Master Thesis

Analysis and Modification of Heatex Model H2 Heat Exchanger

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Faculty of Engineering LTH • Lund University • 2015

LUND UNIVERSITY

HEATEX

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Preface

This thesis details the aims, method and results of my master thesis as a master of engineering. The subject of product development interests me greatly and after initial discussion with Heatex this project came about. It is partly a deep analysis of a products mechanical properties and partly a product development process to solve some of the problems with a current product.

I have learned a lot during this project. The management of time, the planning of a large project by myself and how I prefer to work. Above all I have learned that any plan will only hold as long as everyday life does not choose to get in the way. Sickness, child care and other unforeseen circumstances can bog down a one man project. I have learned to trust myself instead of questioning others but at the same time the uncertainty has been a large part of the project.

I have noticed I do not have many sources. This is in large because not much in this project has been theoretical, mostly elementary mechanical strengthening or, as in the case of the analysis, controlled by others. One source that has helped me greatly is Ulrich and Eppingers *Product design and development* which has guided my work in the modification phase.

My sincere thanks goes out to all the great people at Heatex engineering department. Particularly Eman Stanezai, Johan Boberg and Daniel Björkström. Also thanks to Emil Roos, product planner at Heatex.

Lund, April 2015

Fredrik Engman

Abstract

The product H2 is a new heat exchanger produced, manufactured and sold by Heatex. It has an excellent surface efficiency, in large parts because of its slim features. The slim features does however have a drawback. It isn't as mechanically stable and robust as its earlier cousins. The product tends to deform plastically in lifting conditions, especially the heavier versions needs extra support or, in some cases, had to be assembled on site.

The purpose of this project is to find out which of the H2 product series that cannot be lifted at their present state and modify these so that the assembly can be done on Heatex main production facility.

The analysis was done in a FEM-based program according to the wishes of Heatex. The CAD models were collected and modified to reduce the amount of elements and nodes required by the FEM-based program. The results did not correspond particularly well with real life testing. If testing of one product of H2-series can gather sufficient data the results can hopefully be used to extrapolate between real life data and the other models of H2.

The modification was done largely deploying Ulrich and Eppingers product design and development process. The modified heat exchanger will be built in steel instead of aluminum. The beams will be made out of two separate pieces welded together, preferable before they are delivered to Heatex. To change production the least amount possible the raw material steel beams should be delivered in pieces the same length as the current aluminum beams. The beams are then cut into appropriate size for production and the ends are drilled in drill fixtures. The end plates will be modified to fit the new beams. The rivets are then fastened at a 90° angle from the aluminum beams.

The finished steel heat exchanger should be significantly more robust than its current counterpart however further testing is required.

Keywords: Heatex, FEM, product development, mechanical analysis

Sammanfattning

Heatex nya produkt H2 är deras senaste typ av värmeväxlare. Heatex tillverkar och säljer produkten själv. Produkten är populär på grund av att den har en mycket bra verkningsgrad för sin yta. En stor yta fås till stor del för att den omkringliggande ramen är väldigt tunn. Ett problem med detta är att den inte håller särskilt bra vid lyft som Heatex tidigare produkter, ett problem som gjort att Heatex tvingats att skicka vissa produkter i delar som sedan monteras på plats. Detta är inte önskvärt, varken för Heatex eller för Heatex kunder.

Detta projekt har två delar. Först att analysera H2-seriens olika modeller med hjälp av ett FEM-baserat program för att ta reda på vilka modeller som håller i nuläget och vilka som behöver extra stöd vid lyft. Detta gjordes med Ansys. Resultatet blev långt ifrån mätdata på plats och måste ses som ett misslyckande. Dels beror misslyckandet på begränsningar i programvara men också begränsningar i beräkningskraft. En förhoppning är att med tillräckliga mätdata från verkligheten från en av H2-modellerna så kan analysens data användas för att extrapoleras ut resultatet på de andra modellerna.

Andra delen av projektet handlar om att hitta en lösning på hur man minskar utböjningen, och därmed belastningen, på de tyngre varianterna av H2. Efter en konceptutvecklingsfas kom ett koncept fram, nämligen det att byta de något veka aluminium stängerna till stål. Detta gör dock att hela produktionen av värmeväxlaren och värmeväxlarens detaljer måste ändras eftersom stängerna i produkten inte längre kan extruderas. Tyvärr fanns det inte tid till att testa konceptet utan detta överlämnas till Heatex egna produktion.

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1 Introduction

In the introducing chapter the company, product, current problem, aims, method and limitations are presented.

1.1 Background

In today's fast and sprawling markets the competition is fierce and the market for heat exchangers is by no means different. It is a constant race for who can build the best products, by quality, customization or price, and deliver them on demand. In this fast paced pursuit certain tradeoffs must sometimes be made.

This project's focus is on Heatex H2 series of heat exchangers.

1.1.1 Heatex

Heatex was formed during the 60's and made a corporation in 1987. They have a big experience pool and have had a steady growth with an all-time high turn-over during 2013. They sell their products globally and are well known internationally within their market [1].

1.1.2 Air-to-Air Heat Exchangers

The air-to-air heat exchanger works by crossing two or more flows of air, without them coming in contact to each other, thereby making it possible to exchange heat as can be seen in figure 1.1.

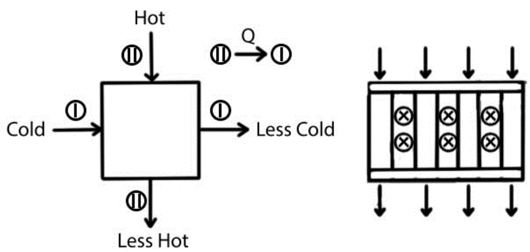


Figure 1.1 Air-to-Air Heat Exchanger

An air-to-air heat exchanger is most often used to cool a closed space but can also be used to recover heat or remove humidity from a ventilation system. This is because the heat exchanger makes it possible to constantly add new fresh air to a system and warm it without having to worry if there is anything harmful in the heating flow of air [2].

1.1.3 H2 Series of Air-to-air Heat Exchangers

The H2 series of heat exchangers are the latest series of Air-to-air products released by Heatex. The products are low weight and has improved performance compared to the earlier series, in large part thanks to the patented surface structures of the plates. The heat exchangers are always custom made to fit the requirements of the customer [3].

The heat exchanger can be ordered in lengths, shown in figure 1.2 as B, of up to 3600 mm however the product changes significantly at certain intervals. At lengths 0-1200 mm The Heat exchanger is one single module, as seen in figure 1.2. When ordered at lengths of 1201-2400 mm two heat exchanger modules are combined. When ordered at lengths of 2401-3600 three heat exchanger modules are combined. In addition the H2 can be ordered with a by-pass, a unit designed to compensate for pressure difference. When ordered with a by-pass lengths of 0-1200 mm is composed of a single heat exchanger module and a by-pass module. When ordered at lengths of 1201-2400 mm two heat exchanger modules and a by-pass, usually placed in the center, is used. When ordered at lengths 2401-3600 mm the product consists of four heat exchanger units and a by-pass unit, usually placed in the center.

The heat exchanger can also be ordered in multiple heights, shown in figure 1.2 as A, from 500 mm up to 3000 mm. A single module is however never larger in heights than 1000 mm. If a larger product is ordered several heat exchangers are clumped together with rivets and glue. Only one measurement is needed for height because the heat exchanger modules are always square.

Figure 1.2 Heatex model H2 [6]

The ends of the heat exchangers are made in steel and the beams holding them together are made in aluminum. The plates are also made in aluminum and can be ordered with varied length between plates, usually between 2-6 mm.

1.1.4 Lifting of the H2

The H2 is lifted by a tool fixed to a traverse. The tool is a thick rectangular steel plate with fixtures at the short ends that grip the heat exchangers short ends as seen in figure 1.3.

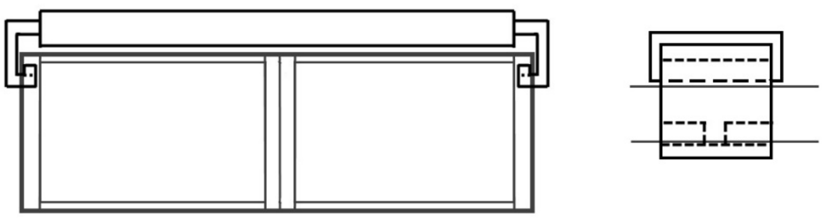


Figure 1.3 Tool for Lifting

1.1.5 Current Problems

The H2-series of heat exchangers are designed for low weight and large effective surfaces and because of this the aluminum beams are very slim. In some heavier H2 modules the aluminum beams bend and sometimes are deformed plastically, something that isn't aesthetically pleasing. Worse however is that the more fragile aluminum plating within gets plastically deformed and the glue between plating and beams gets damaged which threatens the function of the product, sometimes leading to the product being scrapped. An illustration of the bending of the H2 heat exchanger can be seen in figure 1.4.

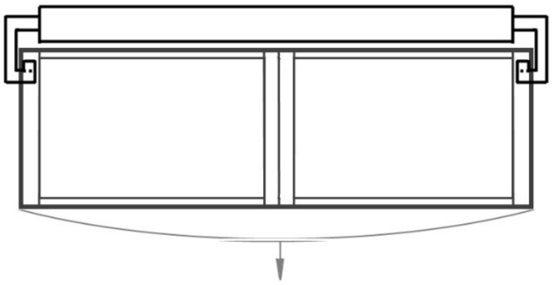


Figure 1.4 Bending of H2

1.2 Aims

The aims for this project are two-fold. The H2 Series of heat exchangers are to be analyzed and a modification is to be designed if necessary.

1.2.1 Analysis

Certain products from the H2 heat exchanger will bend when lifted. The aim for the analysis is to determine which of the current products of the H2 series are structurally sound in their present state and which ones need modification.

1.2.2 Modification

In the cases where the H2 heat exchangers need alteration, the aim for this project is to modify the heat exchangers so that they can withstand the force and momentum from lifting.

The project also aims to address these problems in a way that requires as little investment as possible from Heatex and customers. Therefore the use of present lifting equipment and support for the heat exchangers is greatly encouraged.

1.3 Method

As the aims are two-fold the method used must also be divided into two parts.

1.3.1 Analysis

The method used is getting CAD-modules from Heatex which are modified for the use of FEM-based programs. This method was strongly preferred by Heatex, so an alternative method was not pursued. The method follows some easy steps:

- Acquire the CAD-files from Heatex.
- Modify for FEM-program.
- Add boundary conditions and forces to the model
- Parameterization of length, height, weight and force.
- Simulation of the model with different parameters.
- Evaluate the results

1.3.2 Modification

The modification part of the method will loosely follow the guidelines set by Ulrich and Eppinger [4, pp. 16-17].

- Identification of needs
- Product specifications
- Concept Generation
- Concept Selection
- Detailed Design
- Assembly and Prototype Manufacture

1.4 Limitations

There are a number of limitations with the analysis. One such limitation is the hard limit on nodes enforced by ANSYS Academic Teaching Advanced, which should be 256.000 nodes but was found during the simulation to be close to 56.000 nodes. It is speculated that the number of nodes is underrepresented in the simulation as a large number of models were used and the contact nodes between models may be hidden. As a direct result of the node limit the number of elements is also limited. There is also a limitation in the computational power that can be used during simulation.

The limitations on the modification part of the project was mostly time. There were however some design limitations that needed to be regarded. These were incorporated into the needs of the product instead of listed as limitations.

