consumables. Focus was on the cable handling on the telescopic boom and column gets less attention. Welding head that are shown in the figure 1 needs different kind of cables that powers up the needed movements of the welding head. Also, the welding process itself needs welding current, welding wire and welding flux when in case of SAW process. All these cables and hoses need to be carried smoothly through the column and boom movements.

For the cable and welding consumables management were also considered requirements to make them appropriate. Main requirement was to achieve a smooth movement for the cables through the whole movement area. Cables and wire liners cannot hang down; they must be tightly secured. Welding wire liners cannot be bended too tight to ensure effective wire flow through the wire liner. Implementation method for cables and consumables need to be compatible with transport so they have to be disassembled to fit in containers or truck. And lastly, all unnecessary weight must be minimized so that the structure is not unnecessarily loaded.

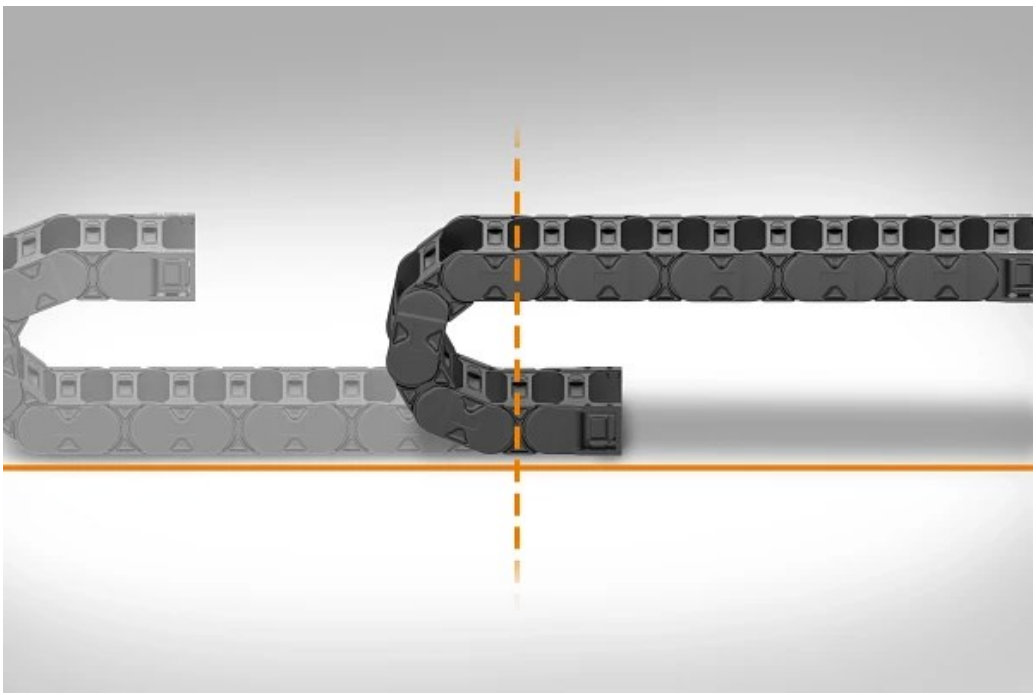

Figure 32. Energy chain movement (Igus 2025).

Experience has shown that energy chains are great option for handling cables through long linear movements. In figure 32 can be seen the energy chain and how it is moving. Because of that the energy chain was chosen to handle the cables and there wasn't any other option for that. A few options were sketched for the welding consumables. First one was to use reel drum. Second idea was to use same energy chain as for the cables. Reel drum proven to be difficult to execute as a working part because welding wire needs large bending radius. The reel would have had two-meter diameter and that would be difficult to fit on machine. So, for that reason using the same energy chain as for the cables turned out to be best option.

As the energy chain selected for suitable option it had to be defined to right type to fit all the cables and consumables. First thing was to outline routes for cables and consumables. After that we could continue to define the energy chain. The number of cables and the space they need could be assessed from similar type C&B. Adding the welding wire liner and flux suction to same energy chain adds one precondition to the chain as the wire liner has minimum bending radius that must not be reduced or otherwise the welding wire won't move freely.

After many drafts most suitable configuration for chains was chosen. As it can be seen from figures 33 and 34 there is two different energy chains. On top of the boom is energy chain that handles cables which are coming along the column. On the side of boom is the energy chain which contains cables and welding consumables. Welding wire liner is coming from back of the boom as the wire is fed from floor.

