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Productivity improvement for the fully automated M1218 gear assembly system.

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**PRODUCTIVITY IMPROVEMENT FOR THE
FULLY AUTOMATED M1218 GEAR ASSEMBLY SYSTEM**

By

Andreas Cziha
B.S., University Ulm, 2007

An Industrial Engineering Thesis
Submitted to the Faculty of the
J. B. Speed School of Engineering University of Louisville
in Partial Fulfillment of the Requirements
for the Degree of

Master of Science
in
Industrial Engineering

Department of Industrial Engineering
University of Louisville
Louisville, Kentucky

May 2012

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FULLY AUTOMATED M1218 GEAR ASSEMBLY SYSTEM**

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A Thesis Project Report
Approved on

April 27, 2012

by the Following Faculty Members:

Dr. William E. Biles

Dr. Gerald W. Evans

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LOCK FLAG

As this thesis contains confidential and sensitive information about ThyssenKrupp Presta AG it will be inaccessible for the public for the two years after submission to the Examination's Office.

ACKNOWLEDGEMENTS

The chance of working on the following topic was of high benefit for me and my company ThyssenKrupp Presta AG. Since the idea for the subject is in basics from my supervisor Toni Ceccon, I want to thank him for his support with some of problems along the way in completion of the thesis. Also I want to thank my parents who supported me during that time and were a valuable supply of helpful suggestions. The biggest gratitude belongs to Ms Anika Walser, who helped me in correction of the thesis and was a very helpful contact point of information along the way. Lastly, I offer my regards and blessings to all of those who supported me in any respect during the completion of the thesis.

ABSTRACT

PRODUCTIVITY IMPROVEMENT FOR THE FULLY AUTOMATED M1218 GEAR ASSEMBLY SYSTEM

Andreas Cziha
Defense April 27th 2012

Fully automated assembly systems are designed for a specific capacity, starting with the machine, the designed product and the infrastructure. The performance must be insured to fulfill the requirements for the whole system. The following thesis describes the improvement of an assembly system to fulfill requirements regarding the “Overall Equipment Effectiveness” (OEE). In a complex environment a good understanding of the technical background is very important. The first section of the thesis gives the technical background of the system. The improvement process is a top down process: the problem is broken down from large problems – indicated by the key performance indicators like OEE – down via Pareto analyze to root cause analysis. The most influencing factor for an inefficient performance of a product is the faulty interpretation of existing knowledge and communication problems. Finally the improvement of the situation is evaluated and changes in the structure of the company applied, to ensure a better performance right from the start for future projects.

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CHAPTER I

INTRODUCTION AND DESCRIPTION OF THE PROBLEM

A. ThyssenKrupp Presta AG

1. History and products

The following master thesis was generated with ThyssenKrupp Presta AG. ThyssenKrupp Presta SteerTec developed out of the former Mercedes-Benz Lenkungen GmbH (MBL). Since November 2005 MBL was owned by ThyssenKrupp Presta SteerTec. Since April 1th 2007 both separate development divisions were unified in ThyssenKrupp Presta AG.

ThyssenKrupp Presta stands for high quality and innovative products in the area of steering gears, steering columns and massive forming products. The massive forming products are mainly used in-house for the steering columns. The products in the area of steering gears reach from trucks and busses to passenger vehicles. This thesis primarily concerns the area of passenger vehicles. There are basically two systems: the traditional Hydraulic Power Assisted Steering (HPAS) and the Electric Power Assisted Steering (EPAS). At the moment the HPAS concept is the dominating system on the market. The high functionality and the relative low prices for the system keep a demand for that type of system. The HPAS systems operate with hydraulic liquids pressurized by 60-120 bars. The steering task is done by valves that guide the pressurized media.

The Electric Power Assisted Steering (EPAS)

The rising concept is the EPAS system. In modern vehicles more and more hydraulic power steering systems get replaced by electro hydraulic or electro mechanical EPS (Electric Power Steering) systems. This trend is pushed further and further by the need of higher safety standards and driving convenience. More drivers for this trend are the reduction of the component variety – therefore the costs for the handling and the unit itself decrease. The active influence on the steering system by the onboard control of the vehicles gives the designers and therefore car manufacturers the opportunity to adjust the handling of the car according to the designers needs by a simple software parameter change. It is not longer necessary to design, store and obstruct different mechanical parts to achieve different handling characteristics. Also out of this the design and build costs decrease. Furthermore the active control of the steering system gives the opportunity to implement safety programs like park assistant and automated guidance control.

The steering impulse transfused by the driver through the steering column enters the system by the input shaft. Here the torque is detected by a hall sensor. The collected data are transferred to the ECU (Electro Control Unit). In the ECU the data are processed regarding the pre-set vehicle values. According to the results, the power pack (motor and ECU) is activated to assist the steering process. The power pack is connected mechanically with a ball screw drive by the drive belt. The rotation movement of the motor is converted, by the rack and the ball screw drive to a linear movement. The linear movement is the actual steering movement. The goal for the future is to make that complex system as reliable and inexpensive as the HPAS system. The technical advantage and the increase of safety the system delivers make it the concept of the near

future. In the following picture the complete “Wheel to Wheel” system is displayed. The red highlighted part is called the steering gear and will be the target for further investigations.

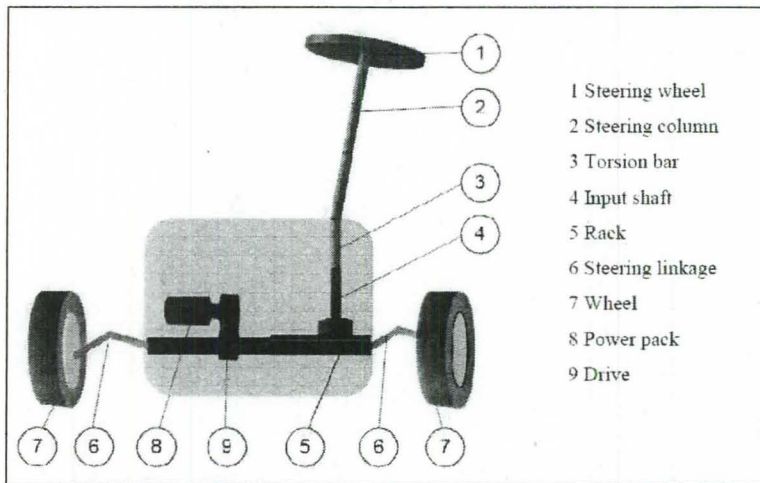


Figure 1. System schematic

The gear is assembled half automated in the assembly machine M1218 in ‘Mülheim an der Ruhr’ in Germany. This production plant is a former “MB Lenk” production facility.

B. Project course and time frame

The production is divided in two major phases which will be described shortly in the following:

Design phase with prototype production:

In this phase no or just small production tools are needed to build pre-series parts for test cars and concept proving. In our case the “Mechatronics Laboratory” in Eschen, Liechtenstein, and Mülheim an der Ruhr, Germany, are covering that part. This section of the development process will not be further investigated and is therefore not relevant.

From Internal SOP to External SOP

The second step during the process is the one from the internal start of production (Internal SOP) to the customer start of production (External SOP). During that period several milestones has to be passed and fulfilled. These steps are described in the Figure 2 and the following explanation:

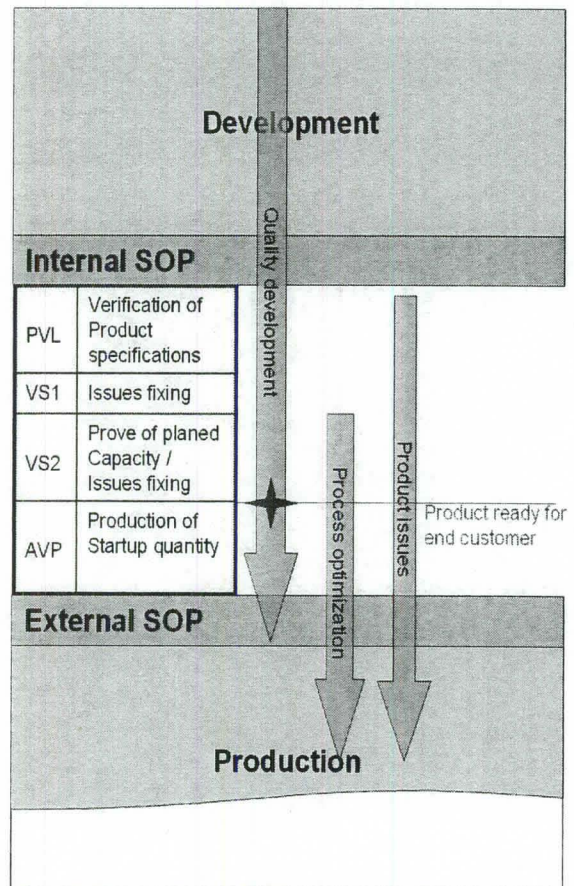


Figure 2. Development chart

1. PVL (Produkt Vorläufe) “Forerunner”

During that state of production the components do not have to be ready for the end customer. They must prove the concept and must be comparable with the manually assembled components in the development phase. During that state **not** all product variations have to be proved and shown to the customer. All the products that are produced must have “road permission”.

2. VS1 (Vorserie 1) “Pre-series 1”

During the “Pre-series 1“-production the first results of the PVL-production must be implemented. Bug fixes and the first process adjustments have to be implemented as well. After that step of the production the product must be equal from manual to automated assembly with no regard to the capacity of the assembly line. During that state all product variations have to be proved and shown to the customer. The parts are used for testing in pre-series vehicles.

3. VS2 (Vorserie 2) “Pre-series 2”

In variation to VS1 the components must be produced with the actual quoted capacity in the “Pre-series 2”. The production also must represent the production process. After that production the components must have end customer quality. As in VS 1 the parts are used for testing but also for show rooms and therefore must represent end customer quality.

4. AP (Anlaufproduktion) “Start-up production”

The last opportunity for minor changes in the production process and the part quality with regard to products quality and production resources is during the start-up

production. The parts have to have the required quality, must be build in the required quantity and also must be build at the quoted price. Due to that the products represent the start of production stage.

5. SOP “Start of production”

After the start-of-production the products must be buildable in repeatable manor. The quality status is fixed and changes cannot be implemented or just under the knowledge and agreement of the customer in the right development gate (so-called “I-Step”). An I-Step is a special BMW-term and means a defined time period during which no changes in the product can be made. This fact makes the “change process” much more difficult. That is why it is necessary to ensure the quality during the stages from SOP intern to SOP extern.

During the further investigation of the thesis the focus will be on those steps.

C. Necessity of topic

The goal of the thesis is to maximize the output at the production facility with simultaneously feeding the information back to the development and design department with respect to other projects. The current output performance the machine and the product are representing, the customer requirements cannot be fulfilled. To manage the startup ramp for the customer’s production the machine must operate with an overall equipment effectiveness of at least 70 %.

The second and also important part is that changes to the product are easier and not that cost intensive before the external start of production, when the product is still in testing phase. In this phase the drawings and the configuration are not closed for changes and different design configurations are tolerated. Also changes do not have to be brought to already existing systems.

The third aspect is to feed the generated information back to the project key functions: plant development and product development. In the following projects the second machine and new products must be designed right the first time.

CHAPTER II

OPTIMIZATION PROCESS

A complex system like an assembly machine is very difficult to improve, a good basic knowledge about all the production steps is essential. In chapter A the basic production knowledge will be given. Chapter B covers the analysis and improvement of the system. The biggest problem is that adjusting at one point in the process is not necessarily the right thing to do. It is important to find the bottleneck in the system and begin the improvement at that point. In the following study I am going approach to from top to bottom.

Beginning with a Key Performance Indicator (KPI) like OEE (Overall Equipment effectiveness) the process will be broken down to the root of the problems.