2 The Aims of the Project

This chapter contains detailed information regarding the aims of the project, both in terms of the analysis and the modification.

2.1 The Aims of the Analysis

The goals set for the analysis part of the project is to divide the current modules of the H2-series of heat exchangers into two groups based on durability. The first group is the ones that are in no need of modification at the present time.

The second group is those that are deemed not to meet the current standards for sturdiness, those that cannot, in their present state, be built in Heatex production facility and sent out to customers.

The analysis aims to determine which current products belong to which group and to set a limit for future reference.

2.2 The Aims of the Modification

The aim of the modification part of the project is to determine whether there is a viable solution in regards to the second group of products in the analysis. This second group is determined by if the products are sturdy enough to safely be lifted from the floor in Heatex production facility, delivered to customer and lifted to the products space of operation without damage to either product or personnel handling the lifting equipment.

A detailed schematic of the modification is to be created and a prototype made. The prototype of the modification should be tested to see if the present problem has been resolved.

3 Method of Analysis of H2-series Heat Exchanger

The following chapter will explain in more detail the method used in analyzing the H2-series of heat exchangers.

3.1 Method Used in Analyzing the H2-Series

The method used was getting CAD-modules from Heatex which are then modified for the use of FEM-based programs. This method was strongly preferred by Heatex, so an alternative method was not pursued. The method follows some easy steps:

- Acquire the CAD-files from Heatex.
- Modify for FEM-program.
- Add boundary conditions and forces to the model
- Parameterization of length, height, weight and force.
- Simulation of the model with different parameters.
- Evaluate the results

3.1.1 Acquire the CAD-files from Heatex

The CAD-files for one model will be supplied by e-mail.

3.1.2 Modify for FEM-program

This means removing holes, fillets and complicated features for the models while changing the stiffness matrix and weight as little as possible. This is necessary for cutting down the number of nodes and elements in the FEM-model which is limited by the license used.

This method does have a drawback however. Without fillets the FEM-program will with increased likelihood calculate stress concentrations in the model which aren't present in the real product. This makes any stress related maximum not reliable for evaluation purposes. Instead of using stress as a factor the strain should be a more reliable source of information.

For further confirmation purposes if the model acts as the real world product the maximum distance the lowest part of the model travels is calculated, denoted δ in figure 3.1. The distance that the heat exchanger bends is easily measured on Heatex production site. This will give an indication of the models difference from the real product.

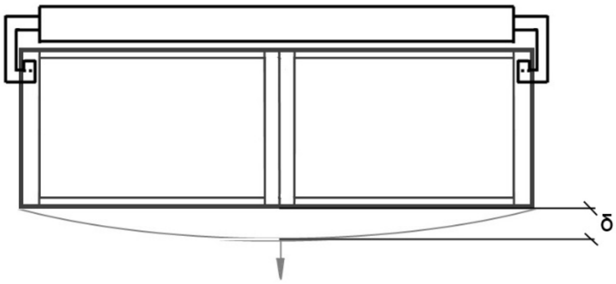


Figure 3.1 Bending Distance

3.1.3 Add Boundary Conditions and Forces to the model

The boundary conditions are added and the forces are added as well.

3.1.4 Parameterization of Length, height, Weight and Force

The time to create CAD-files and set boundary conditions and forces would be substantial if every model of Heatex H2-series would be done by hand. The method of parameterization was chosen instead as it makes it possible to solve many different models without having to change small details manually.

3.1.5 Simulation of the Model with Different Parameters

The simulation is performed with a large number of different parameters. The parameters will be chosen so that a sufficiently large number of products can be covered. Some of the parameters are taken from Heatex own product search engine Heatex Select [5].

3.1.6 Evaluate the Results

An evaluation of the data will be made so that the model is similar to tests on actual products. If the models data is acceptable the data will be used to sort the products into the two categories of no modification needed versus modification needed.

4 Method of Modification of H2-series Heat Exchanger

The modification part of the method will loosely follow the guidelines set by Ulrich and Eppinger in Product Design and Development *[4].*

4.1 Identification of needs

The projects aim is for Heatex to be able to deliver their product without assembly on site, which means the product shouldn't be modified in a way that changes the way the customer uses the product. The identification of needs will be conducted with Heatex in mind, as their current product meets the expectations of customers, and is conducted on site with an observation of the product under lifting conditions and informal interviews with the production crew and engineers knowledgeable of the problem with the current product.

4.2 Product Specifications

Product specifications will be established after the identification of needs. After a set of metrics has been prepared the ideal and acceptable target values will be set.

Usually there is also a step of collecting benchmarking data from competitors. This part has been removed as a quick study of competitors revealed nothing of their mechanical strengths and weaknesses. The information regarding heat exchangers to be readily found only pertains to their effectiveness or outer measurements.

4.3 Concept Generation

The Five-Step Method will be loosely followed and can be found in Ulrich and Eppingers *Product Design and Development* [4, chapter 6]. Step two and three, external and internal search were however switched around by request from Heatex engineers as they thought it may be interesting to see what solutions could be found without the opinions of the engineers polluting the concept generation. The Five-Step Method is as follows:

4.3.1 Clarify the Problem

The objective of the modification is to strengthen the structural integrity of the H2-series heat exchangers. As such the problem is clear enough and will not be further clarified.

4.3.2 Search Externally

Many informal interviews will be had with experts on Heatex production facility.

As previously noted, benchmarking for purely mechanical properties of this type of product is difficult and will not be pursued.

The modification will most likely be mechanically simple and as such is with high probability a non-patentable type.

4.3.3 Search Internally

The internal search is the more creative part of the concept generation. First all the concepts that were readily apparent were listed and sketched out. One largely successful method of the internal concept generation is brainstorming. One brainstorming session was done with the author and a fellow student to add to the first list of concepts.

A large number of product concepts should be generated. These however are almost always sorted into viable and unviable concepts so as to maximize the effectiveness of the concept selection. The unviable group should however be utterly unviable, sometimes the concepts that at first glance seem unviable are sometimes just unfeasible and may lead to great concepts.

4.3.4 Explore Systematically

The concepts generated should now be combined. This projects aims are mechanically simplistic in nature and a limited combination of concepts is to be expected. Remaining unviable or unfeasible concepts should also be pruned.

4.3.5 Reflect on the Solutions and the Process

In a large project with a large team the reflect step of the Five-Step Method can be very important. The project at hand is not that large and the entirety of the team consists of one person making this step somewhat redundant. The process and solutions will be reflected on but will be part of the discussion section of this thesis.

4.4 Concept Selection

The method chosen for concept selection is a combination of Ulrich and Eppingers Concept Scoring and what they themselves call External Decision. [4, p. 125, Exhibit 7-7]. There are some concepts that aren't obviously unfeasible for the project team that experienced engineers can find faults in and the concepts will be discussed with Heatex own engineers prior to Concept Scoring as to raise overall effectiveness.

4.5 Detailed Design

The Detailed Design is the creation of a detailed mechanical drawing outlining the exact dimensions of the finished products parts and notes regarding production.

4.6 Assembly and Prototype Manufacture

The assembly is a drawing of the finished product assembled with detailed dimensions and notes regarding production. Most often a prototype is manufactured so as to see if the finished concept works as intend.

5 Analysis Results

The Analysis Result chapter will describe what was done as well as the result of the analysis section. Deviations from the method will also be explained.

5.1 Analysis

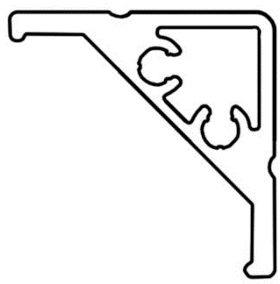
The analysis was carried out according to the method chosen.

5.1.1 Acquire the CAD-files from Heatex

A single parasolid-file was acquired from Heatex detailing a H2-series heat exchanger. A parasolid-file only contains solids and/or surface. To make later steps more effective the product was recreated in a CAD-based program so that certain features could be migrated to the FEM-type program.

The aluminum beams of the H2-series heat exchangers only change their length geometry based on product and so the geometry remains constant. Because of this the aluminum beams can easily be recreated in any CAD-based program from the geometry found in the parasolid-file. The geometry of the aluminum beams can be seen in figure 5.1.

Figure 5.1 The Profile of the Aluminum Beam



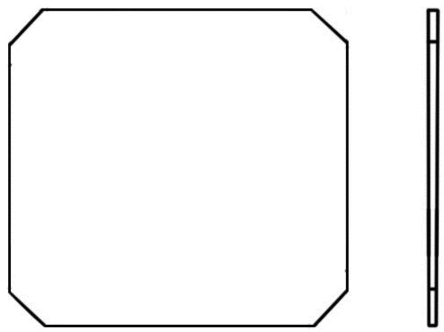
The frames and by-pass frames are also basic geometries. They change more according to product however. For the small heat exchangers the thickness of the sheet metal changes between 1-1.5mm. The frames are squares with sides according to product chosen.

The by-pass measurements change according to the customers wishes, but Heatex recommends certain standard by-passes for certain products and these were chosen for the model. Data for the by-passes, as well as total weight, can be found in Heatex Select, Heatex own calculating tool [5].

The plates in the heat exchanger however proved difficult to model because of two things.

The heat exchanger plating is a large part of what makes the heat exchanger operate at high efficiency as the complex face of the plating makes the airflow turbulent. This makes modelling difficult. To make matters worse the detailed schematics are licensed by Heatex, which means they are restricted. They can however be easily replaced with single plates with simple measurements. The simplified Aluminum plate can be seen in figure 5.2.

Figure 5.2 Aluminum Plate

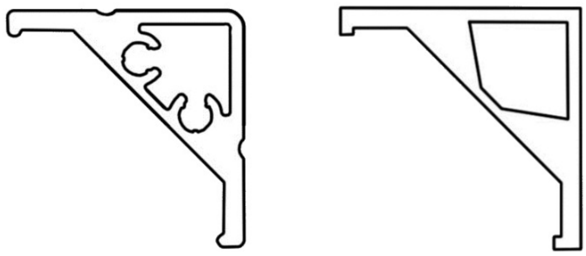


The important part of creating the new CAD-models was to make them robust in terms of the parameterized lengths and heights, as well as making the final assembly robust. To make a parameterized model with a different number of parts proved exceedingly difficult in a single assembly.

5.1.2 Modify for FEM-program

According to the method chosen the process was started by removing holes, fillets and complicated features for the models. The CAD models made were first very similar to the actual H2 product. They were then simplified so that the meshing would be less complex, thereby requiring fewer nodes. This did however not suffice. The plating in the model had to be removed entirely, which does somewhat effect the stability of the product. All rivets were also removed. To minimize changing the stiffness matrix and weight the aluminum beam was modified with some added material as can be seen in figure 5.3.

Figure 5.3 Unmodified and Modified Aluminum Beam



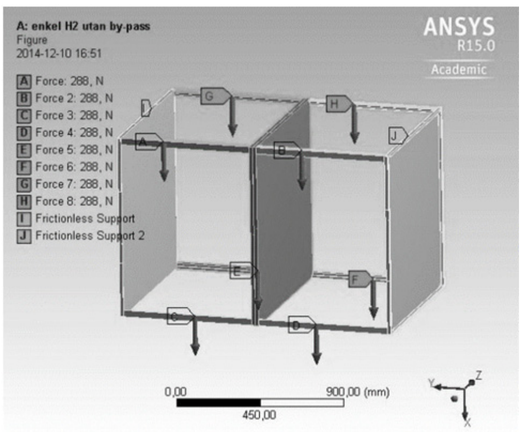
5.1.3 Add Boundary Conditions and Forces to the Model

The plates made the model somewhat complicated. The number of thin elements needed to mesh the model proved too large with the plates remaining and so needed to be removed. This posed a problem with the weight calculation of the model as the total weight of the model would not get calculated by itself. The solution chosen was to take the total weight of the product from Heatex Select and distribute that weight over the aluminum beams. Testing showed that the overall difference should be very small.

