HEAT TREATMENT OF FASTENERS
FINAL REPORT

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Team Nedschroef
Project Team A

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EXECUTIVE SUMMARY

Project Team A of Avans University of Applied Sciences has created the following report in completion the European Project Semester (EPS). Throughout the semester, the project team has been working with the Heat Treatment Department of Nedschroef Helmond B.V. to improve the process of the heat treatment of fasteners.

The overall objective of this project was to implement a system in order to prevent customer complaints due to percent martensite (i.e. core hardness) of the fastener products due to issues with loading of the furnace belt on Furnace #10.

The project team has approached this objective by addressing the following goals, using the Six Sigma DMAIC approach. The major goals of the project included the following:

- To determine which geometric factors of the bolts have an effect on the heat treatment.
- To develop an empirical relationship between bolt geometry and overloading of the belt.
- To implement a measurement system to detect when the belt has been overloaded, by informing the user when 90 percent martensite is not attained in a batch.
- To modify the system to signal when the system has been overloaded with a detection system.

The project consisted of defining the project, using a series of three experiments to measure data, analyzing results of the data, interpreting the results to program an implemented system, and creating a control plan.

The final system included a laser measurement system, programmed to detect when the belt of Furnace #10 is overloaded, meaning the fasteners will not be heat treated to obtain the required grain structure. Project Team A is pleased with the results of the experiment would like to suggests further monitoring of the hardening process, outside of the hardening furnace loading area.

VERSION HISTORY

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1. PREFACE

Project Team A was formed during the European Project Semester (EPS) at Avans University of Applied Sciences in 's-Hertogenbosch, The Netherlands. The team is made up of a four of international students working to complete their undergraduate degrees.

The project team is made up of four members; Jesús Andrés-Cabañas Rodrigo, Michelle Gaedke, Rachel Hook, and James O'Brien. Each member of the team has invested interest in the project due to undergraduate degree requirements. Team members also have motivation stemming from individual backgrounds in project work and coursework at their home universities. Jesús Andres-Cabañas Rodrigo is currently in his final year studying Industrial Engineering at the University of Valladolid in Spain. Michelle Gaedke and Rachel Hook are both Mechanical Engineering candidates working on their senior capstone project for Michigan Technological University in the U.S. James O'Brien is currently on a placement year as part of his studies of Product Design at Nottingham Trent University in the U.K. The multicultural, multidisciplinary team has joined together to analyze the complex problem presented by Nedschroef Helmond.

The EPS program was appealing to each individual of the team for different specific reasons, however each member shares a common interest for travel and culture. Additionally, members of the team share a certain open-mindedness required to go out of one's comfort zone and experience a new culture purely by living and working each day like a local.

Each member of Project Team A has developed their own personal competencies throughout the semester. Michelle took her first trip over the Atlantic and learned how to adapt to living in a place that was completely new to her, all the while completing her final semester as an undergraduate. Rachel who lived in Germany during eight of her teenage years, revisited the European experience as a more mature individual, traveled, and learned things about herself along the way. James, who is used to working on the project design side of things, has learned about the methods involved in engineering management in a cradle-to-grave process. He has also gained insight into tooling processes. Jesús made vast improvements in his English pronounciation that he believes will open doors for him in his future education and career goals. The EPS program has been not only a part of our undergraduate degrees, but an adventure full of learning opportunities that each of us will cherish for the remainder of our lives.

2. INTRODUCTION, CONTEXT, AND OBJECTIVES

Company Overview

Nedschroef Helmond is a company committed to delivering innovative and cost effective fastener solutions to their customers, with a mission of establishing themselves as a global partner to the automotive industry. The company was founded in 1894. On the occasion of the 100-year anniversary, the title of “Koniglijk,” or Royal, was given to the company. A visual of the company’s growth can be seen in the images below. Today, the company in Helmond produces over €700 million pieces yearly, which totals to over 32,000 tonnes of product weight. This output contributes a yearly €93 million in revenue from the Helmond plant; the global revenue is over 511 million Euros. [1]

Figure 1. Nedschroef Helmond location, then and now

The Helmond plant uses cold forging techniques form fastening solutions--bolts, rivets, nuts, and nut-like products-- from large gauge steel wire. In total, there are more than 1,800 product types available to be manufactured. This number is continuously growing as custom solutions are continuously developed. The manufacturing process begins with the steel wire which is pressed used a variety of dies, punches, shapes, and moulds. If required, additional characteristics such as threads or specialized stamps can be added. The products are then heat-treated according to the customer requirements. Additional treatments, such as dipping or coatings can be added. Finally, the products are packaged and readied for shipping. Some major customers of Nedschroef products include DAF, Audi, Scania, VW, Chrysler-Daimler, among others.

Heat Treatment Department

The Heat Treatment Department conducts hardening and tempering to ensure that the fasteners meet the required strength and hardness class. This is needed to prevent unacceptable safety risks in the application of the fasteners. Currently, Nedschroef produces two standard hardness grade products, 8.8 and 10.9, while products with a hardness of 12.9 are in the development stages. The defining characteristic for product quality is core hardness. The requirement for this characteristic is that the product attains, at a minimum, 90 percent martensite grain structures.

Gas-fired, continuous belt furnaces are used for the heat treatment of steel fasteners. A stable degree of loading of the furnace is needed for a controlled heat transfer from the burners to the fasteners. The mass, volume, total height (cross-sectional profile) of the product load, and the geometry of the products are important influences. In order to obtain a low dispersion in hardness and tensile strength, a homogeneous temperature distribution in the furnace is required.

The continuous belt furnace consists of several processes. The products are gravity-loaded from a raised hopper. The project team will focus on the largest of the furnaces, Furnace #10, which has a maximum process capacity of 1,500 kg/hr. From the hopper, the products are washed. Two of the five continuous belt furnaces have dephosphating baths; the remaining three furnaces have a simple prewash bath. Furnace #10 does not include a dephosphating bath. After the bath, the products are dried and loaded onto the belt of the hardening furnace. In the hardening furnace the grain structure is reoriented using a temperature of approximately 900℃. From the hardening furnace, the red-hot products are dumped into an oil quenching bath which solidifies the martensitic grain structure. After the oil quenching, the products are again washed and dried. They are then loaded into the tempering furnace. The tempering furnace heats the products to around 500℃. Tempering seeks to relieve the tensions on internal grain structure and increases the strength properties which reduces brittleness. Finally the products are cooled in an emulsion bath and loaded into containers for further processing. A more in-depth description of the heat treatment process is given in the following section of this report.

Use Cases and Current Process

The Nedschroef Helmond factory is unusual for a manufacturer of fastening solutions in that the products formed in the plant are heat treated at the same location. To better understand this heat treatment process, an overview of the sub-processes is given below.

To begin the heat treatment process of Furnace #10, a forklift is used to position the bin with the recently cold formed fasteners into the loading system. The operator then inputs parameters needed in the process, these include: belt speed, property class, tempering temperature, order weight, number of bins, job number, article number, and time. The loading system systematically loads the products onto a continuous belt using an automated hopper. Figure 2 shows the bin containing fully-formed products being dumped into the hopper. After the hopper, bolts are fed onto weight scales which distributes products in predetermined amounts.

Figure 2. Loading of products onto Furnace #10 hardening belt via an automated hopper

The furnace process begins with water pre-wash. This wash removes the majority of the residual oils from the pressing process. The products are washed, dried, and then transferred to the continuous belt of the hardening oven. This can be seen in Figure 3, below. The transfer from dryer to the oven entrance is critical to even product distribution and therefore provide reliable heat treatment. When the bolts are mounded or bulked too much, they pose a risk for improper heat treatment. This area is where the team will focus for the duration of the project.

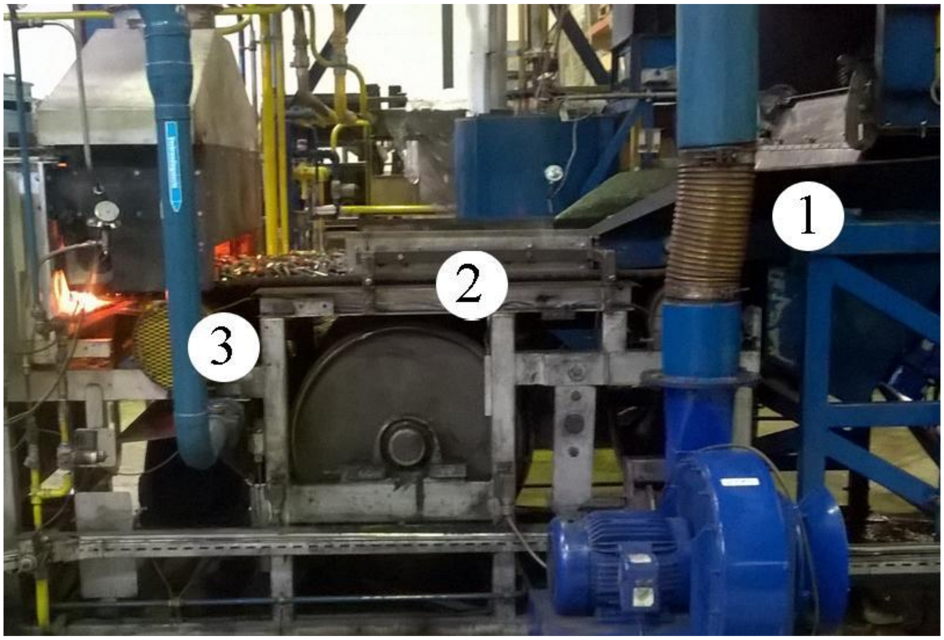


Figure 3. Stages of product loading onto belt of Furnace #10

Following the hardening process, the products are dropped off the conveyor belt, free-falling into an oil quench bath. The quench bath rapidly reduces the product temperature, transforming the steel grain structure from the heated austenite to martensite. It is important that this process occur as quickly as possible because it is critical to the final product hardness.

Once the products have passed from the quench emulsion, they are again transferred to a continuous belt, this time entering into the tempering furnace (Figure 4 and 5). Tempering is done to reduce the brittleness of the products. By heating them to a temperature slightly below the austenite phase, the tensions of the internal grain structure are significantly reduced, resulting in a reliable product.

Figure 4. Products after quenching and on their way to the tempering furnace

Figure 5. Products entering the tempering furnace

For the last step of the process, the products are cooled in a water-based cooling bath and then transferred to containers for further processing (Figure 6). The heat treatment process greatly improves the physical properties of the products. For example, the hardness can be increased by nearly 47 percent for 10.9 grade products. This heat treatment process gives Nedschroef's external customers a dependable and desired product—a factor critical to the company's long-term success.

Figure 6. Products cooled in water emulsion and transferred to containers

Project Overview

Project Team A is to *"prevent customer complaints due to percent martensite (i.e. core hardness) of the product"*. The final product should be composed of 90 percent or greater martensite which corresponds to published Rockwell hardness values. From there, the team will produce a remote measurement system in order to detect and signal when the bolts are "overloaded" upon entering the heat treatment furnace. Overloading of the furnace belt will be defined by the team after initial testing data results are analysed. When bolts are "overloaded" it prevents an even heat distribution around the bolts. Product overloading on the furnace belt results in products that are below percent martensite and Rockwell hardness requirements.

In collaberation with the heat treatment department, Project Team A will work to guarantee that products have at least 90 percent martensite after hardening, indicating that the products have reached the specified core hardness for the customers' requirements. This will be easily indicated using a Rockwell hardness test; there should be little or no variation between a middle test point and an edge test point of a bolt cross section, (30 percent of process range, usually of tolerances).

Stakeholders for this project are external customers, the Nedschroef Heat Treatment, Project Engineering, and Quality Departments, the Project Team, Avans University EPS Program and International Department, the material suppliers, and the manufacturing competitors. For a detailed project plan, refer to Appendix C.

Project Goals

Project Team A has defined the goals of the project, under the guidance of project supervisors, as the following:

- To determine which geometric factors of the bolts have an effect on the heat treatment.
- To develop an empirical relationship between bolt geometry and overloading of the belt.
- To implement a measurement system to detect when the belt has been overloaded, by informing the user when 90 percent martensite is not attained in a batch.
- To modify the system to signal when the system has been overloaded with a detection system.

Project Boundaries

The boundaries of this project are limited to Furnace #10. Project Team A has narrowed the boundaries further by focusing on the loading section of the hardening furnace. The project team will investigate product loading metrics for products treated in Furnace #10 during the 2015 calendar year. The team has limited the time frame as the first incidences of malfunction were treated in Furnace #10 during the early part of the year.

Problem Statement

Since the beginning of the 2015 calendar year there have been three major complaints from customers regarding the core hardness of the products purchased from Nedschroef. The customer complaints are listed in Table 1. The complaints are due to excessive thread deformation and/or total fracture of the bolts. This indicates that specified 90 percent martensite as required for hardness had not been reached during the hardening stage of the heat treatment process.

Table 1. Voice of the customer; major customer complaints in the 2015-2016 year

Date	Article Number	Product Description	Problem Description
2015-01-09	18834181	M10x1.50x25-10.9-2602	3 bolts broken, after investigation hardness value was too low (250HV10)
2015-03-31	18834411	M12x1.75x100-8.8-7403, hex head	Excessive thread deformation
2015-08-25	18441004	M16x2.00x110-8.8-2303, hex head	3 bolts broken in threaded region during assembly

Preliminary theories regarding the cause of this problem are that the products are loaded too heavily on the hardening belt from the dryer. This would cause the products in the most densely loaded regions to not receive the correct amount of heat transfer and therefore not develop the correct grain structure.

Project Requirements

Design Constraints

The hardening furnace loading solution must be designed to adhere to a number of constraints. If the constraints are not met upon completion of the project, the project will not be considered successful. A list of the design constraints can be found Table 2; further description of each constraint follows.

Table 2. Design constraints for the measurement system

Design Constraint	Method of Measurement	Range
Heat Resistant	Temperature	40.0-80.0 C
No Damage to Products	Percentage of products damaged	0%
Loading Area	Height (distance)	0.0 - 140.0 mm
Loading Area	Width (distance)	>=1220.0 mm
Detection	Speed of furnace belt	100.0 - 200.0 mm/min
Physical Characteristics of Product	Length	20.0 - 265.0 mm
Physical Characteristics of Product	Diameter	M8-M16
Interface	Interfaces with current control system (yes/no)	Yes

Heat Resistance

Since temperature defines the heat treatment process, it is necessary that the system is heat resistant. Multiple temperature measurements were taken near the entrance to the hardening furnace to determine an acceptable range. Depending on the distance from the entrance of the furnace, the system must be workable between 40.0 and 80.0 ℃.

No Damage to Products

Producing quality products is the main goal of Nedschroef. Therefore, it will be considered unacceptable for the system to cause any damage to products.

Loading Area

The entrance of the furnace has a height of approximately 140.0 mm and the furnace belt is 1220.0 mm in width. These metrics confine the loading area of the hardening furnace. The system design is required to work within this measured range.

Detection

The furnace belt moves at speeds under 200.0 mm/min. Most often, the hardening furnace belt runs at either 150.0 mm/min or just under 200.0 mm/min. The system must be designed to detect loading within the range of 100.0 - 200.0 mm/min.

Physical Characteristics of Product

There is a wide range of products required to be hardened by Furnace #10. This provided an extra challenge in ensuring the system is adjustable to include all fastener types. Therefore, the ability to work (and adjust) with a range of bolt lengths and bolt diameters has been included as a design constraint. This range includes bolt lengths from 20.0 to 265.0 mm and bolt diameters from M8 to M16.

Interface

The system design must work with the current controls of Furnace #10 and the operator station. This should not be an issue for Team A, but nonetheless the interface is a constraint that binds the project.

Design Objectives

Design requirements were extended to include objectives at various priority levels. Design objectives were assigned SMART target values or ranges with corresponding directions of optimization. A list of the design objectives is included in the Table 3 and further description of each objective follows.

Table 3. Design objectives for the measurement system

Design Objective	Priority	Method of Measurement	Optimization	Target
Quality	High	Percent martensite	Maximize	≥90%
Quality	High	Rockwell Hardness	N/A	Dependent on property class
Quality	High	Amount of customer complaints per year	Minimize	0
Quality	High	Number of product failures per month	Minimize	0
Detection	High	Overloading (height/product density) of furnace belt clearly defined (yes/no)	N/A	Yes
Detection	High	Percentage of time that overloading is detected (alarm is triggered)	Maximize	100%
Efficiency	Medium	Time to detect	Minimize	<1 second
Robustness	Medium	Vibration resistance (frequency)	Maximize	>100 Hz sinusoidal oscillation
Robustness	Medium	Resistant to industrial environment/air pollutants (ANSI/ISA S71.04-1985)	Maximize	G3 rating
Cost	Low	Euros	Minimize	<20000
Interface	Low	Inputs used	Minimize	1 analog input
Ease of Use	Low	Operator can add "overloading" parameters to current inputs (yes/no)	N/A	Yes
Maintenance	Low	Hours of maintenance per month	Minimize	2 hours per month

Quality

Project Team A has defined quality within the scope of the project using a number of metrics. The metrics which should be satisfied include percent martensite and Rockwell hardness. Nedschroef sets a company hardness standard of greater than or equal to 90 percent martensite. The Rockwell hardness follows a trend dependent on percent martensite. Practical application testing is done on certain fasteners to obtain a value for number of product failures. Other dependent qualities come from customer claims, including percentage of complaints. Team A will be satisfied with zero complaints and zero failures.

Detection

The system should detect 100 percent of the time when the furnace belt is overloaded. In order to do so, the team must account for the different loading heights of each type of bolt. In the case of overloading, detection will be complete if an alarm sounds.

Efficiency

This design objective has been set to measure how fast the system can detect an overload. The time of detection must be fast enough to signal before the batch is ready for shipping. The team has set the time of detection objective at a value of less than one second after the batch has reached the furnace to allow for time to react to the failure.

Robustness

The industrial environment has made it necessary for Project Team A to set objectives that address vibration and air pollution. The furnace belt, moving at a steady rate along with other automated movement of the process, induces a slight vibration on the surrounding area. After researching various options for sensors, the team has decided that vibration resistance of 100 Hz or greater will be acceptable to withstand these vibrations. The International Society of Automation (ISA) has set standard in order to classify the corrosive potential of surrounding environments on electronics. The system to be implemented should be built to withstand a G3 rating, or a “harsh” environment. A harsh environment according to the ISA is one in which there is high probability that a corrosive attack will occur [2]. Due to the amount of pollutants in the air near the heat treatment furnace, Team A finds this a reasonable objective.

Cost

At Nedschroef, a detection system on Furnace #10 is an urgent issue that needs a solution and therefore a cost constraint was not specified by the company. Project Team A has estimated the maximum cost of the project to be € 20,000. Although cost is a low priority item, the team is determined to keep below this figure.

Interface

A system using only one analogue input would leave one input open for future use. The project team aims to use one analogue input and can use as many digital inputs as needed.

Ease of Use

Project Team A would like input parameters to be easily entered by the operators, as the process requires currently. The team has set this design objective to avoid possible mistakes.

Maintenance

The maintenance time must be considered because Nedschroef cannot afford to dedicate too many resources on this item. Therefore, Project Team A has set two hours per month of maintenance time as target.

3. MODELING BASED ON EXISTING KNOWLEDGE

The project management approach used by Project Team A was the six-sigma DMAIC strategy. The acronym stands for Define, Measure, Analyze, Interpret, and Control and has been a useful guide in planning the stages of the Heat Treatment of Fasteners Project.

The project has been further broken down into a series of three experiments; the Product Density Experiment, Thermocouple Experiment, and Practical Evaluation Experiment. In the following section a detailed summary of each experiment has been provided. For supplemental information on the experiments, refer to Appendix D.

The experimental summaries are written to correspond with DMAIC. The objectives section defines the goal of the experiment. The apparatus and methods sections are combined to describe how measurements and data were collected. The data summary provides the physical quantification of measurements, the analysis and interpretation sections provide an explaination of results. Finally, the conclusion sections describes the recommended implementation and control plan for the results.

For other project planning details such as the Work Breakdown Structure, and Team Roles refer to Appendix C.

Product Density Experiment

Objectives

The objective of the product density experiment was to determine how the product characteristics, such as length, diameter, mass, head type, and thread size effect the loading density of the product on the hardening belt. The density relationship will be used to calculate the loading limits for proper heat treatment for each fastener type in production. This experiment will be completed using fixed volume containers and the final results will be calculated using statistical analysis software.

Apparatus

This experiment was conducted using a mass balance and fixed volume containers. Two containers with different sizes were used: a red container with an approximate volume of 11,746.6 mL and a blue container with an approximate volume of 5,545.28 mL. The experiment was done using full and half volumes of the blue container and only the half volume of the red container. The full volume of the red container was not used as the container would then become too heavy for the mass balance. The set-up can be seen in Figure 7.

Figure 7. Product Density Experiment apparatus

Experimental Procedures

A. Notify the laboratory staff of the ongoing experiments. Prepare the area for testing, ensure that the mass balance is functional and returns to zero when unloaded.
B. Record all interior dimensions of the containers. These dimensions will be used to calculate the volumes. Mark a line for the half level of each container. Also record the mass of each container.
C. Record the product characteristics of the product being tested to include the length, diameter, head type, thread size, and mass.
D. Fill the container to the appropriate amount and shake it down to reduce the products to the lowest energy state, making them as dense as possible. Mass the bin with the products and record all data.
E. Repeat so that each possible volume (red half, blue half, blue full) has been filled and weighed twice.

