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Determination and evaluation of influencing factors at the Truck_Bushing_Line

Master Thesis

of

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Graz, July 2016

Statutory Declaration

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Unterschrift

Acknowledgement

First of all I want to thank Mr. Dr. Clemens Honeder and the whole Miba AG for offering me many great chances. First I got the opportunity to do an internship abroad in McConnelsville and then this interesting master thesis was offered to me. It was a great, interesting and instructive time at Miba.

Dr. Clemens Honeder offered the project and supported me whenever it was required. He took time to help and advise me and ensured me support from the related experts of the truck-bushing-line.
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I also want to thank my family and my parents in particular who gave me the chance to study mechanical engineering on the Technical University of Graz. A big thank you also to my girlfriend who supported me during hard times and always pushed me to achieve the next goal.

Kurzfassung

Die Ermittlung der Einflussgrößen der Truck_Buchsen_Linie ist Thema bei der Zusammenarbeit von Miba AG Laakirchen und dem Tool & Forming Instituit der TU Graz. Es sollen alle Einflussgrößen, welche auf den Umformprozess der Gleitlagerbuchse einen wesentlichen Einfluss haben, ermittelt und festgehalten werden. Weiters ist es das Ziel sowohl direkte als auch indirekte Einflussgrößen zu finden und die jeweiligen Zusammenhänge zu bestimmen.

Eine große Anzahl an bereits durchgeführten Versuchen muss zuerst strukturiert und ausgewertet werden, um bereits erlangtes Wissen und Erkenntnisse aufzuzeigen. Aufgrund der bestehenden Dokumentation ist eine zusätzliche manuelle Auswertung nötig. Ein Auflisten und Festhalten aller bekannten Einflussgrößen und Qualitätskriterien ist der Grundstein für eine statistische Auswertung. Mittels statischen Werkzeugen wurden alle Zusammenhänge zwischen den gefundenen Einflussgrößen und Qualitätskriterien untersucht.

Für die Qualität eines Verbesserungsprozesses ist es sehr wichtig sich aller Einflüsse und dessen Auswirkungen bewusst zu sein, um die richtigen Aktionen setzen zu können. Das Ziel dieser Arbeit ist eine Auflistung und Gliederung von allen relevanten Einflussfaktoren, um somit für ein besseres Verständnis des Prozesses zu sorgen.

Abstract

Improving productivity is one of the main focuses successful companies have. On the one hand, one can enhance the process steps and on the other hand, the processes itself can be controlled and understood. The focus of this master thesis is the understanding of the processes and its related influencing factors. Therefore, all related influencing factors have to be located and documented.

To know exactly how the processes of the bushing production in the truck bushing line are operating and which levers are influencing which quality criteria, a determination of all influencing factors and quality criteria is required. Therefore, one needs to prepare and evaluate existing trial data to determine the main influencing factors. Collecting and clustering these factors and the related quality criteria provides a basic tool for continuous improvements. With statistical tools the correlations between the factors and quality criteria are evaluated. The received knowledge of the process, its influencing factors and quality criteria function as a starting point for a DoE.

Documentation of all the process related information is the main pillar of successful production. It is also essential to structure and document the experiments to reduce set up time. Moreover, implementing a finite element method helps in the rough design phase and reduces the effort for the practical experiments.

Table of content

1 Introduction

In this thesis I am going to analyze the truck bushing line and detect all the influencing factors which have an effect on the finished product. The bushing line is producing plain bearings for the piston-pin in a truck engine. Determination and evaluation of all related influencing factors is the main task of this master thesis.

Without knowing the correlation between influencing factors and quality criteria, it is rather complicated to adjust and improve the production processes. Therefore, it is essential to collect and structure all factors and quality criteria and reveal the correlation between these. The main goal of this thesis is the evaluation of old experiments and detecting and closing documentation gaps. This thesis shows that it is very important to follow a structured testing procedure that only varies one lever.

In the last few years a lot of experiments were conducted, so there is an extensive list of trial data which have to be completed, structured, arranged according to their relevance and analyzed. Unfortunately, only the obvious variables and quality criteria were documented but not all of the required ones. The first aim is to complete and sort the trial list because many experiments were done in the past with a high variation of influencing factors. Defining adequate quality criteria is essential for the statistical evaluation and to obtain the best results from the data. Statistical analysis should show the correlations between the quality and the influencing factors.

First of all, the truck bushing production is described in detail, how it works and how the different processes interact. The next step is the determination of the influencing factors, quality criteria and the definition of sub processes. Creating an additional evaluation of the old trials was necessary to extract all the relevant information from the measurement sheets. Carrying out this evaluation and collecting these data was the basis for the statistical evaluation where the correlations were detected. One of the important parts is the documentation and closure of information gaps. This should help to make evaluations and reconstruct the processes in the future. A cause and effect diagram was also created to support the user for improving tasks. The last part of this thesis is a guideline for new projects and suggests important points to take into consideration.

The focus of this master thesis is the evaluation of already existing experiment data. Since a new bending sequence was installed during this time, new experiments would not show significant information for the results.

2 State of the art

2.1 Bearings

Definition

Bearings are used for the mobile connection of two parts. Normally there are rolling-, sliding-, air-, liquid- or magnetic bearings used, which depends on the application and the required properties. (Mahle GmbH 2015, S. 60)

History

For centuries, mankind had to use their own physical power and strength to move large objects on the earth. The concept and main application of a bearing is to reduce friction between an object and the surface it is moved on. The first solution of reducing the sliding force was recorded as early as 3500 B.C. It was in Mesopotamia that men first used a bearing to minimize the friction of a wheel. They put a with animal fat lubricated bearing made of wood or leather where the wheel and axle touched. Drawings from 1100 B.C. show moving rocks with rollers to reduce friction. (SKF 2016, S. 5)

2.1.1 Slide Bearings

Benefits of slide bearings

The benefits and advantages of a plain bearing lie in the quiet operation, the less required space and the low costs. Moreover, a plain bearing has the ability to handle a small amount of dirt, vibration, higher speed and also bigger loads than other bearings. The low noise level results from the absence of any moving parts in the bearing. This fact is also responsible for the less amount of space needed, because there is no space for moving parts necessary. No additional moving parts are also the reason for the relatively low costs. (ENGINEERING 2016)

Grooves and holes

Holes and grooves are responsible for the transport of the lubricant into the bearing. They are undesired in the area of the highest load because they reduce the usable area. (Mahle GmbH 2015, S. 69)

Application

Applying slide bearings separates two surfaces which move towards each other. This is done by a film of lubricant which creates a pressure field. Generally, plain bearings are the least expensive type of bearing. They have a high load carry capacity but they are also compact and lightweight. (Mahle GmbH 2015, S. 60)

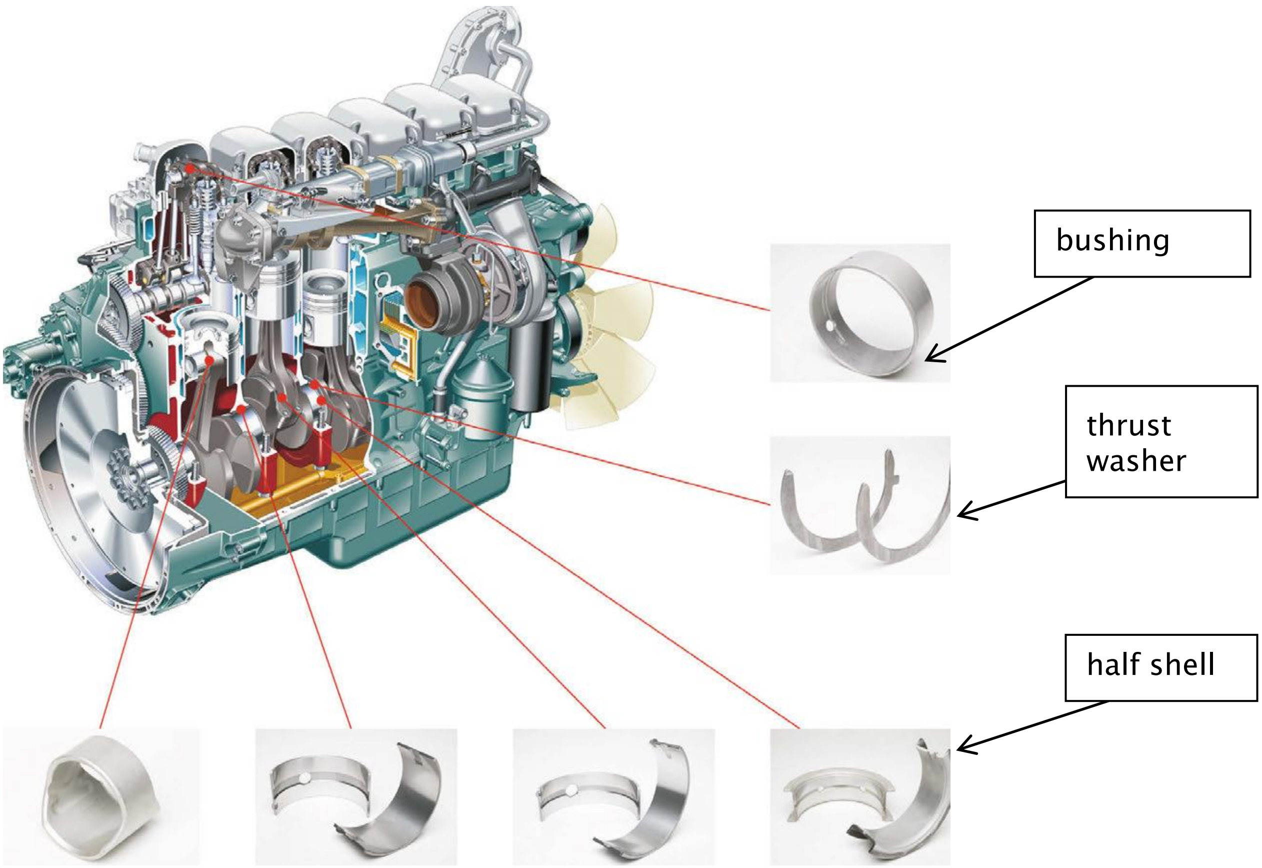


Figure 2.1: Bearings used in an engine (Mahle GmbH 2015, S. 60)

Today bearings are used in almost every imaginable application, such as engines, bicycles, roller skates and every other application where two surfaces are turning or moving against each other.

Different models

Plain bearings can be split into two types: hydrodynamic bearings and hydrostatic bearings.
The hydrodynamic bearing lifts the mating surface by a relatively high rotational speed. The disadvantage provides the lubrication lack when the shaft begins to rotate. It prevents high loads during the startup phase.
Hydrostatic bearings use an external source to force lubricant into the contact zone. The main application is in heavily loaded and slow moving machines, because in these machines the rotation speed is not great enough to form full film lubrication. (ENGINEERING 2016)

2.1.2 Plain bearing production

Production flow:

The previously fabricated material is produced in-house or ordered by an external vendor. First, the forming and mechanical operations are done. Afterwards, the bearings are treated with a special surface technology.

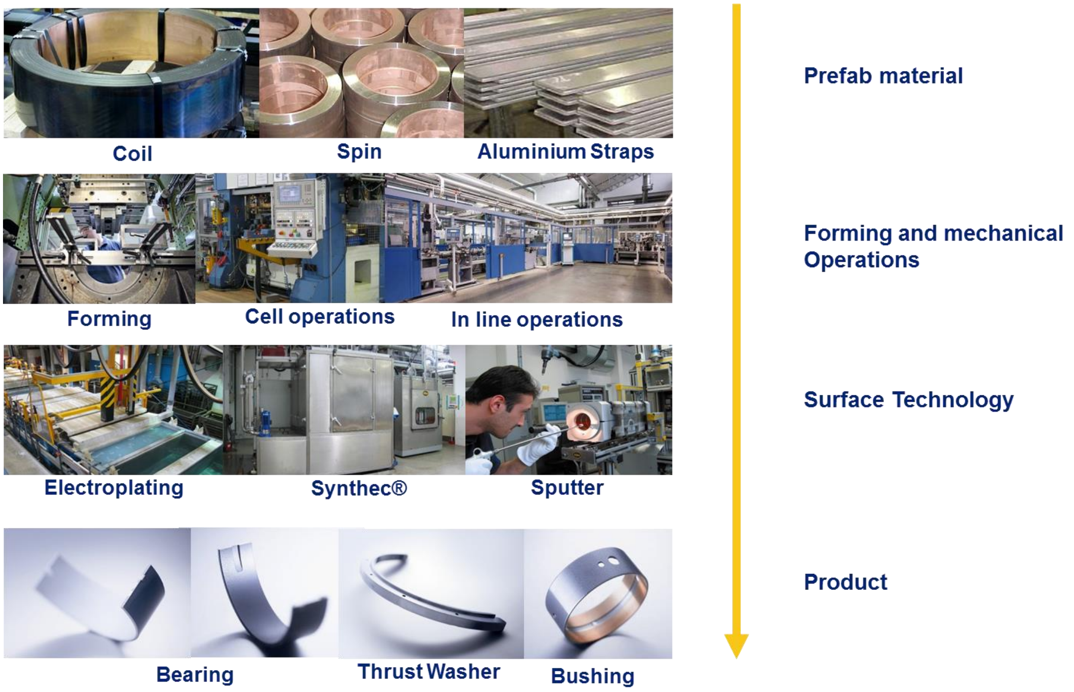


Figure 2.2: Bearing production flow (Miba Gleitlager GmbH 2012)

Starting material and mechanical operation:

There are three different kinds of starting materials. Roll bonding is the combination of two materials which are connected under compression and high force. The finished coil can be delivered as a uniform material or as a combination of two or more different material layers. Another possibility to produce the starting material is the process of spin casting. The third option is compound casting which is the casting of a combination of two or more different materials in the solid or liquid phase. Selecting the starting material depends on the application, the required diameter and properties.

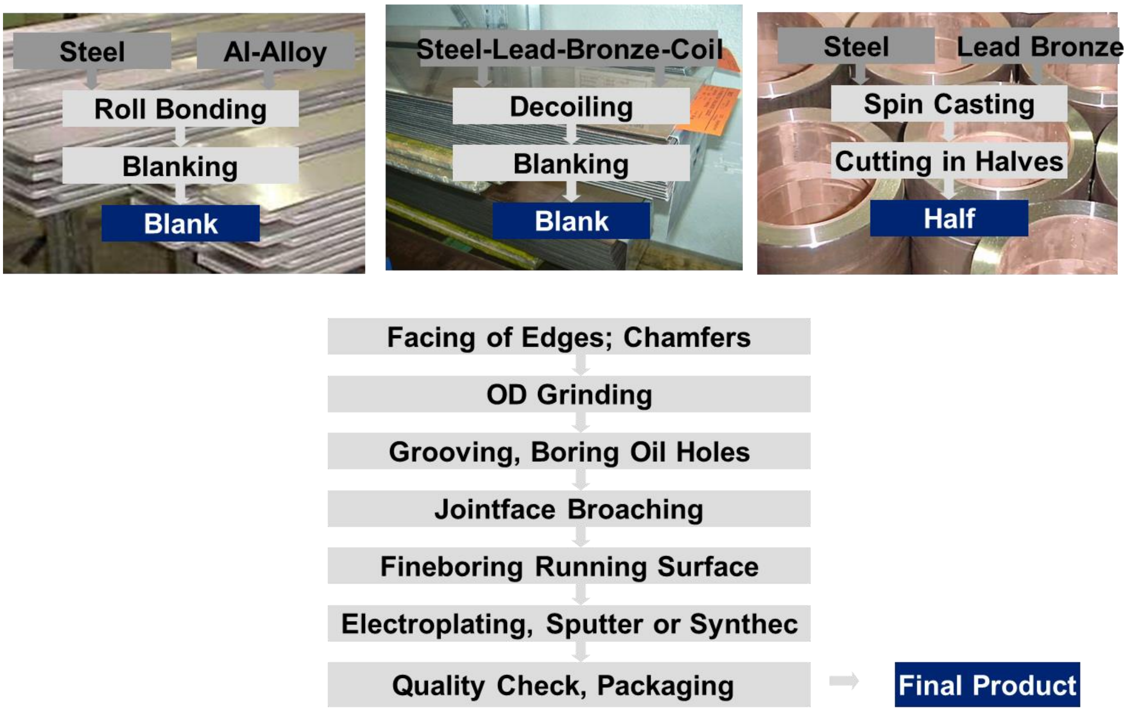


Figure 2.3: Starting material and mechanical operation (Miba Gleitlager GmbH 2012)

Bushings, half shells and thrust-washers:

Table 2.1: Bushings, half shells and thrust-washers (Miba Gleitlager GmbH 2012)

Bushings	Half shells	Thrust-washers
		
Different bushings reduce the friction between two moving parts.	Half shells allow an easy assembly and disassembly of the components	A washer placed between two moving parts to provide a bearing surface for the thrust surfaces of the parts.

Coatings:
Different coating layers have different application fields and consist of different materials. For this truck bushing, the layer should cover and protect the bushing and is also important for the first run-up. It reduces the run-up friction and it is a protection layer for the first tests. In other applications the coating can improve the tribological characteristics like the temperature stability, wear resistance, friction and others. (Miba Gleitlager GmbH 2012)

Table 2.2: Coatings (Miba Gleitlager GmbH 2012)

Electroplating	Synthetic coatings	Sputtering
Lead and tin based overlays with and without particle re-enforcement	Synthetic-Lead Free Overlay completely environmentally friendly during coating and in the application truck up to two stroke bearing dimensions	Aluminum-tin based overlays coated within a special coating process based on central cathode delivering a completely uniform layer

2.2 Production techniques

For the serial production of bearings a lot of different production techniques are necessary. Here are the main techniques listed and roughly explained.

2.2.1 Roll bonding

In order to generate a product which fulfills all the requirements it is not always possible to just use one single material. The requirements could be stiffness, temperature resistance, dry-running properties and others. Material compound is a possibility to meet the needs and create a starting material. (Krenkel 2009, S. 535)
The piston-pin bearing (produced in the truck bushing line) requires the combination of bronze and steel. To combine these two materials an adhesive Cu-Foil is placed in-between. Heat treatment is necessary to reduce the residual stresses of the materials.