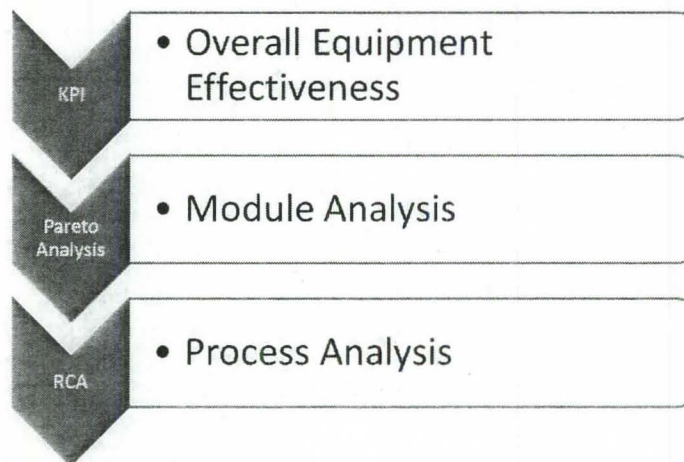


Figure 3. Thesis road map

A. The production process of the BMW F25 steering gear

The assembly machine M1218 basically consists of four production areas, which are:

- the Pre-Assembly
- the End-Of-Line Test (EOL-Test)
- the Rework
- the Final-Assembly

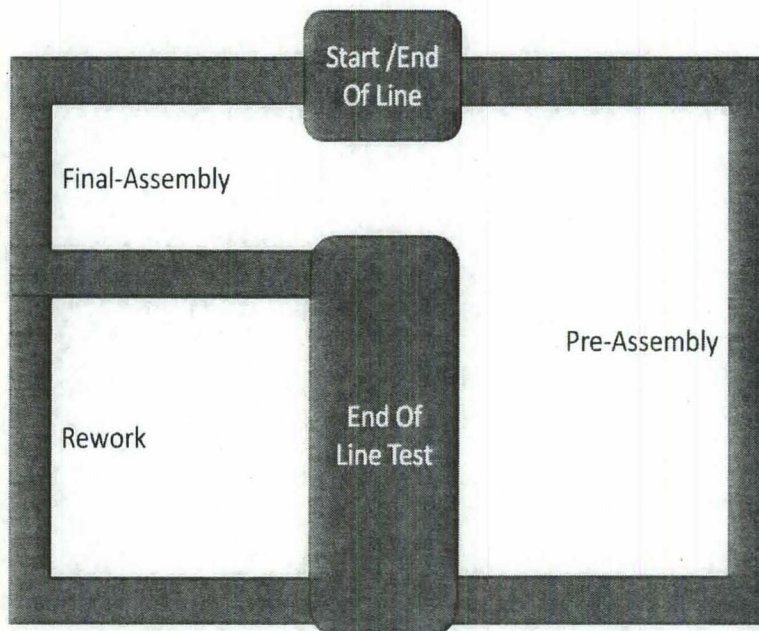


Figure 4. Production line layout

The first area is the Pre- and Basic-Assembly. During these steps the gear is assembled to the state to fulfill the function tests like DSK, EPT17, LU, Air test and Acoustic. These tests will be described later on. After completing the function tests

during the EOL-Test, the gear reaches a gateway, where the decision is made if the gear has to be reworked in the third production area (Rework). In that area the worker eliminates malfunctions in the system. If no errors have been detected during the EOL-Test, the gear can be forwarded to the fourth production area (Final-Assembly and Packaging). During those steps the gears are finalized and prepared for shipping.

For further investigation the production areas are described in detail in the following chapters.

1. Pre-Assembly

Pre- and Basic-Assembly Processes

During the first process step in **Module SA 01** the Data Matrix Code (DMC) is read. Secondly the housing is equipped with a ball bearing, at the same time the bearing is greased. During the third process step the needle bearing is pressed into position and also greased. These two bearings are the bedding for the input shaft. The fourth and final process step is the assembly of the damper.

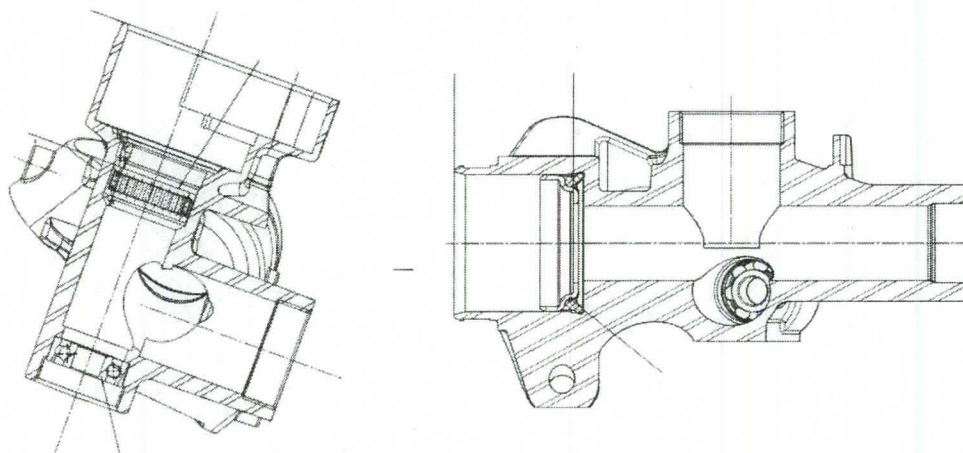


Figure 5. Assembly bearing and damper

The **second and the third module** are operated by the same worker as Module 1. These modules are simple placing stations. The pre-assembled housing is manually removed from fixture in Module 1 and placed on the work piece carrier waiting in Module 2. For verification the DMC on the housing is read. As mentioned, Module 3 is also a placing station. Here the worker assembles the drive belt to the KGT (“Kugelgewindetrieb” = ball screw drive) and places it in the mounting fixture.

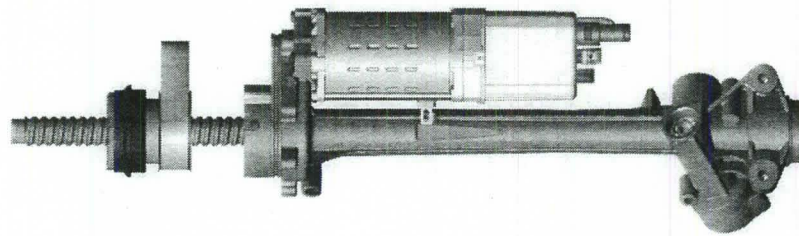


Figure 6. Assembly KGT

The **Module A 04** is a fully automated station. In this station the main components like KGT, “Power Pack” and housing are assembled. The “Power Pack” is provided via conveyor belt from the “Power Pack” assembly machine (this “Power Pack” machine is not part of the research). The production flow is described as follows: The housing is placed in mounting position via a NC axis (Numeric Axis). After that the KGT drive belt assembly is put in mounting position. Next the “Power Pack” is assembled by a robot arm. Finally the “Power Pack” is secured via an automated screw driver.

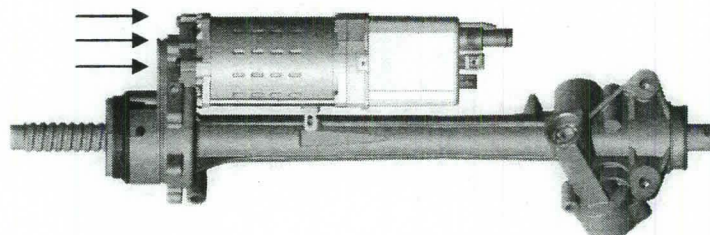


Figure 7. Assembly power pack

In **Module A 05** the tensioning of the drive belt is adjusted roughly. The second task is to grease the KGT in the housing. That is realized by a grease lance which sprays the grease in the pressure peace drilling. To distribute the grease the KGT is moved from the left to the right maximum position.

Module SA 06 is divided into 3 operations as shown in picture below: Operation one puts the input shaft in position. After successfully fitting the input shaft, the nut is attached to the system. The final operation is the assembling of the sealing cap. The cap has two tasks: first to hold the ball bearing in place, second to tighten the area against intruding water.

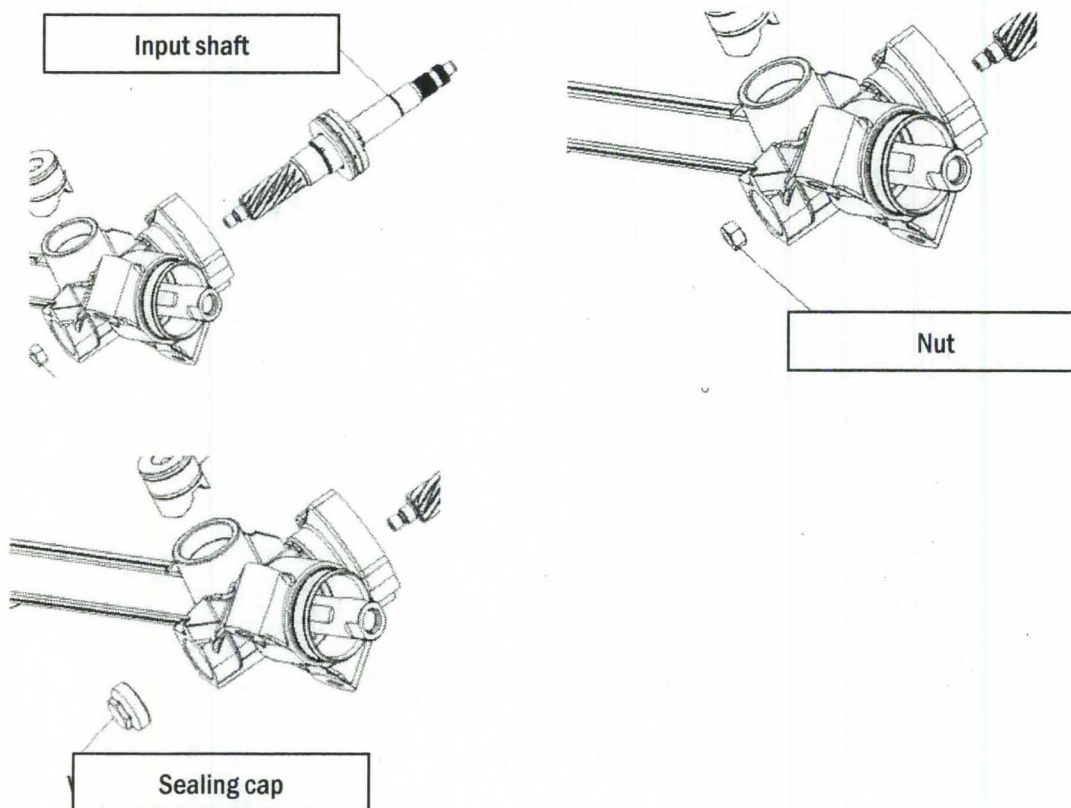


Figure 8. Assembly input shaft

The next **Module A 07** contains just two operations: removing the mounting fixture for the KGT and fitting the cable guidance for the sensor cable as shown in the picture. The two modules are operated by one worker.

In **Workstation SA 08** one screwing, two assembling and two greasing operations take place. The operator of that station places the pressure piece, the adjustment screw and the spring in its place. During the automated assembly the robot arm picks up the pressure piece first and assembles it as shown in the picture. After that the fat spear greases the operation area. Then the spring is assembled. Later the next greasing operation is executed. Finally the adjusting screw is screwed in position. The task of this assembly is to secure the KGT rod in place and to put a defined pressure on the KGT to ensure a safe operation of the gear over lifetime.