Measurement/Data Summary

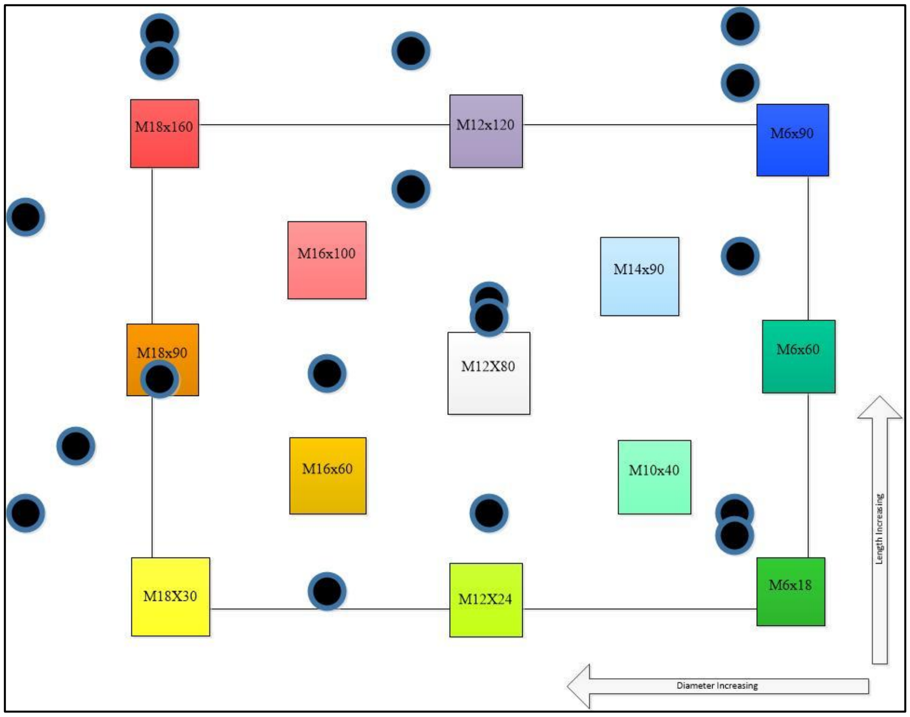


Figure 8. Distribution of bolt types tested

A total of 19 different products were tested. These products were selected from a distribution using the known products in production. As the products needed were not always available, an approximate selection was made. The ideal and actual products are shown on the Figure 8, with the squares representing the ideal products and the dots showing the approximate location of the products that were tested.

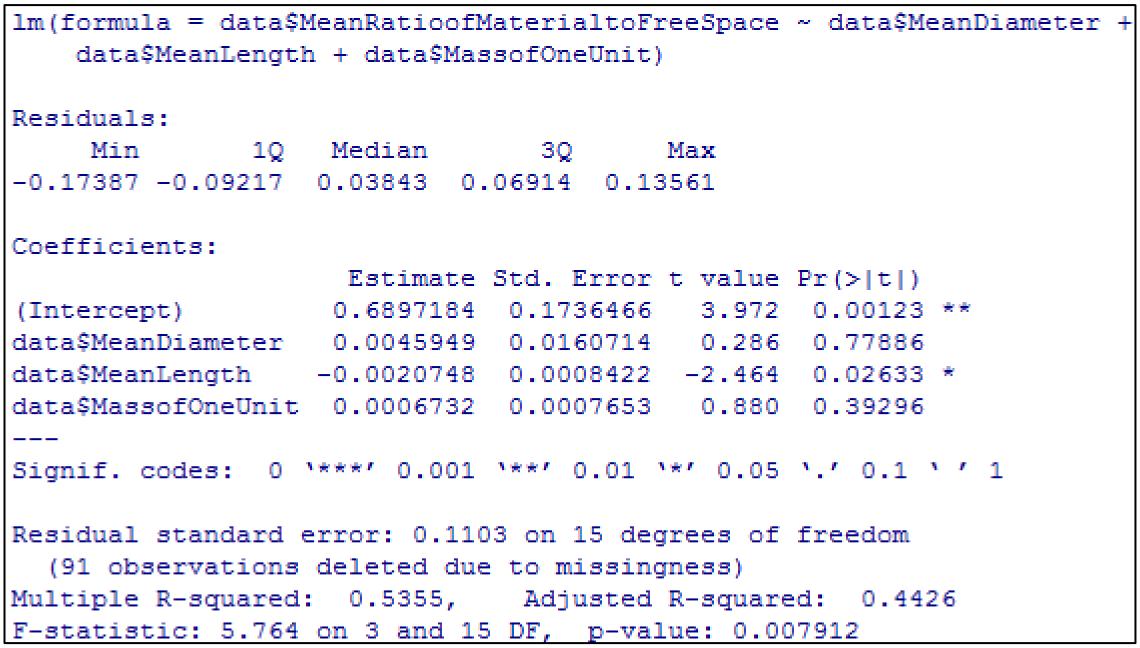
All data was recorded and preliminary calculations were made using Microsoft Excel. The known density of low-carbon steel (7.85 g/cm^3) was used for calculating the volume of steel. A sample of the recorded and calculated values are given in Table 4. A full summary of data points is attached in Appendix D.

Table 4. Sample of measurement values obtained from Product Density experiment

			Bin Properties			Bolt Properties	
Experiment #	Trial #	Article Number	Bin Size	Bin Mass [g]	Total Bin Volume [mL]	Bolt Name	Density [g/cm^3]
1	1	18823158	Blue, Full	587.0	5545.28	M8x1.25x20	7.85
1	2	18823158	Blue, Half	572.5	2559.36	M8x1.25x20	7.85
1	3	18823158	Red, Half	829.0	5873.28	M8x1.25x20	7.85
1	4	18823158	Blue, Half	572.5	2559.36	M8x1.25x20	7.85
1	5	18823158	Blue, Full	574.0	5545.28	M8x1.25x20	7.85
1	6	18823158	Red, Half	829.0	5873.28	M8x1.25x20	7.85
2	7	18834357	Blue, Full	574.0	5545.28	M12x1.50x45	7.85
2	8	18834357	Blue, Half	572.5	2559.36	M12x1.50x45	7.85
2	9	18834357	Red, Half	829.0	5873.28	M12x1.50x45	7.85
2	10	18834357	Blue, Half	572.5	2559.36	M12x1.50x45	7.85
2	11	18834357	Blue, Full	572.5	5545.28	M12x1.50x45	7.85
2	12	18834357	Red, Half	829.0	5873.28	M12x1.50x45	7.85

Interpretation and Analysis

The collected and calculated data was analyzed using several different statistical methods in the R software package [3]. The best correlation that a simple linear fit was able to produce was with a coefficient of determination, R^2, value of 0.34. Due to this low result, more intensive approach was taken using machine learning programs. Four different methods were tested and a comparison proved that the best fit was found using a method based on multiple area regression splines, or MARS [4]. This fit used lines hinged at specific points where the best fit slope of the equation changed. The final R^2 value for this equation was found to be 0.82. After the first round of data analysis, more points were added to the data series. The method of analysis was repeated and the R^2 value for the MARS regression increase to 0.84. This confirmed that the calculated empirical formula was valid for further use.



```
lm(formula = data$MeanRatioofMaterialtoFreeSpace ~ data$MeanDiameter +
    data$MeanLength + data$MassofOneUnit)

Residuals:
     Min       1Q   Median       3Q      Max
-0.17387 -0.09217  0.03843  0.06914  0.13561

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)         0.6897184  0.1736466   3.972  0.00123 **
data$MeanDiameter   0.0045949  0.0160714   0.286  0.77886
data$MeanLength    -0.0020748  0.0008422  -2.464  0.02633 *
data$MassofOneUnit  0.0006732  0.0007653   0.880  0.39296
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.1103 on 15 degrees of freedom
  (91 observations deleted due to missingness)
Multiple R-squared:  0.5355,    Adjusted R-squared:  0.4426
F-statistic: 5.764 on 3 and 15 DF,  p-value: 0.007912
```

Figure 9. MARS screenshot

It can be seen that the data when plotted (Figure 10, first row) show a stepwise format. The stepwise characteristic is removed when the mean of the data are plotted as seen in the second row of graphs. Further inspection shows that the data form random clusters instead of a general pattern. This confirms that it would be difficult to develop a reliable linear fit using the traditional regression equations.

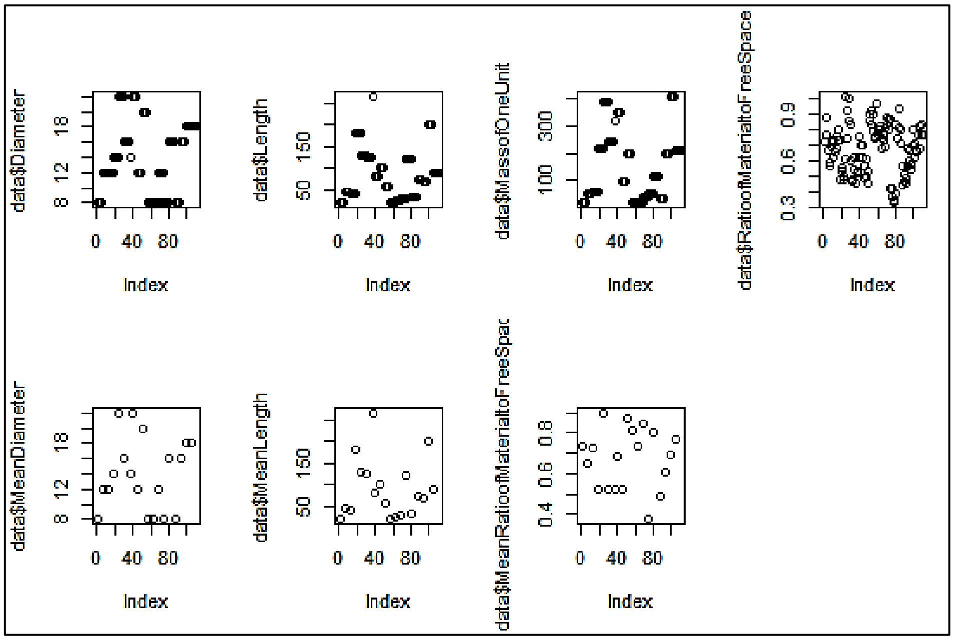


Figure 10. Plotted statistical data

The correlation results from the four machine learning programs are shown. The best correlation is found from optimizing the root mean square error and coefficient of determination. From this graph, it can easily be seen that the ideal method for empirical determination is the MARS©-like (Multivariate Adaptive Regression Spline [5]) program. The MARS©-like program learns from the slope of the line across several regions to develop a system of linear equations that are joined at specific “hinge” points, leading to a continuous empirical equation.

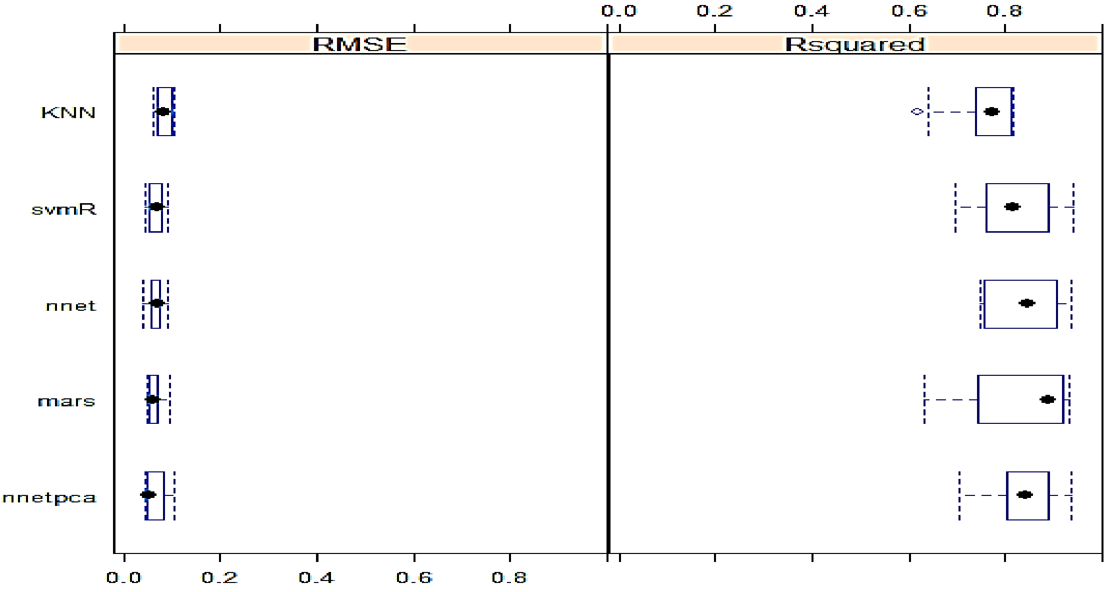
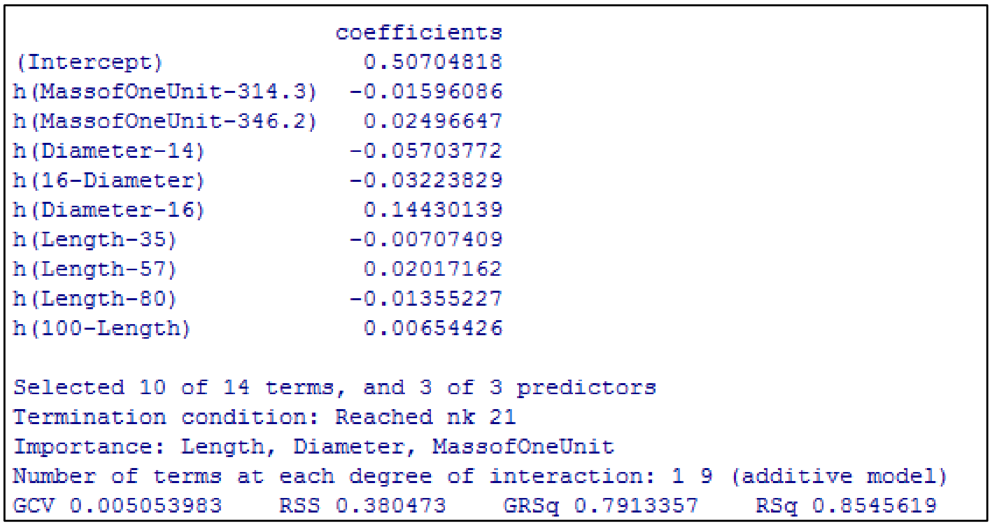


Figure 11. Empirical determination verification using statistical analysis



```
                          coefficients
(Intercept)                 0.50704818
h(MassofOneUnit-314.3)     -0.01596086
h(MassofOneUnit-346.2)      0.02496647
h(Diameter-14)             -0.05703772
h(16-Diameter)             -0.03223829
h(Diameter-16)              0.14430139
h(Length-35)               -0.00707409
h(Length-57)                0.02017162
h(Length-80)               -0.01355227
h(100-Length)               0.00654426

Selected 10 of 14 terms, and 3 of 3 predictors
Termination condition: Reached nk 21
Importance: Length, Diameter, MassofOneUnit
Number of terms at each degree of interaction: 1 9 (additive model)
GCV 0.005053983    RSS 0.380473    GRSq 0.7913357    RSq 0.8545619
```

Figure 12. Coefficients to be used in Product Density Equation

Conclusion

The summary above leads to the equation used for further development of heat transfer principles given by the following equation.

$$
\begin{aligned}
\mathrm{R} = 0.265 &+ \mathrm{a}_1 \max(0, (\mathrm{m} - 194.9)) + \mathrm{a}_2 \max(0, \\
&(\mathrm{m} - 212.4)) + \mathrm{a}_3 \max(0, (\mathrm{m} - 346.2)) + \mathrm{a}_4 \max(0, (\mathrm{D} - 14)) \\
&+ \mathrm{a}_5 \max(0, (16 - \mathrm{D})) + \mathrm{a}_6 \max(0, (\mathrm{D} - 16)) + \mathrm{a}_7 \max(0, (\mathrm{L} - 45)) \\
&+ \mathrm{a}_8 \max(0, (100 - \mathrm{L})) + \mathrm{a}_9 \max(0, (\mathrm{L} - 100)) + \mathrm{a}_{10} \max(0, (\mathrm{L} \\
&- 180))
\end{aligned}
$$

Where *R* is the ratio of product mass to free, or interstitial, space for any given dimension; "m" is the mass of the product in grams, *D* is the diameter, and *L* is the length. Both diameter and length are given in millimetres. For each term, maximum between 0 and the term in the interior parentheses is taken. This leads to the "hinge" points where the slope of the linear fit changes values. The values for the coefficients a1 through a10 are given by Table 5.

Table 5. Coefficients of product ratio equation

Coefficient	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10
Value (x 10-3)	5.28	-7.77	9.27	-68.7	-33.9	127	7.50	9.92	-9.58	4.76

The mass of the products currently in production does not exceed 346.2 grams. For this reason, the fourth term can be assumed to be negligible. However, for the purpose of possible expansion of the product range, this term will be left in the equation.

While there are few assumptions made during testing, it should be noted that this test may vary from the actual loading application on the hardening belt as the belt is a continuous surface and a fix volume was used in tests. To negate any possible under-calculation, the assumed "worst case scenario" was forced by compacting the products as much as possible during testing.

Thermocouple Experiment

Objectives

The objective of the Thermocouple Experiment is to observe temperature variation with time within a solid steel block, which should effectively model the worst case loading of the fastener products on the furnace belt. The conduction at the center of a solid steel block is expected to be transient in nature when temperature change is applied as the block enters Furnace #10. The temperature of the steel is expected to approach the surrounding temperature at an exponential rate, with rapid temperature changes initially followed by a slower and slower temperature change. The Lumped Sum Thermal Capacitance method (LCM) will be evaluated as a method to analyze transient heat conduction.

Lumped Sum Capacitance analysis is based on a number of assumptions:

- Temperature varies with time and location within a solid.
- Initiated when a system experiences a change in operating conditions and continues until a new thermal equilibrium is reached.
- Uniform temperature distribution throughout the body
- A small Biot number, the LCM is generally accepted when;

$$Bi = \frac{\left[h\left(\frac{\forall}{A_s}\right)\right]}{k_A} \leq 0.1$$

Although the LCM is never fully realized in practice, the method greatly simplifies transient conduction problems and serves as a good approximation for heat transfer analysis.

The system will viewed using the first law of thermodynamics, stating the total energy of an isolated system is constant; energy can be transformed from one form to another, but cannot be created or destroyed.

$$\frac{dE_{st}}{dt} = \rho\forall c\frac{dT}{dt} = \dot{E}_{in} - \dot{E}_{out} + \dot{E}_g$$

When radiation and source terms are assumed negligible, and the equation can be integrated from $t = 0$ to any value of t;

$$\frac{T_f - T_\infty}{T_i - T_\infty} = \exp\left[-\left(\frac{hA_s}{\rho\forall c}\right)t\right]$$

In Furnace #10, the assumption is taken that three faces of the steel block experience significant convection, therefore the characteristic length can be substituted.

$$\frac{A_s}{\forall} = \frac{w + 2x}{xw}$$

Where x is the height of the steel block and w is the width.

Making the above assumptions and substitutions, the only unknown value in the heat transfer equation is the heat transfer coefficient, h. The main goals of this experiment are to determine the overall heat transfer coefficient and to the maximum critical height of a load of solid steel in Furnace #10.

Apparatus

To keep project costs down, the material needed for this experiment was manufactured from scrap material and equipment that was readily available at Nedschroef Helmond. A steel block was obtained and an Optical Emission Spectrometer was used to determine the chemical composition of the steel. The spectrometry was conducted to ensure the steel block could be used to model fastener material. Using a benchtop marking gauge, the center of the block was marked, and a pillar drill in the Maintenance Department was used to drill to the center. On the side of the block, another hole was also drilled and tapped to insert a set screw to be used to hold the thermocouple in place. A third whole was created to insert a bolt used to attach a chain to the block. The chain will be used to pull the block out of the furnace after the allotted time. For a visual of this apparatus, see Figure 13.

Thermocouples were fastened to the steel block and plugged into a multi-channel data acquisition unit. The first thermocouple was attached to the surface of the steel block using wiring. The second thermocouple inserted into the center of the block and held in by the set screw. The temperature of the furnace was obtained using the readout from the lab computers.

Safety materials that must be present during the experiment include insulated gloves, a fire retardant lab coat, two fire extinguishers, and a bucket of water. The usual safety protocol of Nedschroef should be observed during the experiment.

Microsoft Excel will be used to record test data and analyze data.

Figure 13. Steel block prepared for Thermocouple Experiment

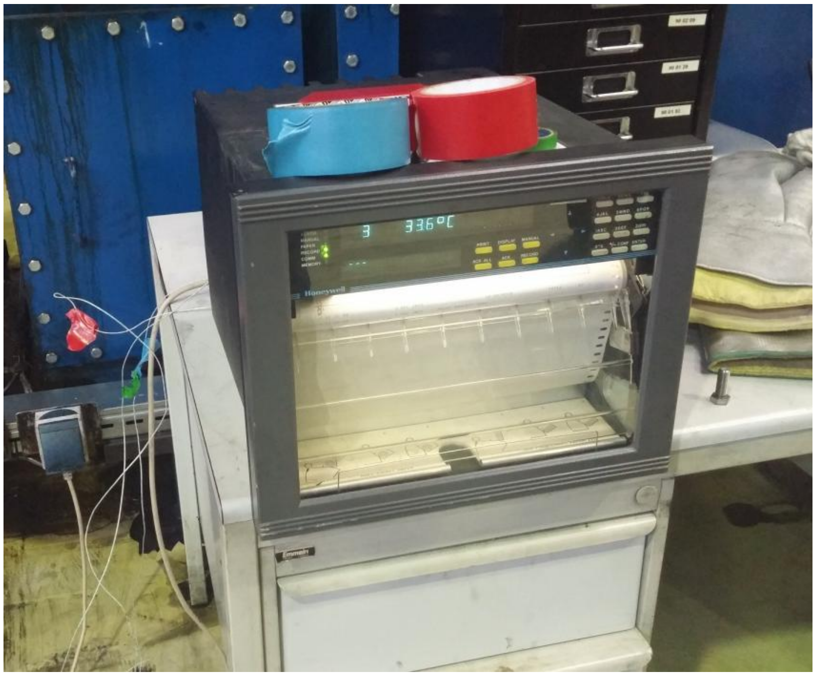


Figure 14. Multichannel data aquisition unit

Figure 15. Steel block fitted with thermocouples, on the belt to enter the hardening furnace

Experimental Procedures

A. Let operators know that production on Furnace #10 will be halted for approximately 45 minutes.

B. Set up steel block and thermocouple apparatus.

C. Monitor thermocouple readout to ensure thermocouples are functioning properly.

D. Record temperature data of the hardening furnace from the lab computers, noting temperatures in the preheat region as well as zones one and two of the hardening furnace.

E. Set up laptop on workbench next to the furnace.

F. Wearing insulated gloves and lab coat, place the steel block on the furnace belt just before the hardening furnace entrance. Hold on to the attached chain for the remainder of the experiment.

G. Start the stopwatch when the steel block reaches the entrance of the hardening furnace.

H. Record temperature readings using Microsoft excel every 30 seconds for each thermocouple.

I. Observe a decrease in the temperature difference between the surface and the center of the steel block. Note when the temperatures are nearly equal, and record readings for three more minutes for a total of 20+ minutes of data points.

J. Carefully remove the steel block from the furnace by slowly pulling the chain. Immediately quench the steel block in the bucket of water as it will be white hot (watch out for steam) and wait until it has sufficiently cooled before removing it from the water.