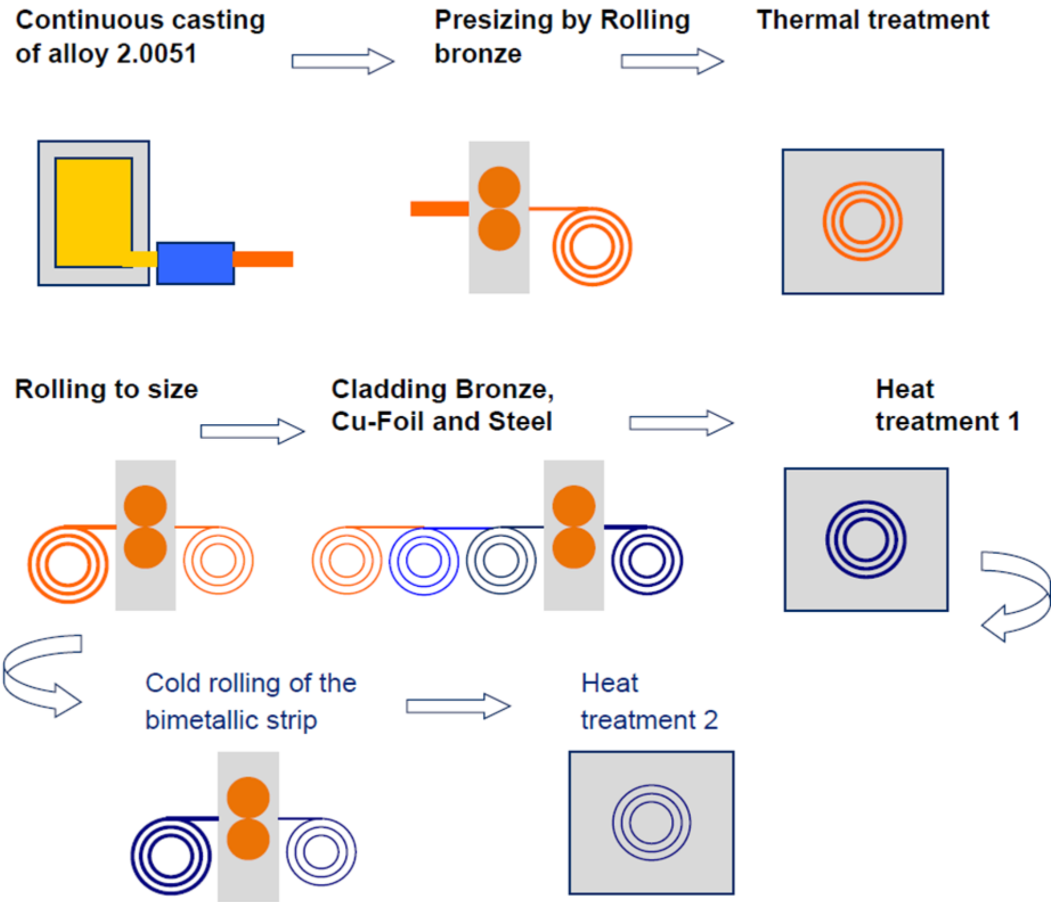


Figure 2.4: Production steps of roll bonding (Miba Gleitlager GmbH 2012)

2.2.2 Metal Forming

As in the DIN 8580 described the manufacturing processes are divided into six main categories: primary shaping, material forming, dividing, joining, modifying material property and coating. SCHULER GmbH (1998, S. 5-24) describes this as follows:

- Primary shaping is the creation of a special form or shape from the molten or formless solid state.
- Material forming is the process of giving a raw material a new form during deformation and machining.
- Dividing is the process of cutting in or separating a local area of material.
- Joining is the assembly of two or more different workpieces to create new sub-assemblies.
- Modifying material property is a process to change material characteristics such as hardening or recrystallization annealing to generate better material properties for certain applications.

- Coating means the attachment of a thin layer to the material to make it more resistant against rust and other damaging factors. Galvanization, painting and foil wrapping are processes for a coating layer.

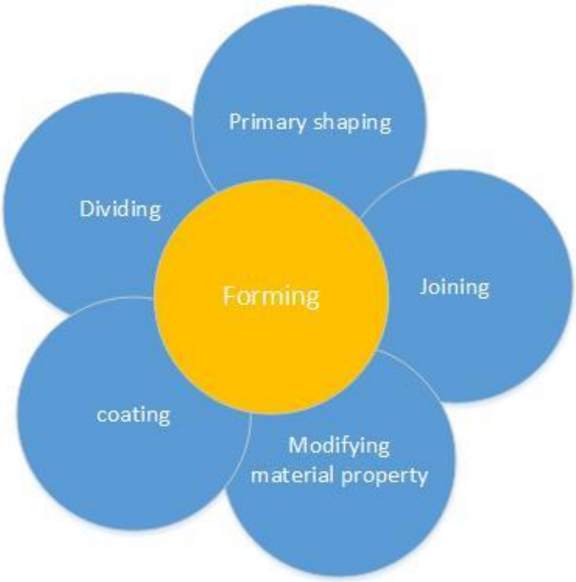


Figure 2.5: Overview of production processes (SCHULER GmbH 1998, S. 5)

The difference between deformation and forming is that forming is a modification with a controlled geometry. Forming processes are defined as chip-less or non-material removal processes. The different forming techniques are classified according to DIN 8582. The classification depends on the applied stress and its main direction. The classification is described in SCHULER GmbH (1998, S. 5-24) as follows:

- Forming under compressive conditions,
- Forming under combined tensile and compressive conditions,
- Forming under tensile conditions,
- Forming by bending,
- Forming under shear conditions.

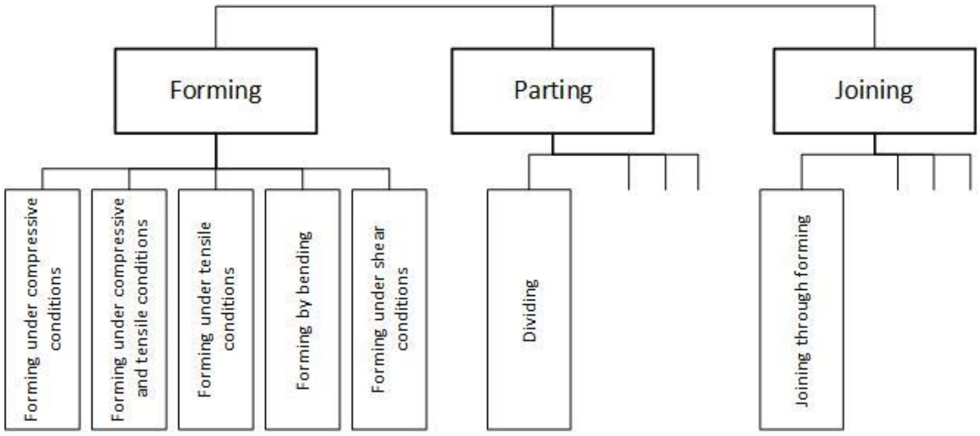


Figure 2.6: Production processes used in the field of forming technology (SCHULER GmbH 1998, S. 6)

The different forming processes are divided into various processing methods as the figure below shows.

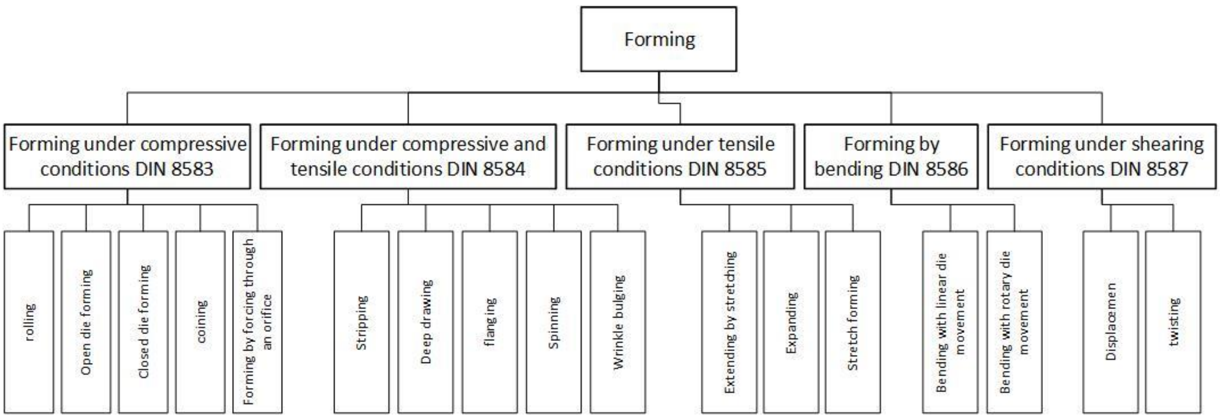


Figure 2.7: Classification of production processes used in forming in accordance with DIN 8582 (SCHULER GmbH 1998, S. 7)

Forming under compressive conditions is divided into five main fields of application. The first one is forming with the technology of rolling. This means forming takes place with rollers in several forming steps with different roller geometries. With this technology one is able to form a specified geometry just with one cycle. This process increases performance and efficiency.

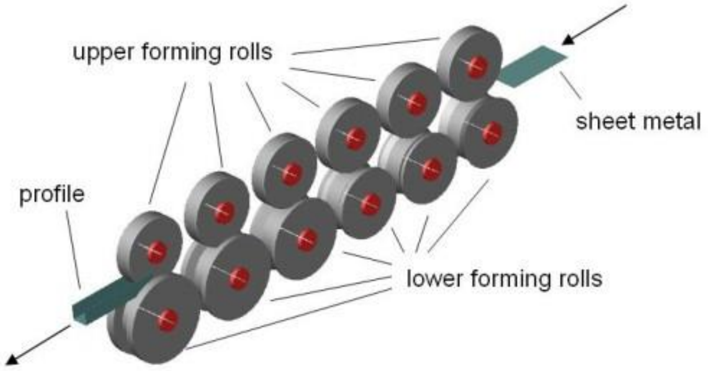


Figure 2.8: Rolling profile (TU-Darmstadt 2016)

Coining is a process where a punch or tool penetrates the material and gives it the desired form. The major application is for the production of coins and medallions. It is a precision stamping form to induce plastic flow on the boundary area of a material. One benefit is the reduction of the grain size and also the work hardening in the surface area while remaining the toughness and ductility in the inner material. It is used for manufacturing high relief or fine features in nearly every industry. Coining is a high tonnage and cold working process because it uses a high force to plastically deform a workpiece.

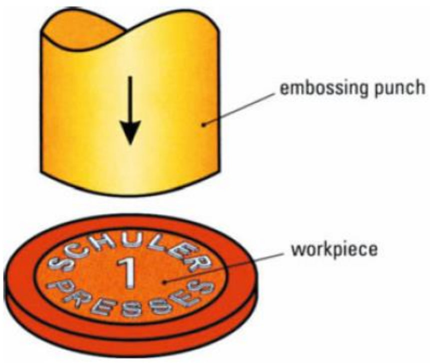


Figure 2.9: Coining (SCHULER GmbH 1998, S. 9)

Bending

Bending is one of the most frequently used forming processes. Many different bending techniques are used for different applications. After the forming process, however, they could spring back and change the final geometry of the part. Therefore, the die has to be designed in consideration of the possibility of it springing back. (Klocke und König 2006, S. 419–446)

Forming by bending

Bending with linear die movement is the process when the components are moving in a straight line. The most important one is die bending where the geometry of the die and the recovery of the material is responsible for the part.

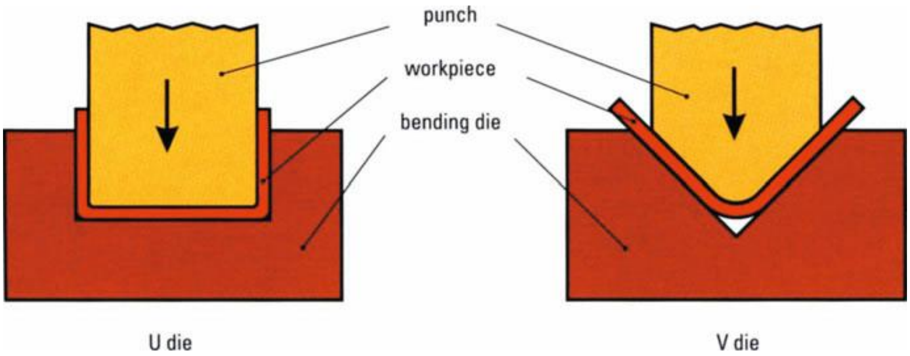


Figure 2.10: Die bending (SCHULER GmbH 1998, S. 16)

Bending with rotary die movement includes circular bending, swivel bending and roll bending. In this process the bending moment is applied by means of rolling. With roll bending it is possible to produce cylindrical or tapered workpieces. Roll straightening is a process to eliminate undesirable deformations in sheet metal.

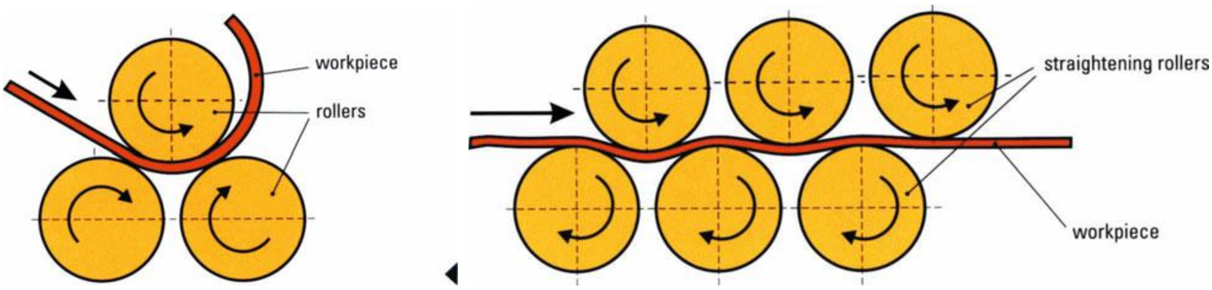


Figure 2.11: Roll bending (SCHULER GmbH 1998, S. 17)

Friction

Friction occurs during the relative movement of two parts in contact. One distinguishes between inner and outer friction during forming. Inner friction happens within the material during plastic deformation. Outer friction appears when two materials are touching each other on the surface. Friction is essential for the forming process and there are lots of factors which influence the dimension of the friction force. (Klocke und König 2006, S. 157)

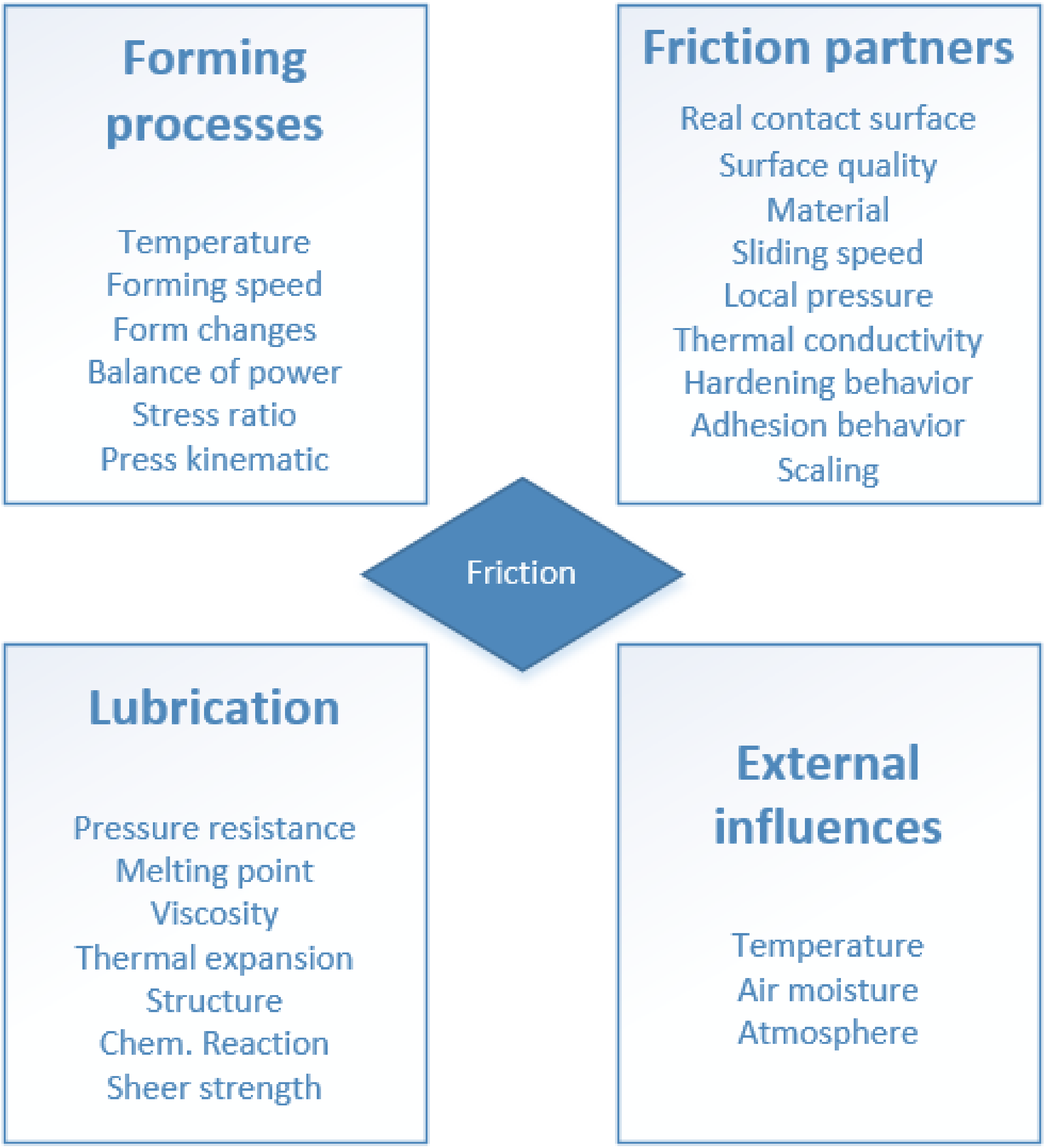


Figure 2.12: Influencing factors of friction (Klocke und König 2006, S. 158)

2.2.3 Tolerances of processes

Different processes lead to different tolerances in surface quality and length of the part. Therefore, the chosen process is essential for the quality of the finished end product. The forming of the bushing leads to a tolerance class of IT8, but the customer requires a quality of about IT5, which is just achievable with an additional process step. In the special case of the truck bushing line an additional grinding process was chosen to meet the customer's needs.