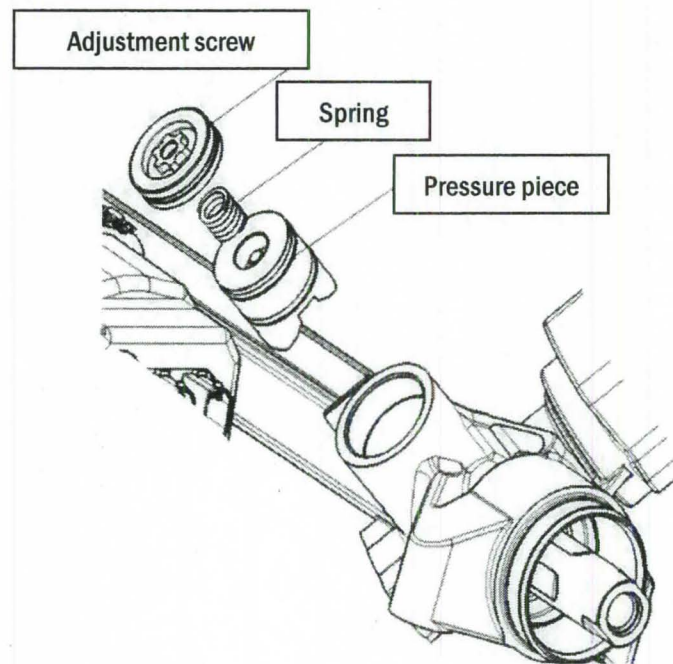


Figure 9. Assembly pressure piece

In **Module SA 09** the sensor unit housing is assembled. This operation is partly automated, the worker just puts the housing in position and the assembly is automated. Those last two modules are also operated by one operator.

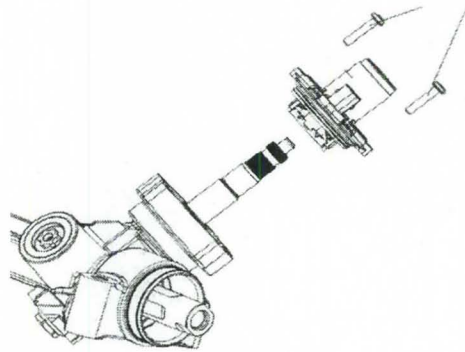


Figure 10. Assembly sensor housing

Due to the fact that not all torsion bars are exactly the same, the electric system must be adjusted to that particular torsion bar. This deviation is generated by minor changes in the raw material. The calibration operation is done in Module A 09-1. The process is fully automated.

Module SA 10 is a partly automated assembly station for the gear housing cover. The housing cover is equipped with the second damper of the gear. Inside the cover the distance disk and the spring disk are assembled during the same process step.

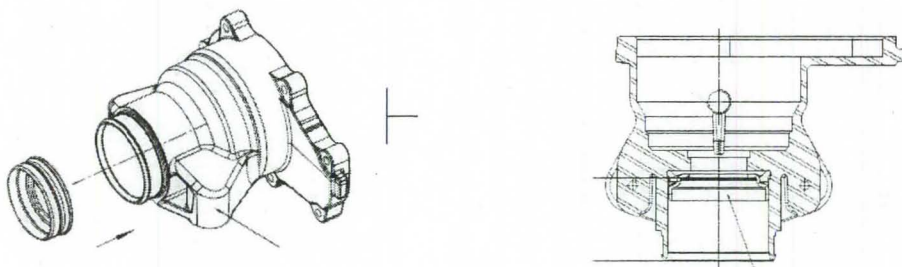


Figure 11. Assembly damper

After the housing cover is finished the worker puts the cover in **Module SA 11**. Here the cover is assembled to the gear via an NC axis powered press. As mentioned the Module SA 11 and SA 10 are operated by one worker.

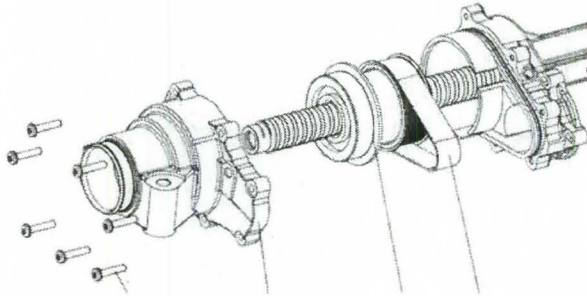


Figure 12. Assembly housing

The fully automated **Module A 12** is used to assemble the housing cover to the gear. In this module the screws and all the screwdrivers are operated fully automated. The screws are fed by a central located screw supplying system. During **process step 13** the final tensioning of the belt is realized. This process step is placed after the operation in Module A12, because the final stability of the gear is reached after the assembly of the housing cover and therefore is important for the precise adjustment of the belt tension.

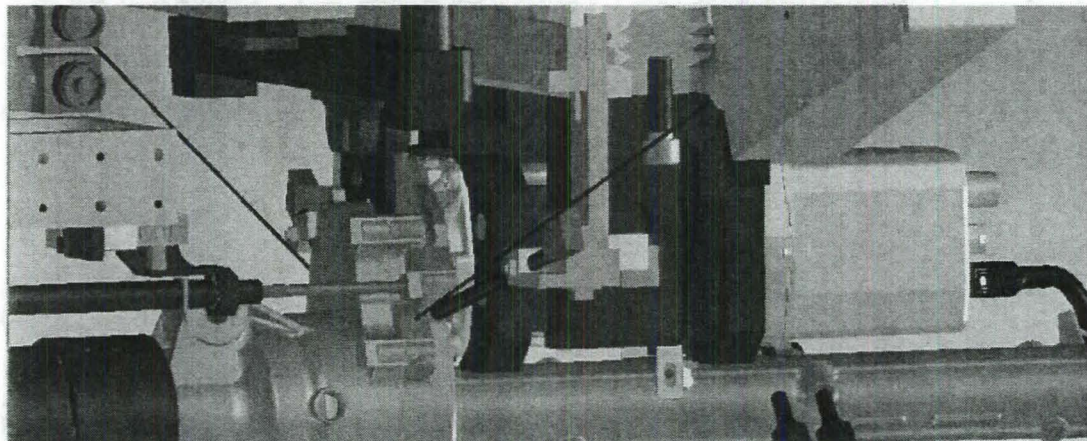


Figure 13. Belt tension adjustment

During the last assembly step in **Module 14** – before the beginning of the EOL-Test – the gear is sealed with a water release valve. As mentioned in the description of process step 11 (see SA11) the valve was placed on the sled. In this station the valve is removed from the sled and automatically screwed to the gear. This operation is realized as shown in the Picture 14 with NC axis and a handling device.

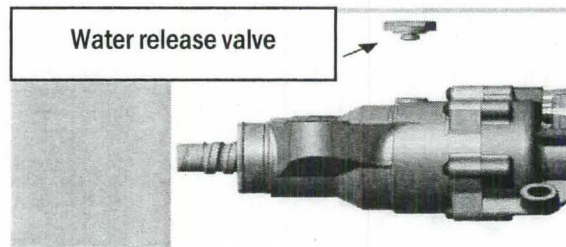


Figure 14. Assembly water release valve

2. EOL (End-of-Line-Test)

The End-of-Line-Test (EOL) is a series of tests to ensure the functionality, the performance and the quality standard which have been communicated with the customer. The test volume is based on in-house experience and negotiation with the customer. In our case the EOL-Test is not really positioned at the end of the line. That is at first glance not understandable, but the position of the End-Of-Line-Test was chosen that all performance influencing process steps are completed till testing. That gives the advantage that in case of malfunction of the gear during EOL the effort of a rework is fairly low. During the End-Of-Line-Test the gear has to fulfill the following tests:

- “DSK (Durchschiebekraft)” - force which is needed to move the KGT:
This criterion is a customer criterion because it affects the experienced handling of the car significantly.
- “LU (Lenkunterstützung)” - short cut for the applied force with which the “Power Pack” assists the driver’s steering movement:
This criterion is also a customer criterion that has to be very repeatable and consistent to the requirements.
- “Air test” - tests the air tightness of the system:
This is an internal quality criterion and is mostly important due to the fact that the electronic component within the gear is not specially treated to withstand humidity. The risk is a total failure of the gear or worse, an automated steering movement.
- “EPT17 (Mittelpunktsteifigkeit)” – the inflexibility of the system around the middle position: This criterion is also a customer performance criteria, it has no effect on the safety. It is only a quality indicator for handling of the vehicle later on the road.
- “Acoustic test” (test to control the emitted noise by the gear):
This test has a combined purpose: The first and most valuable reason for ThyssenKrupp is the possibility to recognize pre damages in the mechanism and electronics of the gear. The second and even more valuable reason for the customer and TKPS (ThyssenKrupp Presta Steering) is that this test gives the possibility to keep the sound design in a defined range.

3. Rework

If the gear does not pass the function test successfully, the gear is passed to the rework circle as mentioned above. This circle is operated by one worker. He receives the cause of the malfunction via display and decides the necessary steps and rework procedure. As an example, the gear fails during the air test: The worker controls the gear with a leak detection device. If the worker identifies the sealing cap as the cause of the malfunction, he disassembles the gear to the state in which the sealing cap is assembled during the process. Then he sends the gear back in the production line to the specific production station.

4. Final-Assembly

In Module SA 21 the worker has to place the inner and outer joint as well as the middle indicator to the tray. The machine controls the worker process for aspects like “placing the part correct” and “correct part” for the product to build. The second task the worker has to perform is a mechanical assembly of the Gore-Tex membrane and the sealing cap for the adjustment screw. Both operations are also controlled for correct execution.

During the following process steps in Module 22-23 the machine automatically calculates the middle steering position and assembles the middle indicator. That middle indication is just for the assembling in the car. It ensures the middle position of the steering wheel while driving straight. Following to that, the right and left inner joint are being assembled automatically as well.

In Module 24 the last not-automated operation takes place: The worker assembles the boot. That operation is hand worked because you need intuition for that operation;

automation would not be lucrative on a long run. That is because the part quality and the handling accuracy cannot be held in that tight range to ensure a stable process.

Finally the right and left outer joint is assembled and the gauge exactness is adjusted automatically. That measurement has to be very accurate because it affects the driving performance of the car directly. After that process step the steering gear is ready for shipping to the customer respectively shipping to the suspension supplier.

Just to give an impression: till that point of production about 200MB of data have been generated during ThyssenKrupp's testing, monitoring and assembling processes. The data consist of screw momentum, acoustic data, pressure forces, production time and so on. All this data has to be stored minimum ten years. Also the data has to be linked to the product as well as to the components used to build the product. The most important aspect is that the retrace ability on component levels as well as on a single production parameter must be given.