Measurement/Data Summary

Properties of steel were extracted from the property tables and parameters used are listed.

Note: The properties are taken at the film temperature, the average between the initial temperature (T_i) and the final temperature (T_f).

Table 6Properties of solid steel at film temperature, Tf=507.6C, used for overall heat transfer coefficient calculation

Properties of Steel	Value	Units
Density, ρ	7660.00	kg/m^3
Specific Heat, c_p	550.24	J/kg-K
Thermal conductivity, k_A	45.39	W/m-K

Table 7. Properties of solid steel at film temperature, Tf=560.0C, used for critical height of solid steel calculation

Properties of Steel	Value	Units
Density, ρ	7636.70	kg/m^3
Specific Heat, c_p	550.75	J/kg-K
Thermal conductivity, k_A	45.34	W/m-K

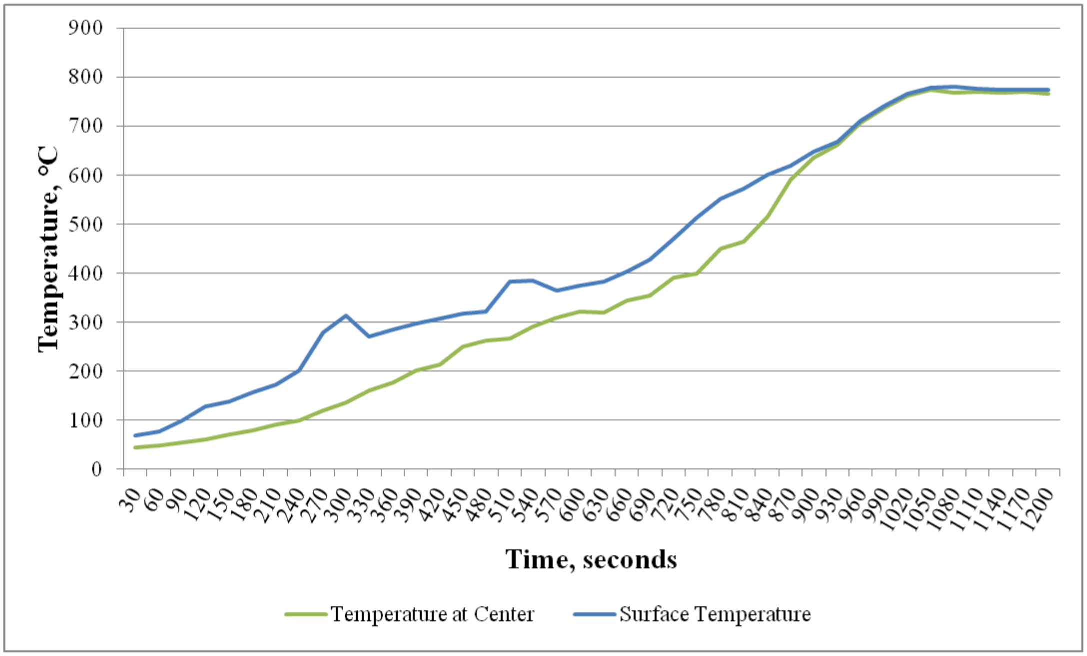


Figure 16. Thermocouple temperatures over time during the solid steel block thermocouple experiment

Interpretation and Analysis

Figure 16 represents the thermocouple readings over time while the steel block was in Furnace #10. The first 10-12 minutes, the steel block was in the preheat stage of the furnace. Shortly after, the steel entered Zone One, at which point it's temperature increased drastically. The steel did not reach the required 890°C due to the fact that it was only in the first zone of the furnace. In any case this was outside the scope of the experiment. The temperature on the surface of the block and the center of the block eventually reached a new equilibrium temperature. At the point of little temperature difference between the thermocouples, the LCM could be used to find the heat transfer coefficient in Furnace #10.

Transient conduction initiated by convective heat transfer in a steel block was used to model the heat transfer in Furnace #10. The LCM was used to analyze results. The temperature and time values used to calculate the heat transfer coefficient are listed in Table 8.

Table 8. Values used in the heat transfer coefficient equation

Parameter	Value	Units
Initial Temperature, $\boldsymbol{T_i}$	249.10	°C
Final Temperature, $\boldsymbol{T_f}$	766.10	°C
Furnace Temperature, $\boldsymbol{T}_\infty$	798.00	°C
Time, $\boldsymbol{t}$	750.00	s

Solving the equation below for the heat transfer coefficient, gives;

$$h = \frac{\left[\left(-\ln\left(\frac{T_f - T_\infty}{T_i - T_\infty}\right)\right)\rho c_p\right]}{\frac{A_s}{\forall} * t} = 167.514\frac{W}{m^2 * K}$$

The use of the LCM was checked using the equation. The result is less than 0.1 meaning the theoretical assumptions are valid and the LCM can be used for approximate results in this case.

$$Bi = \frac{\left[h\left(\frac{\forall}{A_s}\right)\right]}{k_A} = 0.03866 \leq 0.1$$

After the overall heat transfer coefficient was determined and verified, theoretical temperature and time values for the entire hardening furnace process were entered into the same equation to find a critical height limit for solid steel. The temperature and time values used to calculate the heat transfer coefficient are listed.

Note: For this case the assumption of convection has been changed to use all four faces of the solid steel block. This is because as the block enters further in the furnace, the increase in heat causes convection under the belt. The characteristic length equation is updated to correspond to this adjustment. In this case, x is the height of the product load theoretically compacted to solid steel and w is the width of the belt.

$$\frac{A_s}{\forall} = \frac{2(w + x)}{xw}$$

Using this substitution, the critical height limit for solid steel in Furnace #10 was calculated to be 47.015 mm.

Biot number was again confirmed using the same equation.

$$Bi = \frac{\left[h\left(\frac{\forall}{A_s}\right)\right]}{k_A} = 0.0828 \leq 0.1$$

Conclusion

In conclusion, this experiment upheld all assumptions and successfully calculated the overall heat transfer coefficient as well as the critical height value for solid steel in Furnace #10. The overall heat transfer coefficient is 167.514 W/m^2-K. This value was used to then calculate the critical height, resulting in a value of 47.015 mm. If fastener products are so densely loaded on the furnace belt that they are nearly solid steel, they would not reach required hardness if height upon entering the hardening furnace exceeds 47.015 mm. Assumptions of LCM use were validated by checking the Biot number.

Practical Evaluation Experiment

Objectives

The objective of the Practical Evaluation Experiment was to test the theoretical value of critical height obtained from the Thermocouple Experiment. In this experiment, instead of heat treating a solid steel block in the hardening furnace, samples of fastener products will be used. By using samples of Nedschroef's actual products, the experimental procedure will be used to evaluate if the critical height limit can be implemented in a practical sense.

Apparatus

Stainless steel mesh material was cut using a sheet metal guillotine to create platforms for bolts to be attached. Different types of bolts were selected, each had a different diameter and length. Each bolt type was wired in a line with the mesh material at the bottom and the first bolt placed directly on the mesh. Preceding bolt types were wired together on top of the first at 20.0 mm increments. Measurements were taken using both vernier calipers and a tape measure. Figure 17 gives a visual of this apparatus.

Figure 17. Bolts to be measured in the Practical Evaluation Experiment

After the bolts are run through the hardening furnace, they are taken to the Quality Testing Lab within Nedschroef (Figure 18). A closed cabinet bench saw was used to slice the bolts and wet and dry paper of various grit sizes were used to smooth the surface of the bolt that was sliced to be tested. A Vickers Hardness Test Machine was used to measure the hardness of the test specimen (Figure 19).

Figure 18. Bolts after hardening awaiting slicing and hardness testing

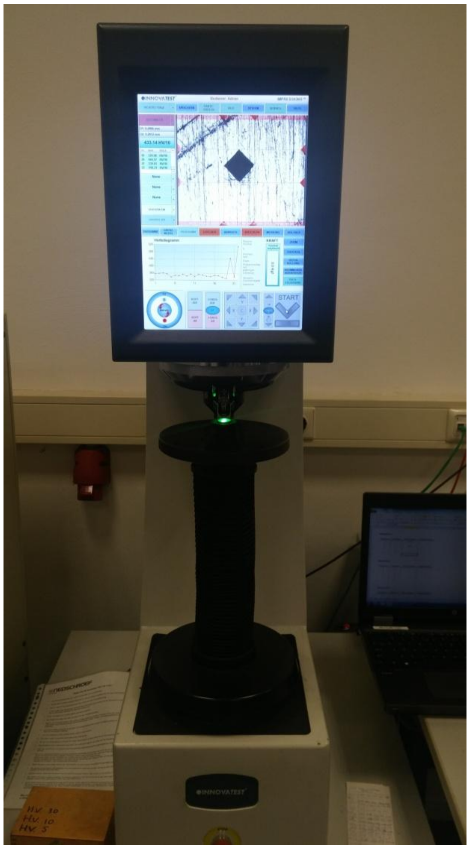


Figure 19. Vickers hardness test

Safety materials that must be present during the experiment include insulated gloves, a fire retardant lab coat, two fire extinguishers, and a bucket of water. The usual safety protocol of Nedschroef should be observed during the experiment.

Experimental Procedures

Run Bolts Through Furnace #10

K. For each bolt type:
    a. Wire the first bolt directly to the one small piece of mesh (approximatly 5x5 cm).
    b. Wire proceding bolts on top of the first bolt at 20.0 mm increments, up to six bolts.
L. Let operators know that production on Furnace #10 will be halted for approximately 45 minutes.
M. Wait for 15 minutes to avoid mixing with previous batch.
N. Slow down belt speed and load the furnace with scrap material.
O. As scraps pile place wired bolts on the belt with the mesh piece lying flat on the belt; make sure to hold wired bolts to maintain their depth.
P. Wait approximately 45-60 minutes for the bolts to make their way through the hardening furnace.
Q. Remove wired bolts for testing before they enter the tempering furnace.

R. Remove bolts from wire for Vickers test and microscopic inspection.

Vickers Hardness Testing

S. Slice bolts which are to be tested just below the head.
T. If necessary, grind away burrs and swarf.
U. Maintain a perfect plane on the slice.
V. Using wet and dry paper, work through grit size chronologically; 240 mm, 320 mm, 400 mm, and 600 mm to provide a smooth and flat surface.
W. Turn on Vickers machine and place bolt speciman on the Vickers test platform so that the green light is in the center of the bolt.
X. Twist wheel to focus the camera.
Y. Check that the sample is flat and smooth, this is indicated by a white screen with very few scratches. If the screen appears to dark, redo step V.
Z. Press start, read, and record the Vickers hardness value output.

Microscopic Inspection for Martensite

AA. Make plugs.
  a. Slice bolts pieces again, this time transversely.
  b. Clean plug surface and add anti-stick powder to the surface.
  c. Place bolt slices on the surface, slice facing down.
  d. Add one scoop of the grey plastic scoop and two scoops of the black plastic scoops.
  e. Twist cap on until counterclockwise and then turn clockwise half a turn.
  f. Start plug making process.

BB. Polish plugs.
  a. Both discs must be turning the same way.
  b. First disc; WATER ON, chalk the disc for two spins, run for five minutes.
  c. Clean plugs with ethanol and dry them.
  d. Second disc; 9 micrometer, WATER OFF, blue spray, grey spray, run for five minutes.
  e. Clean plugs with water and a cotton ball,
  f. Introduce plugs to an ultrasonic bath for five minutes.
  g. Clean plugs with water and ethanol, then dry them.
  h. Third disc; 3 micrometer, use blue spray, do not allow the disc to get dry (use blue spray), 1:30 to 2 minute run time.

CC. Look under the microscope to look for martensite and verify hardness of the bolt. Record any sitings of ferrite, as this indicates reduced hardness.

<u>Measurement/Data Summary</u>

The following tables list the hardness values obtained from the Vickers Hardness Test, as well as the conversion of values to the Rockwell scale. The conversion table of hardness values is included in Appendix D.

Table 9. Vickers and Rockwell hardness results from Practical Evaluation Experiment

M20x80;10.9, Hardening Requirement = 42 HRc

Placement	Depth (cm)	Vickers Hardness	Rockwell Hardness
1	1	510,31	49,82
2	3	411,40	41,93
3	5	433,14	43,88
4	7	467,85	46,73
5	9	453,88	45,61
6	11	449,16	45,23

M18x55;10.9, Hardening Requirement = 42 HRc

Placement	Depth (cm)	Vickers Hardness	Rockwell Hardness
1	1	546,56	52,09
2	3	490,90	48,46
3	5	429,10	43,52
4	7	453,69	45,60
5	9	456,87	45,85
6	11	466,20	46,60

M16x45;10.9, Hardening Requirement = 42 HRc

Placement	Depth (cm)	Vickers Hardness	Rockwell Hardness
1	1	534,74	51,38
2	3	538,62	51,62
3	5	569,35	53,56
4	7	567,82	53,46
5	9	558,81	52,87
6	11	550,60	52,34

M14x50;8.8, Hardening Requirement = 37 HRc

Placement	Depth (cm)	Vickers Hardness	Rockwell Hardness
1	1	446,32	44,99
2	3	438,99	44,36
3	5	419,44	42,65
4	7	427,66	43,39
5	9	414,04	42,16
6	11	446,32	44,99

Interpretation and Analysis

Near the center of the product load (approximately 5 cm from the top) there is a reduction in core hardness, especially for the greater diameter bolts. Only one bolt tested fell below the hardening requirement. This was an M20x80 size bolt with a strength class of 10.9. It failed at a 3 cm depth, which was more shallow than hypothesized. However, results from other trials confirm that the failures are most likely to occur not at the bottom of the load, but in a central location. This confirms the theory that there is convection on both the top of the product load and the bottom of the belt.

Conclusion

The results show that when the product load becomes too high for certain fastener types, the heat treatment from the burners in Furnace #10 is not homogeneous. The bolts present in the lower, middle section of the product load may receive insufficient heat treatment. With more time, the project team would have liked to run more practical experiments to determine the exact critical height which would result in failure.

4. RESEARCH METHODS

Measurement Systems

Research and brainstorming was conducted to produce initial concept ideas. The proposed detection systems are described below and sketches of each can be found in Appendix A.

Steel Bar System

The use of a steel bar was a proposal put forward by the Quality Department at Nedschroef Helmond. The idea was to install a fixed steel beam across the width of the conveyor as a potential solution to remedy the bulking of ‘overloaded’ product. Team A slightly altered this proposal to a hinged beam on a sensor, so that damage to the product would be diminished. When the bar is knocked forward by an ‘overloaded’ amount of product, it will trigger an alarm and alert the furnace operators so that the issue can be addressed.

Laser System

A laser system is a common solution for many industrial applications. For example, lasers are used on the product collection bins at present; these are single point lasers used to detect the height of the product in the bin. When the bin is detected as full, an empty bin is moved into position. It is a nonintrusive way of measuring and collecting data during a process, ruling out the possibility of any damage to the product. There are many types of laser systems with potential for this application, and if found to be feasible, supplier companies would need to be contacted to aid with potential solutions. A sketch of the use of a laser system as a solution is displayed in Figure 20.

Ultrasound System

An ultrasound system is currently used in Nedschroef on the waste collection bins. An ultrasound beam is directed at a single point, and the time taken to reflect back to the sensor is calculated to determine the height of the scrap material. This is a potential solution be used to measure the height of the product on the conveyor belt.

Nylon Bar System

The nylon bar system uses the same principle as steel bar system. It was proposed to use a nylon bar as an alternative because it could potentially cause less damage to the product. Nylon is very resistant to temperature and it is also softer than steel.

Weighted Criteria Matrix Round I

Following initial brainstorming, a weighted criteria matrix was created to aid in the decision making process, Table 10. The solution types are listed as column headers, and each criterion has been given a row. The weight and initial score ranges from one to ten, with ten being the greatest. The weighted score is dependent on how well the criteria are met by the solution type as well as the weight of importance that the criteria have been given. A description of each criteria based on its importance to the problem solution is given below.

Ability to Collect Data

As far as a complete detection system goes, the collection of data is important because allows for assessment and quantification of 'overloading' data after testing. The ability to collect data was given an above average weight, as Team A agreed having data output would be beneficial to the overall solution.

No Damage to Product

Quality products are the number one goal of Nedschroef, and thus this criterion was given the highest weight. Any damaged fastener could cause problems upon application and cause for the loss of loyal customers.

Industrial Proof

The detection solution must be industrial proof due to the nature of the surrounding environment. The system must be able to cope with the influences of the environment, which includes withstanding polluted atmospheric conditions and constant vibration. This criterion was rated slightly above average because it is important; however there are options to increase industrial proof ability; such as adding insulation, adjusting mounting area, etc.

Measurement Ability

Project Team A needs a method of determining 'overloading', and the most straightforward way to do this is to determine the height of the product on the furnace belt. A detection system that measures height has become an important criterion to the overall solution.

Maintenance Requirement

The objective to minimize the amount of maintenance needed affects the decision on solution type. Maintenance is a low priority objective and was therefore given a below average weight.

Range of Detection

The solution system must meet the area constraint; a conveyer belt width of 1220.0 mm.

Cost

Although cost is a low priority objective, it is considered with a low weight in order to ensure a feasible detection solution is selected.

Heat Resistance

A high weight has been placed on heat resistance. Heat resistance is a highest priority constraint because the system will be installed directly outside of the hardening furnace which works at temperatures nearing 900°C. A thermocouple experiment mentioned in the Heat Shield Installation section of this report explains that the temperature in the detection area is approximately 40°C.

Accuracy of Detection

Detection of product 'overloading' should be accurate to a certain tolerance to ensure an even distribution of heat treatment from the hardening furnace to the fasteners.

Table 10. Decision matrix, round one of the decision making process

Criteria:	Weight:	Steel Bar System		Laser System		Ultrasound System		Nylon Bar System	
		Initial Score	**Weighted Score**	**Initial Score**	**Weighted Score**	**Initial Score**	**Weighted Score**	**Initial Score**	**Weighted Score**
1. Ability to collect data	6	0	0	8	48	6	36	0	0
2. No damage to product	9	4	36	10	90	10	90	5	45
3. Industrial proof	6	9	54	6	36	5	30	9	54
4. Measurement ability	8	0	0	8	64	6	48	0	0
5. Maintenance requirement	4	8	32	5	20	5	20	8	32
6. Range of detection	5	9	45	8	40	6	30	9	45
7. Cost	3	7	21	6	18	6	18	7	21
8. Heat resistance	9	10	90	7	63	6	54	8	72
9. Accuracy of detection	8	7	56	9	72	8	64	7	56
Total:			**334**		**451**		**390**		**325**

Results of the weighted criteria matrix show that the laser system was given the highest overall score. The deciding factors came down to the criteria with the greatest associated weights, including no damage to the product, heat resistance, and ability to collect measurements. Project Team A has decided to follow through with these results and further pursue a laser measurement system for the heat treatment of fasteners project.

Supplier Information

Suppliers were contacted and meetings were held to get an idea of the team's options for ordering a laser measurement system. The most feasible laser system solutions were those of suppliers Keyence and SICK Measurement Instruments. Concept sketches for using a laser system is given in Appendix E. These were used to explain project requirements to suppliers.

Keyence LJ-V

The Keyence solution [5] is similar to that of ultrasound measurements, however light is used instead of ultrasonic waves. The sender/receiver would be mounted above the belt. The time is takes for the laser beam to hit the product load and return to the receiver is recorded. Using the time and the angle that the light beam is sent, it is possible for the system to calculate the height of the product load at that point. Due to the range of the Keyence sensor, it will be necessary to purchase at least two sensors to meet the requirements of the application. Installing more than one sensor may introduce further complexity and drive up the price.

SICK MLS400

The SICK MLS400 [6] would also be installed above the furnace belt. The system records a number of points on the screen, representing the area of the product load. The system is precise with a high resolution, and filters may be added to obtain better results. The LMS400 requires programming upon installation which can be completed with Visual Basic or C+.

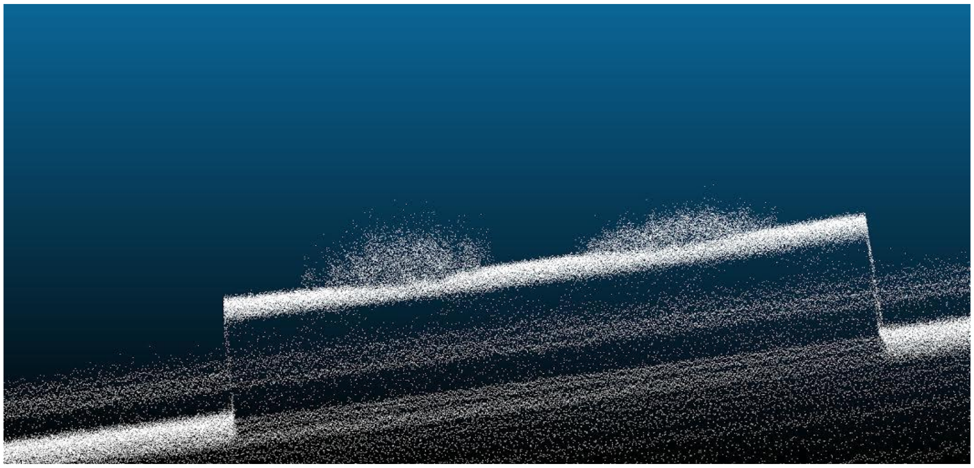
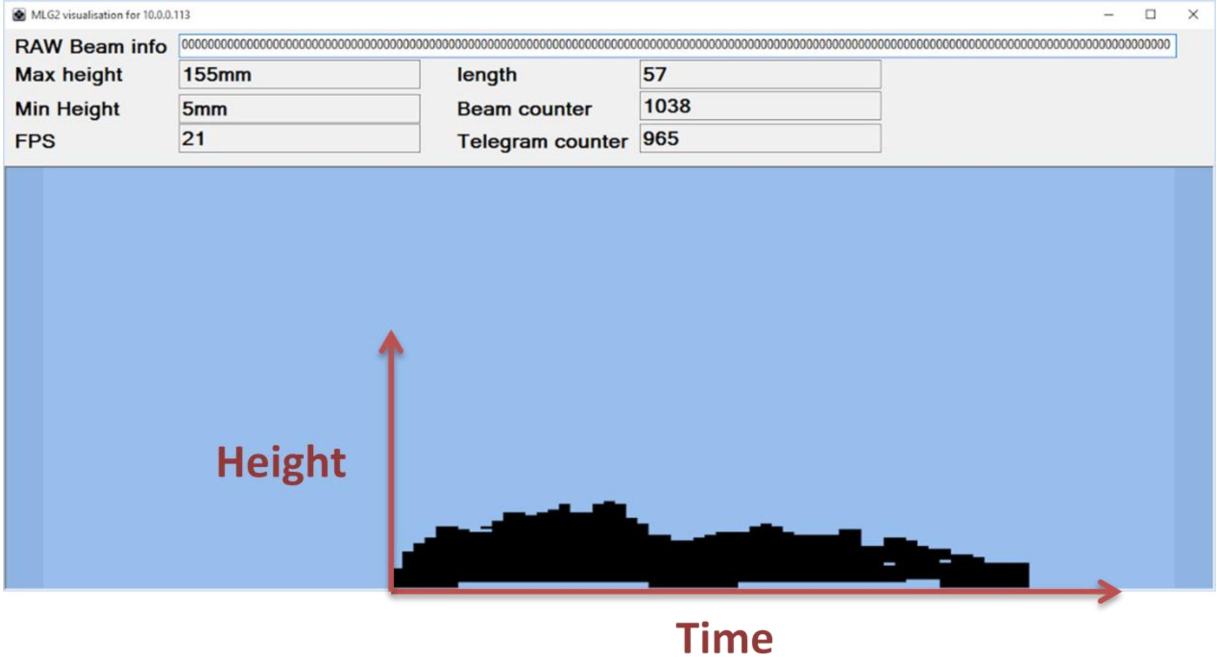


Figure 20. Figure output of SICK MLS400

SICK MLG Pro

The MLG Pro [7] is a light curtain system in which the measurement of height of the product over time is recorded. A sender and receiver would be installed on either side of the furnace belt. The MLG Pro system is available in a resolution of 2.5 or 5.0 millimetres, depending on the application needs. Compared to the other laser systems considered, the MLG Pro is relatively simple to install and would work easily with the current PLC interface.