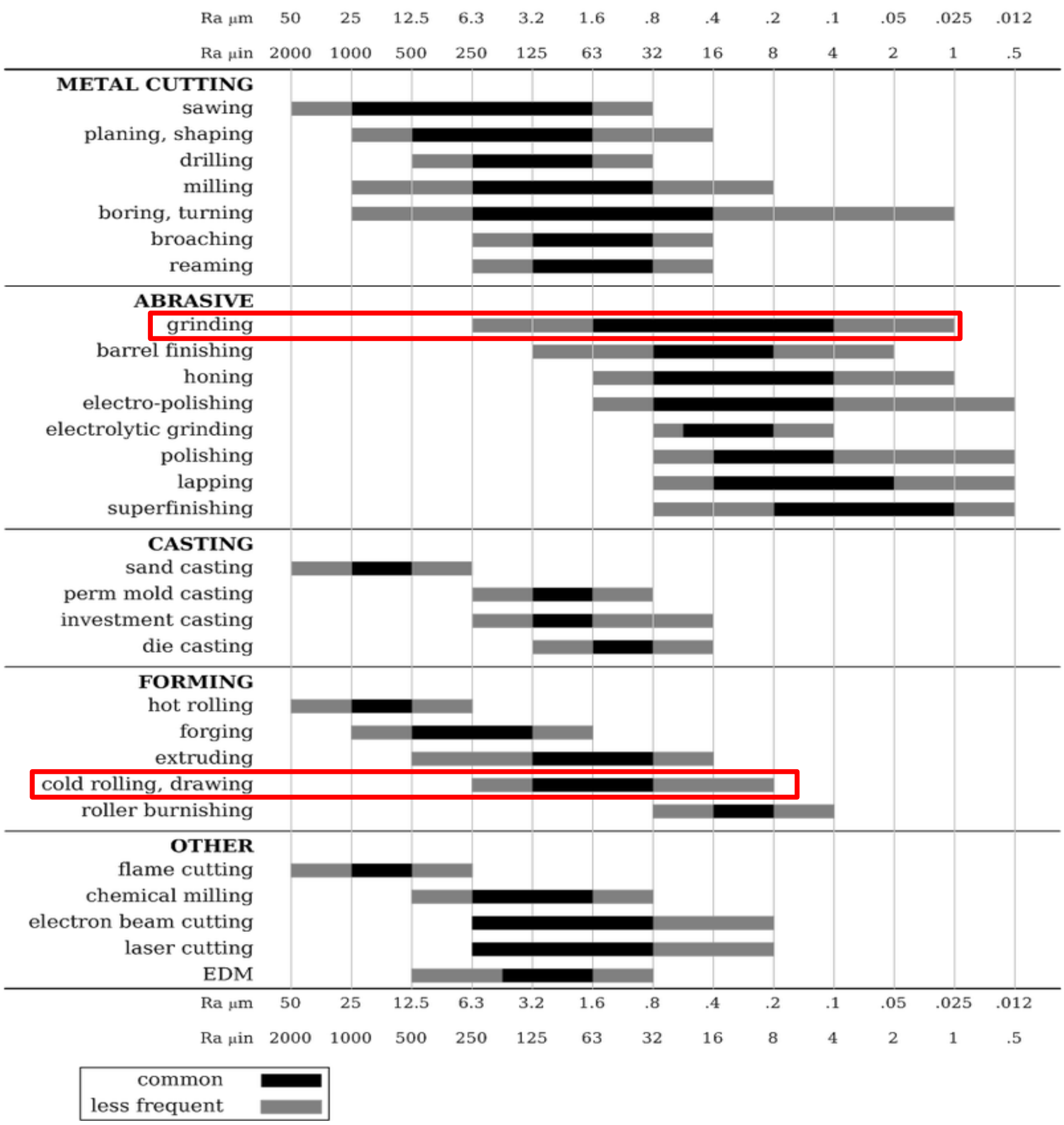


Figure 2.13: Surface quality of processes (Surface finish – Wikiwand 2016)

In Figure 2.13 the surface quality is illustrated to show the differences between the processes. The twelve tolerance fields are shown in Figure 2.14 and demonstrate why the additional grinding process is necessary.

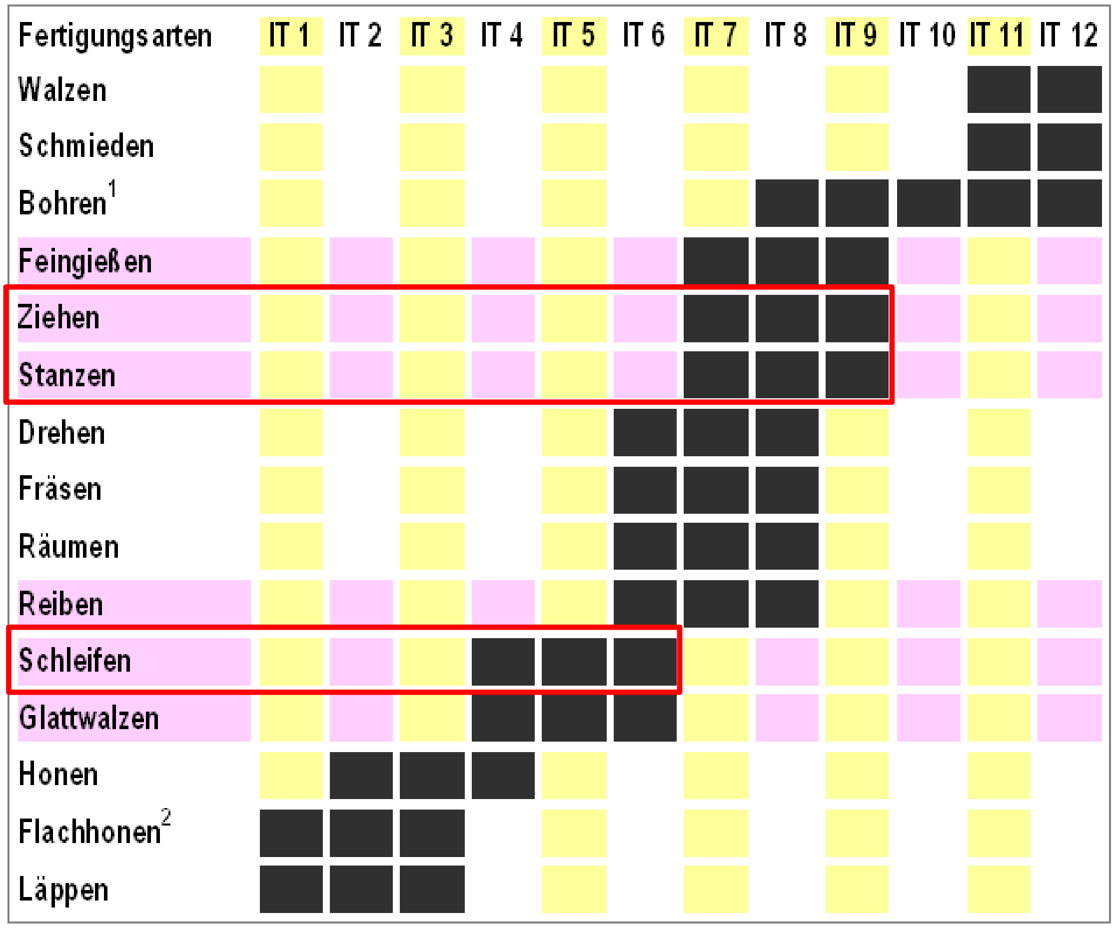


Figure 2.14: Achievable tolerances with processes (Fertigungsgenauigkeiten 2009)

2.2.4 Limits of plastic deformation

Plasticity:

Plasticity is an expression for the behavior and property of a metal piece during the forming process without cracking. The resistance of the work piece depends on: (Klocke und König 2006, S. 57-62)

- Material of the workpiece
- Temperature of the workpiece
- Forming speed
- State of stress in the workpiece

Forming limit:

The forming limit does not describe the limit of the material or its behavior, but the limit of the forming process or related processes. For example: (Klocke und König 2006, S. 57–62)

- Tool breakage
- Too little pressing force
- Inadmissible form or dimensional deviation and
- Inadmissible surface quality

2.2.5 Lubricant in forming process

The lubricant is very important in the metal forming process, because it reduces friction and die abrasion and also cools and cleans the process. Without lubricant some forming processes simply would not work because of the high tribology expectations. In most applications it is possible to bring the lubricant directly to the specific area. Sometimes it is necessary – depending on the application – to attach a specific lubricant layer on the base material. Temperature resistance could also be an important point to take into account especially in forging applications. (Klocke und König 2006, S. 174)

2.2.6 Cutting

The cutting process and all its related factors have a big influence on the truck bushing line and the finished good. For this master thesis the DIN 8588 is relevant, because it describes the process of cutting which is mainly used for the production of the blank.

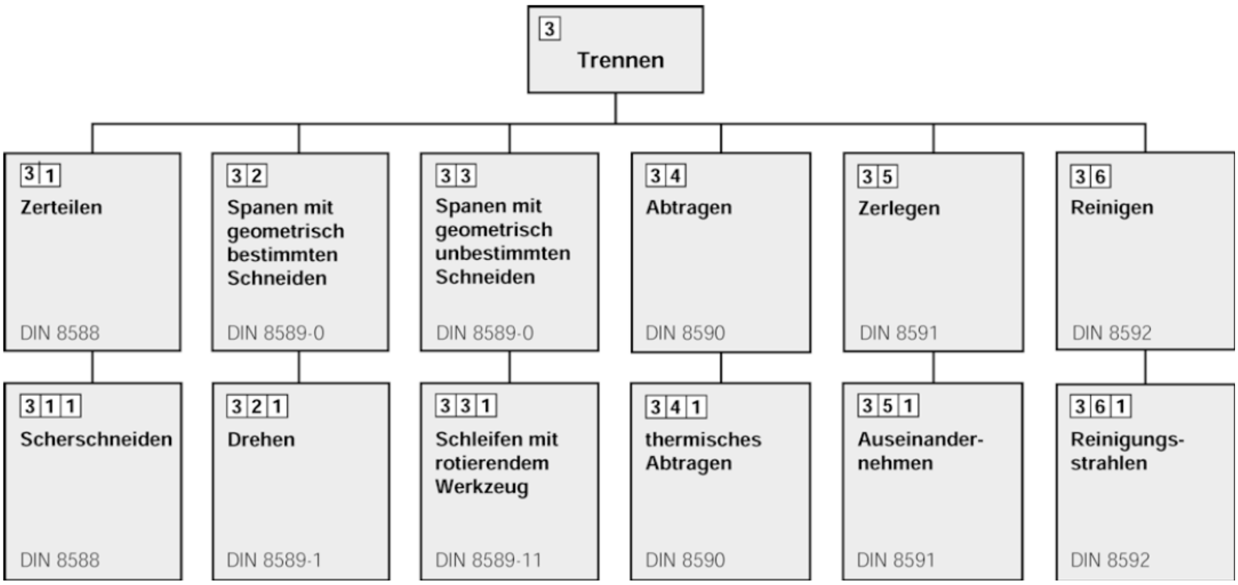


Figure 2.15: Separation processes (Fritz und Schulze 2012, S. 258)

Punching holes and cutting

The cutting process can be done with different geometries of the cutting knife. Figure 2.16 illustrates the cutting process with a parallel cutting tool and also with a diagonal one. The right side shows the punching of a hole. In the first one the workpiece is the cut out, and in the second one the cut out is the waste.

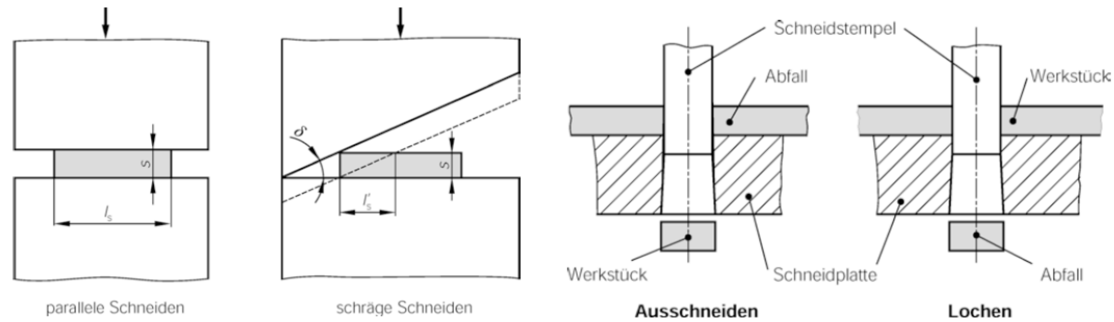


Figure 2.16: Cutting and punching holes (Fritz und Schulze 2012, S. 259)

Cutting gap

To ensure a high quality of the product it is required to define the correct cutting gap. As shown in Figure 2.17, a) portrays a difference that is too small and c) one that is too big. Therefore, it is essential to consider the material and its thickness during the construction phase.

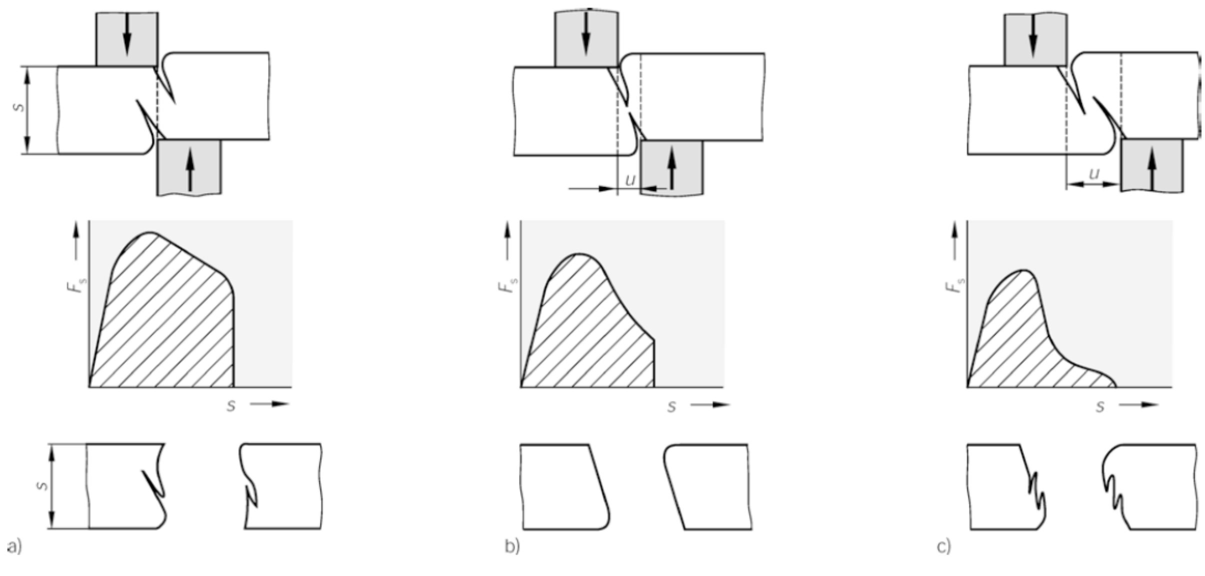


Figure 2.17: Cutting gap (Fritz und Schulze 2012, S. 260)

2.3 Methodology

To obtain the best results of an analysis it is required to have a methodological approach. Therefore, a few tools which could help during the evaluation phase are listed and explained. It is important to understand how these tools are working and how such a tool could be applied.

2.3.1 Finite Element Method (FEM)

The Finite Element Method is a numerical solving method for technical applications. With FEM it is possible to simulate physical processes, for example, the deformation of rigid parts. This would be difficult to analyze with other methods.
The rigid part is split into many small parts with a simple form. These simple forms could be easily calculated with well-known initial functions.
For the user it is essential to have a sound knowledge of the theoretical correlations, because the main task of the engineer is to bring the real part into the FEM system. The main calculation is done by a computer and the engineer is responsible for the evaluation and the plausibility check.
They have to make sure that the result is plausible, because although a FE-program can calculate nearly everything, it is up to the operator to check if this could be correct. During the application there could be a lot of error sources, for example: (Klein 2015, S. 1-11)

- Wrong physical boundary conditions could lead to wrong stress distribution and faulty support reaction.
- If the model is simplified too much, the real stress distribution is not detected.
- When the mesh is defined to wide, the result could also be incorrect.

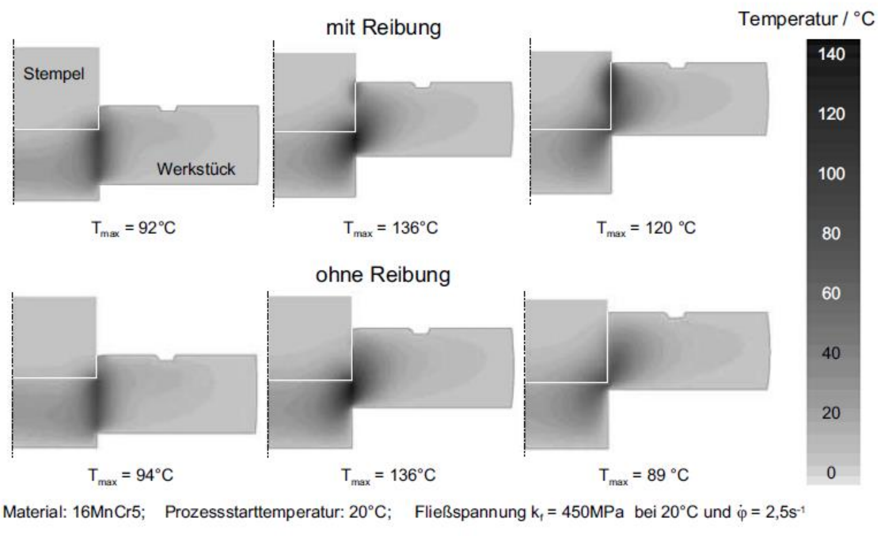


Figure 2.18: Temperature field during fine cutting (Klocke und König 2006, S. 86)

2.3.2 Statistical tools

The first statistical evaluation was carried out at the beginning of the 19th century for the revenue growth of agriculture. For this statistical application the analysis of variance was created.
Screening is a process to check the significance of the influencing factor. With this technique the economic borders are reached very fast, because it takes a lot of effort to do the experiments. It is mostly used for gaining a rough overview and for first evaluations because if there are more factors the screening process is not economic any more. (Gundlach 2004, S. 40)

Data preparation

Before the first evaluations were done, it was essential to check the plausibility of the existing data. Checking the correlation and the correct values is a very important part of the data preparation. If there are comma faults or other transfer errors the result of the evaluation is incorrect. (Gundlach 2004, S. 231)

Failure analysis

For the detection of failures it is necessary to use statistical tools like the pareto-diagram, correlation diagram or the cause and effect diagram. Figure 2.19 shows how these tools correlate and how they work together.

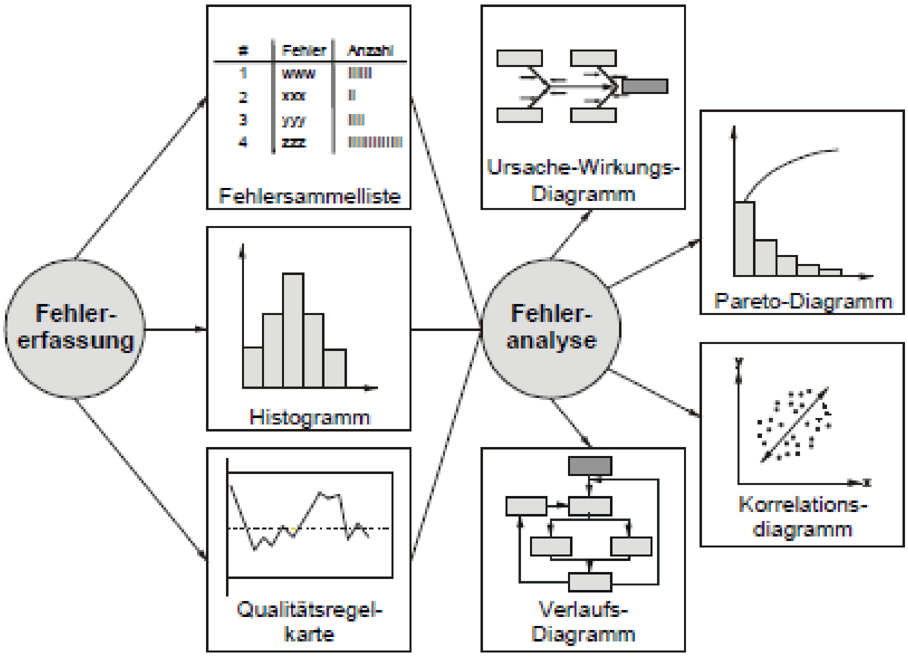


Figure 2.19: Correlation of the statistical tools (Gundlach 2004, S. 39)

System analysis

Figure 2.20 lists and visualizes steps for doing a system analysis. The red arrows mark the relevant path for the master thesis. The screening phase is the most relevant phase, because of the vast amount of unknown influencing factors. If the data are not complete, screening is the first approach to determine the main factors.