The Boundary Conditions proved to be simple enough. The on-site analysis concluded that the heat exchangers were not lifted at a rapid or sudden pace. This means the boundary conditions were that of a free-hanging product only under influence of its own weight. As such the model was fixated in its z-axis over two areas that coincide with the contact between the product and the lifting tool (I and J in figure 5.4). The FEM-model with forces and constraints can be seen below in figure 5.4.

To lessen the computational power necessary the surfaces between parts of the CAD assembly were not simulated as surfaces held together by rivets and friction, but by assuming the entire assembly being one part. This will severely stiffen the model. The weight was then added as forces working on the frame.

Figure 5.4 Boundary Conditions



5.1.4 Parameterization of Length, height, Weight and Force

The programs used in this project were Creo Parametric and Ansys which function as a cohesive unit. The geometry of the modified models were made parameters in Creo Parametric and then, when imported to Ansys, were recognized as Ansys parameters. The forces effecting the model were also made parameters.

The total number of Ansys projects were, as previously stated, four. The H2-series comes as a number of different products depending on the customers' needs. The parameters chosen for this project was frame-size of the square steel plates at the ends of every heat exchanger module and length of the aluminum beams that depend on the length of the finished project, as described in the introduction.

As there had been no problems reported regarding the smaller framed H2 products the analysis was focused on frames 750, 850 and 1000 mm as they are the biggest single heat exchangers in the H2 product-line.

The length of the products vary greatly however, often down to increments of 10 mm. The shorter products were also deemed functional at current geometries and so were not prioritized in the simulation. That leaves the products that are longer than 1200mm. To cut down on the number of simulations needed length increments of 100 mm were chosen.

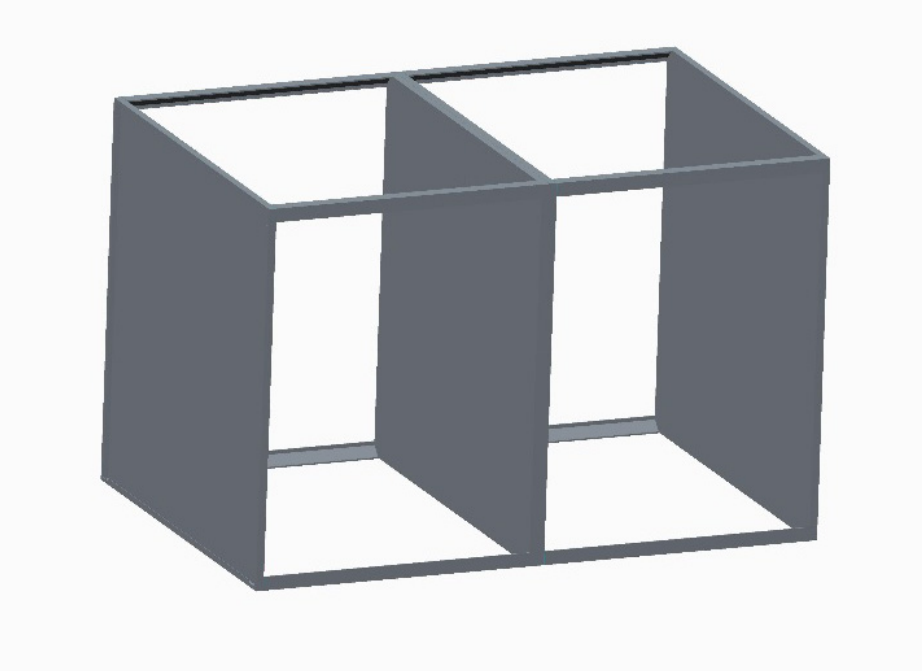
The product changes its parts at certain lengths. At 1201-2400 mm the product has two heat exchanger modules with or without by-pass. At 2401-3600 mm the product without by-pass is a combination of three heat exchanger units and with by-pass four. A table of parameters was made in Microsoft Excell and then imported to Ansys parameter table and can be seen in Evaluate Results section below.

This means that the total number of simulations for each Ansys project was 39, which makes the total number of simulations 156. The model does however support the calculation of a heat exchanger with arbitrary length, frame and by-pass.

The solution chosen was to have one assembly each for every product with increased parts usage. This resulted in four base models as can be seen below.

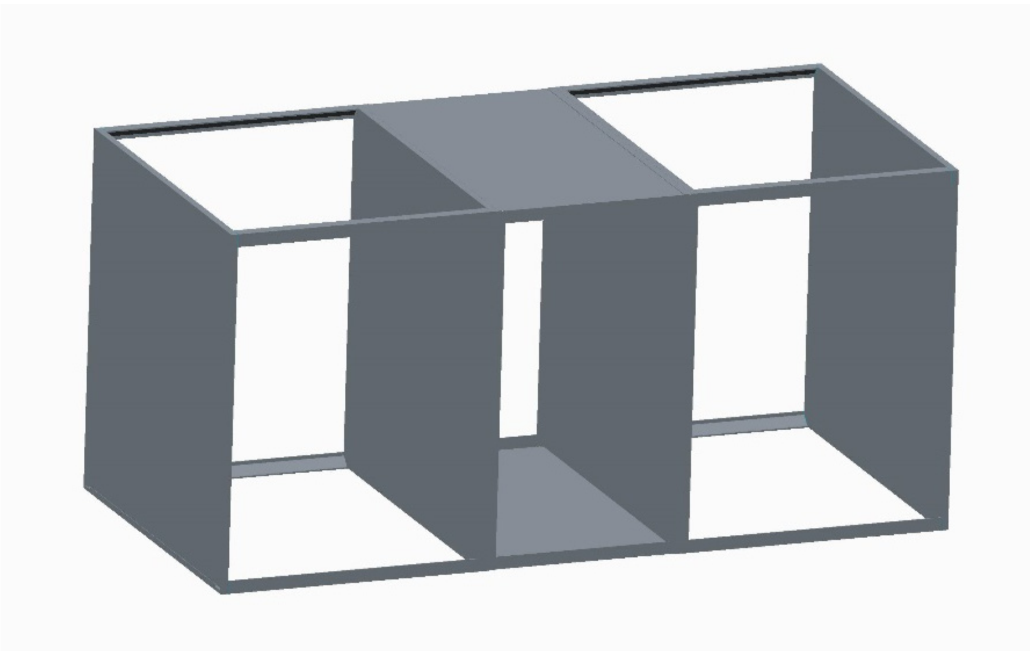
The first simulation model featuring two heat exchanger modules can be seen in figure 5.5.

Figure 5.5 Simulation Model 1



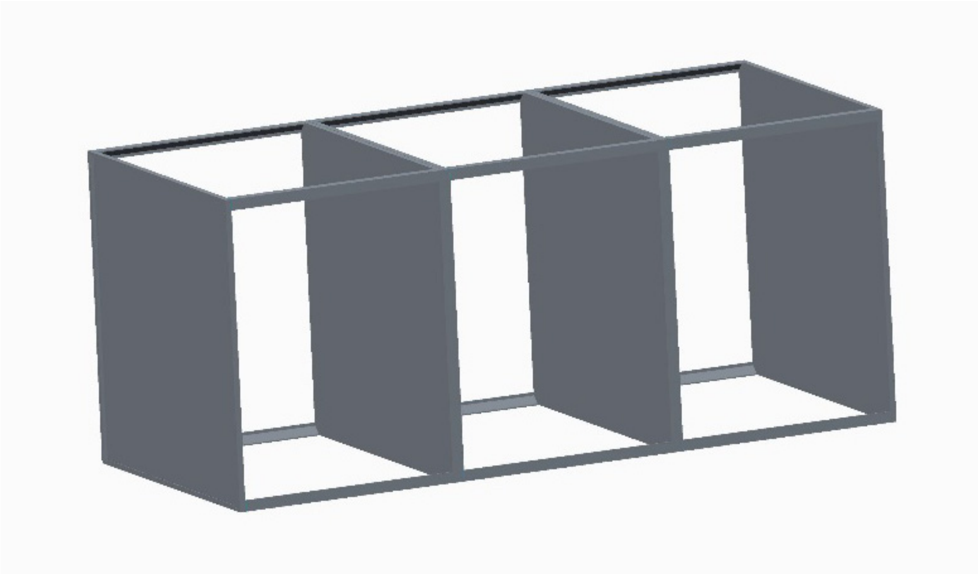
The second simulation model featuring two heat exchanger models and a by-pass unit can be seen in figure 5.6.

Figure 5.6 Simulation Model 2



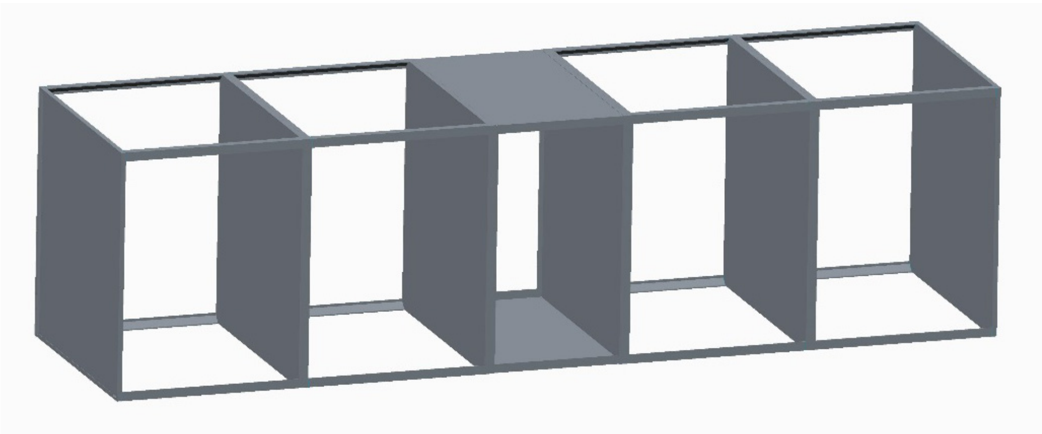
The third simulation model features three heat exchanger modules as can be seen in figure 5.7.

Figure 5.7 Simulation Model 3



And lastly the fourth simulation model featuring four heat exchanger modules and a by-pass unit can be seen in figure 5.8.

Figure 5.8 Simulation Model 4



5.1.5 Simulation of the Model with Different Parameters

The simulation had to be remade numerous times because of small errors, either in the table of parameters or by models not robust enough, but was ultimately successful. The simulation itself of the four projects takes approximately 3 hours depending on computer calculation speed.

5.1.6 Evaluate Results

The results do seem likely with no numbers outside a typical span for stress and strain. The results of the analysis must be compared to measured numbers. The easiest way to do this would be to measure the deformation from flat to hanging position. The maximum deformation was added as an out-parameter. All parameters in the tables used will be presented on the next page.

The in-parameters are:

- Frame — The side of the square frame.
- Alulength — The length of the aluminum beams.
- Force — The force applied to each aluminum beam.
- By-Pass — The length of the by-pass module.

The out-parameters are:

- MPa — The maximum von Mises stress.
- mm — The maximum deformation.
- Strain — The maximum von Mises strain.