RAW Beam info
Max height 155mm
Min Height 5mm
FPS 21
length 57
Beam counter 1038
Telegram counter 965

Figure 21. Figure output of SICK MLG Pro, cross sectional height over time

Weighted Criteria Matrix Round II

A weighted criteria matrix was again created, this time to decide between the laser systems which have been researched. A few criteria were added for this round, including tolerance/precision, response time, and interface. Initial scores were based off of supplier specification sheets for each laser. Again, the weights and initial scores range from one to ten, with ten being the greatest.

Table 11. Desicion matrix, round two of the decision making process

Criteria:	Weight:	KEYENCE LJ-V		SICK LMS400		SICK MLG Pro 5mm	
		Initial Score	Weighted Score	Initial Score	Weighted Score	Initial Score	Weighted Score
1. Resolution	6	9	54	8	48	6	36
2. Tolerance/precision	8	10	80	10	80	10	80
3. Industrial proof	6	4	24	4	24	6	36
4. Response time	8	10	80	10	80	10	80
5. Maintenance requirement	4	8	32	8	32	8	32
6. Range of detection	5	4	20	4	20	8	40
7. Cost	3	4	12	2	6	8	24
8. Heat resistance	9	4	36	6	54	6	54
9. Ease of installation	8	4	32	4	32	8	64
10. Interface	4	8	32	8	32	8	32
Total:			**338**		**344**		**382**

The SICK MLG Pro laser measurement system received the greatest score from the weighted criteria matrix results. Contributions from the Nedschroef Heat Treatment Department and SICK suppliers also supported this result. Project Team A has decided to purchase and install the SICK MLG Pro. Once the installation is complete, the team will work to calibrate laser in such a way that will detect a product ‘overload’ on the hardening furnace belt.

5. IMPLEMENTATION OF RESEARCH

Laser Installation

The laser measurement system was installed by an independent contractor according to the electrical standards published by the manufacturer Sick. The wiring was run as far away from any heat source as possible in order to avoid any possible damages due to high temperatures.

Heat Shield Installation

Initially an issue with the system involved incorrect data output at the operators' station. A representative from SICK came to evaluate the issue, and working alongside the project team, a solution of implementing a heat shield was concluded. Sensors were deemed to be affected by the heat.

Following the visit, bolts were positioned in the place of the sensors, an Insulation Rock wool was then placed around the bolts to see what effect insulating the sensors would have.

Using brainstorming and concept sketching, different potential solutions were taken into account. Initially the plan was to use Aluminum sheet plate of a width of 5.0 mm. with discussion it was considered that a metallic colored plate could conduct heat. It was suggested by the company maintenance department, due to costs of ordering in materials, that there were wall sections from a temporary building available to be used in storage. It turned out the material the walls were made from was an ideal heat shielding material; 1.0 mm steel- foam insulation- 1.0 mm steel, the steel was also painted a white grey color.

The heat shield prototypes were fitted onto the poles using the pre-made grooves. Testing bolts in the place of the sensors were left over the weekend to see how the new heat shield prototypes affected the heat radiation getting to the sensors.

A thermocouple was fitted temporarily within the sensor poles. to test if the heat shields were fit for purpose and were protecting the sensors from heat radiation. The thermocouple read a consistent reading of approximately 35 to 40℃, this is a suitable working temperature for the laser sensors and so no further heat shielding/ insulation is required for the time being. The thermocouple test was run for five days.

After some minor adjustments and tidying up to the prototypes, the testing bolts could be removed and the sensors replaced. Using laser pointers, spirit levels and other measuring equipment, the team was able to align the poles and lasers with the new heat shields on, ready for SICK to come back and set up the system.

It was found that the initial problems with the data were in fact due to the incorrect programming and Teach-In function of the laser. By reteaching and calibrating the lasers, the major part of this issue has since been corrected. Some fine tuning is still needed.

Programming

The sensor was interfaced with the Programming Logic Controller (PLC) on the available channels (Figure 22). As a requirement for the sensor selection was minimal channel space, only one analog channel was used. The sensor installation can be seen sketched on the electrical drawing below. This drawing was also sent to the manufacturer of the furnace for permanent updates.

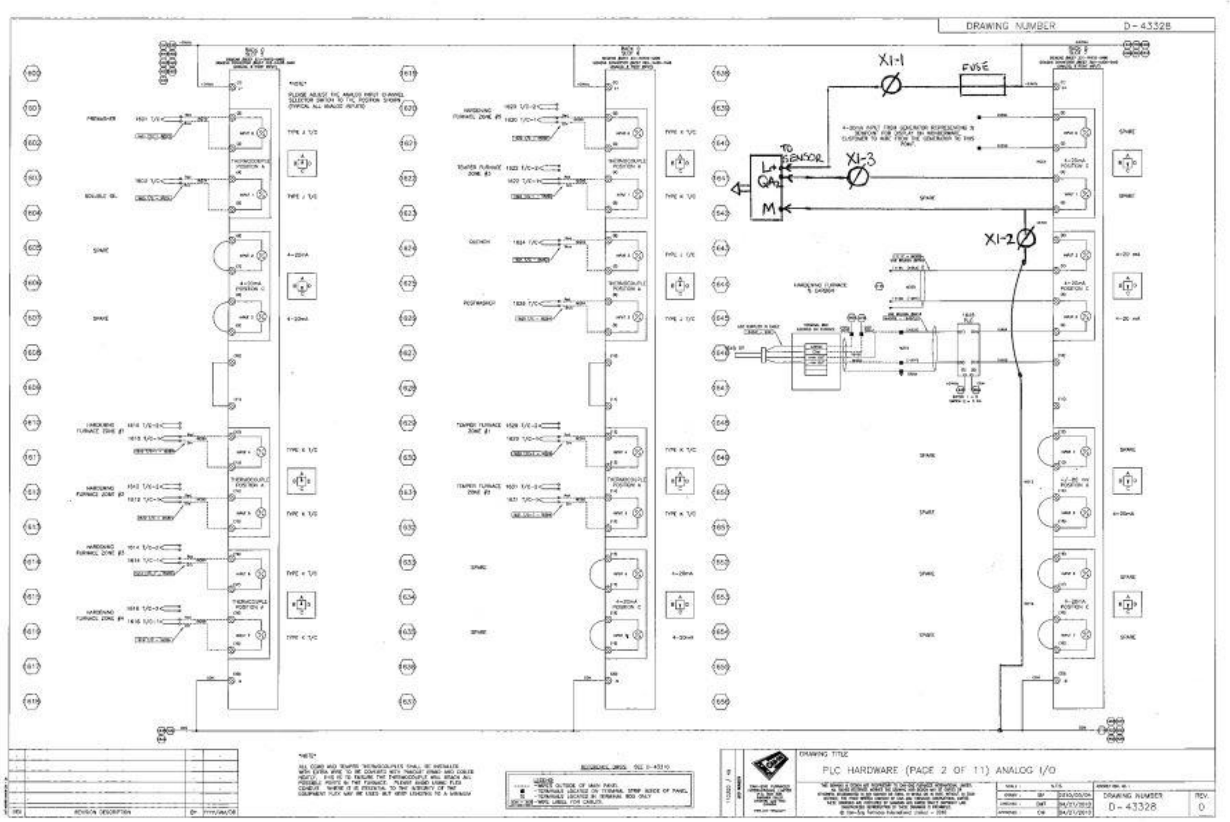


Figure 22. Electrical drawing of the current PLC with sensor added

Initial programming was written and installed on the operators' computer station by the Can-Eng engineering team. As soon as the sensor was running, Can-Eng was able to interface a program that recorded the height data collected from the sensor. This data is permanently stored on the operators' server and can be exported at any time.

The complexity of the program was upgraded as the project practical testing progressed and a more complete model of the heat transfer and loading limits was developed.

From the Product Density Experiment, it was determined that product characteristics of mass, length, and diameter are the most influential on product loading of the Furnace #10 belt. These characteristics are therefore the inputs used to obtain the sought after critical height value output. The ratio of product to free space is then calculated.

$$R = 0.265 + a_1 \max(0, (m - 194.9)) + a_2 \max(0, (m - 212.4)) + a_3 \max(0, (m - 346.2)) + a_4 \max(0, (D - 14)) + a_5 \max(0, (16 - D)) + a_6 \max(0, (D - 16)) + a_7 \max(0, (L - 45)) + a_8 \max(0, (100 - L)) + a_9 \max(0, (L - 100)) + a_{10} \max(0, (L - 180))$$

Coefficient	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10
Value (x 10-3)	5.28	-7.77	9.27	-68.7	-33.9	127	7.50	9.92	-9.58	4.76

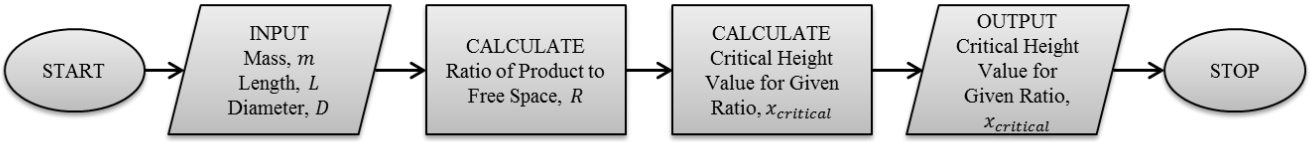


Figure 23. Programming flowchart one; critical height output

From the Thermocouple Experiement results, the critical height of a solid steel, $x_{theoretical}$, block was determined to be 47.015 mm. Using this value, and the ratio of product to free space from the Product Density Experiment, R, the critical height value for a batch of bolt can be found. See Figure 23 for programming logic.

$$x_{critical} = \left(\frac{x_{theoretical}}{R}\right)$$

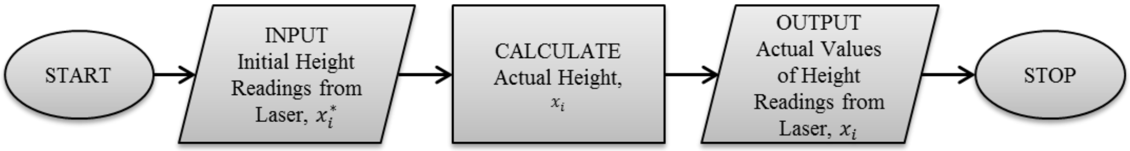


Figure 24. Programming flowchart two; actual height reading from laser

The laser is positioned such that the lowest beam is positioned to hit the flange of the furnace belt; the top of the flange is set as zero. Therefore, it is necessary to add the height of the flange to each height reading to obtain the actual height from the loading surface of the belt. For each height value add the constant p equals 23 mm, which is the height of the flange. This is included in programming by Figure 24.

$$x_i = x_i^* + p$$

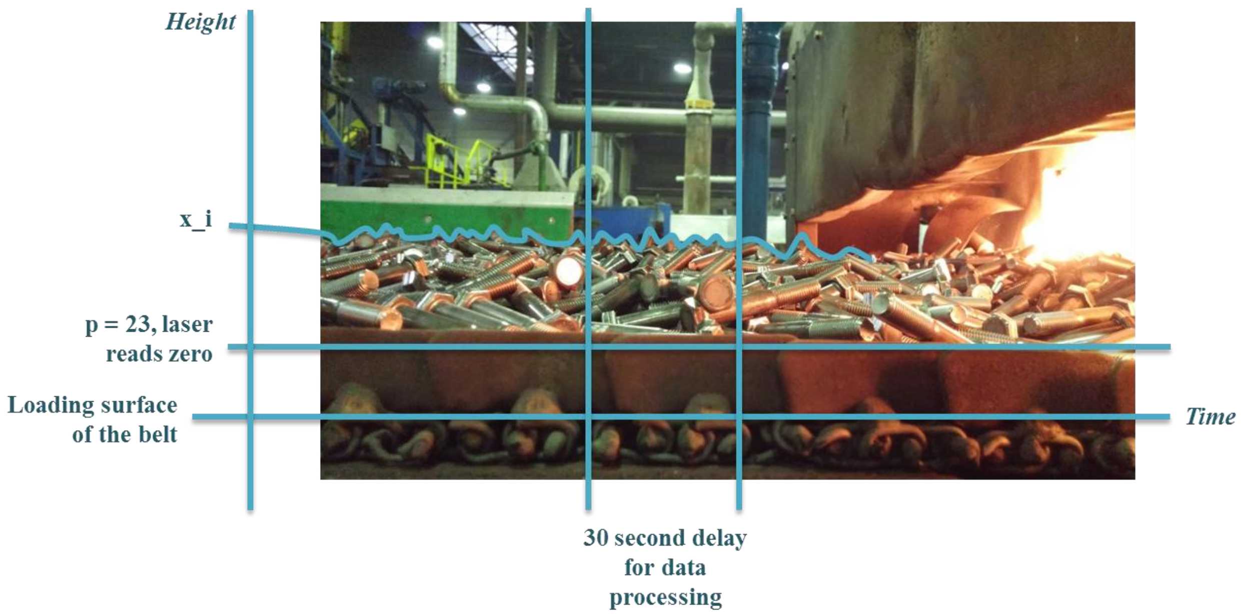


Figure 25. Visual of how Furnace #10 is to be programmed

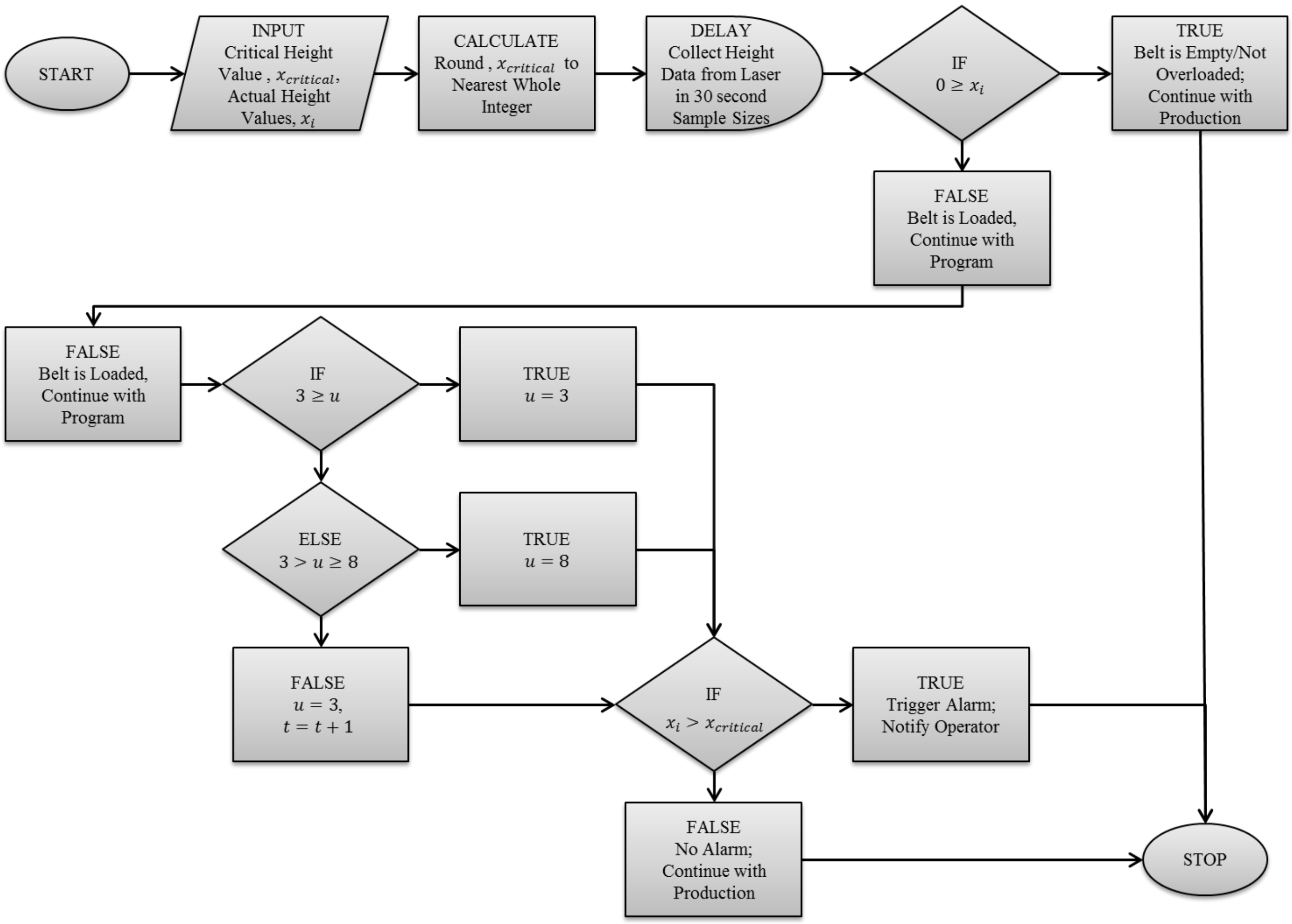


Figure 26. Programming flowchart three; comparison of actual height to critical height

For the bulk of the programming, refer to Figures 25 and 26. Keep in mind that the precision of the laser is 5 mm, therefore values of the critical value will be rounded to easily compare to the actual readings coming from the laser, x_i. The critical value must first be truncated to the nearest whole number. A delay of 30 seconds has been inserted before if statements are carried out to avoid any false triggering. In 30 seconds time approximately 100 mm of belt will have passed through the laser. During this time, if the laser reading is continuously zero, the rest of the program need not be run because that would correspond to an empty belt. However, if there is a reading other than zero the belt is loaded. For critical height limit ($x_{critical}$) to be easily compared to actual laser readings (x_i) consider the number to be made up of a hundreds place, tens place, and units place; h, t, and u, respectively.

$$x_{critical} = htu$$

The following if statements effectively round the initial values of x_i up to the nearest number with a units place value of either three or eight. Since the constant $p = 23$ is added to the readings in the previous flowchart, possible values for the units placeholder will be three or eight. Possible values read by the laser are given in Table 12.

Table 12. Possible values from laser output

Possible Values of Height Output from Laser
$x_i = htu$
28
33
38
43
48
53
58
63
68
73
78
83
88
93
98
103
108
113

118
123
128
133
138
143
148
153
158
163
168

Note that the delay will still be effective, i.e. running the if statements at 30 second time intervals. This should effectively avoid false triggering.

The values of x_i are then compared to the $x_{critical}$ values calculated using the first flowchart. If x_i is greater than $x_{critical}$ product load on the Furnace #10 belt is considered overloaded, an alarm should be triggered, and the operator should be notified as soon as possible.

6. RESULTS

Experimental results are included in the corresponding experimental sections of the report, refer to Section 3; Modeling Based on Existing Knowledge.

Results of the measurement system was judged based on the initial project requirements of Section 2; Introduction, Context, and Objectives. After the measurement system was decided upon and implemented, the project requirements were reevaluated. The results of this evaluation can be seen in Table 13 and 14.

Design Constraints Evaluation

Table 13. Design constraints evaluated

Design Constraint	Method of Measurement	Range	Result
Heat Resistant	Temperature	40.0 - 80.0 C	Laser: -30.0 - +55.0 C w/ heat shield: -30.0 - +80.0 C
No Damage to Products	Percentage of products damaged	0%	0%
Loading Area	Height (distance)	0.0 - 140.0 mm	0.0 - 145.0 mm
Loading Area	Width (distance)	≥1220.0 mm	0.0 - 5000.0 mm
Detection	Speed of furnace belt	100.0 - 200.0 mm/min	Response time: ≥ 3.6 ms
Physical Characteristics of Product	Length	20.0 - 265.0 mm	All fastener lengths
Physical Characteristics of Product	Diameter	M8-M16	All fastener diameters
Interface	Interfaces with current control system (yes/no)	Yes	Yes

Design Objectives Evaluation

Table 14. Design objectives evaluated

Design Objective	Priority	Method of Measurement	Optimization	Target	Result
Quality	High	Percent martensite	Maximize	≥90%	In progress; detection when ≥90% not met

Quality	High	Rockwell Hardness	N/A	Dependent on property class	In progress; detection when RHr value not met
Quality	High	Amount of customer complaints per year	Minimize	0	In progress, requires more system run time to verify
Quality	High	Number of product failures per month	Minimize	0	In progress, requires more system run time to verify
Detection	High	Overloading (height/product density) of furnace belt clearly defined (yes/no)	N/A	Yes	Yes
Detection	High	Percentage of time that overloading is detected (alarm is triggered)	Maximize	100%	In progress, laser programming
Efficiency	Medium	Time to detect	Minimize	<1 second	< 3.6 ms
Robustness	Medium	Vibration resistance (frequency)	Maximize	>100 Hz sinusoidal oscillation	10 - 150 Hz
Robustness	Medium	Resistant to industrial environment/air pollutants (ANSI/ISA S71.04-1985)	Maximize	G3 rating	Protection class III
Cost	Low	Euros	Minimize	<20000	7,107.48
Interface	Low	Inputs used	Minimize	1 analog input	2 analog inputs
Ease of Use	Low	Operator can add "overloading" parameters to current inputs (yes/no)	N/A	Yes	Yes
Maintenance	Low	Hours of maintenance per month	Minimize	2 hours per month	< 2 hours per month

7. CONCLUSIONS AND RECOMMENDATIONS

Recommended Action

When System Signals

Operator should either level out load on the conveyor belt, or continue the heat treatment process but send the batch through the process a second time to eliminate any product that may have not heat treated sufficiently.