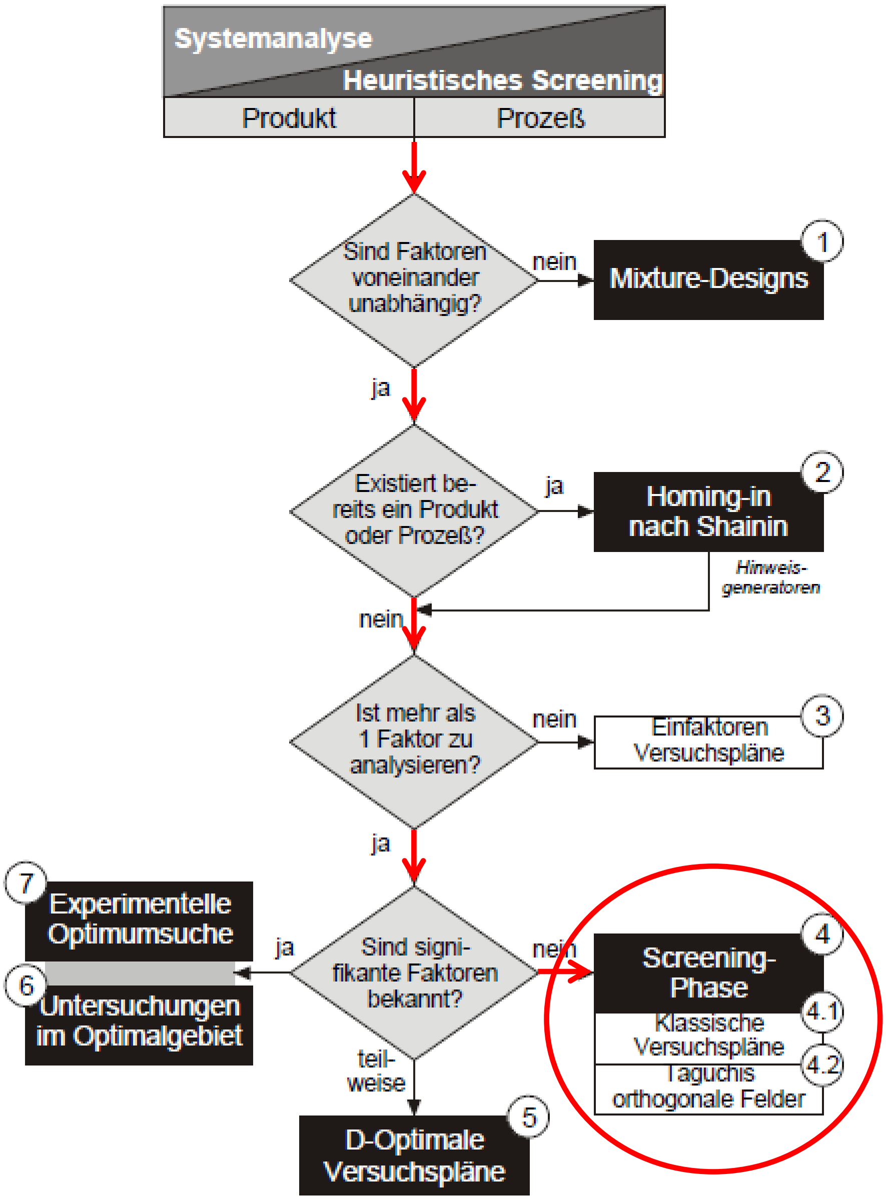


Figure 2.20: Overview of trial plan (Gundlach 2004, S. 215)

Design of experiments (DoE)

The biggest problem occurs with a great amount of influences, because then many experiments are necessary in order to determine the correlations. But this is also the advantage of the DoE, because with this tool it is easy to reduce the effort. A large number of factors require carefulness for the trial plan. In the school physic normally just one factor varies, otherwise it is too hard to determine the exact origin of the result. The DoE, however, enables to not just vary one factor, but it is also possible to determine the main influencing factor. Figure 2.21 shows the number of experiments which are necessary for a certain quantity of factors. As can be seen, for seven factors normally 128 experiments are required. With the part factor trial plan, however, just eight experiments are necessary. This reduces the effort for experiments dramatically.

Anzahl der Faktoren / Versuchspläne	2	3	4	5	6	7	8	9
Vollständige 2^k-Faktoren-versuchspläne	4	8	16	32	64	128	256	512
2^{k-p}-Teilfaktorenversuchspläne Auflösung III	-	4	-	8	8	8	-	16
2^{k-p}-Teilfaktorenversuchspläne Auflösung IV	-	-	8	-	16	16	16	32
2^{k-p}-Teilfaktorenversuchspläne Auflösung V	-	-	-	16	-	-	64	-
2^{k-p}-Teilfaktorenversuchspläne Auflösung VI	-	-	-	-	32	-	-	128
Plackett-Burman-Versuchspläne Auflösung III	3	4	5	6	7	8	9	10
Vollständige 3^k-Faktoren-versuchspläne	9	27	81	243	729	2187	6561	19683
Box-Behnken-Versuchspläne	-	15	27	46	54	62	-	-
Zentral- zusammengesetzte-Versuchspläne CCD	9	15	25	43	77	143	273	531

Figure 2.21: Required experiments plan (Gundlach 2004, S. 85)

The key factor for the success of the statistical tool is the trial design, because this allows both a variation of more factors and also the evaluation of just one factor. When the trial design is sorted according to A− and A+, then on both sides there is the same number of B− and B+. (Siebertz et al. 2010, S. 7-13)

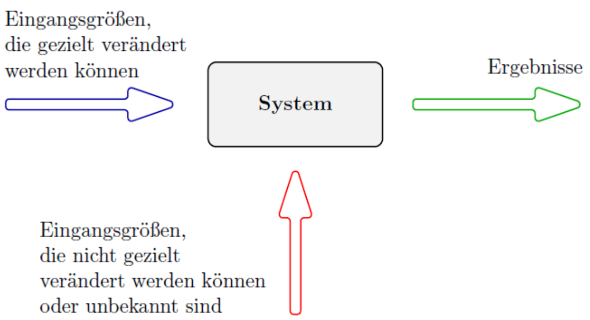


Figure 2.22 System and its boundaries (Siebertz et al. 2010, S. 17)

In Figure 2.22 the system is located in the middle. The left side shows the influencing factors which can be varied in a certain way. The bottom arrow indicates the factors which cannot be controlled or are not exactly known. The combination of this variable input leads to the result, seen on the right side.
The sequence of the experiments is essential, in so far as this is responsible for the results. Deviations could originate from a different charge, the machine or other reasons. Figure 2.23 shows the problems which could occur when different machines, operators or materials are used.

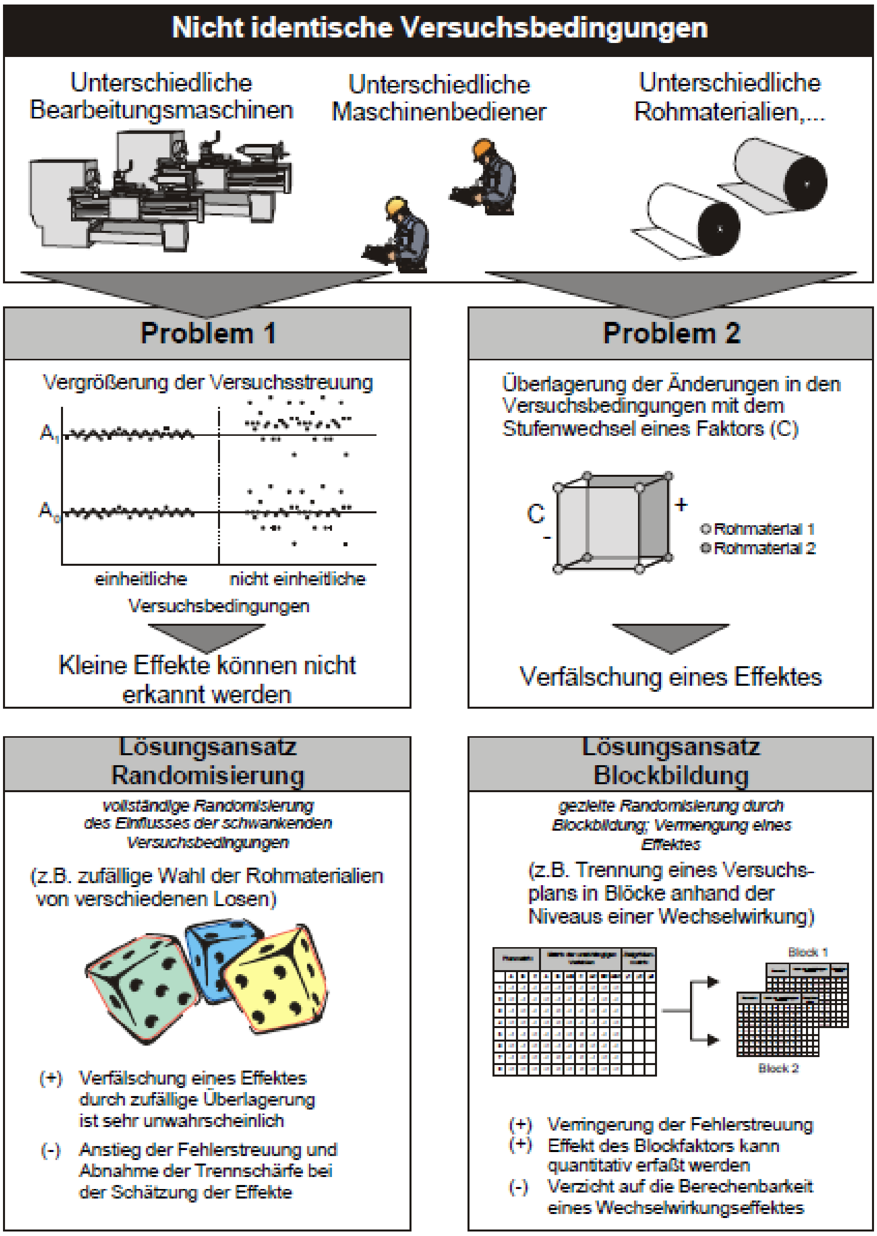


Figure 2.23: Not identical trial conditions (Gundlach 2004, S. 225)

ANOVA:

ANOVA is a powerful statistical technique if the comparison of more than two populations is required. When the dispersion is presented in a data set, ANOVA enables to identify the source of the variation and evaluate the contribution of each factor. In this master thesis the one-way ANOVA is used since it is the relevant one for the screening process.

The ANOVA uses the F-statistic distribution usually with a confidence interval of 95% which proves the significance of the factors. (Camarinha-Matos et al. 2012, S. 1-8)

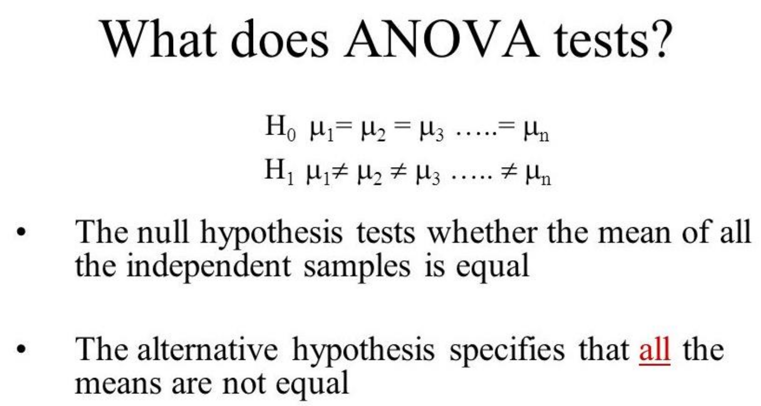


Figure 2.24: ANOVA test (ANOVA hypothesis 2016)

When the level of significance is close to zero, a main effect is detected. This means that the result is statistically significant. If the level is above 0,05 the H_0 will be rejected and the H_1 hypothesis is selected.

Statistic program

The statistical package developed at the Pennsylvania State University called Minitab is used for this master thesis. It was set up by researchers in 1972 and began as light version called OMNITAB. It provides a very effective way to input statistical data, manipulate that data, identify trends and then find answers to the problem. This software helps professionals to work with data and statistics. For instance, it provides the ability to calculate, generate boxplots, scatterplots and histograms. (Minitab 2016)

2.3.3 Fish bone diagram

The Ishikawa diagram is a quality management technique which was invented by Kaoru Ishikawa a Japanese pioneer in the 1960s. It is one of the seven basic tools for quality control and also known as fishbone diagram or cause and effect diagram. The head of the diagram presents the main problem and the potential causes of the problem are indicated in the fish bones. Usually, having brainstorming sessions or doing research leads to detecting the causes. There is no limit for fishbone numbers. If it is required, every fishbone can be subdivided into smaller bones. (Wong 2011, S. 1-3)

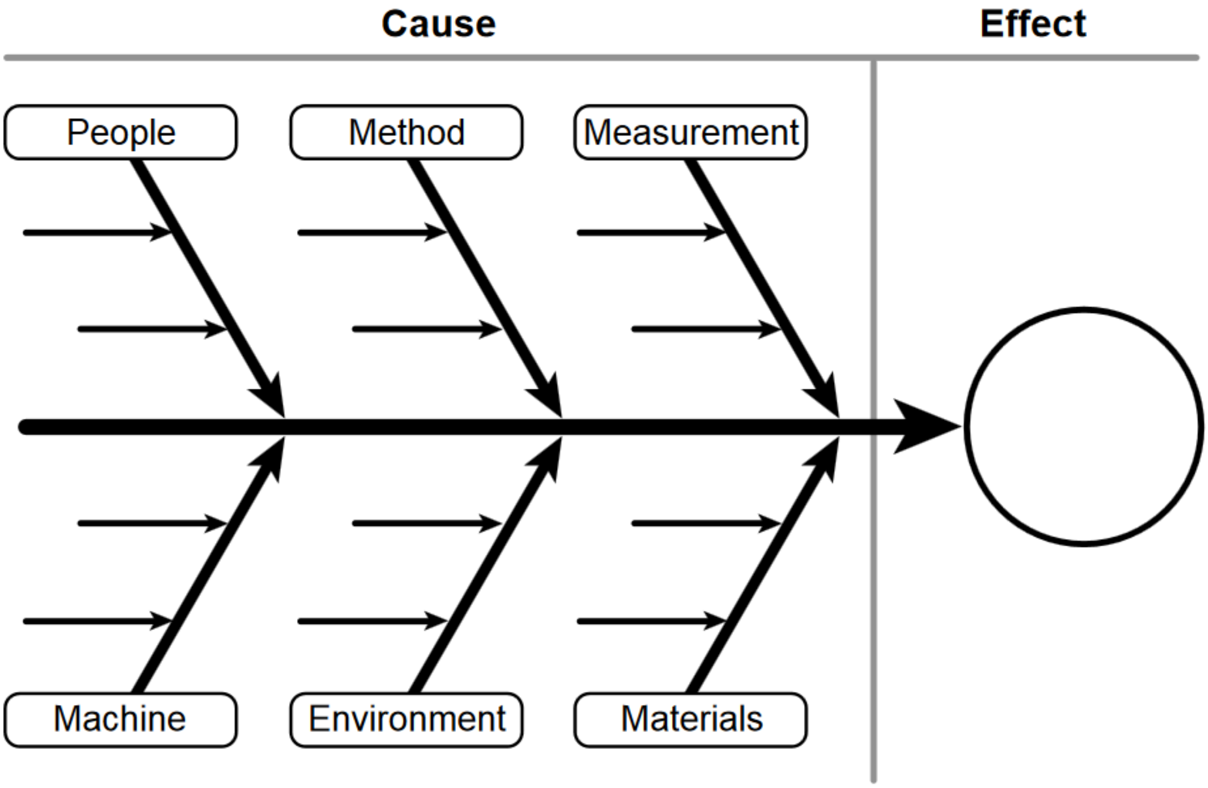


Figure 2.25: Fishbone diagram (Fishbone diagram 2013)

Figure 2.25 shows how such an Ishikawa diagram could look like. The right side suggests the location of the problem. The left side gives the causes listed under main categories. Such visualization greatly facilitates the determination of causes and effects.

3 Truck bushing

3.1 Bushing production

Producing the bushing is not just done within the bushing line. To fulfill quality requirements, additional process steps are required. Reducing production costs could be realized by minimizing additional process steps. Therefore, it is required to know the achievable tolerances of every process.

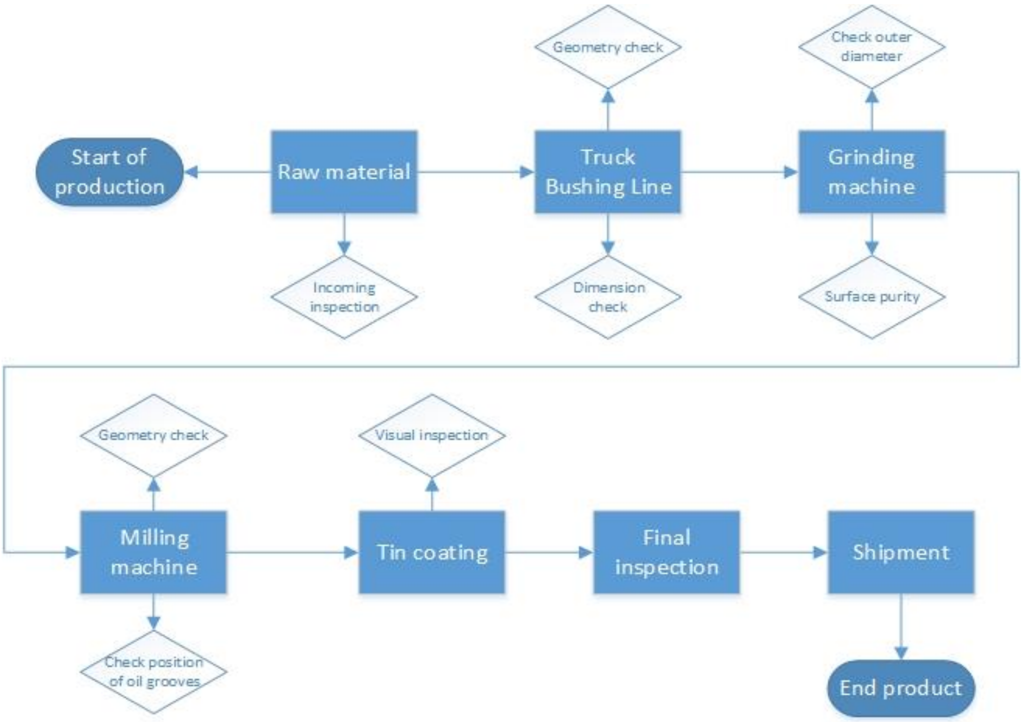


Figure 3.1: Process flow of the truck bushing (Michael Riesenhuber 2016)

Raw Material

Raw material provides the first section of the bushing production. Though it is purchased by an external vendor, the quality is checked continuously by the incoming good inspection. The material consists of bronze, an adhesive layer and a steel carrier layer. Thermo-mechanical treatment steps are taken to achieve the required material thickness and properties. It is bonded to a coil and sliced into four rings afterwards. For shipment, four rings of the raw material are fixed on a pallet.