Three values were added as to make the table more easily read:

- Length — The total length of the heat exchanger
- % of Yield Strain
- % of Yield Stress

The tables 5.1-5.4 below are the in-parameters used and out- parameters received from the FEM-program.

Table 5.1 The parameter table for H2 with length 1200-2400 without by-pass

Frame	Alulength	Force	MPa	mm	Strain	Length	% of yield strain	% of Yield Stress (high)
750	560	119	25,28752481	0,642950064	0,03576%	1200	11,19814%	11,494%
750	610	143	32,70195155	0,970053249	0,04637%	1300	14,52119%	14,865%
750	660	152	37,36436977	1,150157034	0,05289%	1400	16,56480%	16,984%
750	710	161	39,08658758	1,382737223	0,05522%	1500	17,29449%	17,767%
750	760	168	43,26098964	1,743449272	0,06111%	1600	19,13876%	19,664%
750	810	177	48,23584485	2,195379052	0,06812%	1700	21,33257%	21,925%
750	860	185	52,60730216	2,696534154	0,07430%	1800	23,26886%	23,912%
750	910	194	56,43326553	3,202658033	0,07975%	1900	24,97658%	25,651%
750	960	202	62,21980889	3,885412423	0,08793%	2000	27,53795%	28,282%
750	1010	211	67,92979194	4,693103141	0,09599%	2100	30,06206%	30,877%
750	1060	219	73,0287089	5,250072521	0,10315%	2200	32,30486%	33,195%
750	1110	228	74,69941729	6,246884058	0,10557%	2300	33,06324%	33,954%
750	1160	237	80,68502012	7,385006528	0,11401%	2400	35,70447%	36,675%
850	560	170	33,7085428	0,820674558	0,04769%	1200	14,93416%	15,322%
850	610	180	38,37208919	1,093674044	0,05427%	1300	16,99716%	17,442%
850	660	191	43,52803343	1,436551177	0,06155%	1400	19,27784%	19,785%
850	710	202	49,67919917	1,666551543	0,07028%	1500	22,00893%	22,581%
850	760	212	63,25552484	2,25151201	0,08013%	1600	25,09488%	28,753%
850	810	223	71,67411317	2,826978212	0,08899%	1700	27,87125%	32,579%
850	860	234	83,62441267	3,550162083	0,09807%	1800	30,71221%	38,011%
850	910	244	92,52003324	4,332830311	0,10715%	1900	33,55609%	42,055%
850	960	255	102,251947	5,258296475	0,11705%	2000	36,65743%	46,478%
850	1010	266	87,10449208	5,912151519	0,12302%	2100	38,52701%	39,593%
850	1060	277	95,6820455	7,072343232	0,13514%	2200	42,32238%	43,492%
850	1110	287	96,94059867	8,348259327	0,13646%	2300	42,73528%	44,064%
850	1160	298	105,2356285	9,83945457	0,14701%	2400	46,03994%	47,834%
1000	560	231	46,04763303	0,953115373	0,06519%	1200	20,41668%	20,931%
1000	610	245	52,47731687	1,281705867	0,07428%	1300	23,26182%	23,853%
1000	660	259	61,95580713	1,755561028	0,08760%	1400	27,43373%	28,162%
1000	710	274	69,63574968	2,276264348	0,09844%	1500	30,82957%	31,653%
1000	760	288	77,55107692	2,896008524	0,10958%	1600	34,31779%	35,250%
1000	810	303	87,28572782	3,645617948	0,12333%	1700	38,62571%	39,675%
1000	860	317	95,96891298	4,516933093	0,13558%	1800	42,46261%	43,622%
1000	910	331	94,75230936	5,22381047	0,13390%	1900	41,93539%	43,069%
1000	960	346	103,8209326	6,372830171	0,14670%	2000	45,94338%	47,191%
1000	1010	360	112,9730868	7,680432087	0,15961%	2100	49,98774%	51,351%
1000	1060	375	115,5630933	9,189822423	0,16335%	2200	51,15814%	52,529%
1000	1110	389	124,7831122	10,89861112	0,17635%	2300	55,23007%	56,720%
1000	1160	403	134,345774	12,83497556	0,18984%	2400	59,45293%	61,066%

Table 5.2 The parameter table for H2 with length 2400-3600 without by-pass

Frame	Alulength	Force	MPa	mm	Strain	Length	% of yield strain	% of Yield Stress (high)
750	760	168	78,01247104	3,884198782	0,10988%	2400	34,41139%	35,460%
750	793	174	84,85830588	4,523090101	0,11952%	2500	37,43110%	38,572%
750	827	180	90,82180359	5,25296274	0,12792%	2600	40,06160%	41,283%
750	860	186	98,16607176	6,050268855	0,13826%	2700	43,30117%	44,621%
750	893	191	103,9326284	6,89647392	0,14638%	2800	45,84480%	47,242%
750	927	197	111,8468969	7,894004656	0,15753%	2900	49,33579%	50,839%
750	960	202	117,9921436	8,922974184	0,16619%	3000	52,04647%	53,633%
750	993	207	125,676936	10,05147073	0,17701%	3100	55,43624%	57,126%
750	1027	213	132,9103584	11,36463108	0,18720%	3200	58,62691%	60,414%
750	1060	218	141,0305735	12,71291266	0,19863%	3300	62,20875%	64,105%
750	1093	224	148,5750858	14,23772078	0,20926%	3400	65,53664%	67,534%
750	1127	230	157,9276902	15,93835205	0,22243%	3500	69,66208%	71,785%
750	1160	235	165,2010418	17,66503128	0,23268%	3600	72,87037%	75,091%
850	760	212	101,7353377	5,200598577	0,14329%	2400	44,87557%	46,243%
850	793	219	110,5236898	6,029636595	0,15567%	2500	48,75213%	50,238%
850	827	226	117,8506125	6,973556224	0,16599%	2600	51,98404%	53,568%
850	860	233	127,250708	8,001100441	0,17923%	2700	56,13043%	57,841%
850	893	240	134,9767845	9,134554393	0,19011%	2800	59,53841%	61,353%
850	927	247	145,1070464	10,41790207	0,20438%	2900	64,00688%	65,958%
850	960	254	153,3419153	11,79392848	0,21597%	3000	67,63930%	69,701%
850	993	261	163,962679	13,30496848	0,23093%	3100	72,32413%	74,528%
850	1027	268	172,8334512	14,99263458	0,24343%	3200	76,23703%	78,561%
850	1060	275	184,0657056	16,79528418	0,25925%	3300	81,19160%	83,666%
850	1093	282	193,3113513	18,75104025	0,27227%	3400	85,26986%	87,869%
850	1127	289	205,2919174	20,92799631	0,28914%	3500	90,55450%	93,315%
850	1160	296	215,0425333	23,22802538	0,30288%	3600	94,85551%	97,747%
1000	760	288	138,0510822	7,05090535	0,19444%	2400	60,89449%	62,750%
1000	793	298	149,6172533	8,188667314	0,21073%	2500	65,99634%	68,008%
1000	827	307	159,2569508	9,455926206	0,22431%	2600	70,24843%	72,390%
1000	860	317	171,6031009	10,86641376	0,24169%	2700	75,69432%	78,001%
1000	893	327	182,2960698	12,42549916	0,25676%	2800	80,41101%	82,862%
1000	927	336	195,0249231	14,14887967	0,27468%	2900	86,02572%	88,648%
1000	960	346	206,4011352	16,04166243	0,29071%	3000	91,04378%	93,819%
1000	993	355	219,7073905	18,06994351	0,30945%	3100	96,91319%	99,867%
1000	1027	365	231,7607614	20,33590083	0,32642%	3200	102,22994%	105,346%
1000	1060	375	246,6432588	22,87125399	0,34738%	3300	108,79462%	112,111%
1000	1093	384	258,7189386	25,50042316	0,36439%	3400	114,12122%	117,600%
1000	1127	394	274,3887677	28,49499185	0,38646%	3500	121,03320%	124,722%
1000	1160	403	286,9092737	31,51047943	0,40410%	3600	126,55602%	130,413%

Table 5.3 The parameter table for H2 with length 1200-2400 with by-pass

Frame	Alulength	By-Pass	Force	MPa	mm	Strain	Length	% of yield strain	% of Yield Stress (high)
750	460	200	116	22,6140063	0,389660022	0,02727%	1200	8,54012%	10,279%
750	500	220	124	24,74844202	0,511022596	0,03192%	1300	9,99651%	11,249%
750	540	240	130	27,61162283	0,651342718	0,03549%	1400	11,11549%	12,551%
750	580	260	155	35,56577062	0,93235871	0,04579%	1500	14,34154%	16,166%
750	620	280	162	39,82254805	1,160823901	0,05144%	1600	16,10867%	18,101%
750	660	300	168	44,03389509	1,414926908	0,05599%	1700	17,53373%	20,015%
750	700	320	175	48,78795517	1,721579167	0,06216%	1800	19,46872%	22,176%
750	745	330	184	54,66474875	2,132528762	0,06864%	1900	21,49718%	24,848%
750	780	360	190	59,23932839	2,489432904	0,07468%	2000	23,38899%	26,927%
750	825	370	197	65,09905122	2,998198977	0,08209%	2100	25,71065%	29,590%
750	865	390	205	71,07528417	3,543235088	0,08901%	2200	27,87747%	32,307%
750	905	410	212	77,03351724	4,140329897	0,09671%	2300	30,28830%	35,015%
750	945	430	219	83,13887651	4,807176704	0,10342%	2400	32,39059%	37,790%
850	460	200	146	24,36550939	0,494822658	0,03295%	1200	10,31999%	11,075%
850	500	220	155	27,37508933	0,644920445	0,03856%	1300	12,07518%	12,443%
850	540	240	163	30,59642285	0,823725262	0,04309%	1400	13,49612%	13,907%
850	585	250	194	39,86247369	1,202271923	0,05614%	1500	17,58338%	18,119%
850	625	270	202	44,80555417	1,48627808	0,06311%	1600	19,76378%	20,366%
850	665	290	212	49,41133581	1,832768061	0,06959%	1700	21,79540%	22,460%
850	705	310	221	55,10874786	2,227171814	0,07762%	1800	24,30853%	25,049%
850	745	330	231	60,19579038	2,693877354	0,08478%	1900	26,55243%	27,362%
850	785	350	239	66,19468767	3,201959027	0,09323%	2000	29,19855%	30,088%
850	825	370	248	72,72295188	3,792036428	0,10243%	2100	32,07818%	33,056%
850	870	380	258	78,94258001	4,549374935	0,11119%	2200	34,82166%	35,883%
850	910	400	266	85,73650794	5,294539008	0,12076%	2300	37,81847%	38,971%
850	950	420	276	92,09071553	6,171121364	0,12971%	2400	40,62132%	41,859%
1000	465	190	197	31,28291974	0,65719772	0,04406%	1200	13,79893%	14,220%
1000	505	210	210	36,55665793	0,866097431	0,05149%	1300	16,12518%	16,617%
1000	545	230	222	41,23108748	1,110618584	0,05807%	1400	18,18708%	18,741%
1000	590	240	262	52,69422616	1,606522649	0,07422%	1500	23,24349%	23,952%
1000	630	260	275	59,42226171	2,001118313	0,08369%	1600	26,21123%	27,010%
1000	675	270	288	65,77416418	2,510349511	0,09264%	1700	29,01306%	29,897%
1000	715	290	300	72,99821061	3,044674522	0,10281%	1800	32,19959%	33,181%
1000	755	310	313	80,84960995	3,678231985	0,11387%	1900	35,66286%	36,750%
1000	795	330	324	87,59618472	4,378054076	0,12337%	2000	38,63878%	39,816%
1000	840	340	337	96,62816149	5,265551238	0,13610%	2100	42,62279%	43,922%
1000	880	360	351	104,6723779	6,218814597	0,14743%	2200	46,17111%	47,578%
1000	925	370	363	114,0305149	7,360857469	0,16061%	2300	50,29899%	51,832%
1000	965	390	375	123,5840181	8,546680344	0,17406%	2400	54,51305%	56,175%