Laser Maintenance and Housekeeping

Lasers will need to be cleaned on regular intervals, using a non-abrasive cloth and cleaning fluid. It is imperative not to scratch or damage the lenses on the laser units. Whilst cleaning, lasers must not be moved as this will affect the alignment. If the lasers go out of alignment, they will have to be realigned in order to collect reliable data.

Further Development

Despite having a detection system in place, Nedschroef should now look into a solution to eliminate overloading of product in the system. This can be done mainly by sorting out the distribution of the product on the conveyor. However one main aspect to keep in mind is that the potential solution must not cause any damage to the product or conveyor belt. Some potential solutions were brainstormed by the team and concept sketches of solutions can be found in Appendix B, Analysis of Existing Solutions section.

Nedschroef Heat Treatment should also monitor and record other parameters that may effect the hardening process. For example, Furnace #10 must be cleaned as scheduled and build up on the belt must be removed thoroughly during this time. Project Team A noticed issued with the hardening process when the scheduled maintenance did not occur on time. Also, the endothermic gass content of Furnace #10 was being studied during this project duration. Changes to the concentration of the endothermic gas could cause a change in the heat transfer coefficient in turn cause error in Project Team A’s experimental analysis.

Final Remarks

The Heat Treatment of Fasteners Project results are currently being implemented at Nedschroef Helmond. A control plan has been developed and the Heat Treatment Department at Nedschroef has been instructed on how to use the measurement system developed by Project Team A.

A series of three experiments were written and conducted to obtain the information needed to find a solution to the product loading issue at Furnace #10. Results of the experiments were analyzed to come up with a program which would detect the issue and warn the operator. Overall, the project team is pleased with the results of the semester long assignment. Although there were a challanges and obstacles with the project along the way, the original goals were withheld;

- The geometric factors length and diameter of the individual bolts has been determined to have an effect on the heat treatment.
- An empirical relationship was developed between bolt geometry and overloading of the belt.
- A measurement system was implemented to detect when the belt is overloaded, by informing the user when 90 percent martensite is not attained in a batch.
- The system is currently being modified to signal when the system has been overloaded by use of the measurement system and programming.

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APPENDIX A: ABBREVIATION/SYMBOL INDEX

Abbreviation Index

Abbreviation	**Meaning**
EPS	European Project Semester
DAF	DAF Trucks NV
VW	Volkswagen
SMART	Specific, Measurable, Achievable, Realistic and Time-bound.
ISA	International Society of Automation
MARS	Multivariate Adaptive Regression Spline
LCM	Lumped Sum Thermal Capacitance Method
SICK	SICK Sensor Intelligence
PLC	Programming Logic Controller
DOE	Design of Experiments
ASAP	As Soon As Possible
NLT	No Later Than
CTQ	Critical to Quality
FMEA	Failure Mode and Effects Analysis
SIPOC	Suppliers, Inputs, Process, Outputs, and Customers
PDCA	Plan–Do–Check–Act

Mathematical Symbol Index

Math Symbol	**Meaning**
R^2	Coefficient of Determination
h	Heat Transfer Coefficient
Bi	Biot Number
x	Height
w	Width of the Steel Block or Width of the Belt
x_critical	Critical Height Limit
x_i	Actual Height on Furnace Belt/Laser Height Output

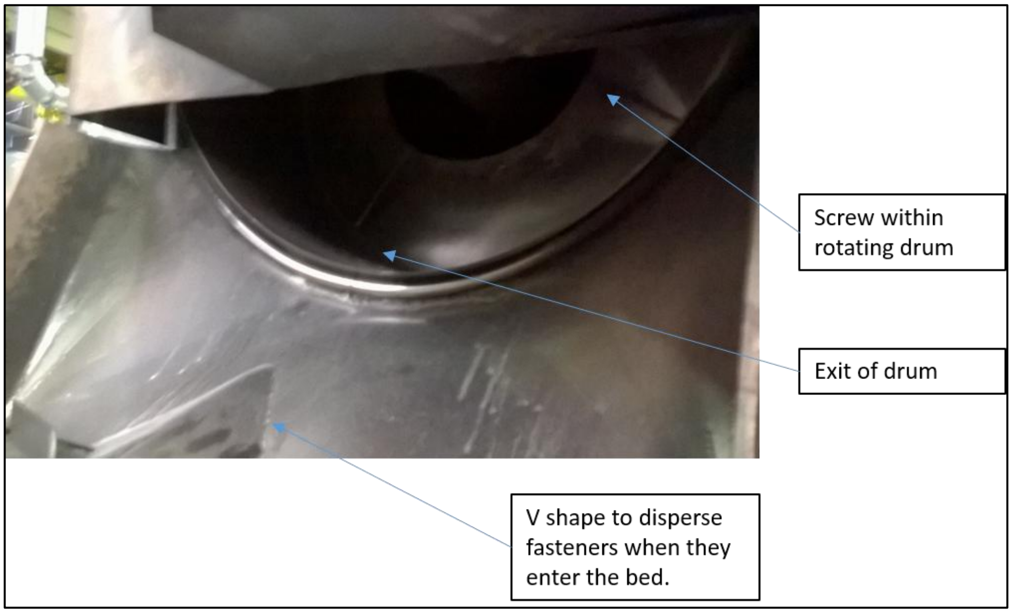
APPENDIX B: RESEARCH/EXISTING SOLUTIONS

Existing Solutions

The Helmond factory is home to 5 distinct heat treatment furnaces. Each furnace is slightly different due to process requirements, reengineering, and manufacturer. The first 4 furnaces, numbers 6-9, are made my Aube-Lindberg of Barcelona, Spain; furnace #10 is built by Can-Eng of Niagara, Canada. Furnaces #6 thru #9 have a maximum capacity of 750 kilograms per hour; furnace #10 is double that at 1500 kg/h. This project is focused on the largest furnace, #10. The following existing solutions for furnace loading and product distribution can be found in the Helmond factory. These solutions were examined as possible inspiration for the future solution for the problem area on furnace #10.

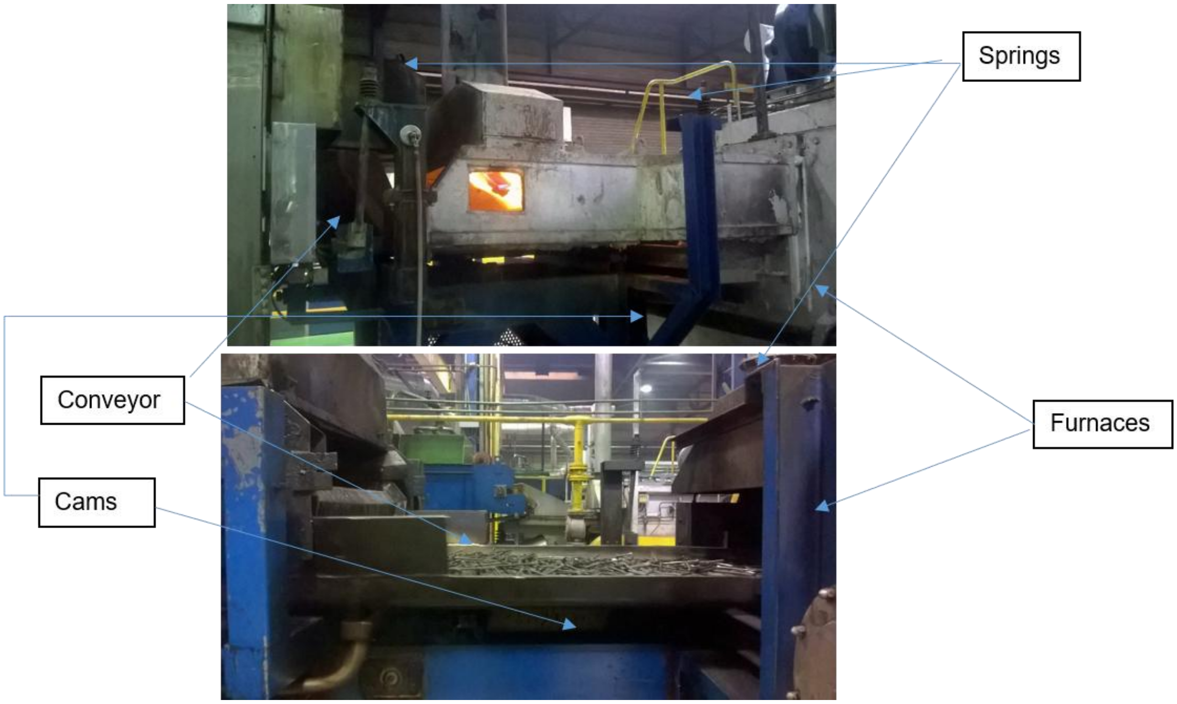
Rotating Drum

The rotating drum seen in Figure 8 can be found on Furnace #6. It has a screw that channels fasteners along the length of the heat treatment oven. At first glance, this is a good method for even heat treatment; however with further examination it presents some problems. The drum is effective for smaller products, but cannot accommodate larger products. Additionally, the drum can only process a relatively small capacity of products. Other problems are presented when the products remain in the same orientation throughout the oven. This can result in potentially unevenly treated products. To help randomize the orientation, a shaker has been added to the system.



Shunter (Large Amplitude Shaker)

A shunter system (Figure 9) can be found on all furnaces at excepting Furnace #10. Within its current application, the shunter is effective in terms of providing an even distribution of the product load entering the furnace. As products are dropped onto the shunting bed, they are propelled forward by means of a spring and motorized cam mechanism.



The forcing of the bolts forward along the bed is an efficient process for larger bolts as it helps them disperse evenly. However, smaller bolts and fasteners are sometimes moved too forcefully or not forcefully enough. If the product loaded is at the end of the batch, there may not be sufficient mass to push products forwards into the oven. This can cause a problem as it increases the risk of product mixing. If fasteners get stuck on the shunting bed, they can only be moved forward when the next product is loaded.

The shunter, therefore, is not a suitable solution for Furnace #10 after two important considerations. First, there is not sufficient space for installation of a shunter given the orientation of the Furnace #10. Second, the loading capacity of Furnace #10 is double that of any other single furnace at Nedschroef. Without drastic adjustments to both Furnace #10 and the current shunting system on other furnaces, implementing this solution would exceed the current capacity of the aforementioned shunting system.

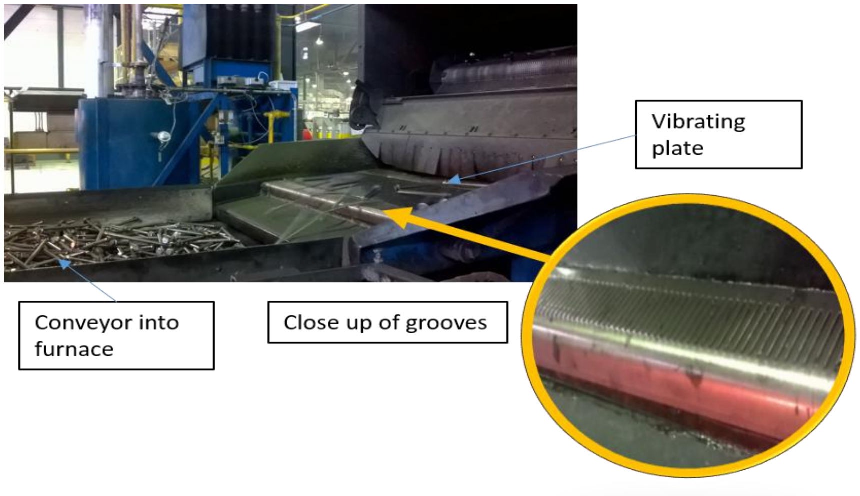
Tipper

The tipper (Figure 10) is unique to Furnace #9. The conveyor belt is loaded in even time increments before the product enters the pre-wash area. The timing is strategically spaced to avoid the occurrence of an overloading event. The downside to this system is the creation of areas of the bulk of the product load with gaps between loads. This uneven distribution of product is unavoidable with the use of this system. Another issue is that larger bolt sizes can get stuck or deform the tipper. Additionally, maintenance is frequently required on the single hydraulic lever that drives the system. Another big issue with this system is the product being loaded to high. If this is the case, all the fasteners do not enter the conveyor for heat treatment and sometimes the products are forced over the tipper into the pre-wash tank.


Load about to be tipped onto conveyor belt.

Vibrating Plate

The vibrating plate is the loading method currently in use on Furnace #10. The vibrating bed is an angled surface with parallel grooves on the lower edge. An off-centred cam and high speed motor drives the plate vibration. The product load is shaken by the vibrations down the conveyor belt upon entering the furnace. This layout can be seen in Figure 11. At the front side of the vibrating plate there is a stiff rubber flap. The flap distributes the products as they fall from the drying belt and prevents detrimental bunching. An issues with this is that product can get stuck and take extra time to pass down onto the conveyor belt. Additionally, for smaller products, the flap is not always successful in achieving even distribution.


Vibrating plate
Conveyor into furnace
Close up of grooves

APPENDIX C: PROJECT PLAN

Project Stakeholders

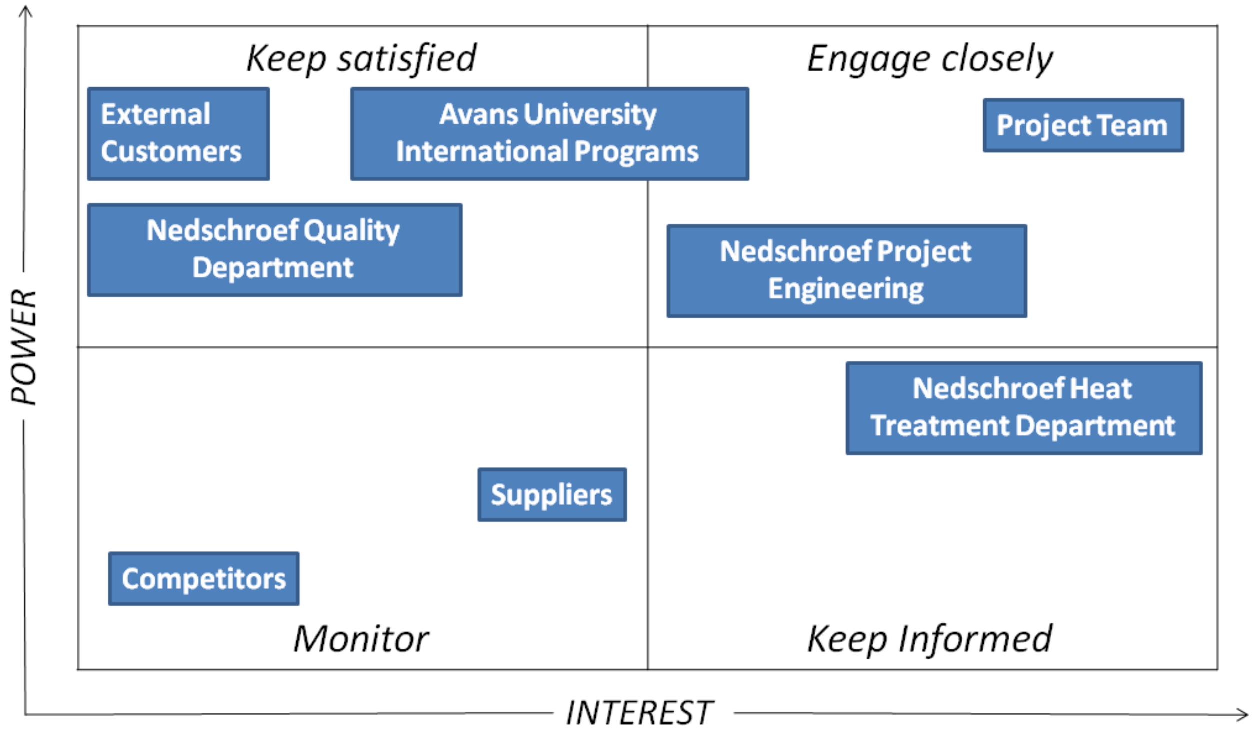
Project stakeholders include the project team, Avans University International Programs, internal customers at Nedschroef, and external customers of Nedschroef products. Stakeholder analysis was conducted to better understand characteristics of each individual stakeholder. An Interest-Power Matrix is used to map the influence that each stakeholder will have on the project. A Communication Matrix follows to outline how the stakeholders will be informed throughout the life of the project.

The project team is first and foremost the stakeholder with the greatest interest and power in the project. The project team is made up of Jesús Andres-Cabañas Rodrigo, Michelle Gaedke, Rachel Hook, and James O'Brien. Each member of the team has invested interest in the project due to undergraduate degree requirements. Team members also have motivation stemming from individual backgrounds in project work and coursework at their home universities.

Avans University International Programs has also invested in the Heat Treatment of Fasteners Project. Project tutor, Ron Dolstra will be highly engaged in the progress of the project through bi-monthly meetings. The project team will also work to keep EPS Coordinator Johan Wouters satisfied with project work and results. On behalf of the EPS program and our mentors, the project team would like to do their best work to maintain a positive relationship between the Avans University and Nedschroef so that this opportunity may be available to other students in the future.

Internal customers are the various employees and departments at Nedschroef who have invested in the project. The Heat Treatment Department is directly involved and has the most interest in the project's progress and success. The project team is working closely with Esther van Beek of Heat Treatment Department in order to meet and exceed the department's expectations. The Project Engineering Department is also closely involved. René van Geffen of Project Engineering is the company contact for the project team. Esther and René are both welcoming to questions from the project team and will be updated on progress in weekly meetings. The Quality Department has power backing the project because customer complaints are reported there. Quality has less concern on how the problem is fixed and will be satisfied if there is a working solution with proper documentation.

External stakeholders include suppliers, competitors, and companies who purchase fasteners directly from Nedschroef. The suppliers and competitors will be monitored throughout the project life. The other external customers include automotive and truck manufacturing companies such as Daf, Scania, Chrysler, and BMW. These are the most powerful stakeholders as the success of the project will be determined based on their satisfaction.



Power-Interest Matrix of internal and external stakeholders for the project

Communication Matrix for all Stakeholders

Stakeholder	Interest	Deadlines	Communication Form	Communication Manager
External Customers	Safety of manufactured products depends on fastener quality	ASAP for project completion	Formal written complaints, status reports on project progress	Nedschroef Quality and Engineering Departments
Nedschroef Heat Treatment Dept.	Sales depend on reliable fastener quality characteristics from heat treatment process	ASAP for project completion; NLT mid-January	Weekly meetings, access to project documents and reports	All members of project team
Nedschroef Project Engineering	Responsible for ensuring efficient results for heat treatment department, lean manufacturing and six-sigma quality	ASAP for project completion; NLT mid-January	Weekly meetings, access to project documents and reports	All members of project team, Heat Treatment Supervisor
Nedschroef Quality Dept.	Tests product to ensure customer needs are met, not able to completely control all results, needs more reliable heat-treatment process	ASAP for project completion; NLT mid-January	Updated as necessary via verbal and email communication	Heat Treatment and Project Engineering Supervisors

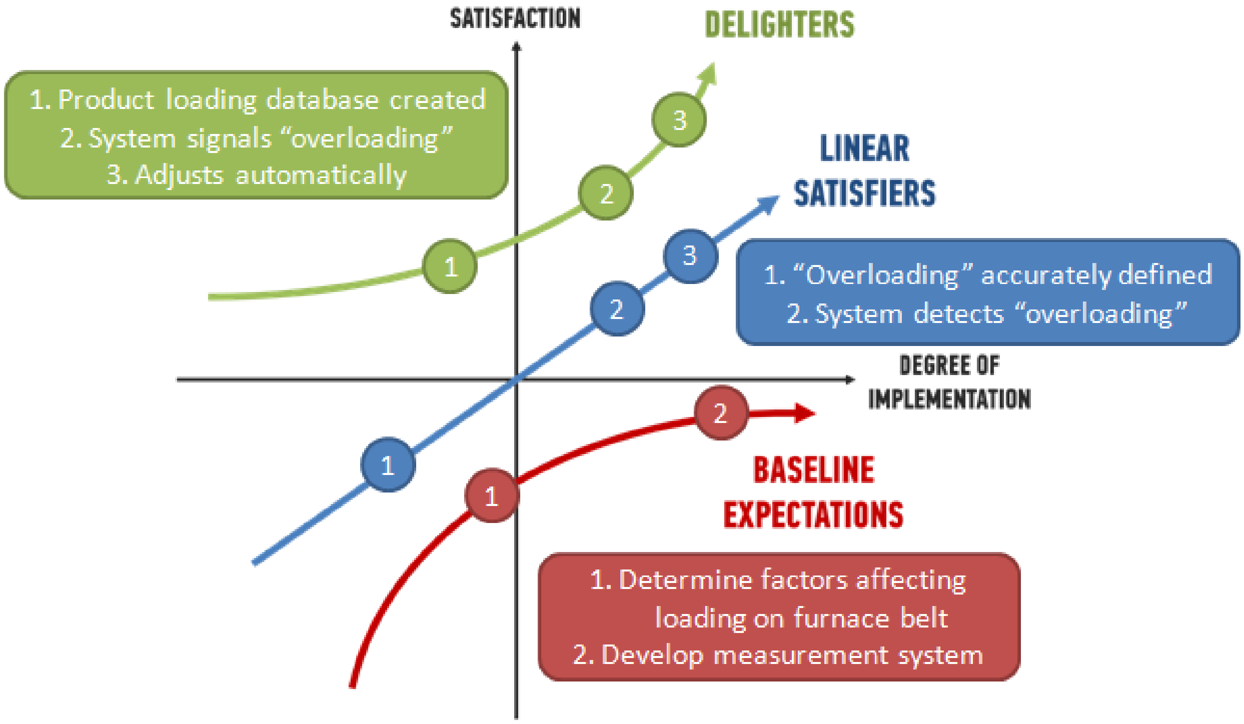
Project Team	Fulfill responsibilities as employees; complete project for academic credit	Internal Deadlines for deliverables and project steps	Daily verbal communication, all resources are stored on common forum	All members of project team
Avans University EPS/Int'l Programs	University reputation and student success, future program opportunities	Interim: 11 Nov. 2015 Final: 28 Jan. 2016	Bi-monthly meetings with advisor, interim and final reports and presentations	All members of project team
Suppliers	Project success has positive effect on supplier sales	None	No communication necessary	Word of mouth, Nedschroef Sales Dept.
Competitors	Project success has negative effect on competitor sales	None	No communication necessary	Word of mouth, news, etc.