Figure 3.2: Raw material delivering and material composition (Michael Riesenhuber 2016)

Truck Bushing Line

The truck bushing line with all the relevant information is explained in detail in Chapter 3.2.

Grinding

The bushing coming from the truck bushing line has an outer diameter of about 57,4mm, but the required diameter is 57,10mm-57,14mm. Tolerance field and surface quality is not achievable at the bushing line. Therefore, an additional grinding process is necessary to fulfill the customer's needs. Feed grinding is the technology used here because of efficiency and quality.

Figure 3.3: Bushing after grinding (Michael Riesenhuber 2016)

Milling

The outer contour cannot be finished at the bushing line, because with the finished outer contour seen in Figure 3.4 the area loading during the grinding process is much bigger in the small area (where the clinch is located) than in the big area. This results in a thickness difference in the diverse bushing areas. Therefore, the additional milling process is required after the grinding step to finish the outer contour. The bushing is oriented with the position dent and loaded into the machine feed by hand. Loading for the milling process is done automatically by the machine. First, one side is milled and deburred. Then, the bushing is handed over to the second work spindle where the other side is done. The bushing is ejected mechanically, so the process can run a certain time without the operator having to pay attention constantly.

Figure 3.4: Bushing after milling (Michael Riesenhuber 2016)

Tin coating
When the bearing is stored for a certain time, the steel layer might begin to rust. To protect the surface, the bushing is, therefore, coated with a tin layer. The layer just serves to avoid corrosion and as an optical enhancement. Thickness of the coating is about 2µm on the whole surface. Degreasing, coating, washing and drying are the necessary process steps for the required quality of the bushing. Figure 3.5 shows a coated bushing in different views.

Figure 3.5: Bushing with tin coat (Michael Riesenhuber 2016)

3.2 Truck_Bushing_Line

The truck bushing line consists of different processes which are described in this chapter. Movement control is done with a master shaft which shows the initial position of the presses. This means the master shaft is rotating from 0° to 360° and all the related axes are controlled with its angle. Drive motion of the presses and all the other moving components are done hydraulically, but steered with the master shaft. Figure 3.6 shows the processes of the bushing line and where they are located in the workflow.

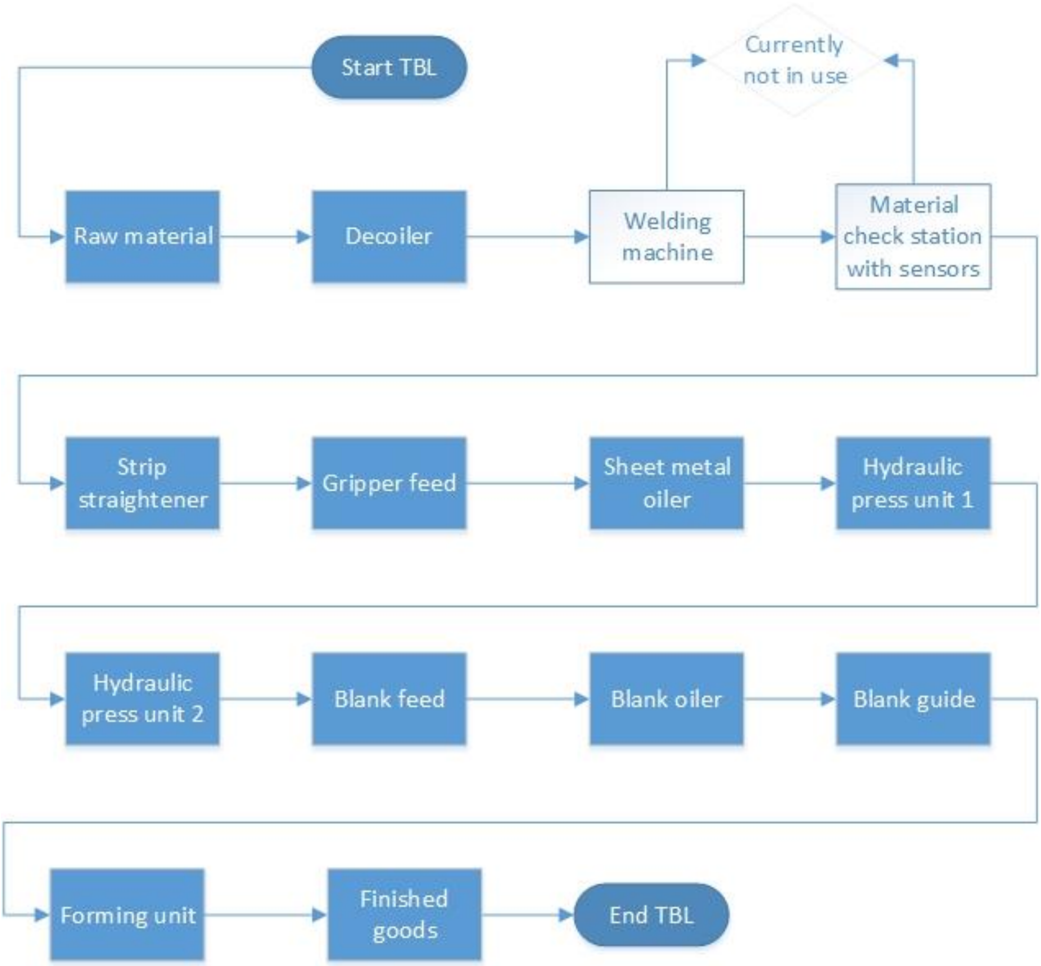


Figure 3.6: Workflow of truck bushing line (Michael Riesenhuber 2016)

First point of the bushing line is the raw material which is very important for a high quality product. The material is delivered and fixed onto a pallet as a coil sliced into four rings.
Because there is no automation, manual loading of the decoiler is necessary.
If an endless material may be required in the future, the welding or grouting machine makes it possible to join two rings without having to load the presses anew.
The material check station with sensors was planned in order to check material failures (which are marked from the vendor) and also when the welding seam is coming. Faulty blanks or bushings should be ejected automatically before leaving the

bushing line. The recent focus is on the bushing quality. Therefore, the welding machine and the sensors are currently not in use. (Pos. 1)
Strip straightening is essential for bending the raw material, because it is delivered as a coil. (Pos. 2)
Movement of the strip through the bushing line is controlled by the gripper feed; its accuracy is very important for the geometry details of the bushing. (Pos. 3)
Oiling the strip is done before the presses. It reduces the sliding force and improves the behavior for the coining and cutting processes. (Pos. 4)
The hydraulic unit 1 holds the precutting and coining process for the oil grooves. (Pos. 5)
Hydraulic unit 2 is responsible for coining the hole, for the fine cutting of the outer surface, the plate length and for the clinch geometry. (Pos. 6)
Feeding the forming unit is done with the blank feeder and the attached oiling station for the forming oil. (Pos. 7)
The forming unit is the last process step in the bushing line before the finally formed product leaves it. It is the form giving process and, therefore, very important for the quality and the additional process steps of the bushing. (Pos. 8)

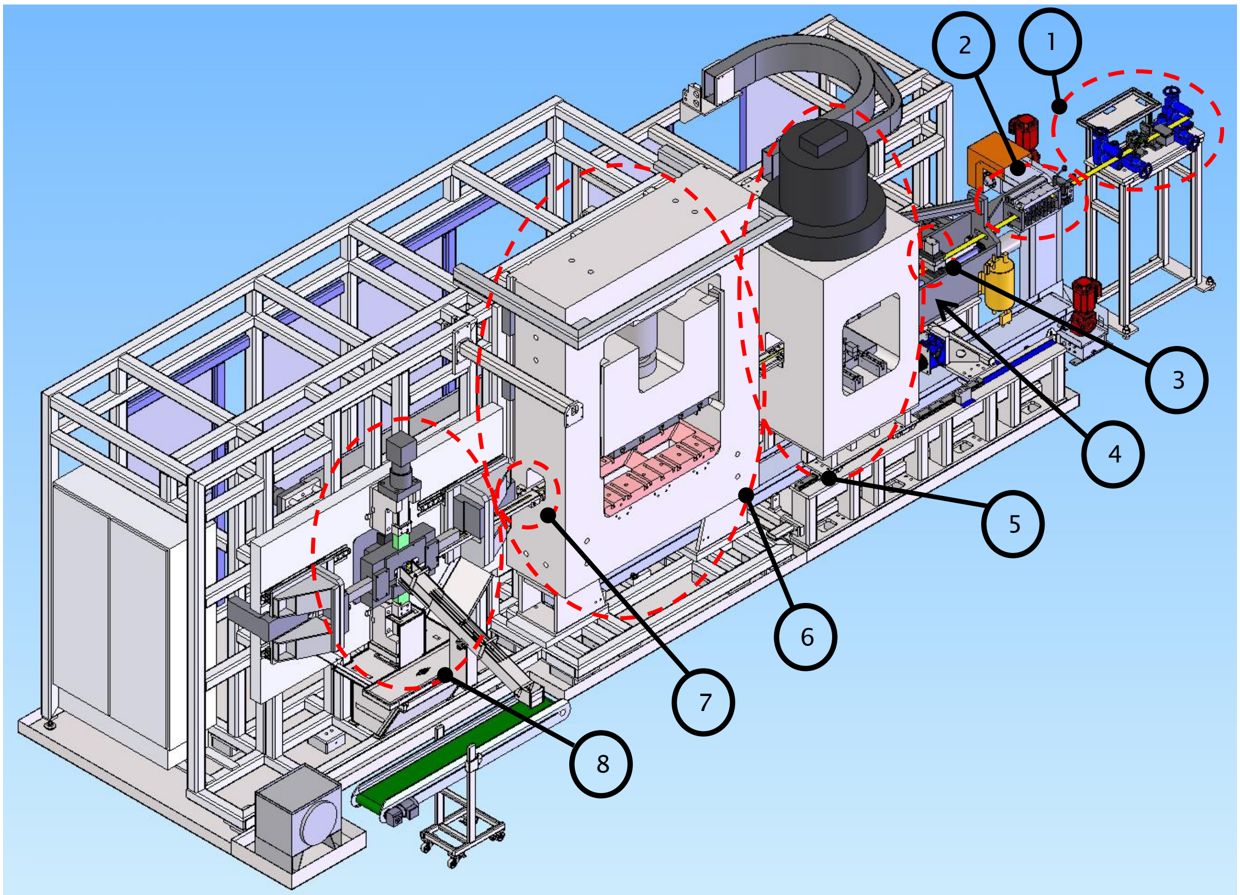


Figure 3.7: Entire truck bushing line (Michael Riesenhuber 2016)

Decoiler

One ring is loaded onto the decoiler and than the decoiler is responsible for providing material for the production. It is equipped with a sensor which checks the slack of the metal strip and initializes the rotation and transport of the ring if required. On the right side of the figure there is the control panel where adjustments can be done.

Figure 3.8: Decoiler (Michael Riesenhuber 2016)

Welding machine

The welding machine is currently not being used because there was too little investigation done in the pretreatment of the material. For an experiment two strips were released from the bronze and the adhesive layer and also the contact phases were pretreated. These strips were welded with the resistance welding machine as seen in the figure below. First experiments revealed that it is possible to weld two rings with a certain amount of preparation.

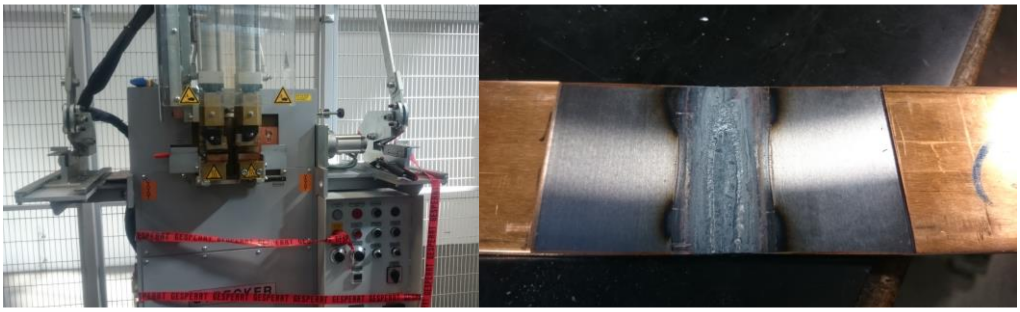


Figure 3.9: Welding machine (Michael Riesenhuber 2016)

Check station

The check station is also currently not in use, since neither is the resistance welding machine and the vendor does not have any quality problems, so there are no marked areas on the strip. The station is equipped with an eddy current sensor for detecting the welding seam and with a luminescence sensor to identify a material quality problem marked by the supplier. Guides at the beginning and at the end of the check station ensure the materials position. The sensors send a signal to the control unit which could eject the faulty bushing through a slide before it comes to the good parts.

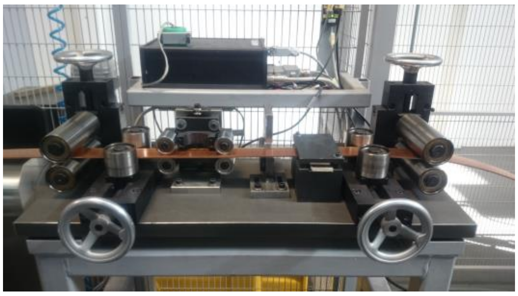


Figure 3.10: Check station (Michael Riesenhuber 2016)

Strip straightener

Raw material is delivered as a coil and thereby it is bent. To avoid a bending of the plate, the strip straightener should straighten the material before it enters the hydraulic presses. Straightening is done with seven rollers; four on the bottom and three on the top, which smooths the material. It should not be fixed too tightly, because than the strip cannot slide back into the pilot release phase of the grip feed.

Figure 3.11: Strip straightener (Michael Riesenhuber 2016)

Gripper feed

Responsible for the movement of the metal strip is the gripper feed. Its linear motion has the same distance and motion as the strip. One gripper is fixed; the other one is driven by a spindle and makes the movement. Accuracy of the gripper feed is guaranteed by a stop on each side. To adjust the stops the movement curves need to be changed. These two stoppers can assure the required accuracy of the moving gripper. When the moving gripper is released, the other one secures the strip and keeps it from sliding back.

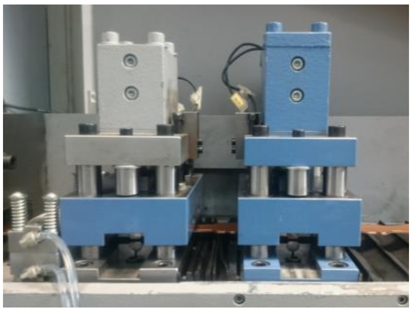


Figure 3.12: Gripper feed (Michael Riesenhuber 2016)

Oiler of sheet metal and plate

The sheet metal oiler covers the metal strip with an oil layer, which improves the formability of the material in the presses.

Figure 3.13: Sheet metal oiler (Michael Riesenhuber 2016)

Hydraulic press unit 1 and die

This hydraulic press is doing the precutting of the outer contour and the coining of the oil grooves. It is a hydraulic press and the motion is done by a hydraulic cylinder. The position of the press can be adjusted by the operator using the control unit.

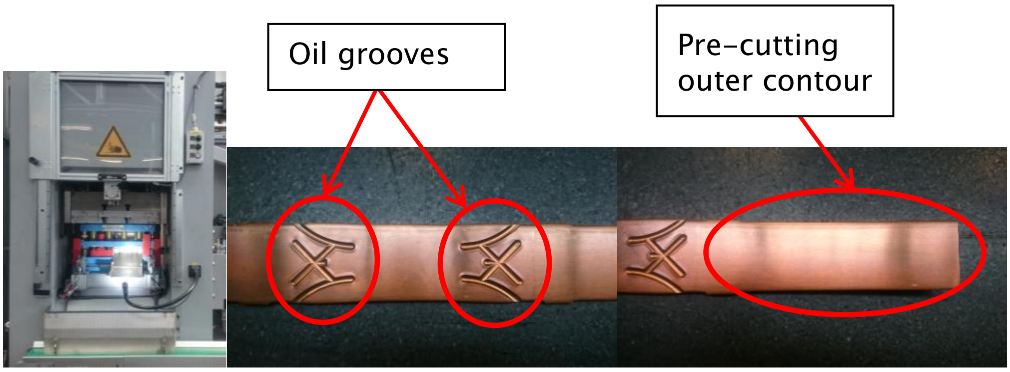


Figure 3.14: Hydraulic press unit 1 with die (Michael Riesenhuber 2016)

Hydraulic press unit 2 and die

In the hydraulic press unit 2 the hole cutting, cutting the position dent, cutting the fine outer contour, labeling and chamfering the blank takes place. The last step in the blank production process is cutting the clinch geometry. For the length of the blank the thickness of the clinch cutter is essential. The cutting quality is a criterion for the function of the clinch.