Table 5.4 The parameter table for H2 with length 2400-3600 with by-pass

Frame	Alulength	By-Pass	Force	MPa	mm	Strain	Length	% of Yield Strain	% of Yield Stress (high)
750	462,5	390	115	43,30170761	1,197059964	0,06099%	2400	19,10043%	19,683%
750	482,5	410	119	48,31937821	1,431068276	0,06806%	2500	21,31373%	21,963%
750	502,5	430	123	51,65480183	1,64847921	0,07275%	2600	22,78499%	23,479%
750	522,5	450	126	54,95933385	1,883193304	0,07741%	2700	24,24263%	24,982%
750	545	460	131	59,23175943	2,194140833	0,08343%	2800	26,12720%	26,924%
750	565	480	142	66,95196197	2,623480657	0,09430%	2900	29,53259%	30,433%
750	585	500	145	70,33355569	2,941569124	0,09906%	3000	31,02421%	31,970%
750	605	520	149	74,58236262	3,321445727	0,10505%	3100	32,89836%	33,901%
750	625	540	153	78,70791221	3,728292215	0,11086%	3200	34,71815%	35,776%
750	645	560	156	82,34551346	4,085260731	0,11598%	3300	36,32270%	37,430%
750	665	580	160	87,9837802	4,626389503	0,12392%	3400	38,80975%	39,993%
750	685	600	164	92,97527843	5,16470718	0,13095%	3500	41,01150%	42,261%
750	705	620	167	96,82979225	5,688987033	0,13638%	3600	42,71173%	44,014%
850	465	380	145	58,05341284	1,548076176	0,08177%	2400	25,60743%	26,388%
850	487,5	390	150	63,24745636	1,831181911	0,08908%	2500	27,89853%	28,749%
850	507,5	410	155	67,52465279	2,108223455	0,09511%	2600	29,78520%	30,693%
850	527,5	430	159	71,48004725	2,398341778	0,10068%	2700	31,52993%	32,491%
850	547,5	450	164	76,165523	2,739741602	0,10728%	2800	33,59670%	34,621%
850	567,5	470	178	87,50683701	3,281870255	0,12325%	2900	38,59937%	39,776%
850	587,5	490	183	92,35231049	3,699738016	0,13007%	3000	40,73671%	41,978%
850	607,5	510	188	97,55155637	4,166414923	0,13740%	3100	43,03010%	44,342%
850	630	520	192	102,7976073	4,708840429	0,14479%	3200	45,34414%	46,726%
850	650	540	197	110,4621531	5,262330422	0,15558%	3300	48,72498%	50,210%
850	670	560	201	115,5407512	5,833781144	0,16273%	3400	50,96516%	52,519%
850	690	580	206	121,3452946	6,487337377	0,17091%	3500	53,52555%	55,157%
850	710	600	210	126,6452897	7,162559836	0,17837%	3600	55,86338%	57,566%
1000	472,5	350	198	72,09216429	1,975119674	0,10154%	2400	31,79994%	32,769%
1000	492,5	370	204	77,51489673	2,290926106	0,10918%	2500	34,19191%	35,234%
1000	515	380	210	82,87667034	2,667239606	0,11673%	2600	36,55699%	37,671%
1000	535	400	217	88,59273264	3,066417158	0,12478%	2700	39,07836%	40,269%
1000	557,5	410	224	96,62435651	3,55653148	0,13609%	2800	42,62112%	43,920%
1000	577,5	430	243	107,996561	4,247735866	0,15211%	2900	47,63741%	49,089%
1000	597,5	450	250	114,3805353	4,806336378	0,16110%	3000	50,45339%	51,991%
1000	620	460	256	120,9400196	5,460184578	0,17034%	3100	53,34678%	54,973%
1000	640	480	262	127,337078	6,114913667	0,17935%	3200	56,16853%	57,880%
1000	660	500	269	136,3978179	6,851780577	0,19211%	3300	60,16524%	61,999%
1000	682,5	510	275	143,5456545	7,701670204	0,20218%	3400	63,31815%	65,248%
1000	702,5	530	281	150,4303236	8,54340018	0,21187%	3500	66,35499%	68,377%
1000	722,5	550	287	157,4819832	9,451818638	0,22181%	3600	69,46549%	71,583%

5.2 Comparison of Results

Looking at the data for comparison makes it clear that the analysis was a failure. The results did not correspond particularly well with real life testing. If testing of one product of H2-series can gather sufficient measuring data the results can hopefully be used to extrapolate between real life data and the other models of H2. The comparative data can be found below in table 5.5.

Table 5.5 Comparison of Results Data

Product	Measured (mm)	Analysis (mm)	A/M
H2A0750-1200-025-2EOO-2-0-0-1200	3	0,64	21%
H2A1000-1220-030-2EOO-2-2-0-1220	11	0,95	9%
H2A1000-1220-030-2EOO-2-2-0-1220	14	0,95	7%
H2A1000-1220-030-2EOO-2-2-0-1220	16	0,95	6%
H2A1000-1250-030-2EOO-2-2-0-1250	15	1,12	7%
H2A1000-1250-030-2EOO-2-2-1-1450	20	0,75	4%
H2A1000-1257-045-1ECI-2-2-5-1482 PT	18	0,75	4%
H2A1000-1440-060-2EOO-2-2-0-1440	15	2,00	13%
H2A1000-1730-030-2EOO-2-3-0-1730	39	3,65	9%

6 Modification Results

The results of the modification part of the project will be presented in the following chapter. Deviations from the method will also be explained.

6.1 Identification of Needs

The identification of needs was done according to the method chosen. A number of informal interviews with engineers and operators at Heatex production site revealed a number of needs and desires. The needs were ground down to the following with * denoting the more important needs:

1. The heat exchanger can be lifted as a whole*
   One of the reasons for the project was that Heatex wants to be able to build their products in their entirety and then lift them. Therefore this is an important need.
2. The heat exchanger can be lifted without plasticity*
   There is no worries for flexing in the product as it won't be lifted more than a couple of times, however the flexing must remain elastic.
3. The heat exchanger can be lifted safely*
   Safety is always an important part of a product needs, and especially when a product is as heavy as the larger heat exchangers in the H2-series.
4. The heat exchanger can be lifted with existing tools
   The lifting with existing tools was more of a desire than a need and as such is not as important. The need will however be recorded as it was not only a desire from Heatex, but of their customers as well.
5. The heat exchanger is easy to produce
   The ease of production is a strong want and has been recorded as such. It effects the production crew as well as pricing. In this need was also incorporated the wants of producing the product with on-site equipment and already used materials. This want, however reasonable, is however low in importance as otherwise it will severely hinder concept generation.
6. The heat exchanger is low cost
   The cost is almost always a strong want in any profit-driven company and Heatex is no different. The product can however handle a steeper price if the handling of the product gets easier or safer.

7. The heat exchanger is well isolated*
   The H2-series are air-to-air flow heat exchangers and need to be isolated from the outside air and also the crossing flows need to be isolated from each other to guarantee a safe product.
8. The heat exchangers effective area is retained when installed
   The effective area is the area where the plates are. The more a concept blocks the airflow through this area the less overall effect the heat exchanger can give. The reason this need isn't ranked as important is that permanent modifications which have a small area of surface that blocks the effective area can be allowed. This will not have any effect however for non-permanent fixtures.
9. The heat exchangers outer measurements are retained
   The product line is already in use today by a number of companies and as such Heatex is very weary of changing the outer measurements of the product more than 1-3 mm.
10. The heat exchangers inner measurements that fixate the plates are retained*
    Much of the cost of research and development for this product was accrued in the development of the aluminum plating that lines the inside of the heat exchangers. To change the geometry of these plates was greatly discouraged and because of that this need was rated highly.
11. The heat exchangers rivets will not deform plastically
    There is some worry over the aluminum rivets that fasten the frames together. They have a sub-optimal placing and may be deformed, or even break, during heavy lifting.

6.2 Product Specifications

A table of specifications where determined after the needs had been sorted as can be seen below in table 6.1.

Table 6.1 Product Specifications

Metric No.	Need Nos.	Metric	Imp.	Units
1	1, 2	Maximum strain allowed through aluminum frame	5	%
2	1, 2	Maximum Stress allowed through aluminum frame	5	Mpa
3	3	The safety standards at Heatex are met	5	Binary
4	4	Can be lifted with current toolset	3	Binary
5	5	Can be produced with current toolset	1	Binary
6	5	Can be produced with current materials	1	Binary
7	5	Does not overtly strain production personell	4	Subj.
8	6	Low cost	4	SEK
9	7, 10	Gap difference for glue between plates and frame	5	mm
10	7, 10	Frame edge inwards follow specified geometry	5	Binary
11	8	Effective area blockage	3	%
12	9	Length difference between old and new	5	mm
13	9	Width Differance between old and new	5	mm
14	11	Placement of screws is safer	3	Subj.
15	11	Maximum strain allowed through aluminum rivets	4	%
16	11	Maximum Stress allowed through aluminum rivets	4	MPa

6.3 Concept Generation

As mentioned in the method choice for the concept generation the five steps from Ulrich and Eppinger was cut down to three steps and some steps were switched in order.

6.3.1 Search Internally

The search internally was done during two different occasions. The first occasion was conducted with only the author of the thesis, the second with the author and a fellow student. After some concepts were deemed implausible the rest of the concepts were sorted to different groups and sub-groups of solutions.

- Changing of the frame
    - Changing the materials
    - Changing the geometry of the aluminum frames
    - Adding supporting beams within the aluminum frames
- Changing the lifting tools
    - Modifying the current tool
    - Lifting with cable
    - Lifting with rope
- Supporting the frame
    - Supporting beams
    - Strengthening the corners or connections
    - Lifting with pallet
    - Lifting in a separate frame
    - Lifting with forklift

Many of these concepts are self-explanatory but, for the purpose of clarity, will be described.

6.3.1.1 Changing the Materials

The weak part of the construct presently is the aluminum beams that are part of the frame. One of the first things should thus be to see if they can be changed in any way. One way to make the overall construct stronger would be to change materials from aluminum to a material with better suited properties.

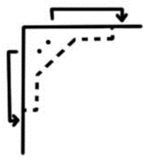
The two biggest reasons for having an aluminum frames is that it can be extruded easily and cut into the correct lengths on-site and it's resistant to moisture.

The sometimes humid intake would very fast ruin a steel construct unless it is stainless, and that can become somewhat expensive. The production setup would also need to be changed as you cannot extrude steel which also means the geometry of the frames would need to be changed. A stainless steel frame would be heavier than its current counterpart but would also be a lot stronger.

Even without the change of materials the framing could be changed. There are however a lot of limitations to the changes that can be made because of the requirements of not changing the outer and inner measurements.