Project Goals

Team Nedschroef has defined the goals of the project, under the guidance of project supervisors, as the following:

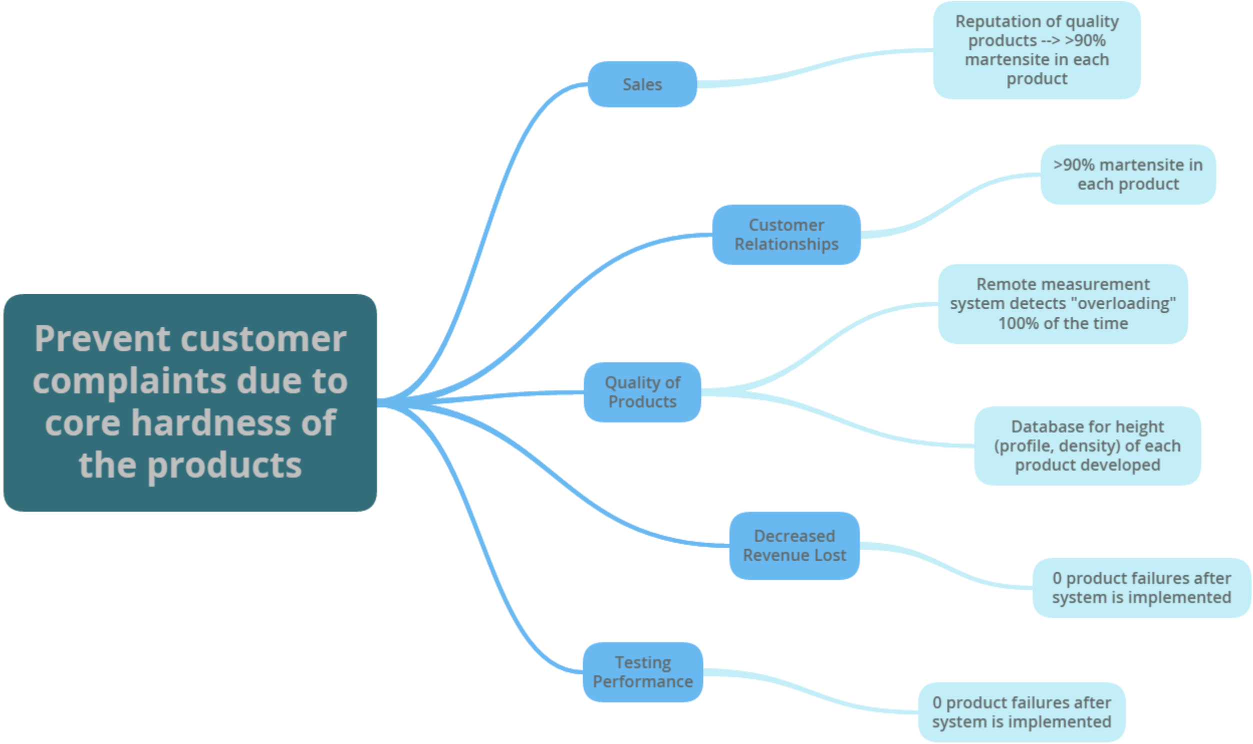
- To determine which geometric factors of the bolts have an effect on the heat treatment
- To develop an empirical relationship between bolt geometry and overloading of the belt
- To implement a measurement system to detect when the belt has been overloaded
- By informing the user when 90 percent martensite is not attained in a batch
- By conducting measurement system analysis
- To create product loading database to set parameters for system
- To modify the system to signal when the system has been overloaded with a detection system.
- To implement a solution which adjusts automatically based on the geometric factors of the product

The Kano Model which illustrates the project goals based on product development and stakeholder satisfaction. The baseline requirements involve determining which product characteristics have the greatest effect on belt loading and then developing a system to measure the loading. The project will be considered complete when a overloading for each product type is defined, a detection system is implemented, and the system is tested thoroughly using Design of Experiments (DOE) and Measurement System Analysis. If time and resources allow, further goals will be considered to exceed the expectations of the stakeholders. These "delighters" include creating a product loading database, signaling when the system has been overloaded, and realizing an automatically adjusting the measurement.

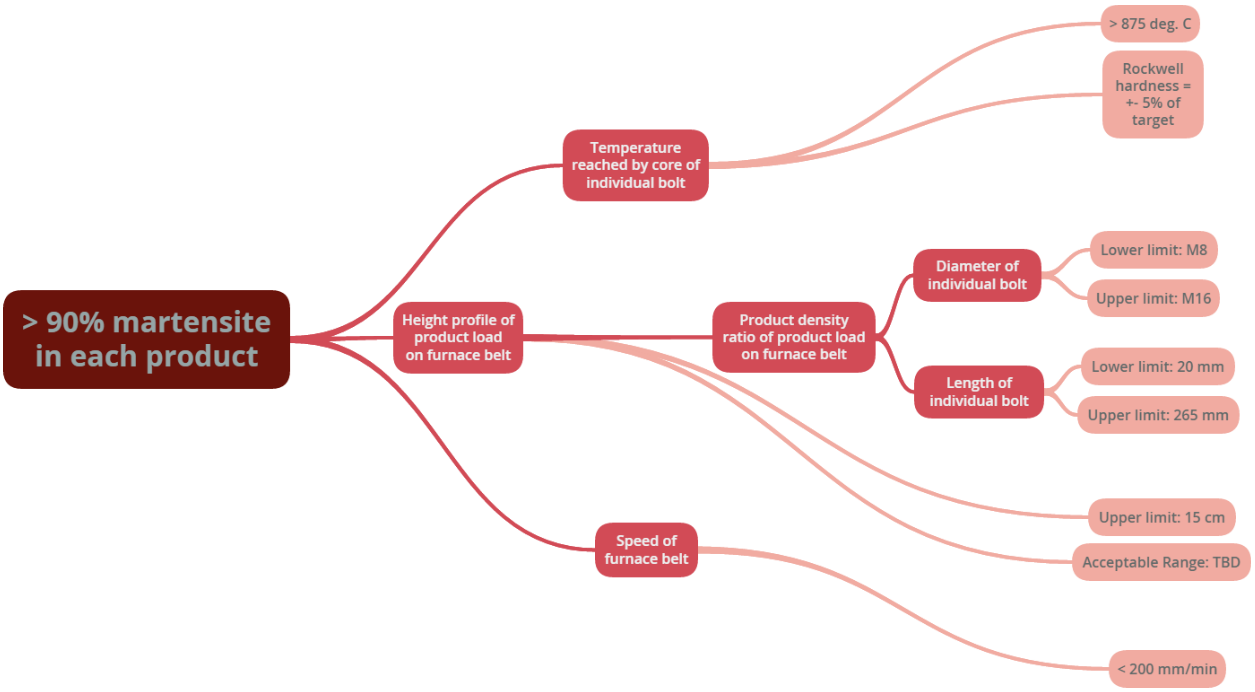


Kano Model for project goals

Following the Kano Model Analysis, Project Team A used a series of Critical to Quality (CTQ) trees to aid in making the customers' expectations measureable.



Broad level Critical to Quality tree for making customers' expectations measureable



Narrowed Critical to Quality tree for making customers' expectations measureable

Program of Requirements

The project team expects to develop a system capable of detecting the overloading and bulking up of product on the hardening belt of Furnace #10. The team intends that this system be further capable of signalling to the furnace controllers when unacceptable loading conditions occur. In order for these goals to be achieved, a test plan to determine loading limits for product quality will be developed and executed.

Boundary Conditions

- Operational up to 80 degrees Celsius
- Cannot damage product
- Two analog inputs or unlimited digital inputs
- Withstand environmental conditions and vibrations

Functional Requirements

- Cover 140.0 cm belt width
- Cover 15.0 cm furnace entrance height
- Detect with furnace belt moving at 200.0 mm/min
- Detection when product is overloaded and therefore will not attain 90 percent martensite
- FMEA criteria values less than or equal to 50 in the heat treatment department

Operational Requirements

- Require no more than two hours of manual maintenance labor per month
- Standard operating procedure should be written to contribute to ease of use

Design Constraints

- Interface with current control system
- Account for all bolt sizes; M8 to M16 and up to 160 mm length

Project Boundaries

The boundaries of this project are limited to Furnace #10. The project team has narrowed the boundaries further by focusing on the loading section of the hardening furnace. The project team will investigate product loading metrics for products treated in Furnace #10 during the 2015 calendar year. The team has limited the time frame as the first incidences of malfunction were treated in Furnace #10 during the early part of the year.

Plan of Approach

Problem Definition

The current problem is caused by the product not meeting the quality requirements of the external customers. This is caused by unregulated processes in the heat treatment department. The project team seeks to define the conditions that cause the product to be less than 90 percent martensitic grain structures and develop a system to detect unacceptable conditions.

Collect Customer Complaints

Once the problem has been fully defined, the project team will compile a database of past customer complaints that are related to the heat treatment department. Of special interest to the project success are the complaints related to product failure due to product hardness. Additionally the project team will investigate complaints related to Furnace #10.

Collect Necessary Properties

The project team will define testing procedures for products related to customer complaints and products treated in Furnace #10. All factors will be investigated for relevancy and a final testing procedure will be written in a formal test plan.

Test and Interpret Parameters

Data will be collected for the products outlined in the test plan. The collected data will be stored electronically for analysis. Design of Experiments methodology will be used to analyze the factors for relevancy and impact on the heat treatment process. Heat transfer model analysis will be conducted using the relevant factors to determine when possible overloading conditions will occur.

Design Remote Measurement

The project team will investigate measurement tools for detection of overloading conditions. This includes contacting measurement system companies and arranging plant visits to determine possible solutions. The project team will conduct design analysis and Pugh decision methods to decide on a final design for measurement. The final design will be installed and programmed to interface with the operator station.

Test Working Detection System

The project team will test the installed system for effectiveness and troubleshoot system errors. A failure modes and effects analysis will be conducted to attempt to mitigate potential problems and their negative impacts. Any current or potential problems will be recorded.

Apply Design Changes and Improvements

Improvements and changes to the design bases on the previous project step will be implemented and tested. The solution should as optimized for the project requirements as possible with respect to the project time constraints.

Document Results

A final report of all project results will be created as a project thesis for the project team's academic requirements. This report will include project management documents, stakeholder analysis, mathematical and physical modeling, design decisions, and any other relevant information regarding the success of the project.

Schedule/Time Management

Team Roles

Each team member is expected to contribute equally to the workload, with each member functioning according to his or her educational background. Additionally team roles have been assigned based on personality testing in order that the organizational aspects of the project are efficiently managed.

Team roles and responsibilities based on educational background and Belbin personality test

Team Member and Background	Role and Personality	Responsibilities
Jesus Andres-Cabañas Rodrigo (*Industrial Engineering*)	Data Acquisition, Shaper/Team Player	Define Parameters/Metrics, Collect Baseline Data, Create Database, Operational Definitions
Michelle Gaedke (*Mechanical Engineering*)	Project Coordinator, Finisher	Project Charter, Executive Summary, Reporting Data, Lessons Learned, Final Report
Rachel Hook (*Mechanical Engineering*)	Research and Development, Resource Investigator	Identify Forces Driving Design, Design Objectives and Constraints, Design of Experiments
James O'Brien (*Product Design*)	Product Designer, Implementation Coordinator, Resource Investigator	Identify Alternative Concepts, Rough Sketches, Conduct Testing, Implement Design Changes

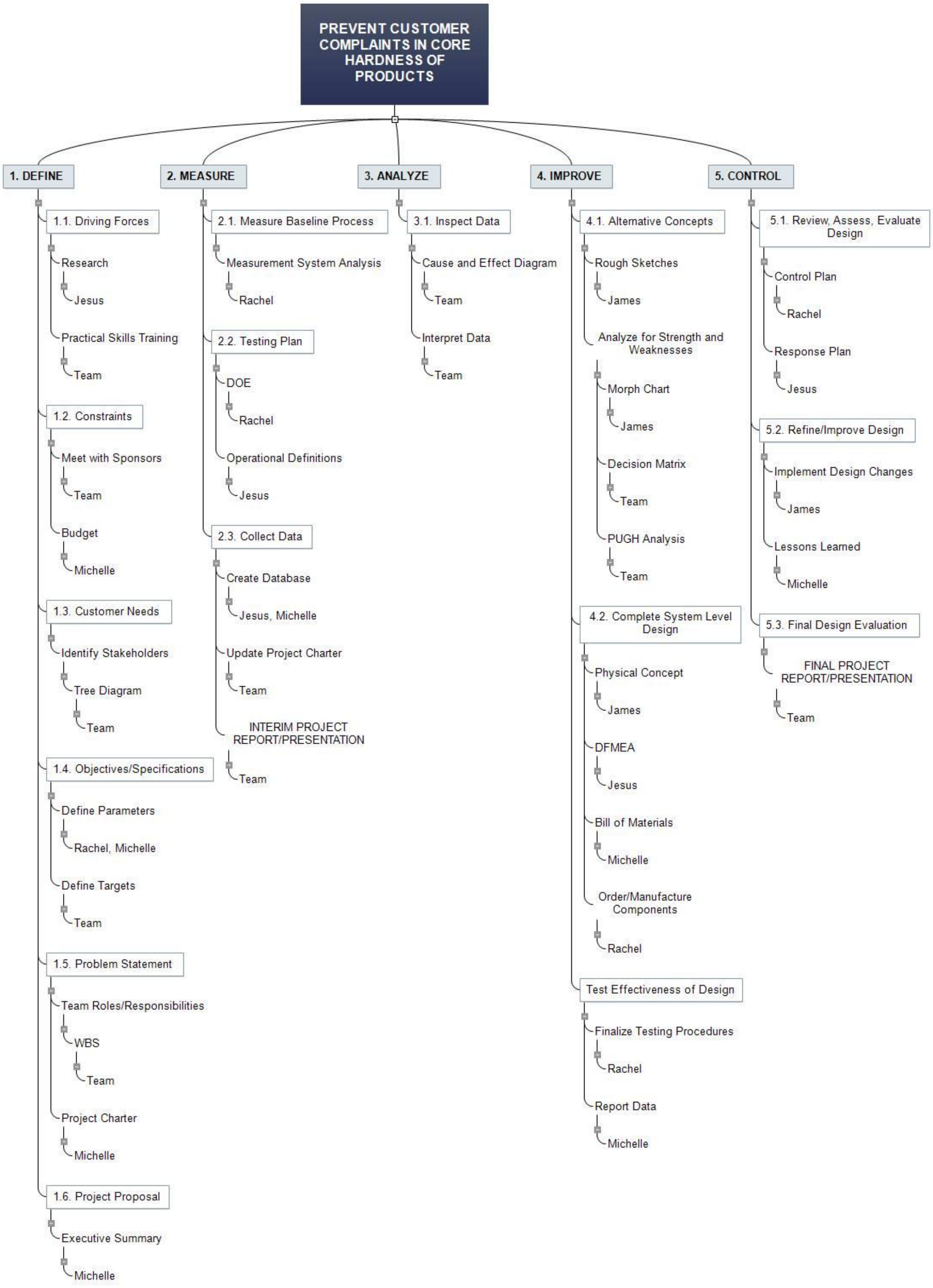
Project Schedule/Deliverables

The project team has organized the scheduled with a sixteen deliverables, each with internal deadlines as listed below:

Project deliverables using Six Sigma DMAIC problem solving method

Deadline	Deliverable	Description
Phase 1: DEFINE		
17/09/2015	D1. Identify Forces Driving Design	Practical Skills Training, Research, SIPOC, Project Concept Statement
24/09/2015	D2. Identify Constraints	Meeting with Sponsors, Budget
01/10/2015	D3. Identify Company/Customer Needs	Meeting with Stakeholders, Expectations, Tree Diagram
08/10/2015	D4. Design Objectives and Specifications	Define Metrics and Parameters, Targets, Table of Design Objectives
15/10/2015	D5. Problem Analysis and Statement	Team Roles and Responsibilities, Project Charter
22/10/2015	D6. Project Proposal	Executive Summary
Phase 2: MEASURE		
22/10/2015	D7. Measure Baseline Process	Value Stream Map, Measurement System Analysis
29/10/2015	D8. Create Plan to Collect Data	Design of Experiments (DOE), Operational Definitions, Design Testing Procedures
02/11/2015	D9. Collect Data	Create Database, Potential Causes and Goals, Update Project Charter, **Interim Report/Presentation (02/11/2015)**
Phase 3. ANALYZE		
13/11/2015	D10. Inspect Data	Cause and Effect Diagram, Interpret Data
Phase 4. IMPROVE		
20/11/2015	D11. Identify Alternative Concepts	Rough Sketches, Analyze for Strengths and Weaknesses, Decision Matrix, Morph Chart, PUGH Analysis
04/12/2015	D12. Complete System Level Design	Summary of Design Decisions, PDCA/PDSA, Physical Concept, Detailed Sketches, Bill of Materials, DFMEA, Begin Ordering/Manufacturing Components
11/12/2015	D13. Test Effectiveness of Design	Finalize Testing Procedures, Prototype, Conduct Prototype Tests, Report Data
Phase 5. CONTROL		
18/12/2015	D14. Review, Assess, and Evaluate Design	Control Plan, Response Plan, Control Charts
08/01/16	D15. Refine and Improve Design	Implement Design Changes, Lessons Learned
22/01/16	D16. Prepare Final Design Evaluation	Documentation, **Final Report/Presentation (29/01/2016)**

Work Breakdown Structure



APPENDIX D: SUPPLIMENTAL EXPERIMENTAL DATA

Product Density Experiment

			Bin Properties		
Experiment #	Trial #	Article Number	Bin Size	Bin Mass [g]	Total Bin Volume [mL]
1	1	18823158	Blue, Full	587.0	5545.28
1	2	18823158	Blue, Half	572.5	2559.36
1	3	18823158	Red, Half	829.0	5873.28
1	4	18823158	Blue, Half	572.5	2559.36
1	5	18823158	Blue, Full	574.0	5545.28
1	6	18823158	Red, Half	829.0	5873.28
2	7	18834357	Blue, Full	574.0	5545.28
2	8	18834357	Blue, Half	572.5	2559.36
2	9	18834357	Red, Half	829.0	5873.28
2	10	18834357	Blue, Half	572.5	2559.36
2	11	18834357	Blue, Full	572.5	5545.28
2	12	18834357	Red, Half	829.0	5873.28

Bolt Properties						
Bolt Name	Density [g/cm^3]	Steel Grade	Mass of One Unit [g]	Diameter [mm]	Length [mm]	Head Type
M8x1.25x20	7.85	10.9	16.7	8.0	20.0	Hex
M8x1.25x20	7.85	10.9	16.7	8.0	20.0	Hex
M8x1.25x20	7.85	10.9	16.7	8.0	20.0	Hex
M8x1.25x20	7.85	10.9	16.7	8.0	20.0	Hex

M8x1.25x20	7.85	10.9	16.7	8.0	20.0	Hex
M8x1.25x20	7.85	10.9	16.7	8.0	20.0	Hex
M12x1.50x45	7.85	8.8	50.8	12.0	45.0	Round, Spline Drive
M12x1.50x45	7.85	8.8	50.8	12.0	45.0	Round, Spline Drive
M12x1.50x45	7.85	8.8	50.8	12.0	45.0	Round, Spline Drive
M12x1.50x45	7.85	8.8	50.8	12.0	45.0	Round, Spline Drive
M12x1.50x45	7.85	8.8	50.8	12.0	45.0	Round, Spline Drive
M12x1.50x45	7.85	8.8	50.8	12.0	45.0	Round, Spline Drive

Total Mass [g]	Mass of Product Load [g]	# of Bolts	Total Bolt Volume [mL]	Volume of Free Space [mL]	Ratio of Material to Free Space	Percent of Space Occupied
18868.6	18281.6	1095	2328.9	3216.4	0.724	42.00%
9034.0	8461.5	507	1077.9	1481.5	0.728	42.12%
20827.1	19998.1	1197	2547.5	3325.8	0.766	43.37%
9959.2	9386.7	562	1195.8	1363.6	0.877	46.72%
18025.5	17451.5	1045	2223.1	3322.2	0.669	40.09%
19257.6	18428.6	1104	2347.6	3525.7	0.666	39.97%
16260.4	15686.4	309	1998.3	3547.0	0.563	36.04%
7984.3	7411.8	146	944.2	1615.2	0.585	36.89%
20171.3	19342.3	381	2464.0	3409.3	0.723	41.95%
8745.5	8173.0	161	1041.1	1518.2	0.686	40.68%
17273.5	16701.0	329	2127.5	3417.8	0.622	38.37%
20272.4	19443.4	383	2476.9	3396.4	0.729	42.17%

Thermocouple Experiment

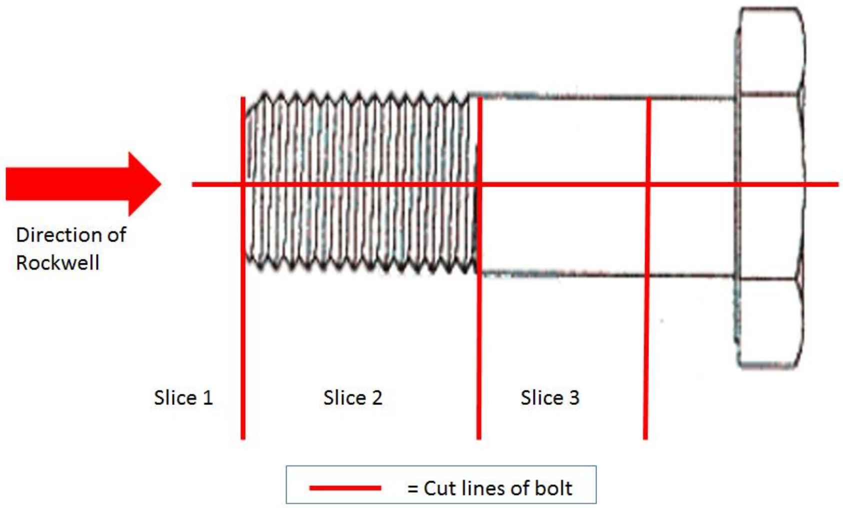
INPUT: fastener properties		
Mass, m	0	g
Diameter, D	10	mm
Length, L	25	mm