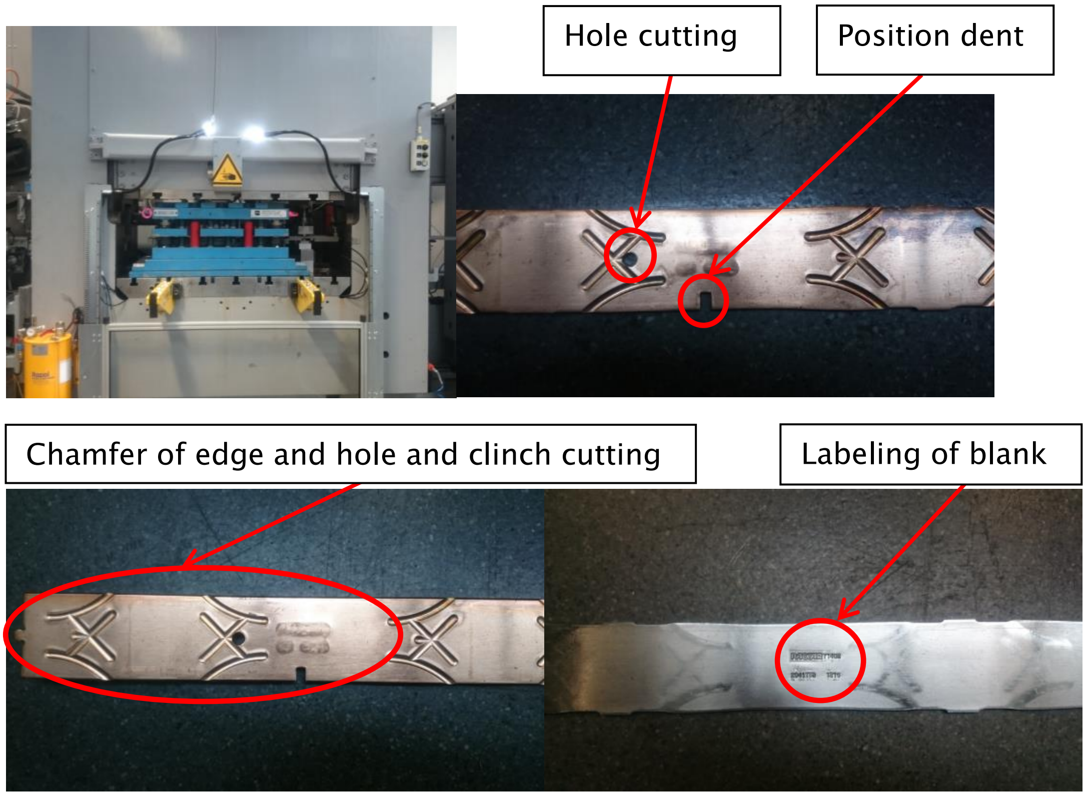


Figure 3.15: Hydraulic press unit 2 with die (Michael Riesenhuber 2016)

Blank feed

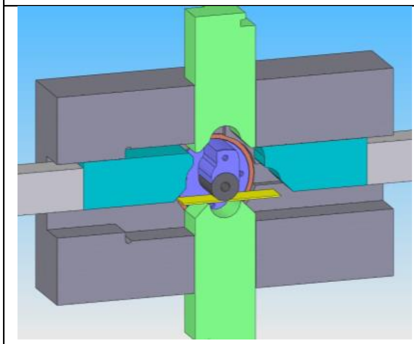
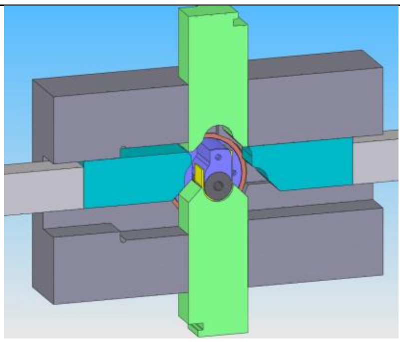
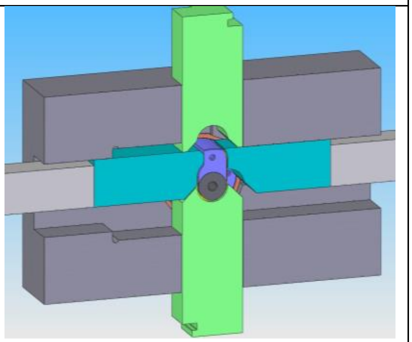
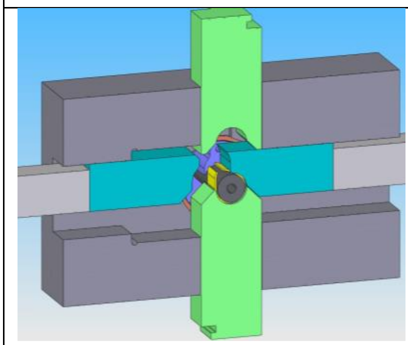
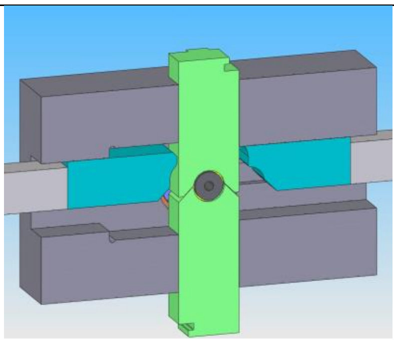
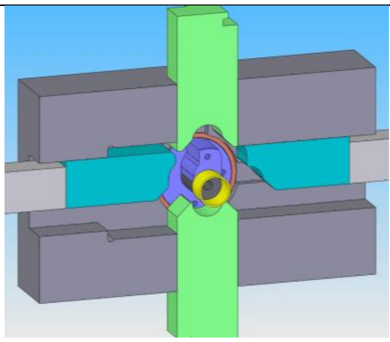
The finished blank is transported with rollers into the forming unit. During the transport it is oiled with a special forming oil to improve the behavior for the forming process.

Figure 3.16: Finished blank (Michael Riesenhuber 2016)

Forming unit

The last and surely the most important step for the quality of the finished product is the forming unit. In the forming unit, the blank is formed in four steps. The single steps are explained in Table 3.1. It is a four slider system, where the sliders left and right are only preforming. The final form is given by the sliders from the top, from the bottom and also from the mandrel. Ejection of the finished formed bushing is done with the preforming mandrel.

Table 3.1: Bushing forming process (Michael Riesenhuber 2016)

Initial position with blank inside	First bending with bottom slider	Preforming with slider left and right
		
Removal of preforming mandrel, further preforming slider right	Final bending and clinching with top slider	Ejection with preforming mandrel
		

Process steps according to master shaft

A short description was made to enable a better understanding of the processes and to comprehend when exactly every press is moving. The angles are indicated from the master shaft which is already explaind in chapter 3.2:

H1 beweg: Is the moving gripper feed, it releases at 20° and fixes at 185°

H2 fest: Is the gripper which does not move, it releases at 50° and fixes at 355°

A_3 P-Prägen: Is the hydraulic press unit 1

A_4 Presse: Is the hydraulic press unit 2

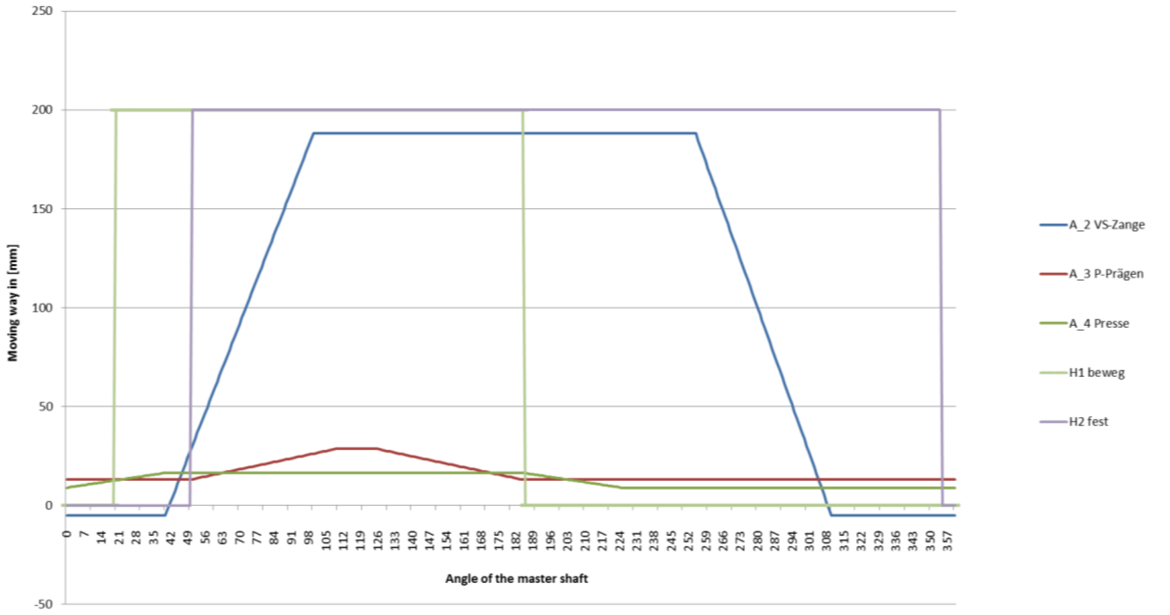


Figure 3.17: Motion of presses (Michael Riesenhuber 2016)

Figure 3.17 shows the movement of each single press. Between 50° and 185° both grippers are open for the reason that the material can not slide back but sliding back is necessary. During the coining process, the material stretches and needs more space between the two presses. During this time the strip is fixed in the press unit 2 so he can not lose his ideal position. Adjusting and finding the right values and moving ranges for each presses was difficult, because all influences have to be considered. At the beginning of the adjustment work, the two grippers were not opened and so the plate length varied to a great extent.

Production limit for truck-bushing-line

Material thickness: 0,5mm-4,0mm

Outer diameter: 20mm-80mm

Width of bushing: 20mm-80mm

3.3 Bearing

Application

The bushing from the truck bushing line is applied as a piston-pin bearing. It is used for reducing friction and increasing efficiency of a truck engine. The inner diameter is finished at the customer’s site, because the bushing is first pressed into the con-rod and then drilled into the final position.

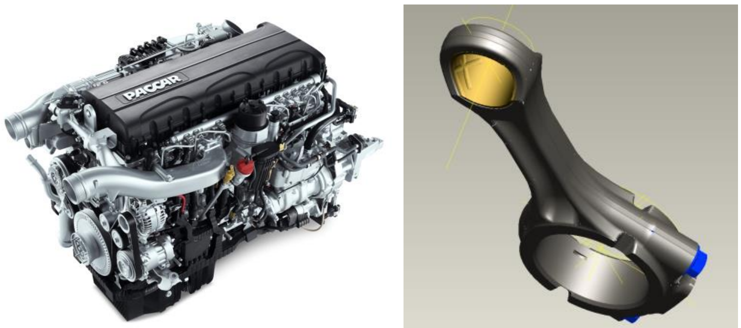


Figure 3.18: Application of piston-pin bearing (Miba Gleitlager GmbH 2012)

Geometry of the bushing

Normally the blank for the finished bushing should have an outer contour such as seen in Figure 3.19, but when the contour is finished in the bushing-line there occurs the problem of different grinding pressures, which leads to a different wall thickness of the final product. This is the reason why the bushing is produced cylindrical and the outer contour is milled afterwards. For the application as piston-pin bearing, the geometry with the outer contour is required.

Figure 3.19: Cylindrical and contoured blank (Michael Riesenhuber 2016)

Outer diameter after bushing line:	about 57,3mm
Outer diameter after grinding:	about 57, 1mm with specific force applied
Roundness after bushing line:	about 0,14mm
Roundness after grinding:	about 0,06mm
Bushing width: after bushing line:	about 47,8mm
Bushing width after milling:	about 20mm small side and 44mm big side

4 Objectives of the Master Thesis

The aim of this master thesis is to determine the location of the levers for the quality criteria of roundness and diameter for the truck bushing line. These levers are important for improving of the roundness, which leads to a shorter grinding time and, therefore, to cost reduction. The content of this master thesis is divided into two parts. The first part is concerned with splitting up the process into different sub processes and listing all influential criteria according to these sub processes. The second part deals with the localization of the information gaps and the development of tools and ways to close these detected gaps. Improving the process could reduce the developing time and costs for new projects.

Initial situation

The truck bushing line is currently operating in serial production. Controlling the process, its deviation and the quality of diameter and roundness is difficult, because the process and all the related influential factors are not well known. In fact, improvements are brought about by conducting trials and looking for errors. This means that when someone comes up with a new idea which could potentially improve the process, the required parts are ordered and installed. Then a small number of examples are produced and measured and if the results show any enhancement, the modification will be implemented. If the modification does not yield the expected results, the idea will be rejected and a new one will be created. Unfortunately, this can lead to the loss of good innovations since the rejected ideas might actually achieve improvements in other constellations.

The truck bushing line enables to produce bushings with a roundness of about 0,12mm-0,16mm. The reason for the limited roundness lies in the following grinding process: If the figure for the roundness of the bushing is too big, the surface of the bushing will not be totally even everywhere after the grinding step. This problem could be avoided with a bigger diameter of the bushing, but this leads to a problem with the remaining material thickness after the grinding process. This is mainly the problem for the contoured bushings, because their material width is different in some areas, which results in a different grinding pressure. A smaller diameter and roundness means that the grinding stock is smaller and, therefore, the difference of the material thickness of one bushing after grinding is also smaller. This shows why it is necessary to improve the roundness.

Task formulation

This master thesis aims at getting a better understanding of the process and all the related influences. Preparation and evaluation of initial trial data should show the quality criteria and all the connected influencing factors. The overall goal should be the improvement of the roundness of the bushing. A further point of investigation is whether or not the process and its documentations are done in a structured way. This thesis should show the necessity to create a design of experiments or for other statistical evaluation methods in every area in the future.

Systematic approach

Concerning the systematic approach it is important to do it step by step. The first task is to analyze existing trial data. A considerable amount of important information can be extracted from that. It is necessary to collect these data, provide missing information, structure and list it and put it in a form so that it can be evaluated. Furthermore, it is also important to identify and exclude the data which are irrelevant or could lead to a mistake in the evaluation.

Grouping the factors, the quality criteria and the sub processes is the first step to enable a statistical evaluation. The objective of the statistical data analysis is to detect the main influencing parameters for a specific quality criterion. The results from the statistical evaluation have to be checked for their feasibility. It is necessary to understand the relations between the factors and the quality criteria to define the right influences. One has to consider here, though, that there is not always just one factor responsible for one quality criteria.

Evaluating and collecting the old trial data gives insight into the location of any information gaps. This knowledge should be used for future projects in order to fill these gaps and facilitate further evaluations. The aim is to document as much as necessary in order to be able to examine a certain experiment in the past and to do the same a second time. Therefore, it is required to keep records of the entire machine related data. One should save as much data as necessary, but as little as possible in order to avoid data garbage.

Another very important part of this master thesis is defining improvements for further projects and structuring them in a way so they can easily be applied for future projects. It should also support operators of adjustment tasks in order to achieve expected goals faster.

5 Process analysis and results

This chapter combines the process analysis and the obtained results. Determining and validating the information gaps provides the main part of this thesis. The aim is to support further projects and guarantee shorter adjusting time and, therefore, a higher productivity of the truck bushing line. For the process analysis it is necessary to collect and complete old trial data. The obtained results should support the operator during adjusting work and should help him to shorten the development and run-up time of a new product.

5.1 Structure of the master thesis

Figure 5.1 shows the main steps of the master thesis and how these stages interact. It shows the single steps which were taken in order to achieve the final result.

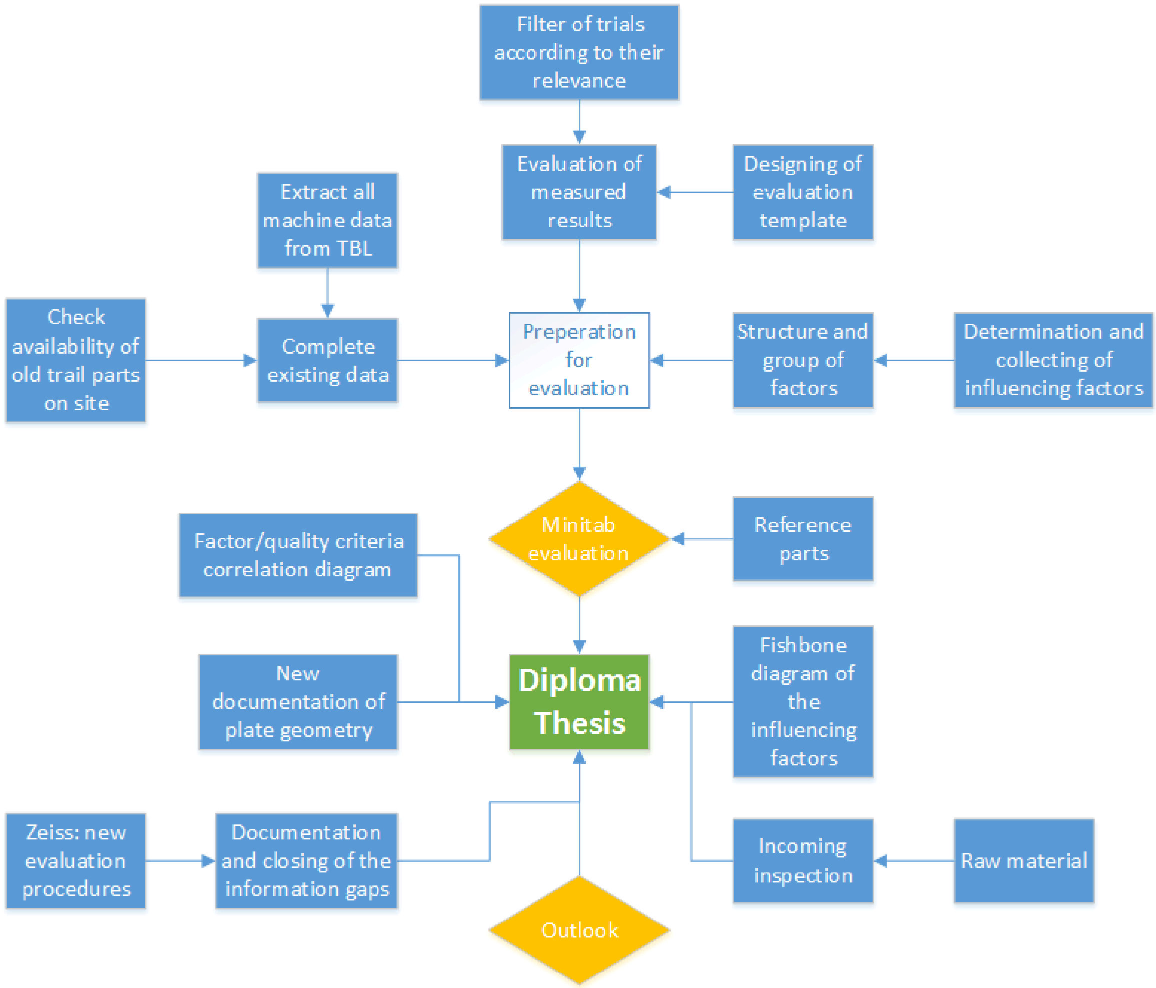


Figure 5.1: Structure of the master thesis (Michael Riesenhuber 2016)

5.2 Sub processes

It is necessary to divide the whole process into its main components to analyze the individual processes separately. Therefore, it is important to make sure what the main sub processes for the bushing line essentially are. For the most part it is not possible to break up every influencing factor into only one sub process, but it gives the operator a rough overview how the process works and which factors are relevant for which process.

Material

The raw material is a three component material which consists of the base metal, an adhesive layer and the bearing metal on the top. In this case the bearing material is CuSn5Zn1, the bonding foil is a Cu-PHC and the base metal is a C10 steel.
The reason why three different materials are used lies in the material specific properties. A combination of different materials leads to a better performance for the different applications. In detail this means that the steel layer is a carrier layer with the required stiffness for the press in operation. On the inside of the bushing there is the bearing layer with the required dry-running and lubricant properties.
An important component for the finished product to be of high quality is the incoming goods inspection. The inspection and documentation of the raw material is the first step towards a high quality product. Incoming inspection is responsible for the quality check of the delivered material, which includes its thickness, hardness and chemical composition of the different layers. If there is any variation of quality the material will not be delivered to the bushing line.

Table 5.1: Checked criteria and its tolerances from incoming goods inspection (Miba Gleitlager GmbH 2012)

Criteria	OT	UT	unit
Wall thickness	2,900	2,800	mm
Steel thickness	2,200	2,100	mm
Foil thickness	0,100	0,000	mm
Bronze thickness	0,700	0,500	mm
Width of strip	50,300	49,700	mm
Hardness steel		158	HB
Hardness bronze	110	80	HV
Surface roughness	5,000	0,000	RZ

Periphery

Definition: The outer limits or edge of an area or object.

Periphery describes processes which are not in the defined area. This sub-process includes for example maintenance, operator, bushing output, strip straightener, blank guide, coil loader, decoiler, blank oiler before forming, blank feeder, material test station with sensors, roller feed, sheet metal oiler before press and the coil welding or grouting machine.