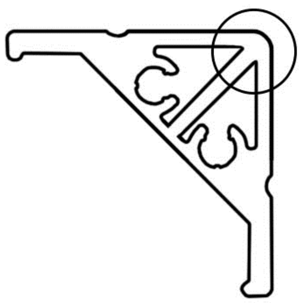
A change inspired by the needs list was the placement of the aluminum rivets. The rivets are placed centrally, close to each other, in the aluminum beams to fasten them to the steel frames. It would be beneficial to have a wider placement as to not concentrate the stresses. In discussions with Johan Boberg the possibility emerged of moving the rivets further out the geometry and place those at a 90° angle because this would lessen the hinging effect on the rivets. The relocation of the rivets can be seen in figure 6.1.

Figure 6.1 Relocation of Rivets



The aluminum frames are hollow and could have supporting beams within. The question is if the hollow space can fit a large enough support for it to matter. This would be a permanent addition to the heat exchangers as the supports cannot be removed when the frame is glued in place. The supporting beams could also be added as a permanent feature in the extrusion. During one of the informal interviews the subject was raised about adding to the extruded feature. There seems to be some problems with the extrusion already being quite thick at places and adding in a support feature would make the extrusion cool in a sub-optimal way resulting in a lot of stress resulting in warped frames. This problem area can be seen below in figure 6.2.

Figure 6.2 Problem Area When Cooling



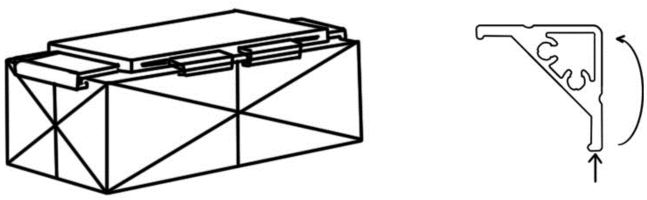
6.3.1.2 Changing the Lifting Tools

In some ways the lifting of the heat exchanger is sub-optimal. Lifting at the edges causes needless strain and breakage. From this arrived the idea to change how the construct is lifted by changing the lifting tool. This can be done in a variety of ways.

One major draw-back however is that not only the lifting tool at Heatex needs to be changed but also the tools at Heatex customers.

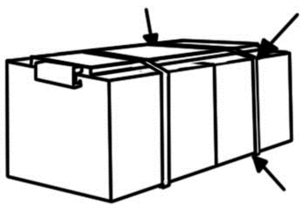
One way is to make the lifting clamp lift from the sides as well as the edges, preferably spread out over a couple of points. This would mean that the overall stress of the aluminum frames closest to the edges would lessen. This could be done by adding grip-points on the traverse. A problem with the H2 is that the edges that works best to be lifted through are very thin which doesn't leave much room for more sets of clamps. The clamps would also have to work on a large number of different products, either through modifying the clamp for certain products or constructing a new one for larger products. Another worry would be that the aluminum beams would be subjected to extra momentum because of the geometry which would build up pressure in the top of the more fragile aluminum plates. The lifting tool and the momentum that the aluminum beam will experience can be seen in figure 6.3.

Figure 6.3 Clamping and Possible Momentum



In a similar fashion lifting can be performed as currently but with the addition of cable or rope simply secured around the heat exchanger and traverse. The traverse would probably have to be modified in this instance so that the rope or cable won't squeeze the frame as seen in figure 6.4.

Figure 6.4 Rope Lift and Possible Squeeze

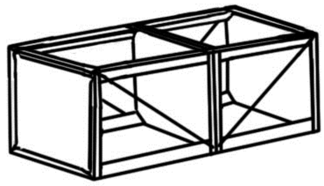


6.3.1.3 Supporting the Frame

Another way of ensuring the structural integrity of the heat exchanger would be to strengthen the frame through permanent or non-permanent means.

By adding supporting beams at a 45° angle some of the stress in the construction can be lessened. This solution could be permanent in which case it will negatively impact the effective area of the heat exchanger. If it is non-permanent there would be some logistical issues, mostly the de-construction on-site and the disposal of the beams, and also the cost to factor in. A heat exchanger with supporting beams can be seen in figure 6.5.

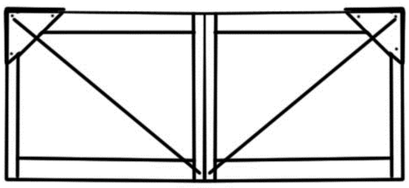
Figure 6.5 Supporting Beams



Another way could be to add permanent fixtures on the outside of the heat exchanger that can strengthen the frame purely by adding material. This would however change the outer measurements of the heat exchanger. If the heat exchanger needs to be able to be lifted when on the side or upside down the beams would need to be added to all sides of the heat exchanger as well, furthering the problem of the outer measurements being added upon.

A lot of the stresses in the current product is concentrated on the corners of the construct. By strengthening these places the construct should be more rigid and therefore not deform as much. This solution does however have the same drawbacks as the beams. Corner supports can be seen in figure 6.6.

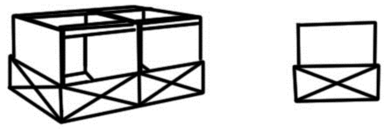
Figure 6.6 Corner Supports



The heat exchangers today are already loaded on pallets. If Heatex invested in some robust pallets the heat exchanger could be fixed on pallets which would take some stress away from the product. This solution only works if the heat exchanger doesn't need to be turned about. When producing the bigger heat exchangers they often do need to be turned, sometimes upside down, which makes this concept somewhat unfeasible.

Lifting in a separate frame would take virtually any stress away from the product itself. It is a clumsy method and to properly secure the heat exchanger would probably take a considerable amount of time. Heatex customers would also need to buy and maintain a suitable frame. A cage to hold and transport a heat exchanger can be seen in figure 6.7.

Figure 6.7 Cage



With some changes to the outer frames the product could be carried by forklift. The use of forklift has the added benefit of easily moving around the product at the production facility. This forces Heatex customers to buy and maintain forklifts however, and could cause problems when production wants to roll the heat exchanger over.

6.3.2 Search Externally

The first part of the external search was to present the results of the internal search to engineers at Heatex. A quick list was drafted with explanations and sent to Daniel Björkström for input. In return certain blanks in information was filled and some concepts were discussed in more detail. The change to stainless steel seemed to pique some interest as well as the supporting beams which the team had actually tested on some of the heavier products with some success. Daniel Björkström drafted his own concept of a sheet-metal beam made in one piece however the multiple sharp bends in steel could prove problematic.

An informal interview was later held with Johan Boberg where many of the pros and cons of the different concepts were discussed. When discussing the possibility of a stainless steel frame it came to light that there was a similar product produced in stainless steel and the beams were made in two parts welded together. This design with some modification was added as a concept.

6.3.3 Explore Systematically

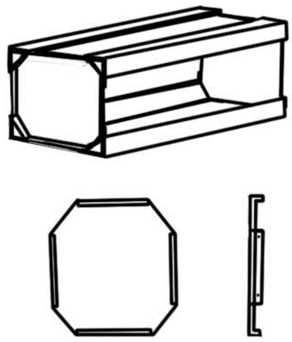
A large number of combined concepts can be generated using with a small number of concept parts, as such only the concepts that survived basic pruning will be presented.

6.3.3.1 Concept 1 – Steel Heat Exchanger

The first concept builds purely upon material constants. Stainless steel is heavier than aluminum however it also has a much higher specific strength. The frames of the current heat exchanger are made in stainless steel so there should be no problem in regards to working environment. If the beams are made out of steel then extrusion will not work, the frame needs to be produced differently. As previously noted there already exists a stainless steel frame in production at Heatex. It does however have the drawback of having to be ordered at the precise length that the customer specifies instead of, as it is now, the beams are delivered in large amounts at lengths of 8 m that are cut by production to the length that is needed for the product. The reason being that the beams two parts are welded together in intervals. This concept aims to by-pass this by pacing out the weld-points in such a way that Heatex can cut it any length they wish and continue their current production.

To address the worries of the aluminum rivets they will be placed at a 90° from current schematics and further out along the frame. The holes for the rivets can be easily drilled if an appropriate tool is bought. A sketch of concept one can be seen in figure 6.8.

Figure 6.8 Concept 1

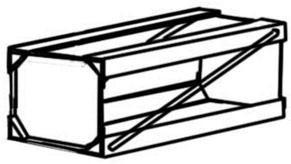


Pros for this concept are over-all higher strength, no direction on supports so the heat exchanger can be turned freely and outer and inner measurements will be the same as it is currently.

6.3.3.2 Concept 2 – Fixed Support Steel Heat Exchanger

The second concept is the first concept with added support beams. This will give an even sturdier product but will slightly lower the effectiveness of the heat exchanger. If the beams are thick they will also widen the product somewhat. The beams will also only be helpful in one plane of movement, if the heat exchanger is rotated they will do virtually nothing. Concept one with added support can be seen below in figure 6.9.

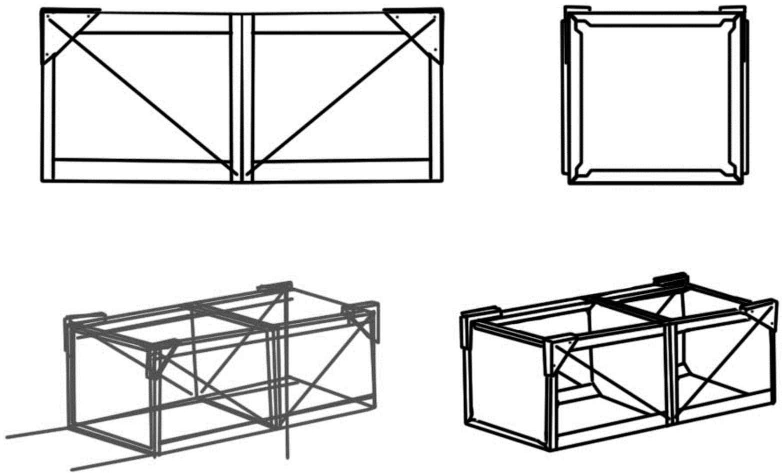
Figure 6.9 Concept 2



6.3.3.3 Concept 3 – Over-all Strengthening

The third concept is simply a strengthening of the aluminum frame structure. Strengthen the corners with steel sheet and add supporting beams on the sides, as shown in figure 6.10. This concept needs to be tested to see if it can handle the load properly.

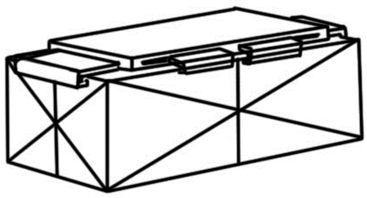
Figure 6.10 Concept 3



6.3.3.4 Concept 4 – Tool Change

Changing the tool to have more grip surfaces to the heat exchanger would lessen the amount of stress in the outer parts of the beams. One problem with this concept is this only allows for the heat exchanger to be lifted from a “flat to the floor” position. It would be difficult to design a tool that is as strong, cheap and flexible as to allow a 45° rotation. This means that if Heatex customers want to install the heat exchanger in a 45° position as well as straight lifting they would probably need at least two sets of tools depending on how many different lengths of products they use. Concept four can be seen in figure 6.11.

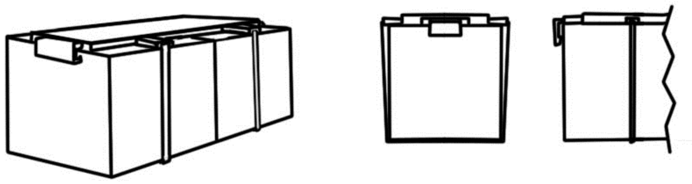
Figure 6.11 Concept 4



6.3.3.5 Concept 5 – Rope Lift

The same line of thought as the previous concept. If you add more surface and more centralized surfaces the stress maximum can be significantly lowered. This would probably need a change in the tool as well to not get a constricting effect on the heat exchanger. Just as the previous concept the 45° lifting could pose a problem. The rope lift concept can be seen below in figure 6.12.