Coeffiients of the density equation	
a1	5.28E-03
a2	-7.77E-03
a3	9.27E-03
a4	-6.87E-02

a5	-3.39E-02	
a6	1.27E-01	
a7	7.50E-03	
a8	9.92E-03	
a9	-9.58E-03	
a10	4.76E-03	
OUTPUT:		
Density Ratio, R	8.06E-01	
Theoretical Maximum Height for Solid Steel, x	4.7015	cm
Theoretical Maximum Height with Ratio Applied, x*	5.84E+00	cm

Practical Evaluation Experiment

Earlier trial experiment results:



Target Rockwell Hardness Range = 32-39

	Bottom		**Middle**		**Top**	
	Rockwell Value	Deviation from Target	Rockwell alue	Deviation from Target	Rockwell Value	Deviation from Target
Slice 1	27.62	13.69%	30.97	3.22%	-	-
Slice 2	28.74	10.19%	36.97	-	-	-
Slice 3	28.90	9.69%	31.07	2.91%	-	-
Average	28.42	11.19%	33.33	-	-	-
Microscopic Analysis (martensite?)	Yes		Yes		Yes	

Hardness Conversion Table

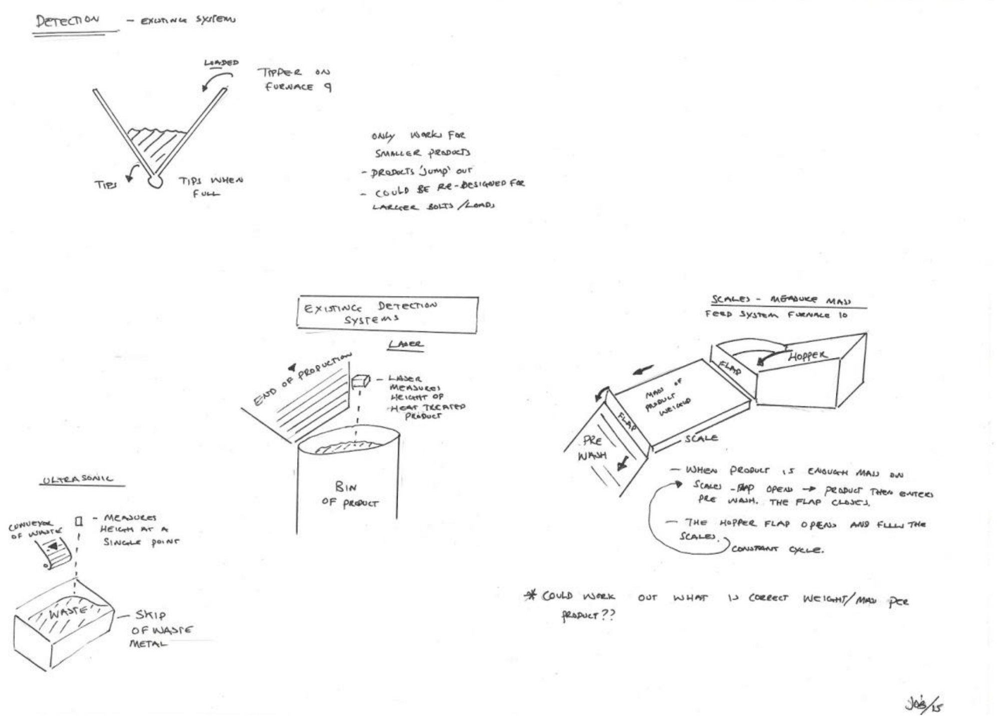
Tensile Strength (N/mm$^{2)}$	**Brinell Hardness (BHN)**	**Vickers Hardness (HV)**	**Rockwell Hardness (HRB)**	**Rockwell Hardness (HRC)**
285	86	90		
320	95	100	56.2	
350	105	110	62.3	
385	114	120	66.7	
415	124	130	71.2	

450	133	140	75.0	
480	143	150	78.7	
510	152	160	81.7	
545	162	170	85.0	
575	171	180	87.1	
610	181	190	89.5	
640	190	200	91.5	
675	199	210	93.5	
705	209	220	95.0	
740	219	230	96.7	
770	228	240	98.1	
800	238	250	99.5	
820	242	255		23.1
850	252	265		24.8
880	261	275		26.4
900	266	280		27.1
930	276	290		28.5
950	280	295		29.2
995	295	310		31.0
1030	304	320		32.2
1060	314	330		33.3
1095	323	340		34.4
1125	333	350		35.5
1155	342	360		36.6
1190	352	370		37.7
1220	361	380		38.8
1255	371	390		39.8
1290	380	400		40.8
1320	390	410		41.8
1350	399	420		42.7
1385	409	430		43.6
1420	418	440		44.5
1455	428	450		45.3
1485	437	460		46.1

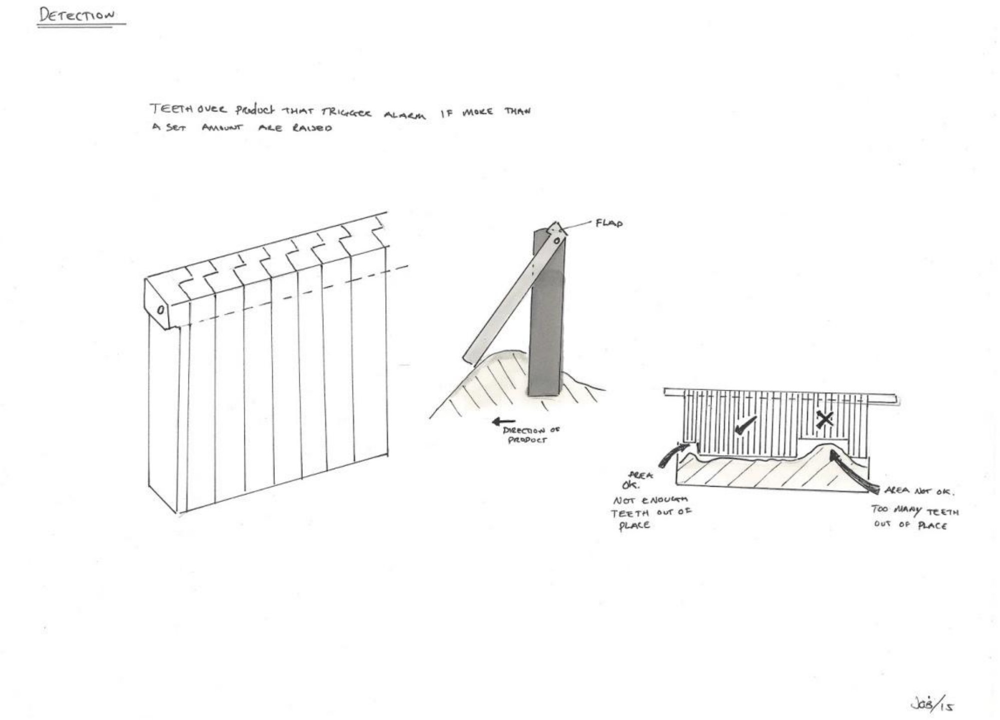
1520	447	470		46.9
1555	456	480		47.7
1595	466	490		48.4
1630	475	500		49.1
1665	485	510		49.8
1700	494	520		50.5
1740	504	530		51.1
1775	513	540		51.7
1810	523	550		52.3
1845	532	560		53.0
1880	542	570		53.6
1920	551	580		54.1
1955	561	590		54.7
1995	570	600		55.2
2030	580	610		55.7
2070	589	620		56.3
2105	599	630		56.8
2145	608	640		57.3
2180	618	650		57.8

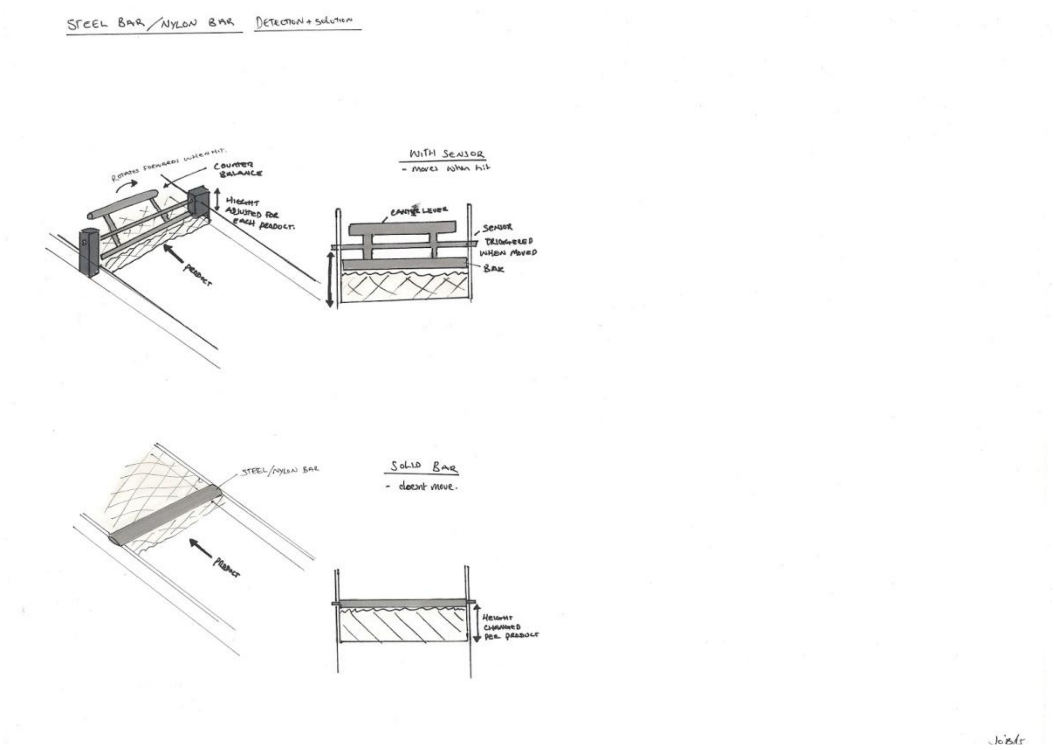
APPENDIX E: CONCEPT SKETCHES

Detection Phase Concepts

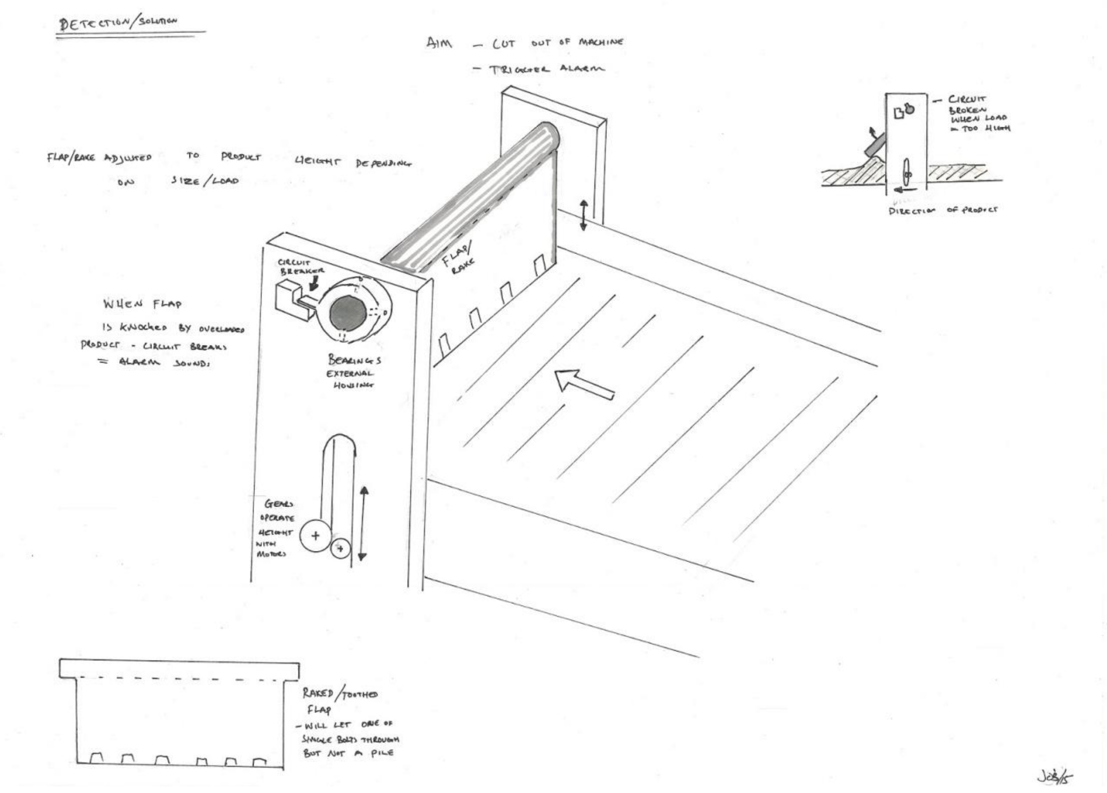


1. Existing detection systems within Nedschroef.
2. Concept of using flaps with sensors.

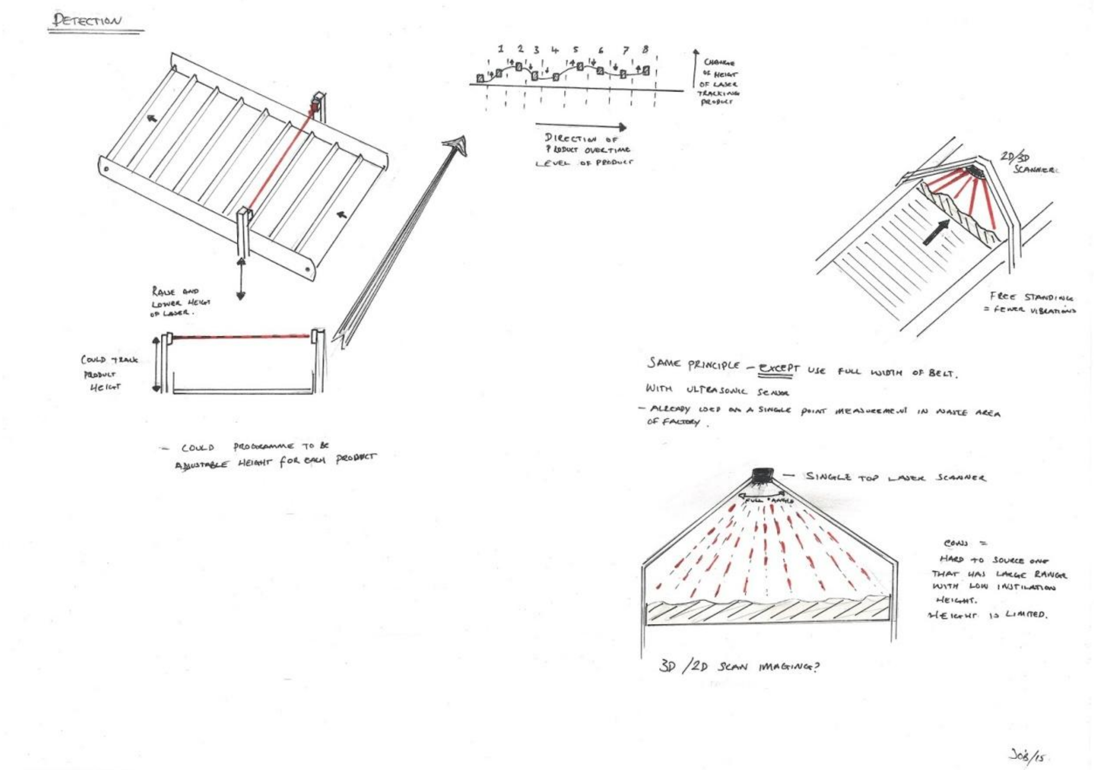




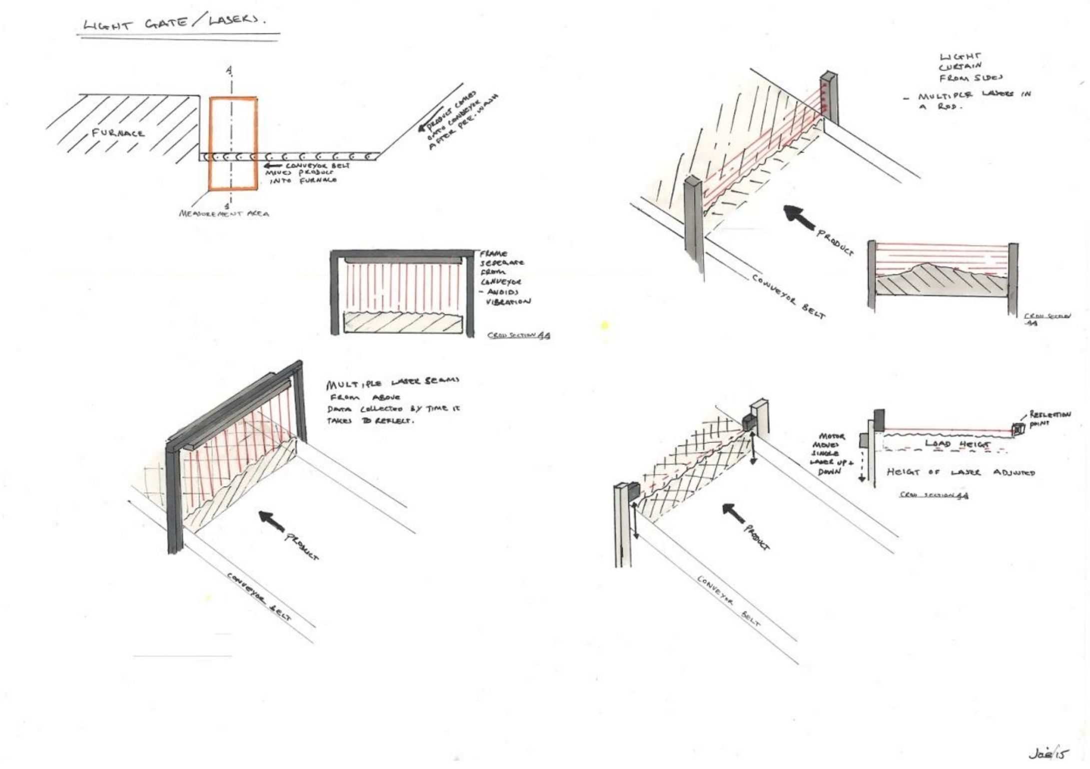
3. Bar system concepts.
4. Bar with a cut off switch.



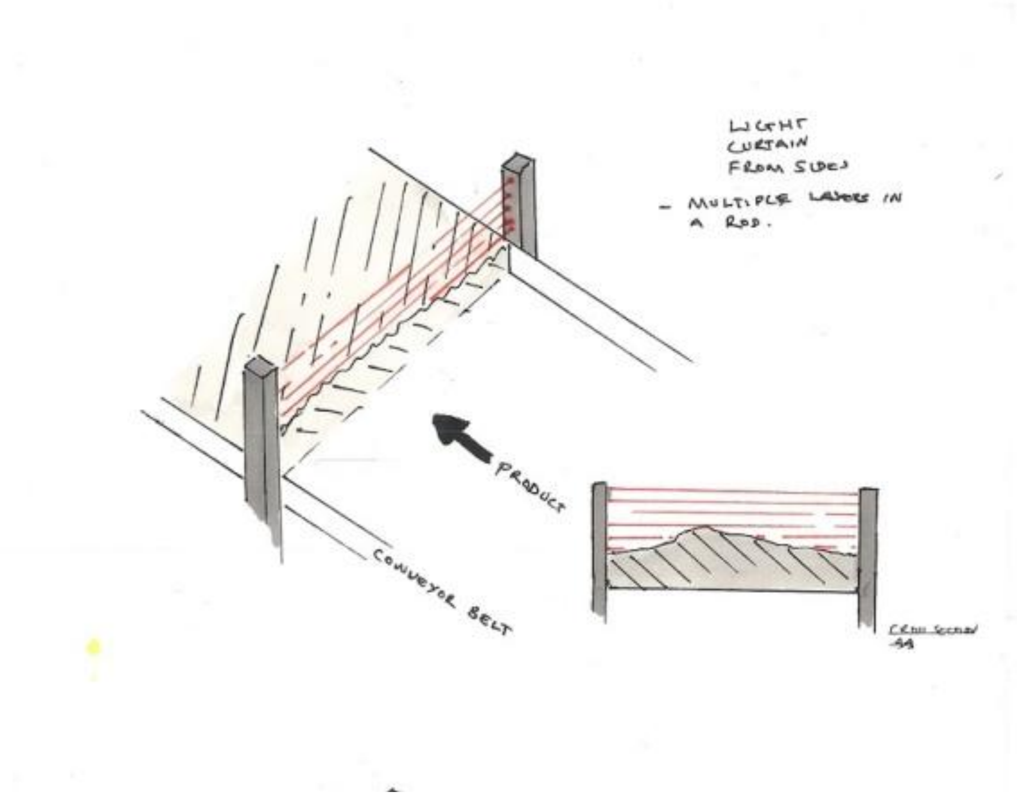
5. Concepts of using laser detection, inspired by research of many companies:



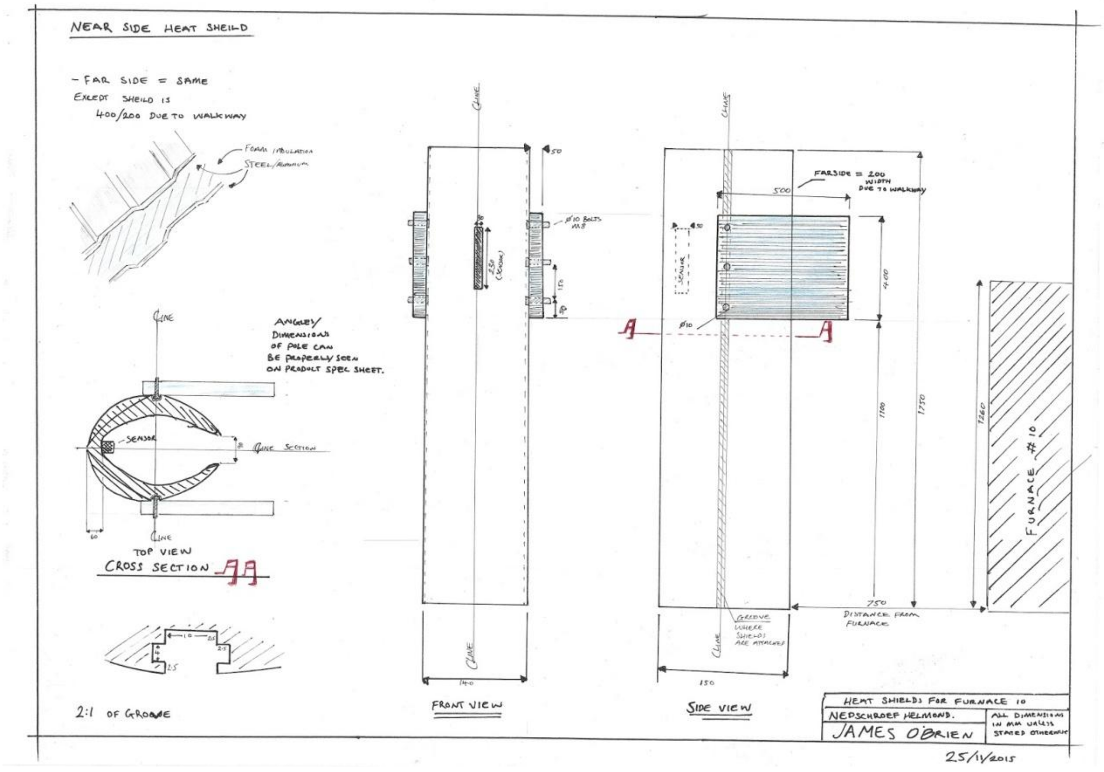
6. Concepts of using laser detection, inspired by research of many companies.