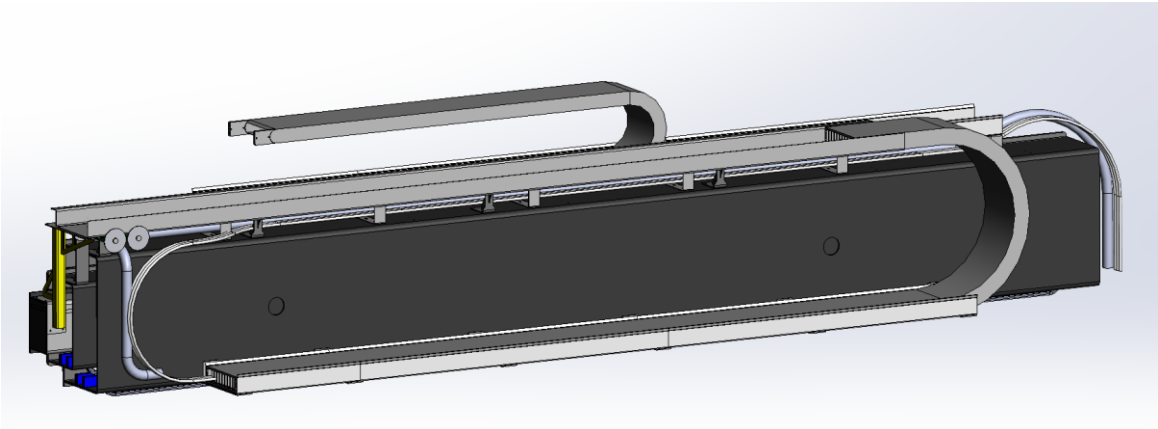

Figure 33. Telescopic boom with energy chains and wire liner.

At the end of energy chain selected a channel as the movement doesn't require the energy chain to reach out to the end of boom. Reason to choose channel is weight saving as the channel weights less than energy chain and can be more cost-effective. This will reduce the moment caused to linear saddles and slewing ring when boom is deployed.

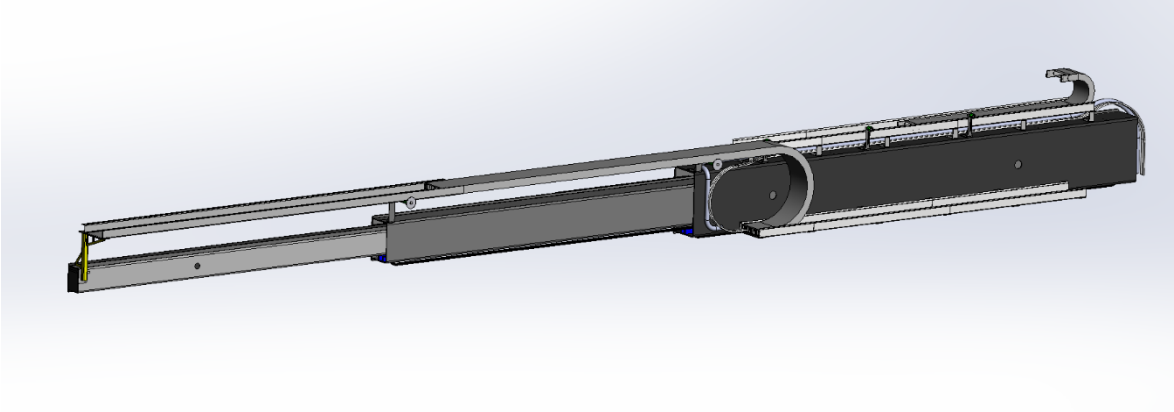

Figure 34. Energy chain configuration when boom deployed.

Fully extended boom causes the unsupported length of the channel and energy chain to increase too much to bear the weight as the length can be seen in the figure 33. Also, the channel has long unsupported length when boom is folded. When unsupported length is too long the chain starts to hang and service life becomes short. A solution was needed for this. Each boom end had enough space so there could be attached support rollers where chain and channel can roll over. This same option doesn't work on phase 1 boom as the energy chain sweeps along the side of boom and there couldn't be any obstacles ahead.

Options for supporting channel were many. First option was to have supports that are equipped with springs and get out of the way as energy chain sweeps. This option contains several moving parts that are critical for service life. Second option was to make a flange on the side of channel which takes support from separate support rollers. Decision from these two options solved for simplicity and option two was chosen to refine further.