The mentioned processes are not directly related to the quality of the end product, but all of them could influence the results indirectly. It is necessary to list every single process to become aware of all the influencing factors.

Gripper feed

The gripper feed is responsible for the plate length and the whole transportation of the material through the presses. Precisely adjusting the gripper is necessary to produce an accurate blank. A gripper which is too tight could damage the material surface but one that is too loose could allow the strip to slip during feed motion. Adjustments are possible concerning the clamping force, the material of the clamper and the feed distance.

Hydraulic press unit 1

The press unit 1 is the first one of the two presses in the truck bushing line. This press is responsible for the pre-cutting of the outer contour and the forming of the oil grooves. Pre-cutting is necessary because the material thickness in a defined area is used for guiding the strip. Without this step the material is widened in a specific area during coining and then the strip could not slip through the dies.

Oil groove coining is done with one punch but two oil grooves, each groove on another plate.

Hydraulic press unit 2

In the cutting press the final cutting, cutting of the hole, coining of the chamfers and trimming with the clinch geometry is done. Accuracy of the gripper feed is required to achieve constant quality because the distances in the die are defined.

Plate

The plate is the slug for the forming process. A constant plate is very important for the tolerance of the bushing, otherwise the dimensions of the finished product will vary. Included is the plate length, the thickness, the hole, the oil groove and its geometry details.

Forming process
It is the last step in the truck bushing line and the form giving process for the bushing. The roundness, the surface quality and the quality of the closed clinch is defined by the forming unit.

Environmental influences
This sub-process describes all the influences generated by the environment, such as air pressure, air moisture, temperature and other factors which are hard to affect. All the environmental influences are just mentioned because most of them can hardly be adjusted in a certain way.

5.3 Influencing factors

Influencing factors are factors which can either have a small or big impact on the quality of the finished bushing. First, it is required to determine all factors and list them according to the sub-processes. The list of factors should serve as a tool for the operator which he can use for the adjustment work. Determination of the main factors is rather simple, but a defined testing procedure is also needed. Factors that have a small impact on the product unavoidably need a DoE, because otherwise the real factor might not be figured out.

5.3.1 Determination of the factors

Determination of the factors is a highly important part of this master thesis, because if a factor is missing it could lead to a false conclusion. Therefore, a strong focus is laid on the truck bushing line and all the related tasks. It is impossible to identify every single factor but it is very helpful when the main factors are documented.

Observation of the process
To get an idea of the process and its operations, it is necessary to work manually on the bushing line. It took some weeks to get all the information about how the machine is working. Some failures showed the weaknesses of the bushing line and some factors appeared accidently. Documentation of the detected factors is the first step to obtain a full picture of all the influencing factors.

Evaluation of existing data (old trials)
In the past a couple of experiments were done to define the best settings for the bushings quality. This trial process was an uncoordinated variation of obvious

influencing factors and, therefore, an information pool for finding the main factors. All the old experiments were scanned and the factors which are not yet considered for observation of the bushing line were noted.

Brainstorming session

To make sure most of the factors are ascertained, a brainstorming session was held. All the members of the session were familiar with the bushing line and the finished product. This ensured the quality of the brainstorming and avoided possible misunderstandings among the participants. The fact that employees from various departments provided different perspectives on the issue resulted in the benefit of having a large collection of knowledge.

All factors were collected, sorted out, adapted and listed to the related sub-process.

5.3.2 Influencing factors

Table 5.2 Influencing factors (Michael Riesenhuber 2016)

<table>
<tr>
<td>Plate
Geometry
Flatness of the blank
Position dent
Change of length and width
Hole size/position
Clinch shape
Burr from cutting
Surface quality
Oil groove size/geometry
Chamfer hole/edge
Date stamp
Damages</td>
<td>Raw material
Contamination level
Ratio steel/bearing material
Adhesive foil
Material quality
Quality of windings
Material properties
Material dimensions
Material surface
Bearing material
Base material
Uniform properties over the batch
Coefficient of friction
Anisotropy</td>
</tr>
<tr>
<td>Forming unit
Maintenance
Forming process
Forming oil
Stop position of plate
Slider geometry
Slider position
Slider travel distance
Slider force
Slider quantity
Tool material
Tool surface
Stiffness of all components
Mandrel dimension
Mandrel clearance
Gap mandrel/slide bottom and top
Forming speed</td>
<td>Hydraulic press unit 1 and die
Maintenance
Tip over upper die section
Waste material
Cutting gap
Formation of chips
Geometry of die components
Pressing speed
Pressing force
Press position
Stiffness of all components
Movement of press Wear of cutting device
Pneumatic clamping of die
Coining tool design
Change of length and width of workpiece
Sheet metal slide resistance
Exact die position in press
Bending of the metal strip</td>
</tr>
</table>

Gripper feed

- Maintenance
- Wear of moving parts
- Clamping force
- Travel speed
- Accuracy travel distance
- Contamination of sheet metal
- Material combination of the workpiece
- Condition of moving thread
- Material and condition of the clamping device

Periphery

- Maintenance
- Operator
- Bushing output
- Blank guide all presses
- Decoiler
- Coil loading in decoiler
- Blank oiler before cutting
- Blank oiler before forming
- Roller feed
- Coil welding or grouting machine
- Material test station with sensors
- Strip straightener

Hydraulic press unit 2 and die

- Maintenance
- Waste material
- Cutting gap
- Formation of chips
- Geometry of die components
- Pressing speed
- Pressing force
- Stiffness of all components
- Change of length and width of workpiece
- Sheet metal slide resistance
- Travel distance press unit 2
- Wear of cutting device
- Pneumatic clamping
- Cutting tool design
- Labelling punch
- Chamfer geometry
- Exact die position in press
- Bending of sheet metal

Other

- Maintenance whole system
- Experience of employee
- Plate seize at clinch
- Hydraulic oil
- Cutting oil
- Forming oil
- Machine rigidity and stiffness
- Tool design
- Level and orientation of the tools
- Pneumatic chip blowing out
- Air humidity
- Dirt and abrasion
- Oil film in the tools
- Temperature of all oils
- Machine temperature
- Position of the tools in the press
- Level and orientation of bushing line
- Magnetism
- Contamination whole system
- Quality of measuring equipment

All known influencing factors are collected and listed for an overview of all factors. This list is a first collection and has to be expanded if new relevant factors appear.

5.3.3 Fishbone diagram – Cause and effect

Determination of the factors is the first step afterwards the factors are sorted according to the sub-processes. For reason of simplicity the factors and the sub-processes are arranged as a fishbone diagram. This gives an overview of the cause and effects of the truck bushing line. For a detailed structure see Figure 5.40.

Figure 5.2: Fishbone diagram cause and effect (Michael Riesenhuber 2016)

5.4 Measuring

Measuring means using a reference standard or sample for the quantitative comparison of properties. Measurement accuracy depends on the measurement device and the experience of the operator. The measuring instruments measure different geometries and have different tolerances and, therefore, they are used for different applications depending on the required tolerances.

5.4.1 Measuring devices

Caliper

A caliper is used for length measurement of the oil groove, the diameter and position of the hole and the plate length and width. A standard caliper has an exactness of about ±0,1mm depending on the application and the operator.

Thickness gauge

A thickness gauge is used for the measurement of the material thickness or the thickness of a workpiece. Depending on the application an exactness of about ±0,02mm could be achieved. At the truck bushing line the gauge is used for measuring the raw material thickness and the rest thickness of the material after punching the oil groove.

3d measuring machine

The 3d measuring machines which are used at Miba are from the German company Carl Zeiss. At Miba the two machines that are used for the geometry check of the bushings are, firstly, the ZEISS PRISMO navigator with a deviation of 0,5 + L/500 µm in length direction depending on the measured length and, secondly, the ZEISS CONTURA with a variance in length of 1,5 + L/350 µm also depending on the measured detail.

5.4.2 Measurement sequence

Different measuring devices are used for different applications and also in different process steps. The length measurement of the plate, measuring the positions of the oil grooves and the measurement of the material thickness are done before the forming process takes place. The 3d geometry check is done after the forming process but before grinding, when the bushing is in the finished rolled form.

Caliper

The caliper is used for length measurement of the dimensions
a (start of the first oil groove),
b (position of the hole),
d (start of the second oil groove),
g (length of the blank),
j (distance position dent) and
B (width of blank)

The dimensions of c, e, f, L, h and l are not checked again because they are defined by geometrical aspects like geometry of the punch or clinch.

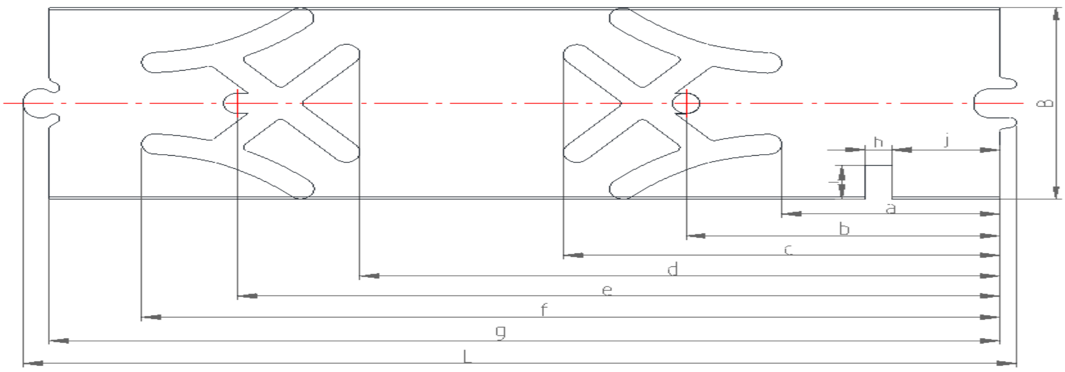


Figure 5.3: Plate dimensions measuring (Michael Riesenhuber 2016)

Figure 5.4: Length measurement procedure of plate (Michael Riesenhuber 2016)

This measurement process is very error-prone and the result depends on the experience of the operator.

Thickness gauge

Material thickness of the blank is measured with a thickness gauge as can be seen in Figure 5.5. Tolerance of such a standard thickness gauge is about ±0,03mm and the material thickness varies between 2,85mm and 2,88mm as the incoming goods inspection showed. Rest thickness of the wall in the area of the oil grooves is also measured with this device, for which the tolerance is 1,95mm-2,25mm after the grinding process.

Figure 5.5: Measuring procedure with a standard thickness gauge (Michael Riesenhuber 2016)

3d measuring machine (new situation)

For the 3d machine a correct positioning of the bushing is required because otherwise the feeler crashes into the material. Positioning is also important for the evaluation afterwards. Therefore, the bushing is placed with the clinch because this positioning is easy and brings good results. First, the bushing is measured at the outer surface to determine the center of the bushing. The next step is measuring the whole outer surface to determine about 1200 measured points. These points are arranged according to the center and the result is printed on a sheet with the selected tolerance, as explained in Chapter 5.4.4.

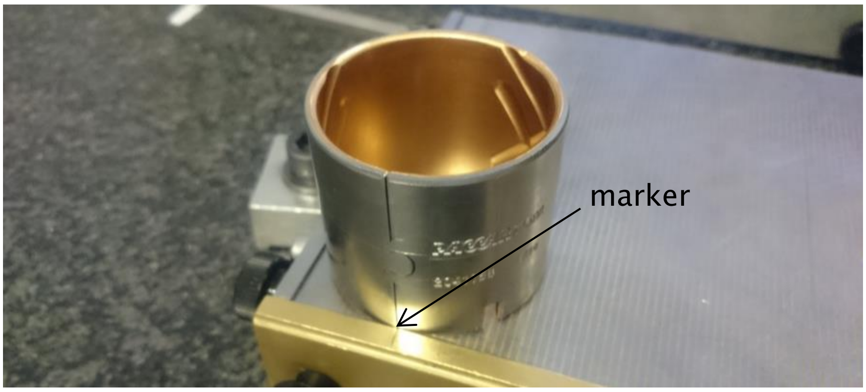


Figure 5.6: Positioning the bushing in 3d measuring machine (Michael Riesenhuber 2016)

5.4.3 Zeiss old situation and old forming unit

The bushing was measured with two centered tracks, one at the top and one at the bottom of the bearing (the exact position is described in detail in Figure 5.7). There is always a difference between these two because of the clearance of the mandrel during the forming process.
For the old situation the bushing was measured and the received data were arranged to the particular average diameter of the measurement track, as can be seen in Figure 5.8. The tolerance field was ±0,1mm and the enlargement factor was 100.

Explanation of bottom and top side

To describe the position of the measurement track the designation of “bottom” and “top” was created. The meanings of these terms are not obvious for outsiders. Thus, to avoid misunderstandings the positions of the measurement tracks are shortly illustrated.

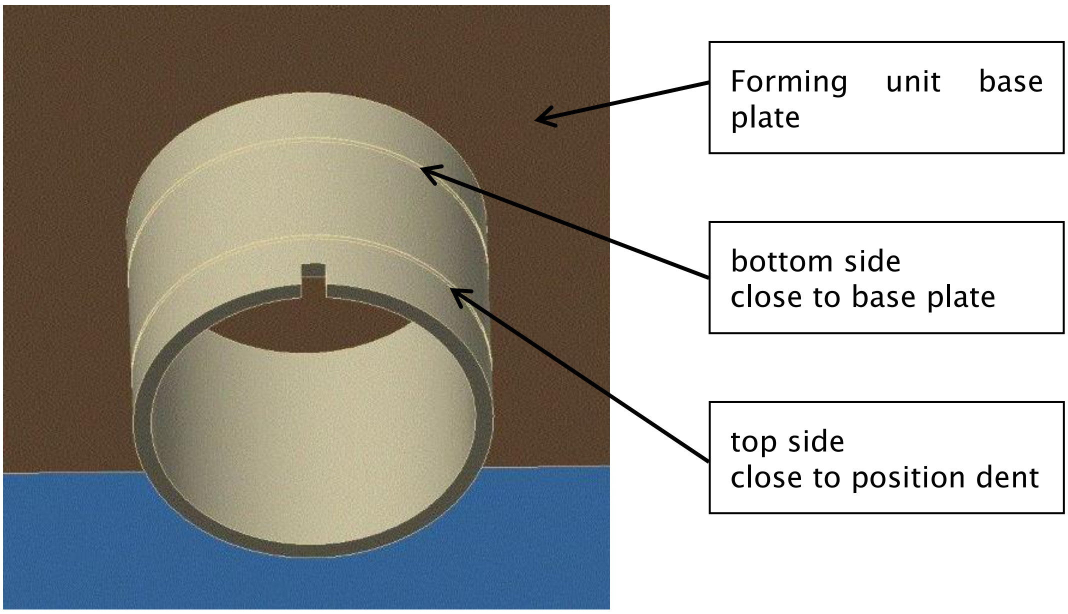


Figure 5.7: Explanation bottom and top side (Michael Riesenhuber 2016)

For the new roundness evaluation the designation is not “bottom” and “top side”, it is “opposite dent” (bottom side) and “at dent” (top side).

Roundness evaluation – "top"

Top evaluation was done by the position dent (bigger distance to the forming unit ground plate).

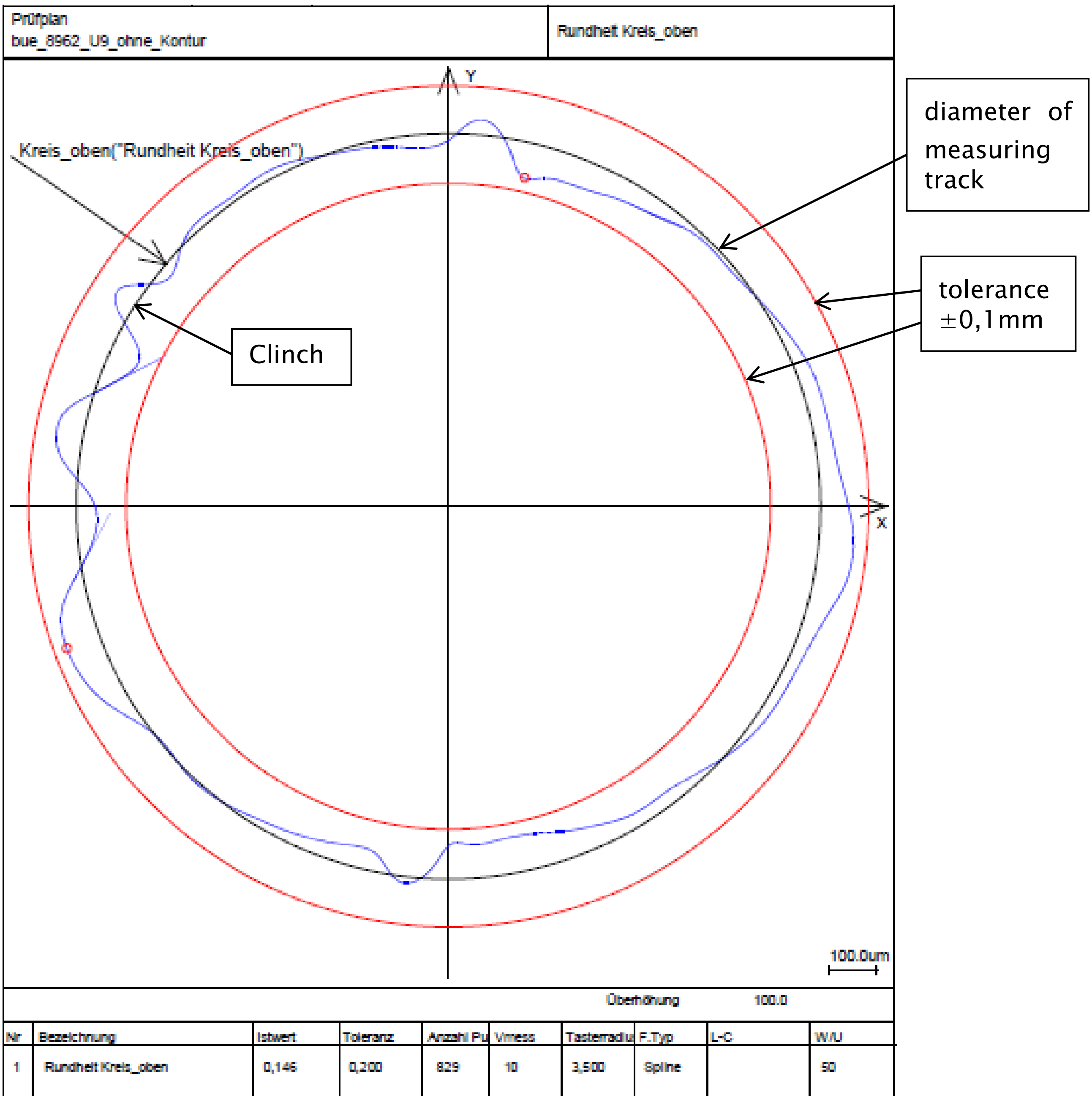


Figure 5.8: Measurement note old situation page 1 (roundness top) (Michael Riesenhuber 2016)

Roundness evaluation – "bottom"

Measurement track for the bottom evaluation was next to the ground plate of the forming unit. Evaluation and drawing of the graph was done similar to the roundness evaluation top.