B. Improvement Process

1. Actual condition before improvement
 - a. Definition of the Overall Equipment Effectiveness

The OEE is a measurement for the effectiveness of a production cell. It is used as a Key Performance Indicator for three different aspects of the cell. The first is availability, the second is performance and the last is the quality of the cell. The OEE represents the line loss within these three categories.¹

¹OEE für das Produktionsteam

b. OEE-Analysis

The starting point is the current Overall Equipment Effectiveness (OEE) of the machine. The OEE is currently 55% and the goal is to increase the OEE by 15%. The OEE is calculated by multiplying three factors:

The first factor is the **availability** of the machine. It represents the capability of the machine to produce parts and is affected by machine breakdowns and maintenance. In this thesis, the focus is not on availability since the machine runs with an availability of 90% – during the startup several shifts were monitored. The goal was to confirm the counter that is implemented in the machine. As shown in the picture below the shift has simply been monitored in five minute blocks.²

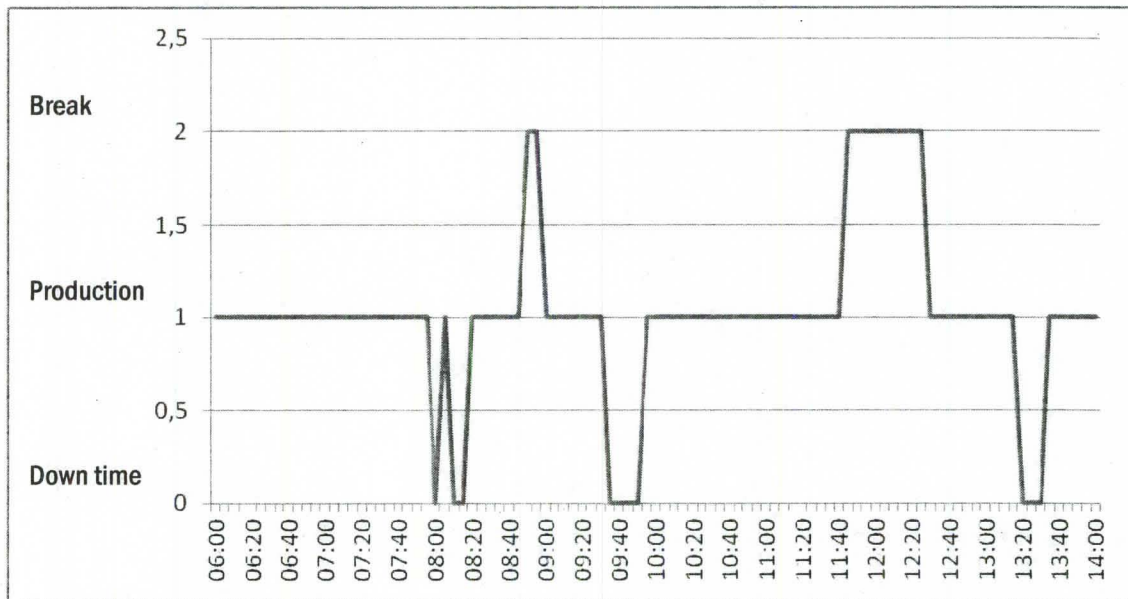


Figure 15. Production analysis

² Koch Arno, OEE for the Production Team

There are three different production situations: situation 1 = production, situation 2 = break (the production personal is on a scheduled break) and finally situation 0 = the machine is in an unscheduled break. As a result of that monitoring I calculated the availability as follows:

Scheduled time = 485 min. – 55 min. break = 430 min.

Available time = 430 min. scheduled – 45 min. unscheduled downtime = 385 min.

Availability = 385 available min. / 430 scheduled min. = 0,895 → 89.5%

The second factor is the **performance**, in our case the performance is described as parts produced in period, disregarded of the quality of the product. In this study all parts being produced had been counted whether they are good or bad parts.³ The average during the shifts monitored was 361 parts. Therefore the performance of the machine is calculated as follows:

Available time = 430 min. scheduled – 45 min. unscheduled downtime = 385 min.

As mentioned the rate to produce one part is 60 seconds, therefore 60 parts per hour.

Time to produce parts = 361 units * 60 seconds / part = 361 min.

Performance = 361 min. / 385 min. = 0.937 → 93.7%

The work center quality is the last factor defining the OEE. The work center quality is defined as good parts enter the machine and finished good parts exit the machine.⁴ During the monitored shift the system produced 245 good parts.

Quality = 245 Good Parts / 361 Parts Started = 0.679 → 67.9%

³ Koch Arno, OEE for the Production Team

⁴ Koch Arno, OEE for the Production Team

The required value for the project is minimum 86%, currently the assembly line runs with 67.9% work center quality.

This leads to the following result of the OEE:

$$\text{OEE} = 0.895 \text{ Availability} \times 0.937 \text{ Performance} \times 0.679\% \text{ Quality} = 0.569 \rightarrow \mathbf{56.9\%}$$

As mentioned at the beginning of the chapter, the required OEE-Target is 70%.

The highest potential for improvement has the work center quality. The goal of the thesis is to break the missing 32 % work center quality down and improve the OEE by 13%.

The minimum work center quality is calculated as shown below:

$$\text{Quality target} = 70\% \text{ OEE} / (89.5\% \text{ Availability} \times 93.7\% \text{ Performance}) = 0.835 \rightarrow \mathbf{83.5\%}$$

2. Analysis procedure

a. Pareto analysis – assembly stations 1-14 (Preassembly)

i. Definition of the Pareto analysis

The Pareto analysis is a very common tool in problem solving techniques. It is used to identify the factors that influence the result with the most significance. It is also called the 80-20 rule. This means 80% of the problems are caused by 20% of the options, or 20% of the time invested in a project generates 80% of the success or result.⁵ This method dampens outliers and is most suitable for our investigation. It would be inefficient to investigate every single production failure or error because of the high amount of processes and variables in the process. The steering gear contains over 5,000

⁵ Koch Richard, Das 80/20-Prinzip. Mehr Erfolg mit weniger Aufwand

mechanical design parameters and with this method it is possible to find the most influencing parameters.⁶

ii. Procedure of the Pareto analysis

The module analysis was realized in two steps: During the first step the complete assembly modules were monitored. The goal was to find the most critical modules resulting in the most loss of work center quality. Therefore the production was monitored from start-up (internal SOP on January 1st 2010) till VS1 (April 15th 2010). The improvement must be accomplished till the customer SOP (September 2010). The resulting NIO operations within the module were monitored in this part of the analysis. As shown in the picture below the missing 32% of work center quality is caused by several modules.

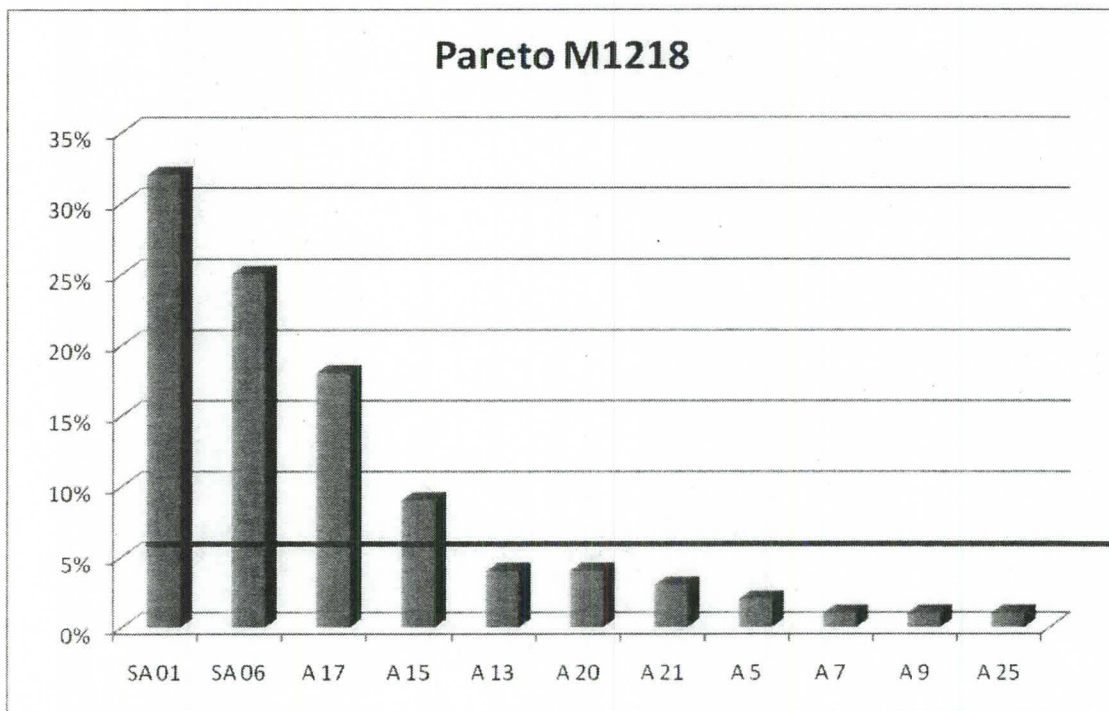


Figure 16. Pareto analysis before improvement

⁶ <http://de.wikipedia.org/wiki/Pareto-Verteilung>

Table 1. Critical Modules

Line module	NOK Rate
SA 01 Barring and damper assembly	32%
SA 06 Input shaft assembly	25%
A 17 DSK Friction test	18%
A 15 EOL Air test	9%

In the following step the complex operations within the four modules will be broken down in single operations. Each single operation will be monitored and evaluated for the most critical process step. The goal is to find the most critical process in the assembly module. With help of the second Pareto analysis it was possible to identify the processes with the highest influence to the output of the machine. As shown in the following picture the most critical processes for module SA 01 are: pinion barring assembly, ball barring assembly and the damper assembly.

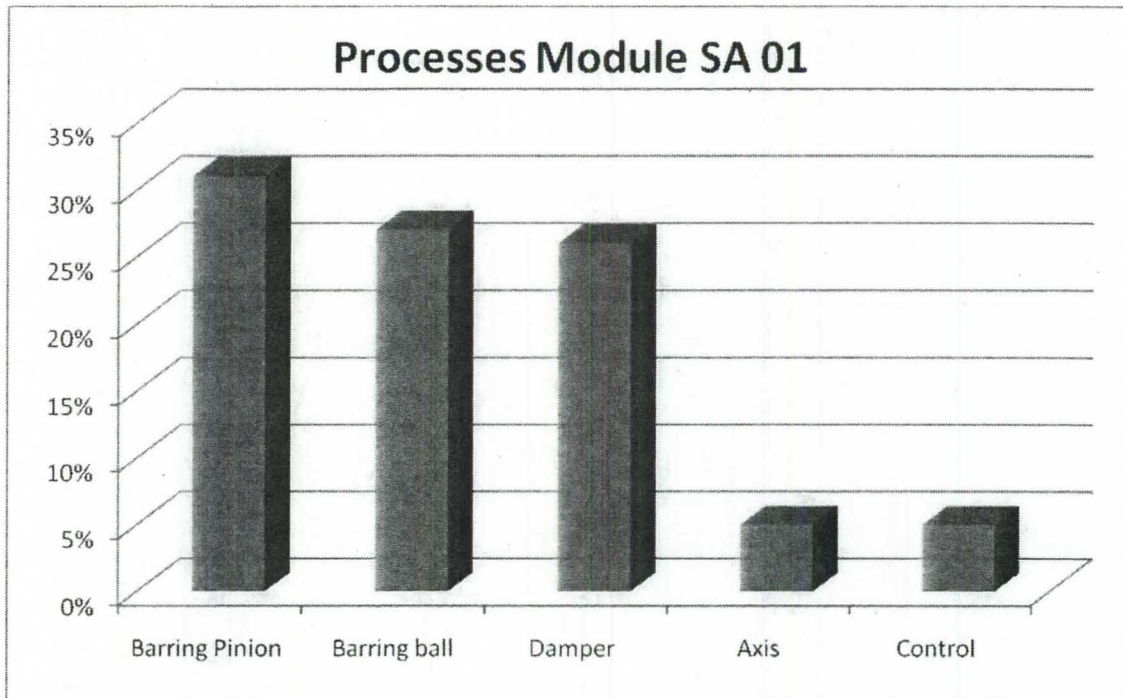


Figure 17. Pareto analysis – Module SA 01

For the bad performance of the module SA 06 there is just one process step responsible as shown in the chart below: it is the assembly of the sealing cap. The two other aspects (friction test and air test) will be discussed later in the thesis.