Final design for channel support can be seen in figure 35. The idea here is to make a flange on side of the channel which takes support and slides on top of rollers when boom is driven backwards. As the channel is always supported from back and front, the middle part could be supported only from the side. The shape of rollers is thought to be conical and the flange to be edged downwards to achieve guiding feature for the energy chain and channel. Guidance for chain and channel would prevent movement to sides and keep them straight.

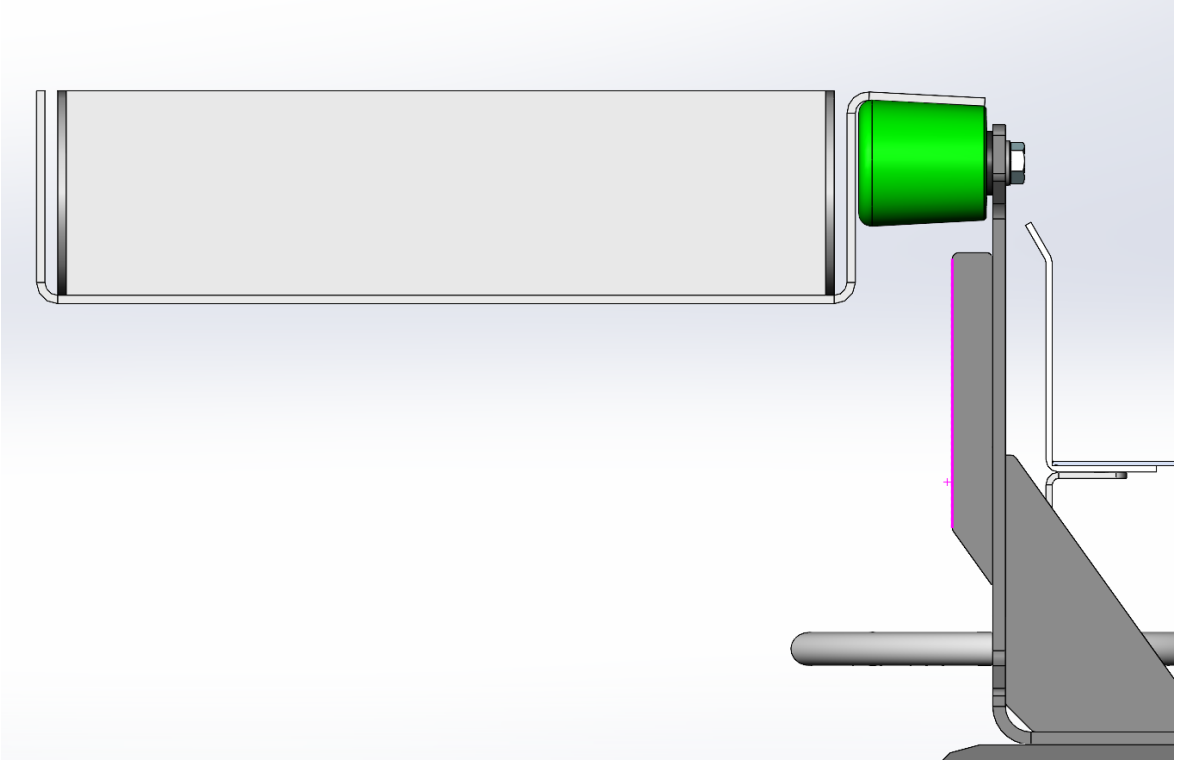

Figure 35. Channel support.

6 Discussion

This section is going through the results from notable parts for the project and how to refine those further when designing the ready product. This should help to identify what needs to be done and what to consider in the future.

6.1 Optimal boom design

Calculating the optimal cross section for different booms is very good way to produce structures that has enough capacity but are still cost-effective. With the equations that are used on this thesis, the results for booms are slender. I.e. the optimal booms are tall and narrow when loaded vertically. This kind of structure has lower resistance to warping and lateral load due to optimization for deflection in vertical direction. FE-studies should be continued with more precise models and focus on high stress spots. It could also be useful to examine the dynamic loads resulting from failure situations for example due to a broken lifting chain.

Manufacturing side must be considered if the design is carried out based on optimal results. Previously mentioned tall and narrow beams could be complicated to fabricate because of deep side plates in relation to with. Channels and profiles should be easily possible to fabricate.