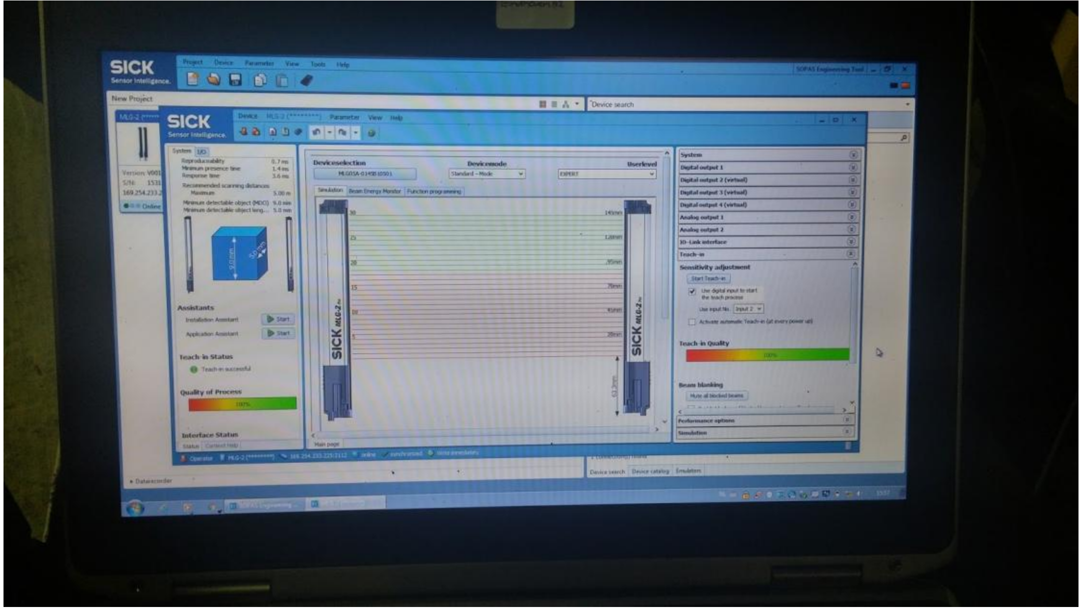
7. Concepts were shown to companies, a “laser light curtain” was the detection system that SICK could cater to:



8. Heat shield design to protect installed lasers from heat radiation:

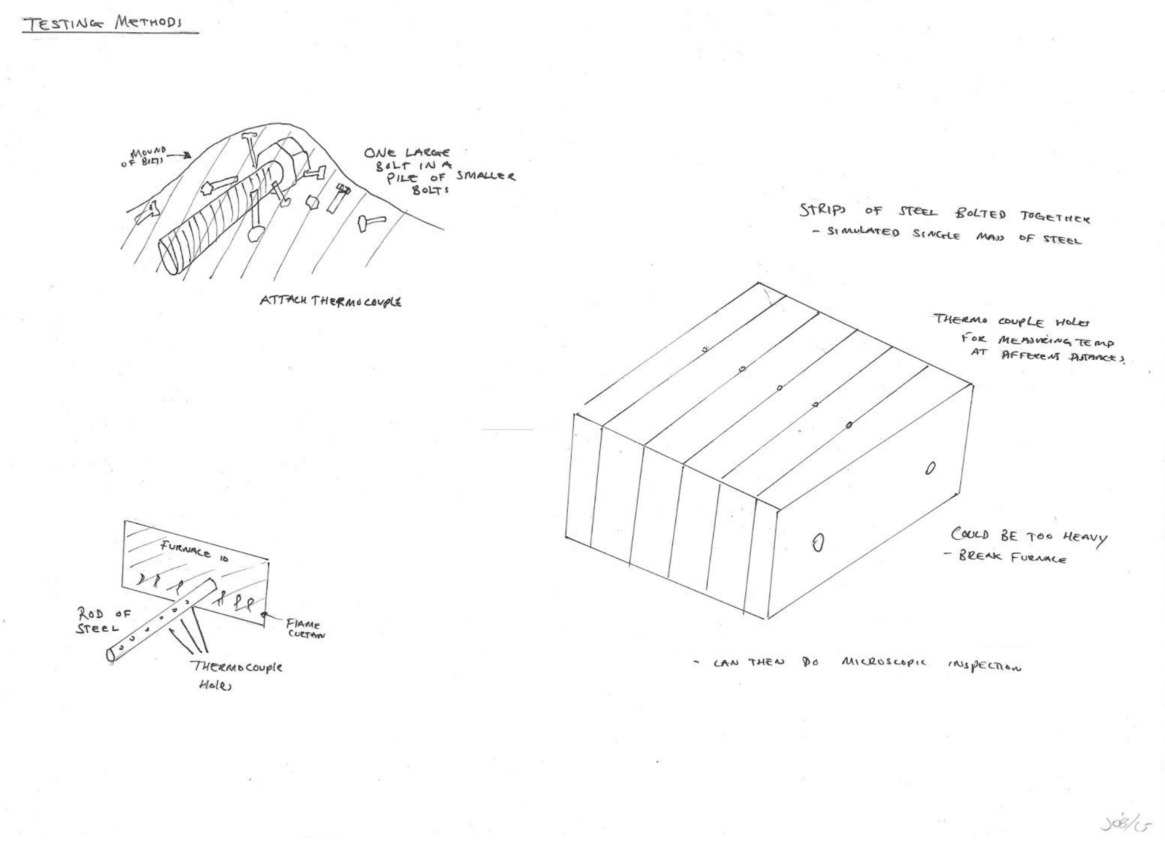


9. Installed and programmed system in operation:

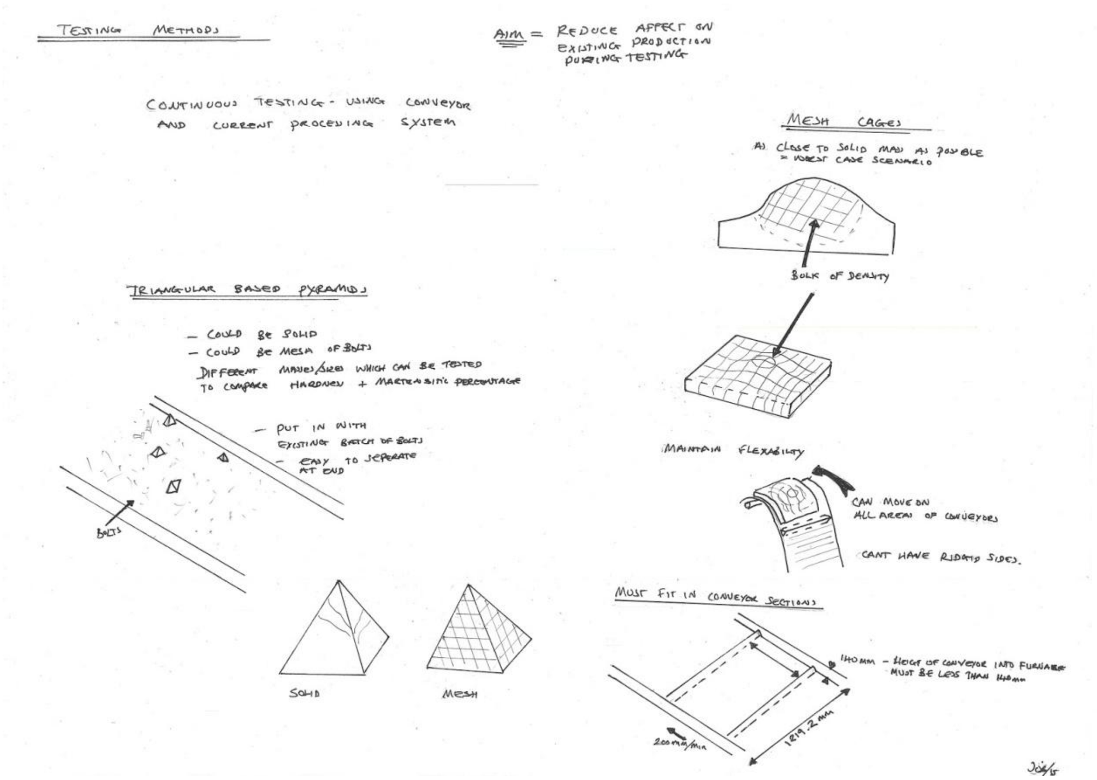


Testing and Measure Phase Concepts

1. Worst case scenarios.



2. The use of mesh cages, this idea was build on and developed.



TESTING METHODS

AIM = REDUCE AFFECT ON EXISTING PRODUCTION DURING TESTING

CONTINUOUS TESTING - USING CONVEYOR AND CURRENT PROCESSING SYSTEM

TRIANGULAR BASED PYRAMIDS

- COULD BE SOLID
- COULD BE MESH OF BOLTS

DIFFERENT MASSES/SIZES WHICH CAN BE TESTED TO COMPARE HARDNESS + MARTENSITIC PERCENTAGE

- PUT IN WITH EXISTING BATCH OF BOLTS
- EASY TO SEPERATE AT END

MESH CAGES

AS CLOSE TO SOLID MASS AS POSSIBLE = WORST CASE SCENARIO

MAINTAIN FLEXABILITY

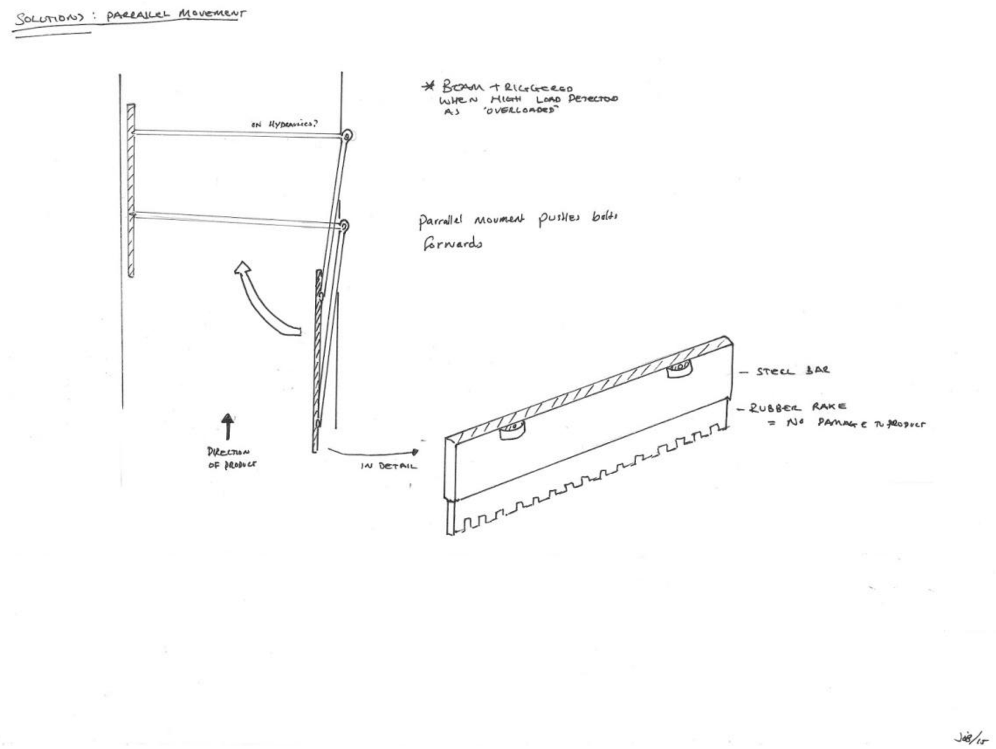
CAN MOVE ON ALL AREAS OF CONVEYORS

CANT HAVE RIGID SIDES.

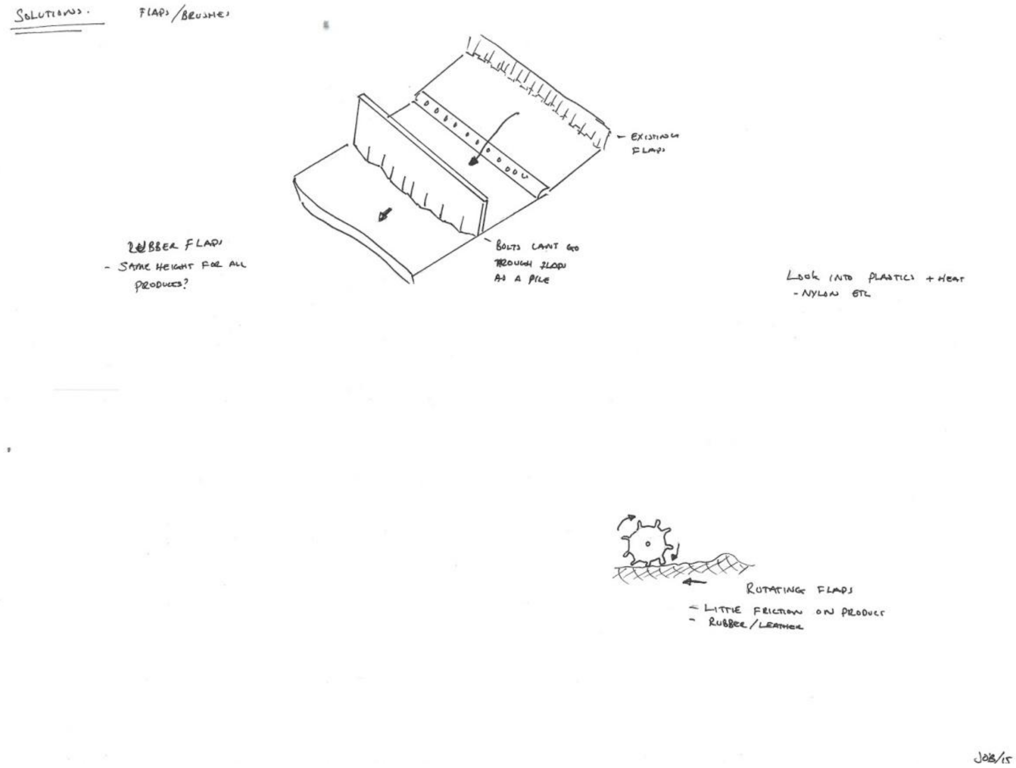
MUST FIT IN CONVEYOR SECTIONS

140MM - HEIGT OF CONVEYOR INTO FURNACE MUST BE LESS THAN 140mm

Solution Concepts



1.

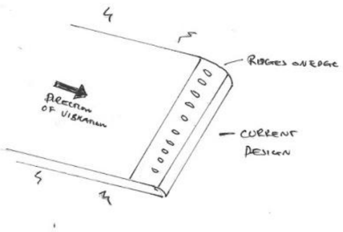


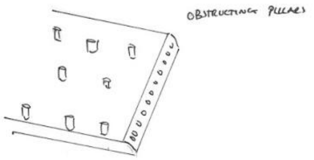
2.

Solution Concepts

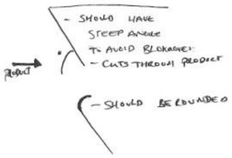
AIM - ADD TO EXISTING SYSTEM
- OBSTICALS ON VIBRATING BED TO DISPLACE PRODUCT

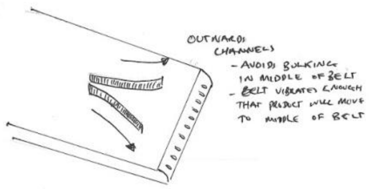
VIBRATING TABLE AREA

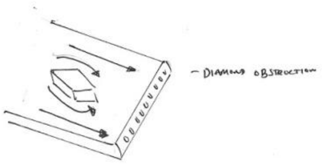




OBSTRUCTION SHAPE







3.
4.

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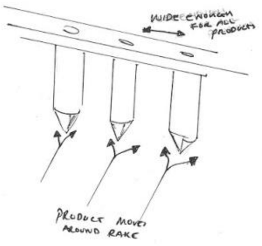
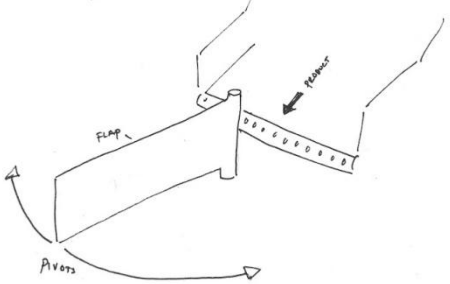
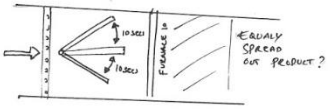
SOLUTIONS

RAKE
- COULD BE PLASTIC/RUBBER/STEEL



PIVOTING FEED FLAP





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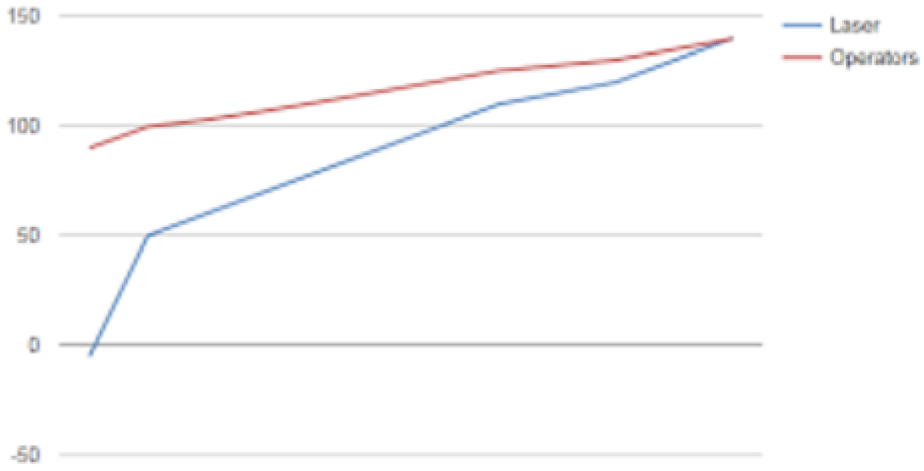
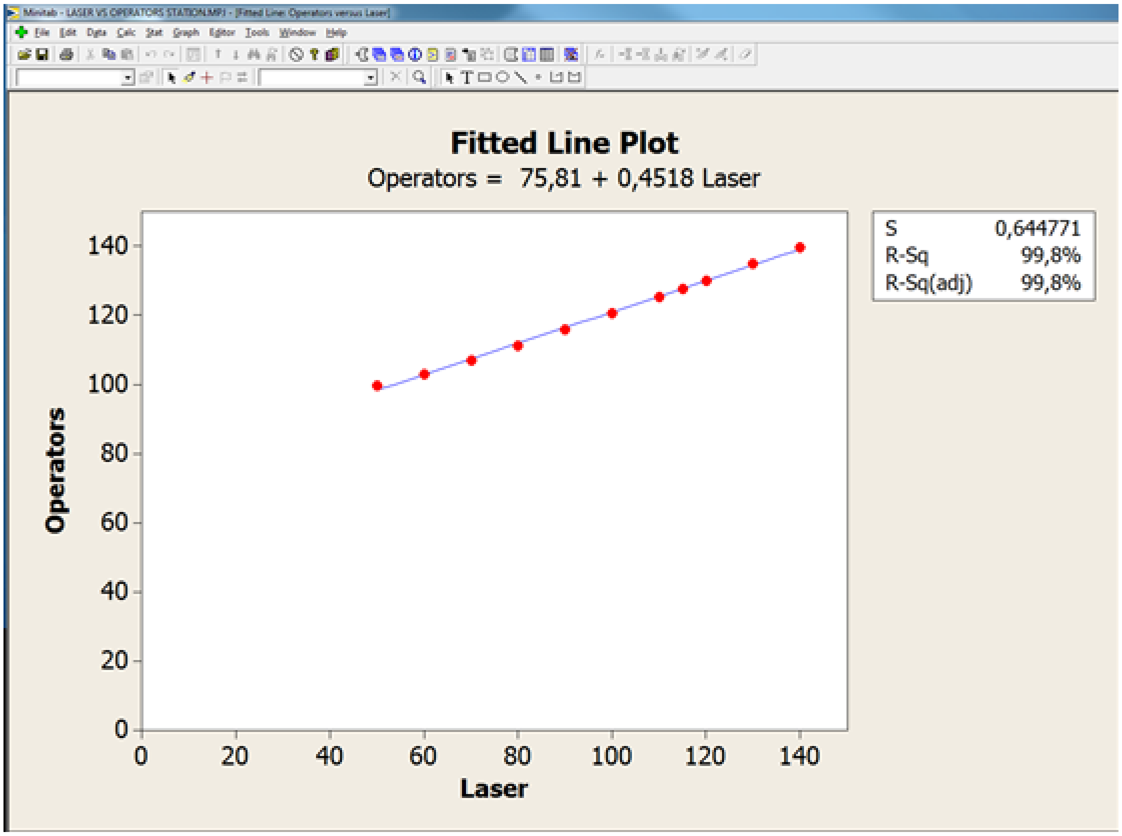
APPENDIX F: LASER INFORMATION

Using Excel readings were taken from the laser output and compared with the operators station .output.





Using Minitab to check the corrolation of the output of the laser versus the output of results from the PLC and operators station. They prove to be 99.8% the same corrolation. Therefore it is the fault of the laser for sending out high signals.