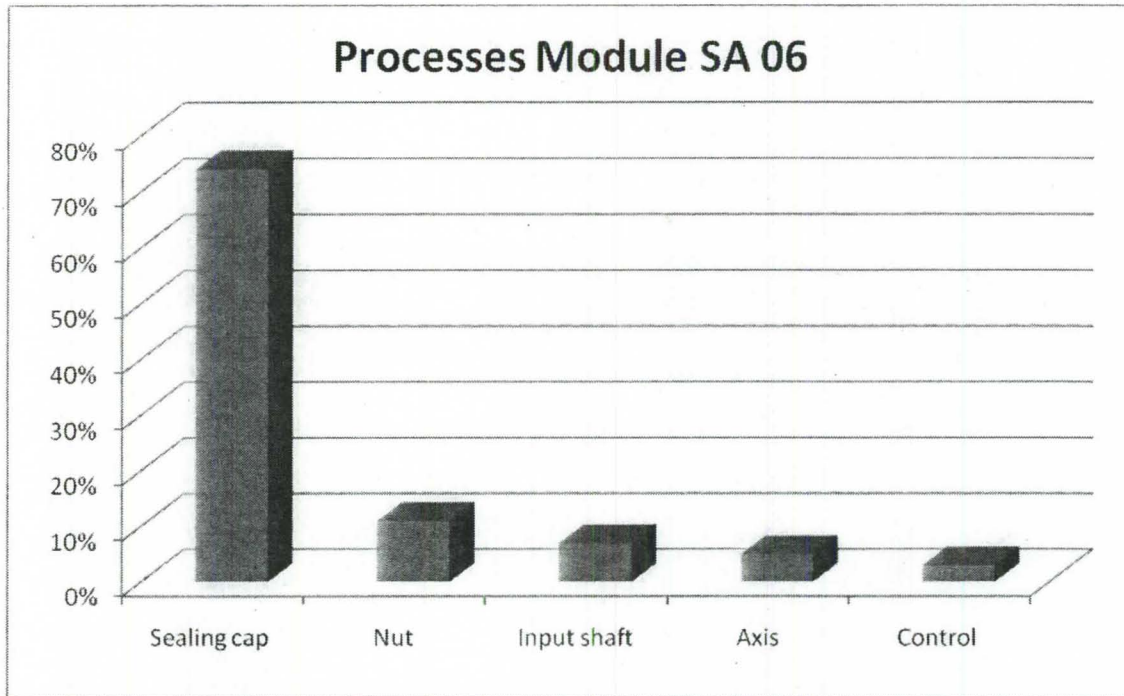


Figure 18. Pareto analysis – Module SA 06

a. Root cause analysis (RCA)

i. Definition of the Root cause analysis

The Ishikawa diagram was developed by Ishikawa Kaoru, who was born in Tokyo 1915 and died April 16th 1989. His thoughts about quality are still present and widely used. He developed the diagram during the 1940s to identify quality problems. Later the diagram was also used as a general problem solving technique.⁷ A cause-and-effect-diagram is a graphical technique to display and highlight the interlink from cause to the experienced problem – ergo the effect.⁸ The effect (problem) is that the sealing /fixing process is not ok.

Six factors are relevant for that process. These are:

⁷ G. F. Kamiske, J. P. Brauer: Qualitätsmanagement von A-Z

⁸ von Eiff Wilfried, Professionelles Personalmanagement

- Method: Type of mechanical connection between these two parts
- Material: Materials used in that connection
- Measurement: Control of the machine / measurement system of the assembly machine
- Environment: Surrounding activity that ensures the logistical path of the product
- Machine: Parameter the machine works with; is the machine really capable of completing the task correct?
- Human: This factor is representing potential mistakes, misunderstanding or lack of knowledge.

ii. Application of the RCA – Module SA 01

The RCA for the first station was interesting because all three operations did not operate within normal scrap rates. On the first glance it can be said that the problem accruing affects all three operations in the same way. Below you can see the Ishikawa diagram for the **damper assembly** operations.

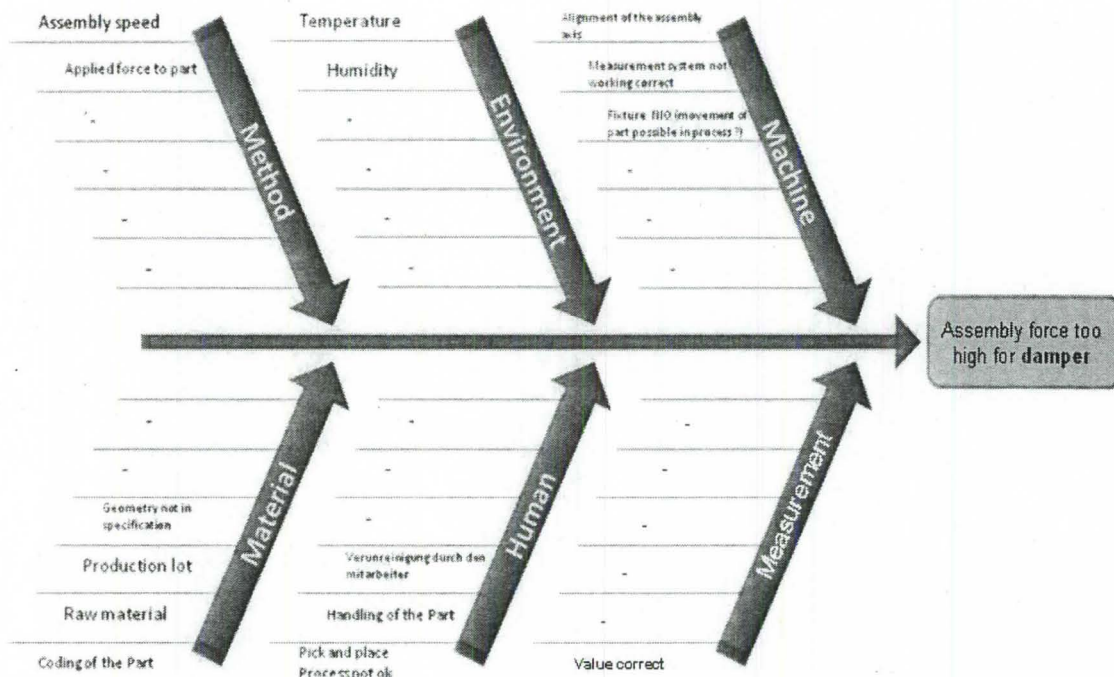


Figure 19. Ishikawa damper assembly

During the analysis it turned out that not all influences effect all three operations in the same way. Therefore it was necessary to divide the operations further. In the next step the damper assembly had been split in a separate analysis. Further on the two assembly processes had been discussed alone starting with the damper assembly. As shown below several factors could have been eliminated right away. One example is the handling and logistical transportation of the goods. The goods are handled in the same way as in other applications and the interface in this application is comparable to others. Further on the measurement system could be eliminated. During the setup of the machine the measurement system was calibrated and controlled with the proper MSA process (MSA = Measurement System Analysis). The MSA ensures accuracy, repeatability, reproducibility, stability and linearity of the measurement system. The MSA has 3 types:

- **Type-1-study**

The type-1-study basically focuses on the accuracy and the stability. A known value is measured 50 times (minimum 25 times) based on the standard deviation the process Capabilities Cp and Cpk are calculated.

- **Type-2-study**

In this study the repeatability and reproducibility are measured. This study is only applied if the type-1-study was successful. In the type-2-study you measure 10 parts two to three times. This measurement is performed by three different operators respectively on three different locations with different equipment. It is also important that the measurement is independent (results cannot be remembered and cannot be seen by each other). After finishing the measurement the span and mean is calculated for each operator / location or/and type of equipment. The value of the highest and the lowest mean for each operator results in a statement for the reproducibility. Finally the overall mean and the span are resulting in a statement for the repeatability.

- **Type-3 study,**

Typically the usage of that type can be found in automated measurement systems as in our process. The type-3-study is therefore a special case of the type-2-study.⁹

It turned out that the fixation of the raw material in the machine was causing the high scrap rate for that part. If the worker does not work carefully, the damper can slide to one side and therefore the alignment of the parts is not correct. In the picture 20 you can see the mis-positioned and the correctly positioned parts in the fixture.

⁹ <http://de.wikipedia.org/wiki/Messsystemanalyse>

The material quality was measured and there are no deviations to the drawing. The concentricity and the geometric position of the assembly positions are correct and have the right surface specifications. Therefore the material is also eliminated. The human aspect can also be eliminated since the process is an automated process.

Further on the method is being observed: One factor in the category was the assembly speed. Two other different speeds had been tested by increasing and decreasing the speed from the starting value with no significant result. In the picture below the mean of the assembly force in the process is plotted for all three speeds: Test 1 represents the normal speed, Test 2 the slow speed and Test 3 the high speed.

As you can see in the histogram above there are small differences. The speed has some impact on the result but is a minor part of the problem. The force is more influenced by the production lot of the raw material.

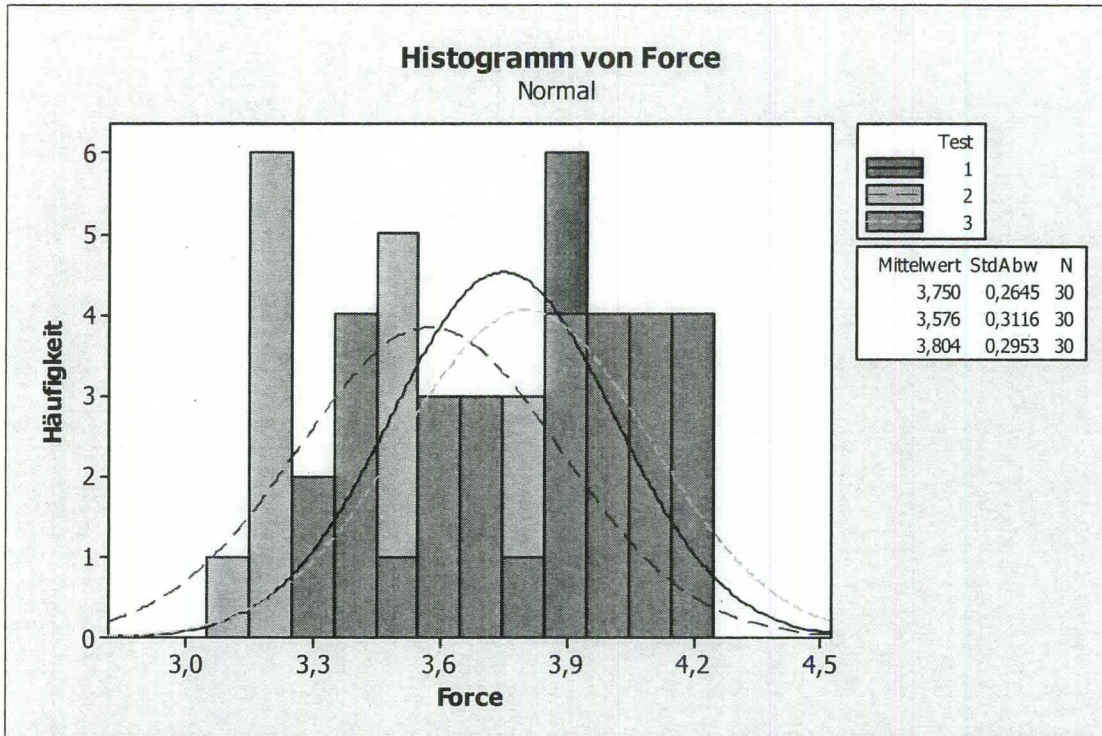


Figure 22. Histogram – Bearing assembly force

The temperature has no impact on the result. Different temperatures had been tested and no significant change in the process could be found.

In the final step, the allowed maximum assembly force given by the supplier was observed. During that observation it turned out that the supplier did not calculate the force with all machine tolerances. The calculation contained only the interface between bearing housing and temperature. After the recalculation of the interface (including the misalignment of the machine, the offset of the fixation and the positioning failure) the calculated force increased by 25%.

With the changed parameter the process worked and delivered stabile good results.

iii. Application of the RCA – Module SA 06

As mentioned in chapter II B. 2. a. ii) the sealing cap assembly operation is responsible for the bad performance of module SA 06. The following RCA will cover this process step in detail.