6.2 Options for booms

Two different style of boom design were introduced. One with linear guideways and one with sliding rollers. Use of linear guideways are common style in C&B's and therefore threshold for using it is lower because there is a much of knowledge about it. Sliding rollers is not as common as linear guideways.

Booms with sliding rollers usually have more clearance and is looser while linear guideways have hardly any clearance. With more clearance there may have a bad influence on some welding situations and there can occur welding defects, example when welding longitudinal

with booms movements. Clearance can be decreased in sliding mechanism with sliding pads that are each side but with tighter clearance the movements might need more power from the motor.

The option with sliding pads could be developed further to version with fixed sliding pads instead of rollers. Fixed sliding pads would reduce the point load, as the load would distribute more evenly than with rollers. However, the rollers and sliding pads need more studying and simulation to support the design. In addition, the maintainability needs to be considered as how highly wearable parts could be changed and how often do wear parts need to be replaced.

The construction of booms with linear guideways increases the mass when compared to construction with sliding rollers. With current options the linear guideway-versions is xx% heavier than the other. This weight difference will be reflected to other structures and of course it has impact on overall cost because of the amount of steel, linear guideways and the machining.

There was also considered to use aluminium in phase 3 boom. As there can be seen on chapter 4.2.2 the aluminium profile proved to be heavier option than the steel version. The price of the aluminium in general can be expected to be 50% higher than steel price which makes the use of aluminium more expensive. Earlier discussed advantages of aluminium profiles could be still considered if it gives benefits to overall cost as there is no need to fabrication. However, fabrication is a large part of the overall cost of single steel boom.

6.3 Cable and welding consumables handling

Well-made cabling and organized hoses give a more convincing effect to whole machine. That is why the cable and welding consumables should be handled and done systematically. Also, maintenance and service are easier to do because of this. Options that are shown in chapter 5 are based on solutions that are used previously and proven functional. Adding the welding wire liner to energy chain would improve even more the organization of cables. All that’s left to do with this concept is check the width of energy chain. This can be executed when all the necessary cables and hoses are known.

7 Conclusions

As the size of the workpieces increases and can't be manufactured with old machines anymore, it becomes crucial for the manufacturing equipment to scale accordingly. Large workpieces present unique challenges, such as the need for improved precision, increased handling capabilities and enhanced stability during welding process. By ensuring that the manufacturing equipment grows in capacity and capability alongside the workpieces, we can maintain high quality welds, improve efficiency, and ensure the safety of processes.

Purpose was to do a concept design of telescopic welding tower to meet demand from wind tower manufacturing. For the concept there was goals and targets to achieve. Main goals were to come up with solutions for telescopic boom, column and how to handle cables and welding consumables. And based on these solutions there could be done cost estimation to have accurate estimates.

For the telescopic boom two options were done with different movement mechanisms. Considering these, both have their pros and cons which can influence the choice for use. S355 steel was chosen as the material for booms. HS-steel and aluminium were also considered as alternatives, but study showed that they cannot be utilized sufficiently to gain advantage. Cross-section that was chosen to booms was welded box beam because it can be utilized best for attaching other components to booms. The limiting factor in the design of the booms was deflection which was used for calculations. The booms were allowed a certain amount of deflection. Two options were chosen for the implementation of boom movement. One with linear guides and saddles and one with roller sliders. In final design process, a more suitable option has to be chosen from these movement options depending on case and needs.

Energy chain and channel was chosen to be used for cables and welding consumables. Channel is attached to end of boom and energy chain is attached to channel and phase 1 boom. Welding wire liner can be also fitted to energy chain when the radius of energy chain is large enough, as the welding wire can't be rounded too tight to ensure smooth movement. Support rollers turned out to be a good option to support the energy chain from the end of booms. Channel is also supported with support rollers through the shoulder when boom is packed to avoid hanging of chain and channel. Selected option for cable and welding

consumable handling seems like a promising option based on previous use of similar products.

Overall, this thesis was meaningful to do, because there is going to be benefits as thinking about the final design process. Goals that were targeted at the beginning were fulfilled and as a result there is ready concept model of welding tower. As it can be seen in figures 29 and 30 the space saving result is remarkable compared to conventional fixed boom when boom is packed to back. Results are being reviewed, and the final design process can be started smoothly. Needed follow-up actions based on concept design are presented which will help in future. Future research and development should focus on finishing the design, optimizing performance and maybe searching for additional applications to fully realize the benefits of telescopic welding tower.

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