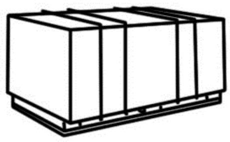
Figure 6.12 Concept 5



6.3.3.6 Concept 6 – Lifting with Support

The last concept is to lift with some form of support. If the current heat exchanger could be lifted with its pallet it would take away a lot of the stress that the construction faces at the moment. This will not help Heatex customers to lift and install the product. It also has the same problem as concept four and five, the 45° lifts would need a specially built pallet, which then needs to be brought back to production. The lifting with a frame solves the 45° issue but only adds to the issues of cost, installation and logistics. A heat exchanger fixed to a pallet can be seen in figure 6.13.

Figure 6.13 Concept 6



6.4 Concept Selection

The concept selection process was carried out in accordance with Ulrich and Eppingers "Concept Scoring" and is presented bellow in table 6.3.

Table 6.3 Concept Scoring

		Concept 1		Concept 2		Concept 3		Concept 4		Concept 5		Concept 6	
Selection Criteria	**Weight**	**Rating**	**Weigthed Score**	**Rating**	**Weigthed Score**	**Rating**	**Weigthed Score**	**Rating**	**Weigthed Score**	**Rating**	**Weigthed Score**	**Rating**	**Weigthed Score**
Liftable	25												
Easily Lifted	5	8	40	8	40	8	40	9	45	6	30	6	30
Stress Tolerance	10	8	80	10	100	5	50	5	50	7	70	7	70
Deformation	5	8	40	10	50	5	25	5	25	7	35	7	35
Ease of Turning	5	8	40	8	40	8	40	6	30	4	20	4	20
Safety	20	8	160	9	180	6	120	6	120	7	140	7	140
Cost	20												
Use of existing tools	7,5	10	75	10	75	10	75	4	30	4	30	10	75
Change in production	7,5	3	22,5	2	15	8	60	10	75	10	75	10	75
Logistics	5	10	50	2	10	10	50	10	50	10	50	4	20
Effective area change	20	10	200	8	160	8	160	10	200	10	200	10	200
Outer Measurements Changed	15	10	150	8	120	8	120	10	150	10	150	10	150
Total Score	100		857,5		790		740		775		800		815
Rank			**1**		**4**		**6**		**5**		**3**		**2**

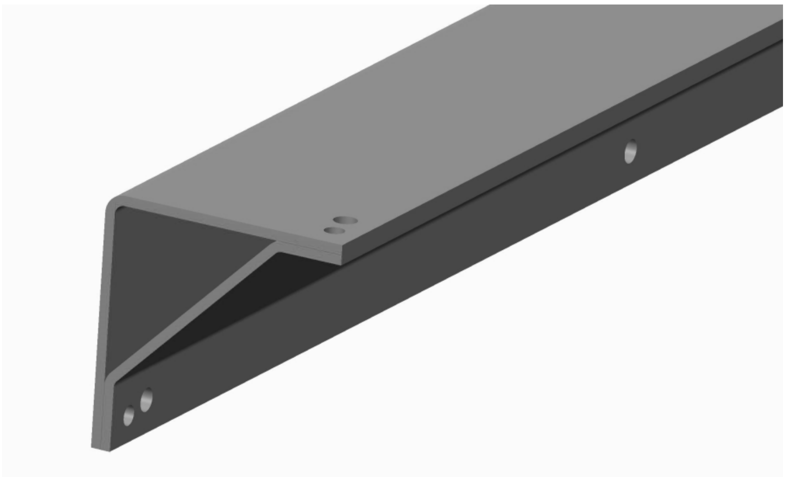
Although concept 2 was only in fourth place I would recommend it over the others if the supporting beam is permanent and the fall-off from productivity is deemed to be insignificant by Heatex engineers.

6.5 Detailed Design

As described earlier, the steel heat exchanger would be made differently from the current H2 products.

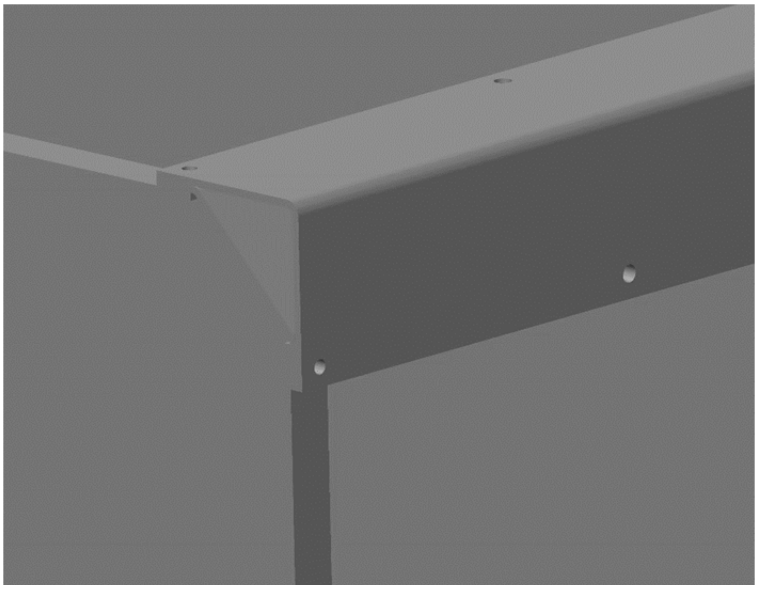
The beams would be two bent pieces of sheet steel with fixed lengths of 8m. They would be welded together in an interval of 140 mm to make it possible for Heatex own production to cut the beams into appropriate lengths. The outermost holes for the rivets would be drilled by a fixed piece of machinery specifically for this task. A CAD-model of the steel beam can be seen in figure 6.14.

Figure 6.14 Steel beams



The plating would need to be changed as well to fit with the new steel beams as well as the placement of rivets as can be seen in figure 6.15.

Figure 6.15 Steel Frame



The detailed design of Concept 1 can be found in appendix A.

6.6 Assembly and Prototype Manufacture

The prototype assembly and manufacture will be performed by Heatex.

7 Discussion

Chapter seven is the discussion part of the thesis.

7.1 Analysis Discussion

The analysis of the H2-series heat exchanger did not have many degrees of freedom. The method chosen seems to be optimal. The results were not fully consistent with the data gathered from the testing of the product. Both will be further discussed.

7.1.1 Method Discussion

In the initial briefing of the project between the author of the project and Heatex the analysis section was discussed at length and the way the analysis was to be executed and the goals for the analysis was made clear.

The method chosen was to step-by-step establish a simulation of the H2-series product. The modifying for FEM-type programs is fairly straight forward and was made with input from Axel Nordin, a member of the Faculty of Engineering at LTH.

The analysis was severely limited in the use of elements and computation power. This meant that the simulation would be limited to purely structural equations and the parts of the model would be seen as fused together. The largest part of the rigidness should however be that the parts weren't pressed together by the rivets, with friction between parts as a result, but one big part. This means the model would be substantially more rigid then its real life counterpart. This was readily apparent when tests were done on heat exchangers dipped in a protective coating. The measured deformation was in this case a tenth of the un-dipped products. With a program without the hard limit on number of elements the model would be more accurate as well.

With more computational power and more elements the simplification of the product would be much more limited and the type of connection between parts could be specified for close to real life conditions. The aluminum plating, that separates the airflows, could also be added to the model instead of a fixed weight which would eliminate the need to acquire the weight of the products, Ansys can add the gravitational forces if the material data is correct.

7.1.2 Results Discussion

The results were not very convincing when compared to data from testing. A large part of that has been discussed already in the previous section. The results should not be deemed entirely a failure however. The comparative numbers should be correct across the product ranges. If the limits of one group of H2-series heat exchangers would be measured then the point of failure should be translatable to the other products.

7.2 Modification Discussion

The modification was a much less limited part of the project. The basis for method was mostly derived from experience and the methodology borrowed from Ulrich and Epinger.

7.2.1 Method Discussion

The method chosen was that of Ulrich and Epinger modified to fit the current project. Reviewing the work does reveal some flaws in the gathering of needs.

One such flaw is the interviews, which were never written down and also conducted in a non-formal way. A number of formal and structured interviews might have yielded more needs, or more nuance to the needs already known. The logic of only gathering needs from Heatex itself is partially flawed. As author I stand by the assumption that new needs would not be found, however without actually conducting them it cannot be ruled out.

In a similar vein, the benchmarking could have been more thorough. At this instance it is more of a matter of the estimated workload added against the benefits of finding patented mechanical solution that would solve such a mechanically simple problem.

7.2.2 Results Discussion

The concept chosen was the steel heat exchanger. The concept scoring performed was partially flawed by the fact that many of the weights and scores were very subjective. If the concept scoring would have been carried out in a group of people that were familiar with the problem I would place a greater trust in this method.

7.3 Initial and Final Schedule

The Initial Schedule was constructed by average time of projects worked at in courses and some guesswork. It would probably not be very far from the mark if there were no complications during the project.

There were a lot of time sinks throughout the project. Some of them were unavoidable such as sickness and child care, things that were out of the authors' hands. The latter half of the project also suffered from time constraints because of financial difficulties and during this time the project was worked on roughly 4h/day. There were some avoidable time sinks that do comes to mind however.

The project spanned the summer months of June, July and August. This was in hindsight not a good idea. Not only were the resources limited at the university because of routine maintenance, client key changes, updating of both hardware and software etc. There were also a lot of Heatex regular staff which were on summer vacations. As was the case at Christmastimes from mid-December to mid-January. A rough estimate of the final time schedule can be seen below in table 7.1.

Table 7.1 Time Schedule

Time Table						
Month-Year	Time Planned	Time Taken				
April-14						Analysis
May-14						Modification
June-14						Writing Thesis
July-14						
August-14						
September-14						
October-14						
November-14						
December-14						
January-15						
February-15						
March-15						
April-15						

8 Conclusions and Recommendations

The conclusion of the project and recommendations on further points of study.

8.1 Conclusions

The conclusion to the analysis part of the project are 4 tables of parameters that do not correspond to testing data. The models should however correspond internally and the analysis can hopefully be used as a guideline if one model of heat exchanger can be thoroughly tested.

The modifications conclusion is a steel heat exchanger that can bear the weight of the heavier models and has similar area efficiency to the current model.

8.2 Recommendations

If a successful analysis of the project is required by Heatex the project could be repeated with less limitations. Make the analysis the sole purpose of the project, supply a program license not hindered by hard limits on nodes or elements and computational power necessary for the calculations.

The modification on the H2 should be tested thoroughly so that it satisfies Heatex standards in both structural integrity and use.