Environment as the causing factor can be eliminated because the same type of logistical process for purchase, handling and shipping is applied and working in other products like Daimler W211. Materials as housing and cap itself could also be eliminated because housing and cap is a working connection in the W211 series as well. The question if the coding material is the right to work with was answered by looking at the design. According to the supplier of the coding, the tolerance band in the design is sufficient of the coding and has no effect on the screwing process, except for slightly higher torque. The factor “measurement” was checked several times during the testing process and is therefore no longer an influencing factor since not coded caps can be assembled easily. Parameters like axial feed and mis-positioning were also eliminated by tests with not coded caps. The speed in the screwing process was tested by variation of the speed with no positive results.

As shown in the graphic above only one factor is left over: misunderstanding. All the process steps were controlled for irregularities. In that process it turned out that the supplier for the cap produced according to an old quality complain. According to this complain he produced the cap at the upper tolerance band. After changing the production process at the supplier the assembly process did run with lower failure rates.

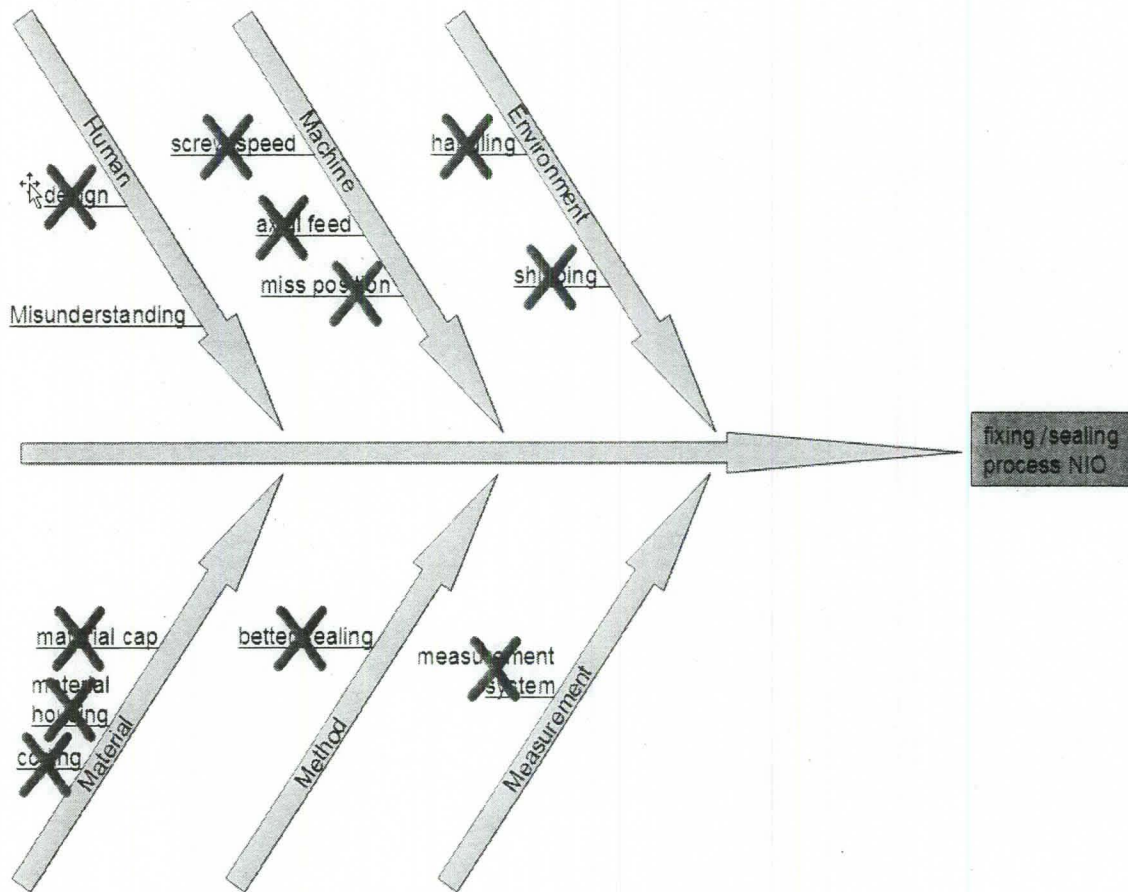


Figure 23. Fishbone – Sealing cap assembly

iv. Result of the RCA

The modules and processes were tested after applying all changes to the processes. Before the changes the system was able to produce 245 good parts. The goal of the RCA was to stabilize the processes and lift the production rate. The machine was able to deliver app. 300 good parts after the previously discussed optimizations. In the following part of the thesis the EOL-Test will be discussed to generate more improvement.

b. Process adjustment EOL-Test – Module A 15

During the End-Of-Line-Test the steering gear (power pack and housing) is being tested for water resistance. Therefore the gear is being sealed on the electrical and mechanical connection interfaces as shown in the picture below. The evacuation is realized via the drive belt measurement opening.

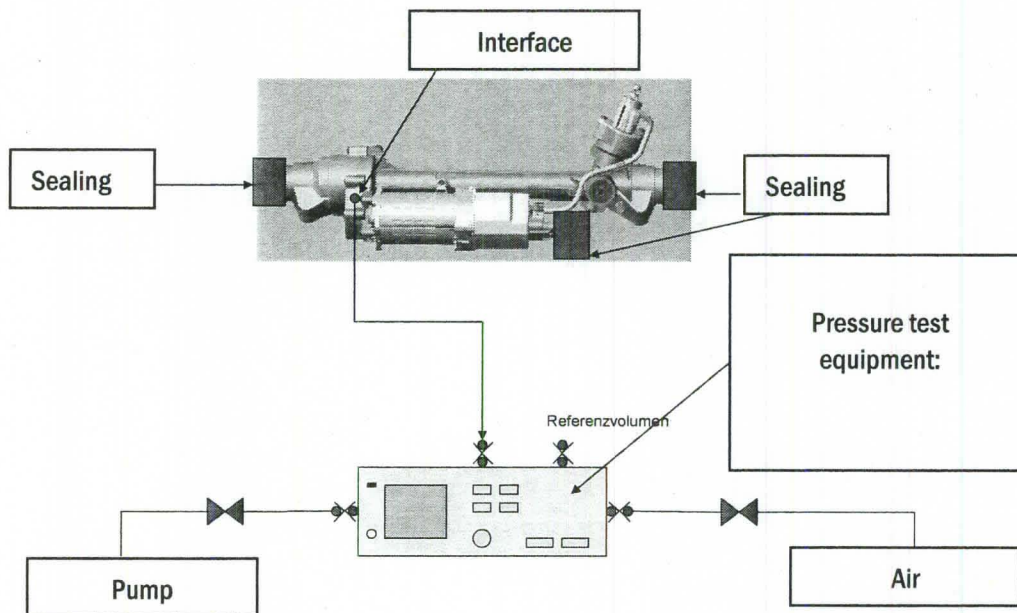


Figure 24. Evacuation fixture

The steering gear basically consists of two components: the space that contains the KGT (rack and ball screw driver) and the space that contains the ECU (electro control unit) and the motor. The spaces are connected via a Gore-Tex membrane. The membrane is designed to hold water out of the ECU area and allow air circulation within the gear.

The development of the testing conditions is based mainly on customer requirements and the most extreme working conditions the gear has to perform. The

sealing points have to withstand pressure within a divined range. The first step was to generate the testing pressure. Therefore the maximum temperature difference is needed, the gear has to withstand. The gear reaches temperatures up to 120°C during full load and has to operate at temperatures of -40°C. For this operation the temperature difference is only relevant to the freezing point (0°C). The risk of damage by ice is rated as minor and therefore not given. As mentioned above the gear is equipped with a water release valve. Due to that the maximum pressure which can react on the gear is round -0.3 bar. The calculation has also been tested as shown in the picture. During the test the gear was equipped with a pressure measurement system. After reaching the maximum temperature of 120°C the gear was paced into water that was held exactly at the freezing point 0°C. The measured values of 0.3 bar confirm the calculated result. Therefore the test conditions can be canceled out of future investigations.

i. Parameter definition

The definition of water resistant is a leakage of less than 0.6ml/min during the operation condition of the part according to customer requirements.

ii. Accuracy of measurement

The **measurement quality** is inconstant during time. Therefore the task was to find the optimum test time for the system. Influencing factors are:

- Temperature differences in the gear
- Temperature changes during the measurement

Temperature differences in the gear are generated during the assembly process or the operation and performance of the gear. Since the performance test takes place past the

air test there is no need to take that point in further consideration. During the assembly process it is possible that different parts are on a different temperature level. To evaluate the influence of that process distortion the production time of the gear has to be considered. The components have a minimum time to adapt the environment temperature of twelve minutes.

The production of the gear has twelve serial process steps from the beginning till the air test. Combined with the cycle time of 60 seconds, the minimum time for the single component at the production line is twelve minutes. Refilling components are handled by a Kanban system and the FIFO principal. Components that are of high volume have a minimum inventory of 55 pieces, which equals a time of 55 minutes for components to adapt to the surrounding temperature.

To ensure the process stability all critical components (components which can store thermal energy in a significant way) have been measured as shown in the following table. The components have been cooled down to 0°C and controlled heated up to 21°C. The time between start and when the components reach 15°C is critical.

The relevant components were equipped by a temperature sensor which recorded temperature during time. The measurement shows that only the motor and the KGT are critical components, since they are not a high volume component. The range at the line is higher than 60 minutes.

Table 2. Gear temperature

	Housing	KGT	Input shaft	Motor	ECU
Start temperature	0°C	0°C	0°C	0°C	0°C
End temperature	15°C	15°C	15°C	15°C	15°C
Surrounding temperature	21°C	21°C	21°C	21°C	21°C
Time elapsed	8.2 min	25.3 min	9.1 min	19.2 min	7.2 min

Temperature differences during the measurement cannot occur because the machine is in a temperature controlled environment. To receive a good signal and therefore a reliable measurement with a flow of 5ml/min the measurement must be longer than 5 seconds. The **filling and evacuation time** is the time which the system needs to generate a constant pressure in the gear. That is necessary to ensure that no pressure differences within the gear are detected as fake leaks during the measurement.

The filling time is influenced by pressure inconsistencies in the gear. Pressure inconsistencies are generated by small connections between the single volumes of the gear. As shown in the Picture below the gear consists of four main volumes (the KGT space, the ECU, the motor and the sensor) which are connected via small holes and gaps. The problem is that the flow is related to the size of the gap/hole and the time. The most critical interface is between the power pack and the Housing of the gear. These two areas are connected via a Gore-Tex membrane. The problem is that during the test it is possible that air flows between these two areas would be recognized by the machine, and counted as NIO. The task is to find the shortest possible time to evacuate the gear. Therefore the

gear was charged with the test pressure of 300 mbar. As shown in the picture below the pressure stabilized after 6 seconds. That time represents the filling / evacuation time.

After adjusting the parameters and controlling the part temperature, the process is more stable. The results did improve slightly, however.

In the next step the bad gears were examined to find the actual leakage. In the picture below you can see that most of the gears had no detectable leakage, they were falsely detected by the machine.

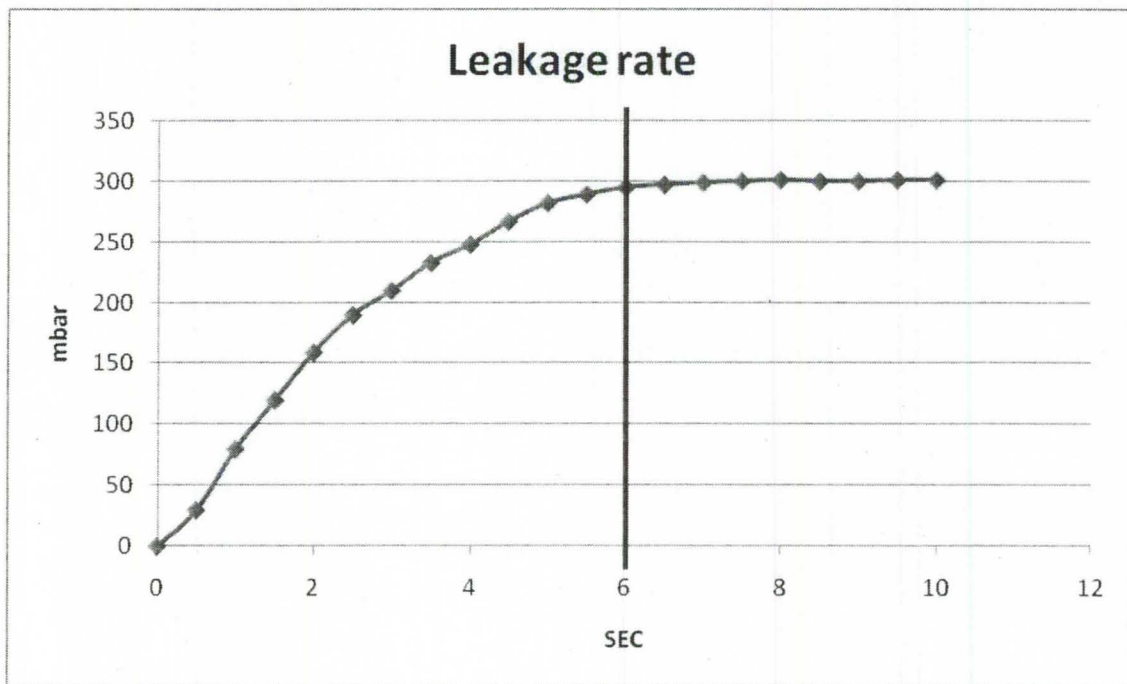


Figure 25. Evacuation time

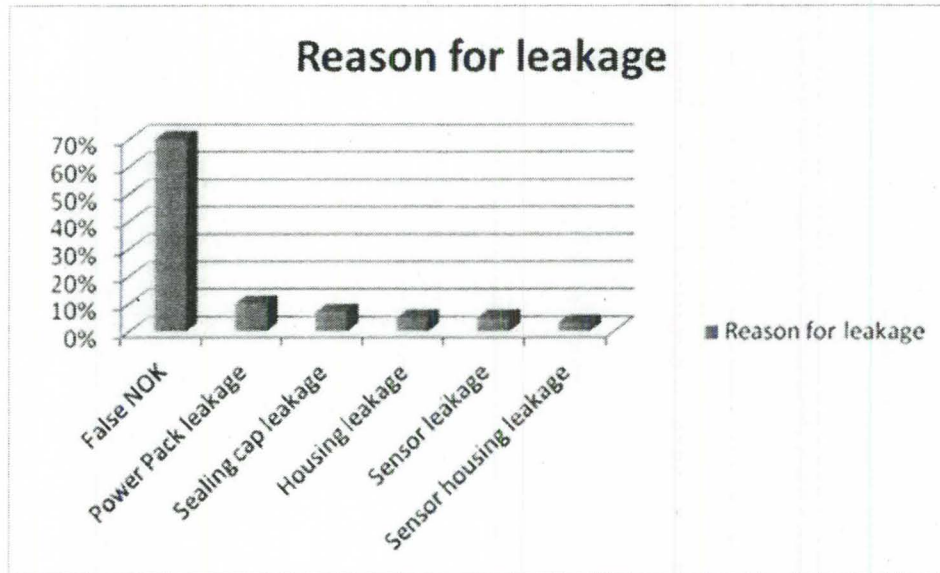


Figure 26. Pareto analysis leakage steering gear

The sealing of the machine were not suitable for the operation. The sealing was brittle after producing a view parts. After the redesign and the replacement the rate of falsely detected gears went down to 4% and therefore solved this problem.

c. Process improvement via KDD and Data Mining – Module A 17

i. Definition of KDD and Data Mining

The goal of knowledge discovery in databases (KDD) is to utilize the generated data and try to find useful information. KDD is the next step to data warehouse. Knowledge discovery in databases assumes that data are organized, cleaned and maybe arranged in the necessary way.

The definition of the term "knowledge discovery in databases" is from Usama Fayyad: „knowledge discovery in databases is the nontrivial process of identifying valid, novel, potentially useful and ultimately understandable patterns in data” (Fayyad, Piatetsky-Shapiro, Smyth 1996) .

The goal of KDD is to find the so-called “patterns” in the pile of generated data. Patterns are structures, intersections and influences that affect the product properties.¹⁰

Data Mining is the systematic use of methods to find patterns, mostly statistical and mathematical tools. Data Mining is on step in knowledge discovery in databases.¹¹

ii. Necessity of KDD

Resulting from the high degree of automation the amount of products has dramatically increased during the last years. As a result of that the amount of data generated also increased. That alone would result in a high effort to analyze the data. Additionally to the increased amount of products generated also the complexity of products and operations has dramatically increased. That fact itself increases the effort of analyzing the generated data. The increased effort is an effect resulting from the increased value of intersections, interactions and dependences of the complex operations.¹²

Especially in the area of electro mechanical components both factors – the increased volume of products as well as the increased complexity of the production process – result in a dramatic increase and effort in analyzing and interpreting the generated data. As mentioned earlier the gear generates roughly 200Mb of data until the product reaches the final production step and can move on in the supply chain.

iii. Application of KDD and Data Mining in CRISP-Process

The Cross-Industry Standard Process for Data Mining (CRISP-DM) was developed by Daimler-Benz, Integral Solutions Ltd., NCR and OHRA in 1996. It is

¹⁰ Witten Ian H., Eibe Frank, Data Mining – Practical Machine Learning Tools

¹¹ Mandl Heinz, Reinmann-Rothmeier, Wissensmanagement: Informationszuwachs – Wissensschwund?

¹² Agrawal R., Psaila G, Active Data Mining

divided in six phases.¹³ In the following the phases are going to be described and their implementation on the situation at ThyssenKrupp. The workload of each phase is different and depends on the problem as shown below:

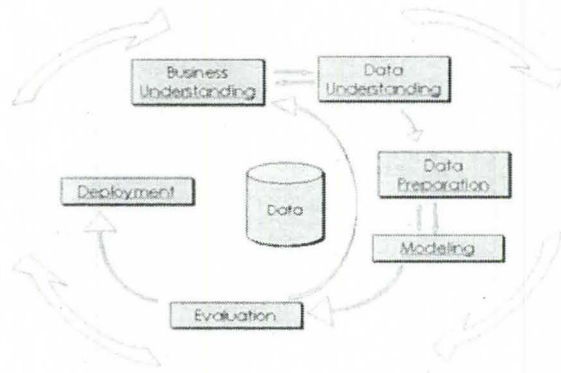


Figure 27. CRISP Data Mining Model

- | | |
|---------------------------|-------------|
| 1) Business Understanding | ~ 10 % |
| 2) Data Understanding | ~ 20 – 30 % |
| 3) Data Preparation | ~ 50 – 70 % |
| 4) Modeling | ~ 10 % |
| 5) Evaluation | ~ 10 % |
| 6) Deployment | ~ 5 % |

For the DSK measurement we decided on a stepwise approach. The clear defined goal is to implement production plant internal data and first tier supplier information as shown in the picture below. That represents the first step. The second step is to implement the sub supplier information as well but this aspect is not part of that thesis.

¹³Otte R., Otte V., Kaiser V., Data Mining für die industrielle Praxis

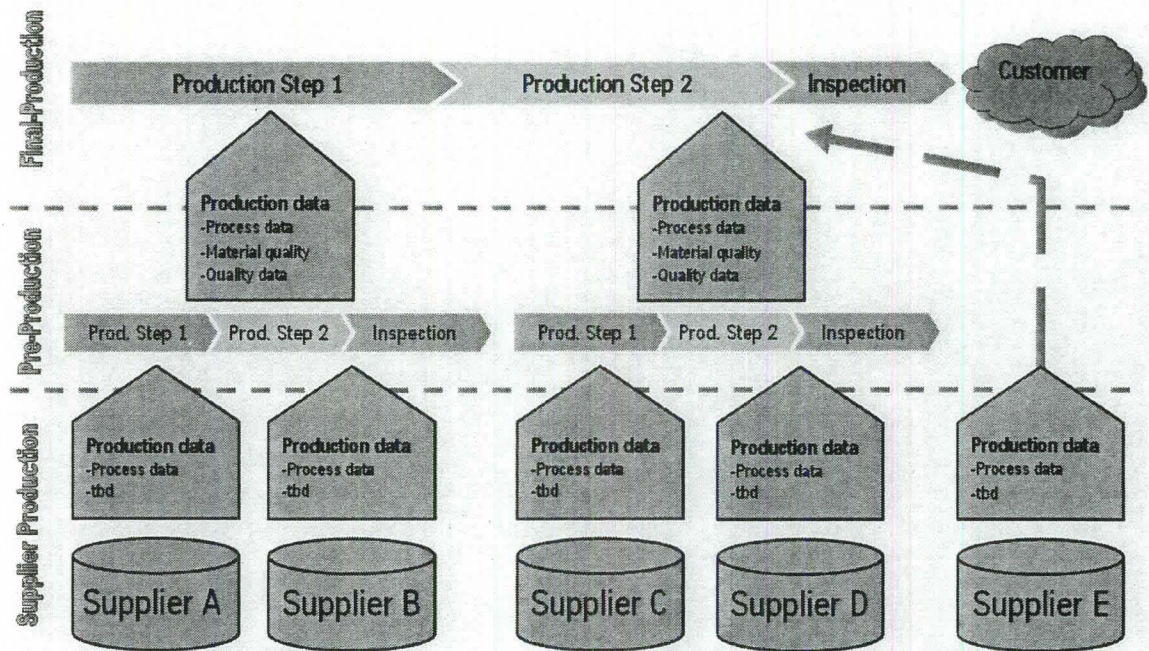


Figure 28. Data mining process TKPS

Business understanding

The key aspect is to understand the company's need and define the goal clearly, respectively break the goal down to the basic problem. In this thesis, it has been focused just on the decrees of the DSK value in the steering gear. During the first step, the influencing components have been defined. In this case, there are several factors like the moving force of the KGT production data, the power pack production data and the housing production data; for simplification the focus lies on these factors.

Data understanding

Data understanding is basically joining and canalizing of the data, bringing it in the form needed, ensure the quality and integrity of the data. This step was not too difficult in this case because all the preparation work was done by the data management system that has been installed. As mentioned earlier, the ability to track down single

components down to their origin is been given. The only improvement that has to be done was to bring this information together.

Data preparation

This step requires most efforts because the knowledge about the process and product is of very high importance at that point. In this step the final data set is broken down to generate the single values responsible for the problem respective influencing the problem. The data are being rearranged, added and reformatted, using “Minitab”. Visualized in the following pictures the influence of KGT friction, KGT axial play and motor friction on the result of producing a good part with respect to DSK or a bad part is shown.