References

[1] http://heatex.com/en-GB/Company-News/the-Company

[2] http://www.uk-exchangers.com/air-to-air-heat-exchangers.htm

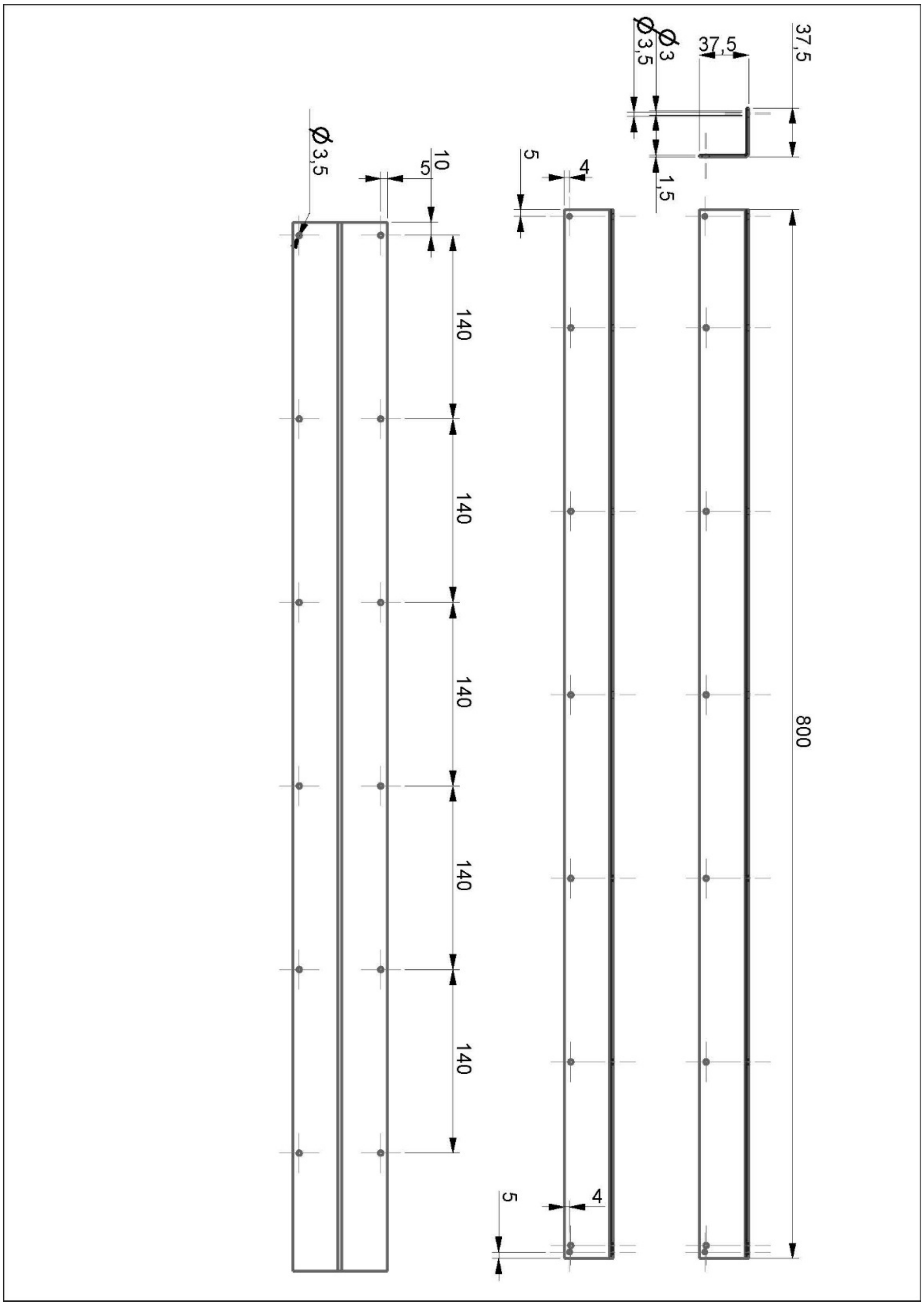
[3] http://heatex.com/en-GB/Products/Cross-flow/Model-H2

[4] Ulrich, T. K., Eppinger, D. S (2008). Product design and development. Mcgraw.Hill/Irwin, New York, USA

[5] http://heatexselect.heatex.com/

[6] http://heatex.com/~/media/Files/Product%20Data%20Sheet%20pdf/PDS_H2_Imperial_1501.pdf

Appendix A: Detailed Design of Concept 1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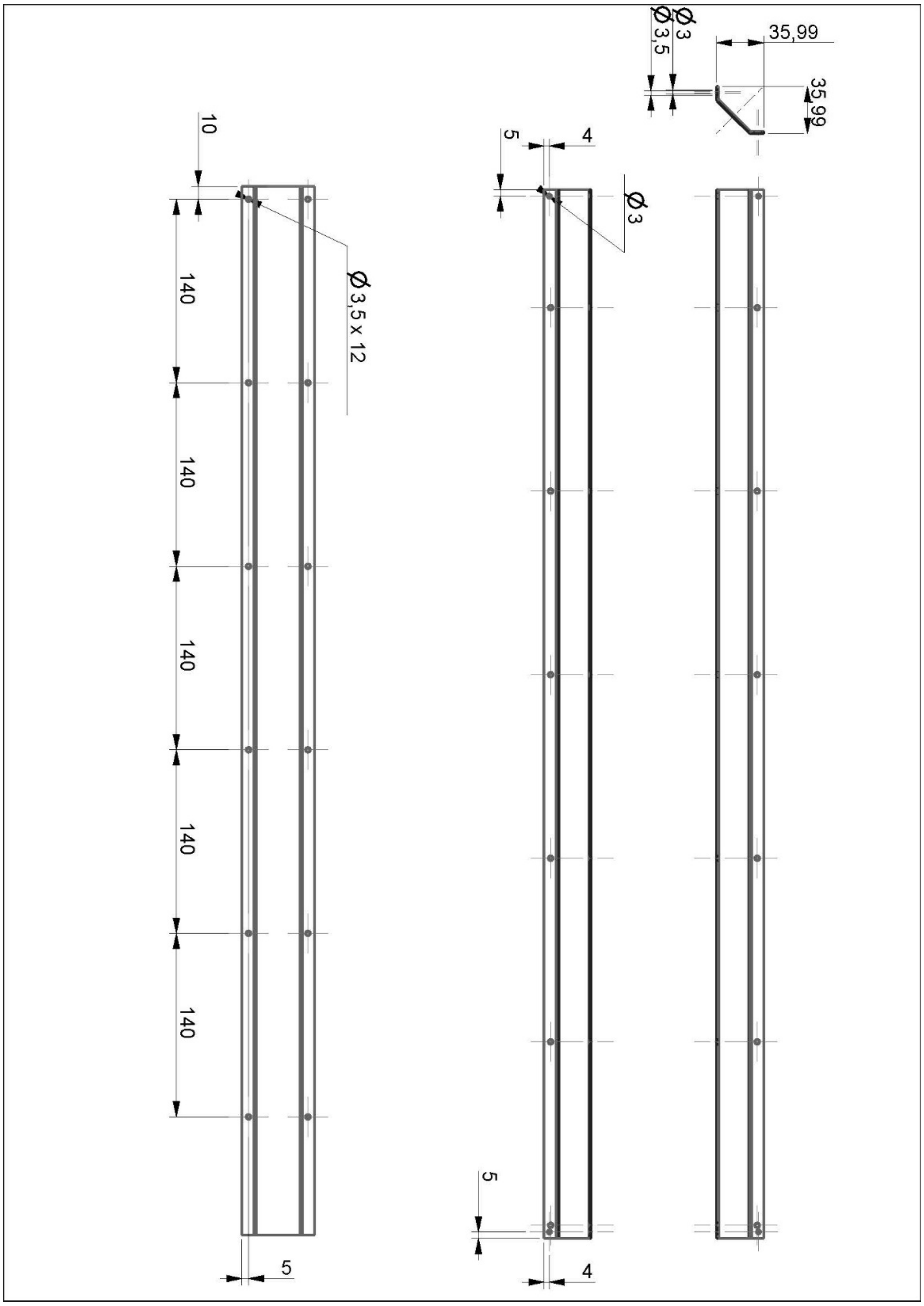
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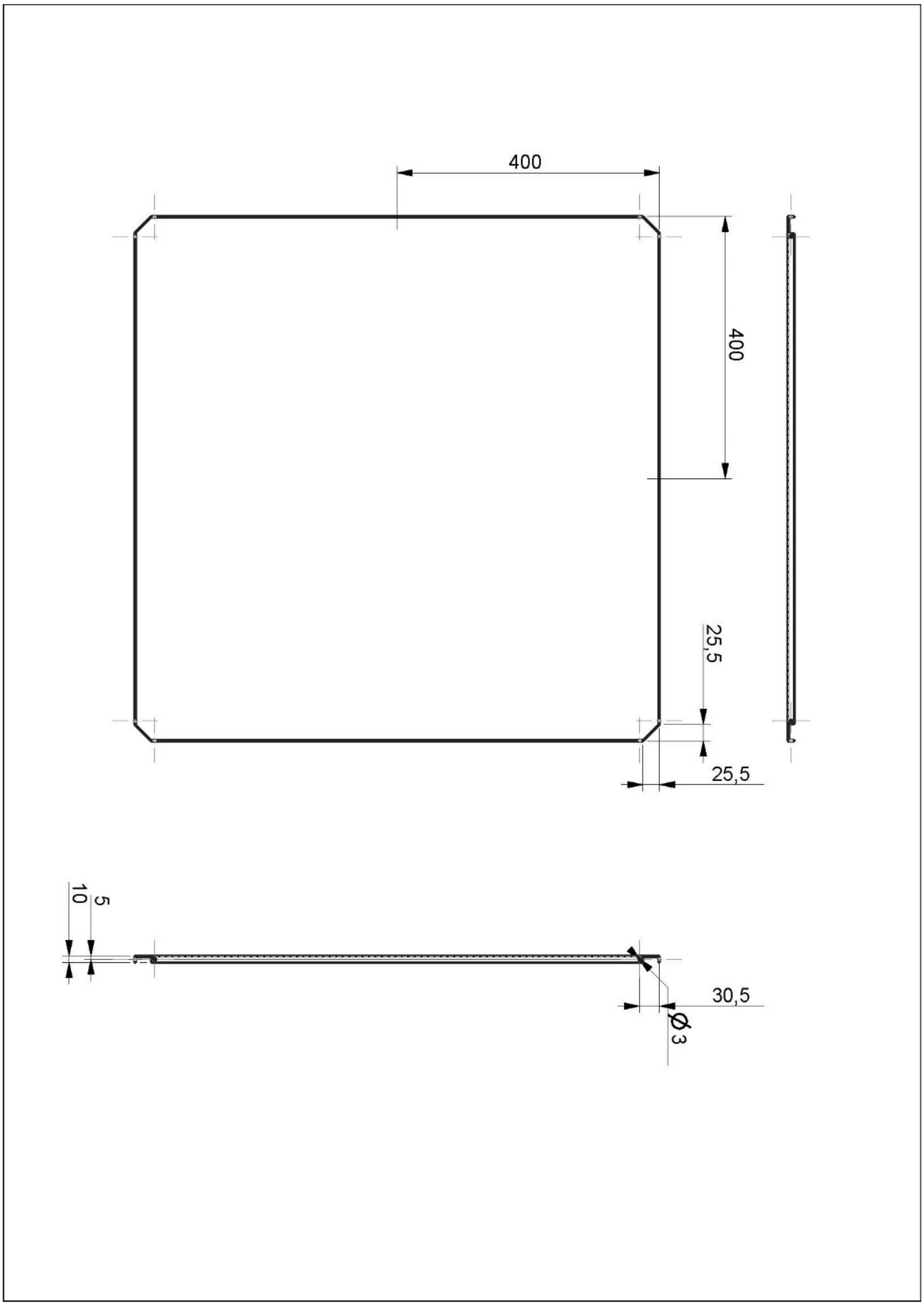
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