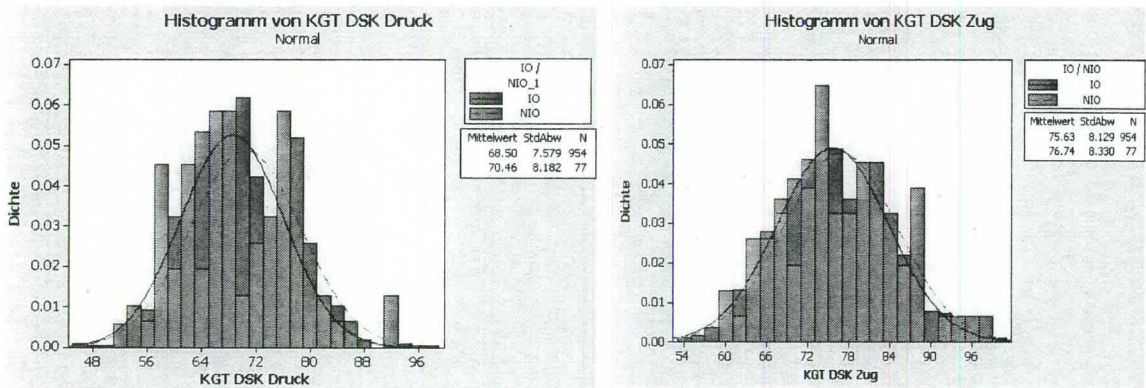


Figure 29. Histogram KGT friction

The friction of the KGT has an influence or tendency that high friction value will more likely result in a high value of DSK in the assembled gear. Instead, for the axial play an impact on the DSK value cannot be seen.

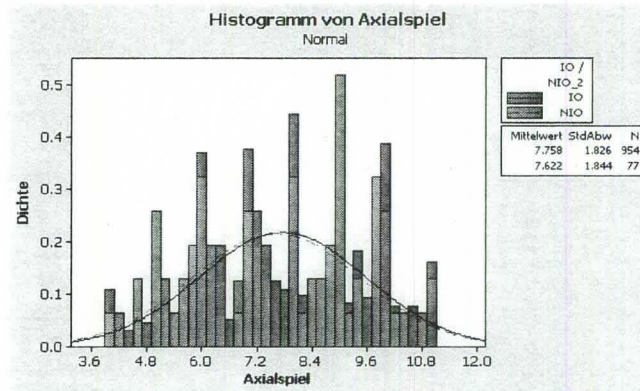


Figure 30. Histogram KGT Axial play

The motor is a significant influence on the DSK value of the gear. As shown in the histogram power packs with a low friction level tend to deliver a better result in DSK value as power packs with a high friction level. For this Project just over 25 parameter intersections for the DSK issue have been analyzed.

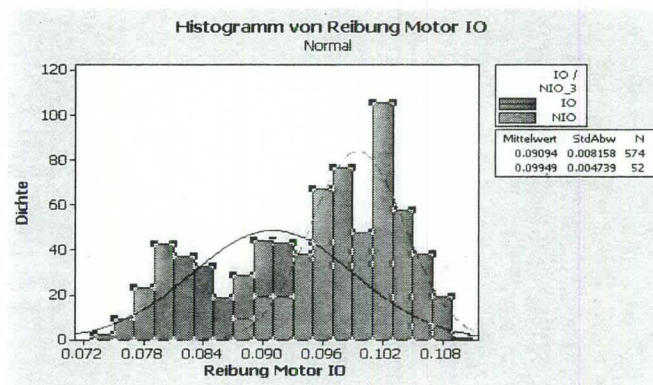


Figure 31. Histogram - Motor friction

Modeling

Modeling is one of the central KDD phases. It is an iterative process to generate an algorithm that represents / describes the conditions in a way to understand and steer the topic towards the set goal. Resulting from the so far generated information, the implementation of the algorithm in our logistic tool took place, to feed those best matching components to the assembly line. Therefore the best utilization of the machine and an increase of the OEE were possible.

Evaluation

During the evaluation phase, the generated theory and resulting actions are tested if they fulfill the expectations. Throughout the test run the algorithm was tested if the production result was as planned. The second part is to verify the business aspect of the improvement. The question is if the planned changes are cost effective. In this project, this was realized with a cost-benefit-analysis:

- ➔ On the cost side: programming cost for the logistic system and cost for data storage
- ➔ On the Benefit side: decrees of labor cost and decrees scrap rates

Deployment

In this phase the actual realization of the project takes place. After this realization the review of the changes takes place and is used for “final adjustments”.

3. Goal condition after improvement

After implying all the improvements the OEE of the system was generated again. Therefore the system produces 5 shifts. The Pareto diagram based on the previous result changed like shown in the picture below:

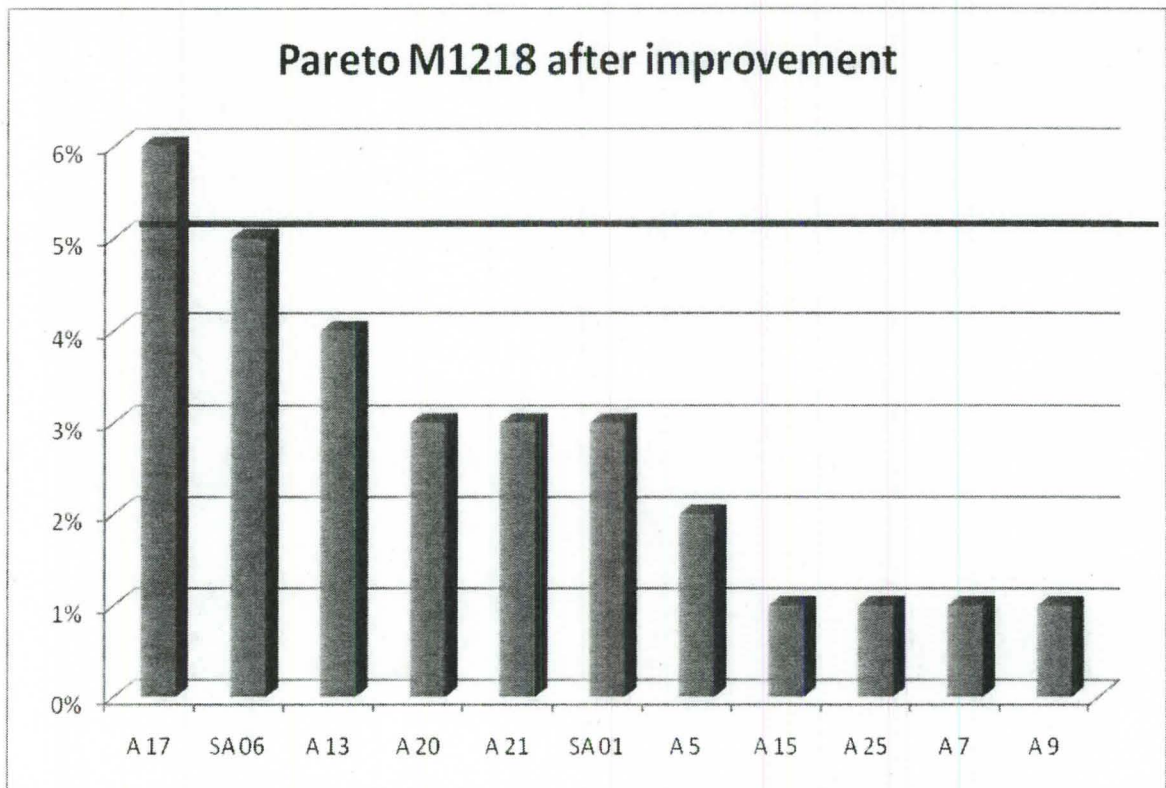


Figure 32. Pareto analysis after improvement

The average of the shifts was taken for the following calculation. The system produced on average: 365 parts per shift, 329 good parts per shift, scheduled time 430 minutes per shift, downtime per shift 45 minutes.

Availability:

Scheduled Time = 430 min.

Available Time = 430 min. scheduled – 40 min. unscheduled downtime = 390 min.

Availability = 390 available min. / 430 scheduled min. = 0.907 → 90.7%

Performance:

Available Time = 430 min. scheduled – 45 min. unscheduled downtime = 390 min.

Production rate: 60 seconds per part, therefore 60 parts per hour

Time to produce parts = 365 units * 60 seconds / part = 365 min.

Performance = 365 min. / 390 min. = 0.936 → 93.6%

Quality:

Quality = 329 good parts / 365 parts started = 0.901 → 90.1%

Overall Equipment Effectiveness after improvement:

OEE = 0.907 availability x 0.936 performance x 0.901 quality = 0.765 → 76.5%

With the resulting 76.5 % we achieved the goal. The capacity of the machine is now high enough to satisfy the customer demand.

CHAPTER III

BENEFIT AND PURPOSE OF THE THESIS

A. Results of the thesis

The benefit for the company is divided in two major categories:

The first and the most visual is the direct reduction of production losses. As mentioned earlier the ratio of supplied parts to the machine and the IO quality and IO function produced by the machine increased. As a result of that the productiveness of the machine increased and more components can now be produced by the production system within the same time.

Another and also important point is that the flexibility increases and the risk of producing waste decreases. If the production machine runs with a low scrap rate, the stored volume of products and components in stock decreases. Therefore changes required by the customer or internal, for example, can be applied to the product much easier – ergo the flexibility is better. The benefit of having less material stored, is the reduced risk of having to scrap or rework the stored parts, in case of a design change; therefore resulting in waste reduction. Finally the last benefit is that if the design is robust enough from the beginning no avoidable problems accrue during the startup.

B. Changes at ThyssenKrupp Presta

The changes at ThyssenKrupp are significant. The previously described problems result mostly from inefficient communication. One result can be that interfaces which were designed for one specific requirement are used wrong in the “new design”. After the design phase of a product the production plant and the design department meet for a workshop. In that workshop all design aspects and questionable assumptions are discussed. Finally the open points are defined and addressed to the participating divisions.

C. Final Word

For me the most obvious benefit of the project was to dive deep in the mechanical assembly of a steering gear. That technical knowledge will help me to understand technical problems more detailed in future. Since that type of problems will be part of my daily business the benefit is obviously. Also a really important point was that I had the chance to experience problems that occur when companies operate in different countries. Liechtenstein (Eschen), Hungary (Budapest) and Germany (Mülheim an der Ruhr) are geographically not too far away from each other and also the cultural differences seem not to be different. But differences are present and even harder to apply to: In this case differences are not clearly visual like color of skin, language or look.

For example the German people are often regarded as rude because of the way they formulate questions. In Liechtenstein more often the term “Can I please get ...?” is used when in Germany you express more efficient “Can I get ...?” These little differences transfer over time to an attitude if not recognized and applied to.

The last aspect is the overview over the whole company and the processes which are behind the production process. The formal organization processes are just one part I had the chance to get to know. The most valuable part in a big company like ThyssenKrupp Presta is the informal organization and the processes behind it.

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4-year course at the University of Applied Sciences Ulm

- diploma in production engineering and organisation
- acquired knowledge in maths, physics, technical design and statistics in the basic study period
- during the main study period I received knowledge in thermodynamics, facility layout planning, factory development, leadership, quality management and control
- diploma thesis: freight vehicle tracking at Wieland Werke AG

August 2006 – January
2007

WORK EXPERIENCE:

Summer Jobs
July – October 2000,
February – March 2003

Rohde & Schwarz, Memmingen, Germany
- built adapters in which electronic devices can be tested - designed layouts for electronic circuits

Alternative Military Service
November 2000 –

Tannenhof, Wiblingen, Germany
- social service (as an alternative to military service) in an home for physical and mental disabled people
- assisted them in their jobs and daily lives

Apprenticeship
September 1997 –
July 2000

Rohde & Schwarz, Memmingen, Germany
- apprenticeship as communication electrician, specialized in wireless transmitting
- acquired knowledge and skills in electronic development
- received basic instructions in manual metal processing
- attended a technical college for acquiring theoretical foundations during this education

Internship
August 2004 – February
2005

Melnor Inc., Winchester, VA, USA
- acquired knowledge and skills in the engineering department
- received basic experience in production control

Project Manager May
2007 – February
2009

Kennametal Extrude Hone, Erkheim, Germany
- experience in project management
- ran international project from the incoming order till maturity phase
- optimized the process structure in the project department