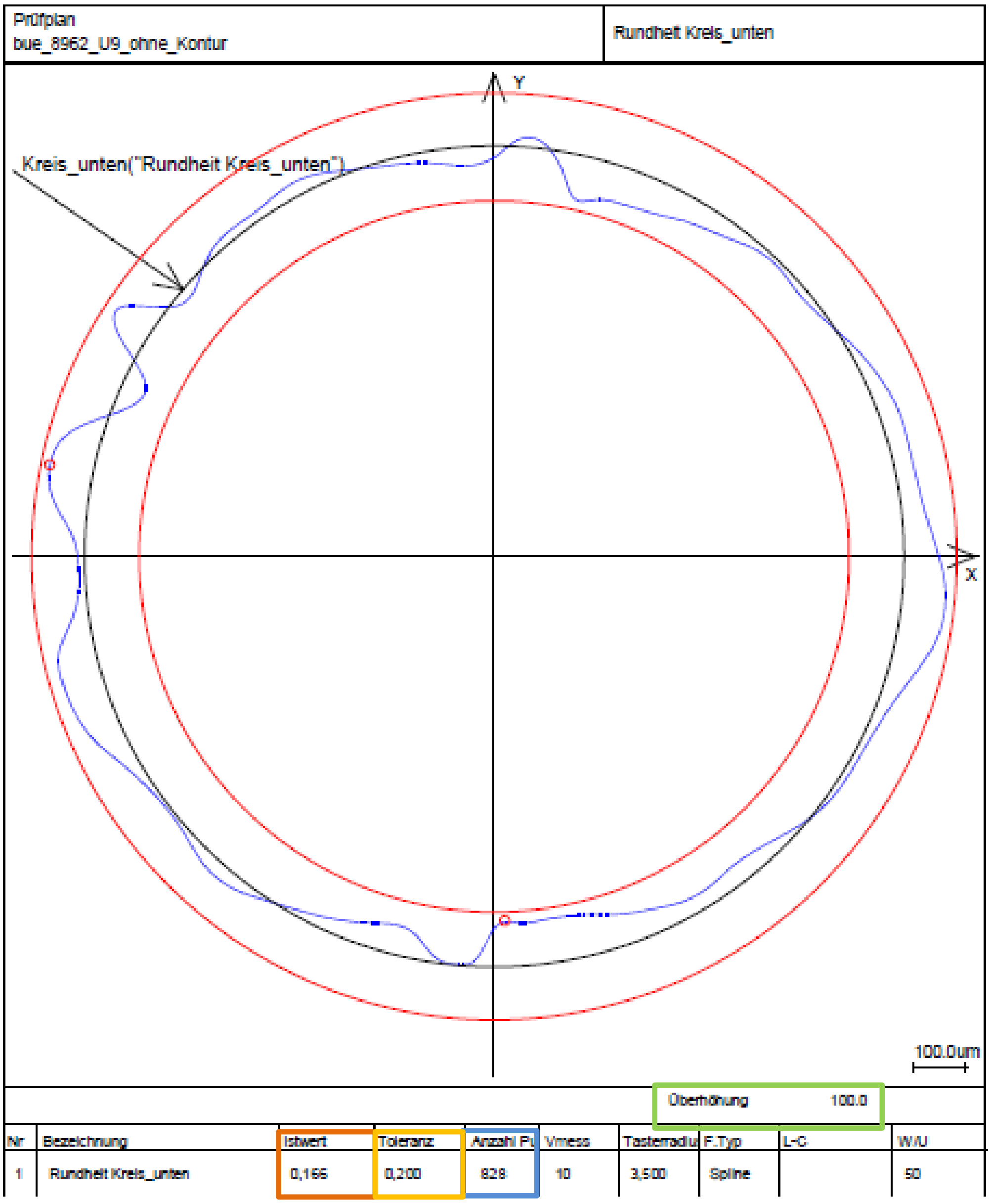


Figure 5.9: Measurement note old situation page 2 (roundness bottom) (Michael Riesenhuber 2016)

- Form deviation
- Tolerance
- Measured points
- Enlargement factor

Inspection report

After measuring the results were presented in the inspection report. It consisted of a comparison of the geometry data, its deviation and its tolerances. There is no tolerance for the diameter since the roundness determines how much oversize for the grinding process is needed.

	Istwert	Sollwert	Obere Tol.	Untere Tol.	Abweichung
Gesamtergebnis					
Prüfmerkmale gesamt:		4			
...In Toleranz:		2			
...außer Toleranz:		2			
...über Warngrenze:		0			
...nicht berechnet:		0			
Koord.systeme gesamt:		1			
...nicht berechnet:		0			
Textelemente gesamt:		0			
Durchmesser Kreis_oben					0.226
·	57.346	57.120	0.000	0.000	0.226
Durchmesser Kreis_unten					0.253
	57.373	57.120	0.000	0.000	0.253
Rundheit Kreis_oben					|---
	0.146	0.000	0.200		0.146
Rundheit Kreis_unten					|----
	0.166	0.000	0.200		0.166

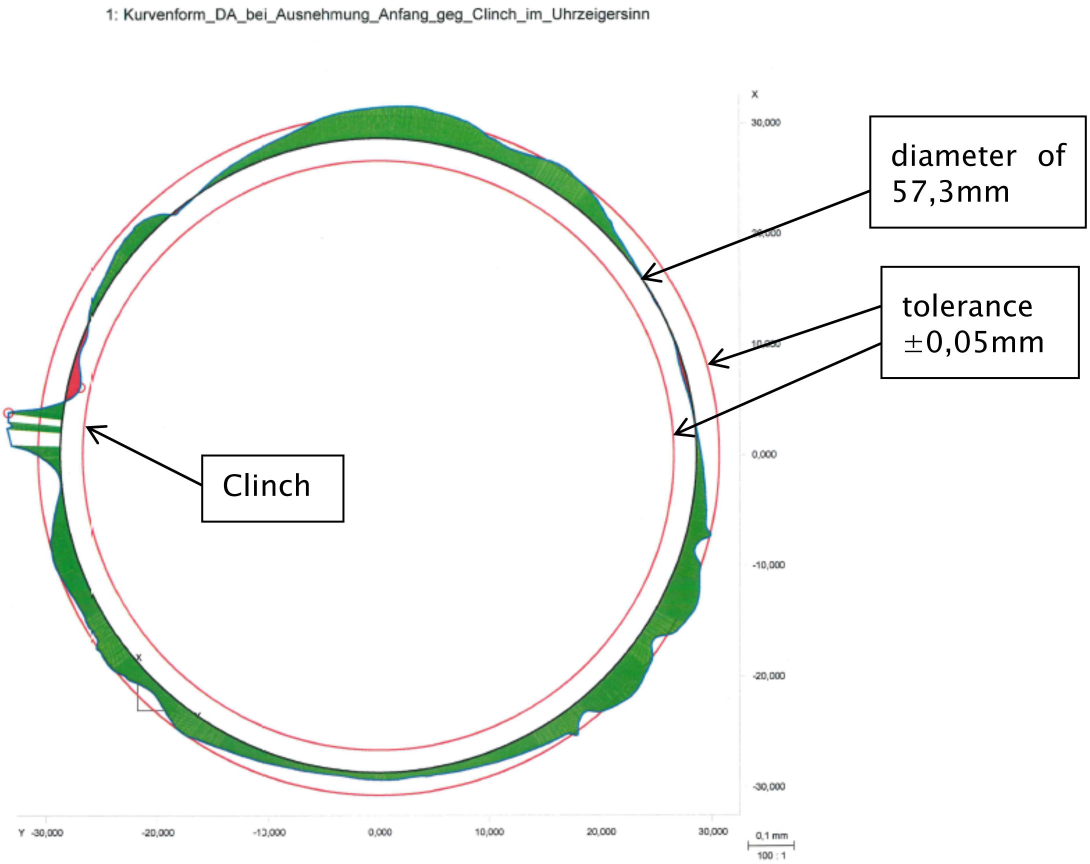
Figure 5.10: Measurement note old situation page 3 (inspection report) (Michael Riesenhuber 2016)

5.4.4 Zeiss new situation and new forming unit

To generate a uniform measurement evaluation the process needed to be changed. For the new process the bushing is measured and the center is detected. Afterwards, the roundness evaluation is carried out and the result is printed to the specific center. The base diameter is the previously defined figure of 57,3mm, which is expected to be the best one for the following machining. The tolerance field is reduced to ±0,05mm while keeping the same enlargement factor of 100. This diameter is the same for every measurement and bushing, which makes it much easier to compare different bushing evaluations. By detecting the center the roundness can be printed at its real position.

Roundness evaluation – "at dent"

Below is a roundness evaluation for the track close to the position dent according to the new situation.

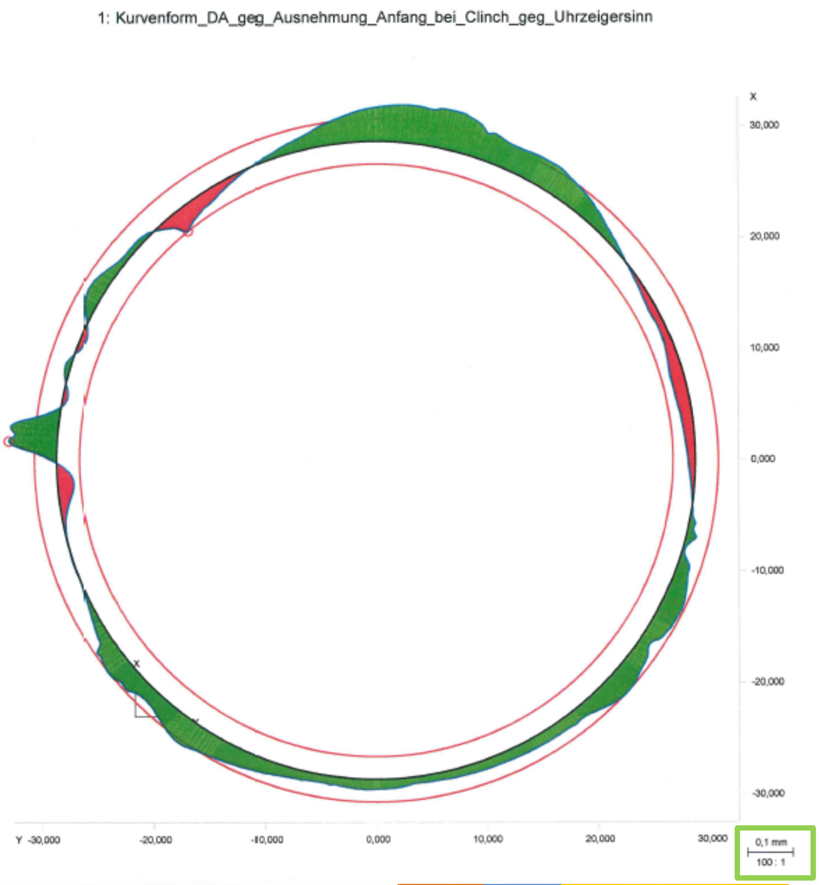


Nr	Bezeichnung	Sigma [mm]	Form [mm]	Anzahl Punkte	Untere Tol. [mm]	Obere Tol. [mm]	MinInd	Min Abweich...	MaxInd	Max Abweich. [...
1	Kurvenform_DA_bei_Ausnehmung_...	0,039	0,149	1189	-0,050	0,050	1158	-0,028	1179	0,121
	Einpassergebnis	Translation	X [mm]0,004	Y [mm]0,005	Z [mm]0,000	Rotation	X -0.002	Y -0.001	Z 0.000	

Figure 5.11: Measurement note new situation page 1 (roundness at position dent) (Michael Riesenhuber 2016)

Roundness evaluation – "opposite dent"

There is still a difference between the two tracks when carrying out the new evaluation, as can be seen in Figure 5.11 and Figure 5.12. This derived from the clearance of the mandrel.



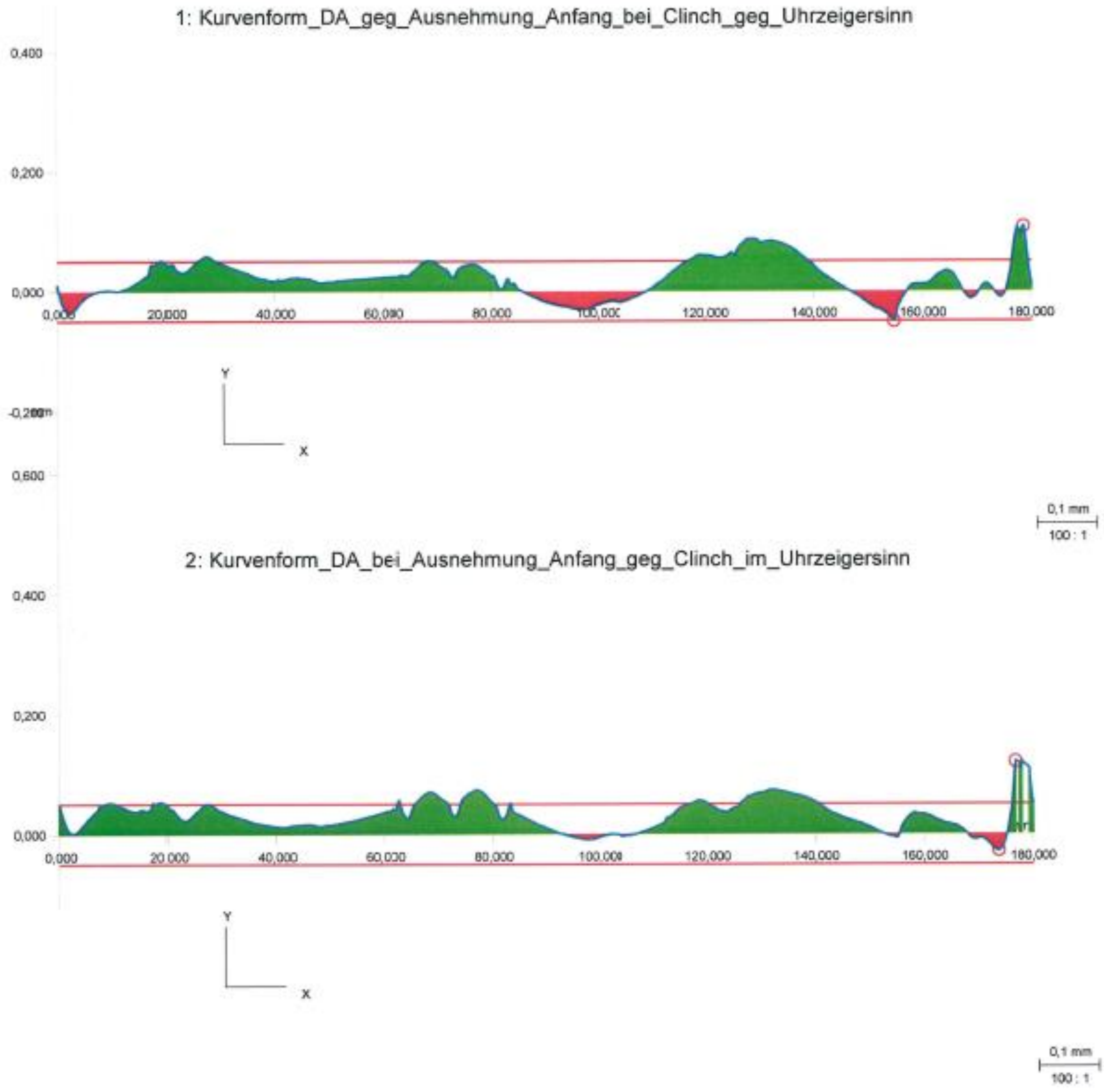
Nr	Bezeichnung	Sigma [mm]	Form [mm]	Anzahl Punkte	Untere Tol. [mm]	Obere Tol. [mm]	MinInd	Min Abweich...	MaxInd	Max Abweich. [...
1	Kurvenform_DA_geg_Ausnehmung_...	0,037	0,158	1201	-0,050	0,050	1032	-0,050	1191	0,108
	Einpassergebnis	Translation	X [mm]-0,004	Y [mm]0,005	Z [mm]0,002	Rotation	X -0.001	Y 0.000	Z 0.000	

Figure 5.12: Measurement note new situation page 2 (roundness opposite dent) (Michael Riesenhuber 2016)

- Form deviation
- Measured points
- Tolerance
- Enlargement factor

Roundness evaluation unwind

The third aspect of the new situation is the unrolled evaluation. It gives an idea where the roundness swings are located and how big they are.



Nr	Bezeichnung		Sigma [mm]	Form [mm]	Anzahl Punkte	Untere Tol. [mm]	Obere Tol. [mm]	MinInd	Min Abweich....	MaxInd	Max Abweich. [...
1	Kurvenform_DA_geg_Ausnehmung_...		0,037	0,158	1201	-0,050	0,050	1032	-0,050	1191	0,108
	Einpassergebnis	Translation	X [mm]-0,004	Y [mm]0,005		Z [mm]0,002	Rotation		X -0.001	Y 0.000	Z 0.000
2	Kurvenform_DA_bei_Ausnehmung_...		0,039	0,149	1189	-0,050	0,050	1158	-0,028	1179	0,121
	Einpassergebnis	Translation	X [mm]0,004	Y [mm]0,005		Z [mm]0,000	Rotation		X -0.002	Y -0.001	Z 0.000

Figure 5.13: Measurement note new situation page 3 (unwind) (Michael Riesenhuber 2016)

5.4.5 Difference between old situation and new situation

Switching from the old to the new situation brought about some changes. Affected is the program as well as the orientation of the bushing. The new situation causes benefits in some areas and provides support for the operator when carrying out adjusting work. It should also be the starting point for the process of closing information gaps.

Orientation of bushing at 3d machine:
Old situation: bushing is aligned to hole for measurement
New situation: bushing is aligned to clinch for better orientation

Using the clinch facilitates to align the bushings in the same way every time. It is also easy for the operator to find the correct position of the bushing in the 3d machine.

Centering the measuring track of bushing on pdf:
Old situation: the track was centered according to the three smallest figures
New situation: firstly, the bushing is measured and centered; secondly, the track is put on the this particular center

The new situation makes it possible now to see the real orientation of the bushing and the roundness. The center of the roundness is the actual center of the bushing.

Tolerance field diameter:
Old situation: the tolerance field was ±0,1mm
New situation: the tolerance field is reduced to ±0,05mm

Reducing the tolerance should increase the quality because it is necessary for the contoured bushing to have a higher quality of roundness for the final grinding process. The tolerances are no criteria demanded by the customer, though; they are just defined figures from Miba.

Orientation of hardcopy:
Old situation: the measuring track was mirrored when you stand in front of the machine
New situation: location of measurement note is the same like the forming unit

It is easier for the operator to see the correct sliders which are responsible for a specific area. Everyone can read the evaluation sheet now.

Measurement points (quantity)
Old situation: 830 points on average were measured for the evaluation
New situation: 1200 points on average are measured for the evaluation

Although adding more measured points did not considerably influence the results, it did not show any disadvantages and is thus defined as a new standard.

Saving raw data:
Old situation: raw data were rejected, which made it impossible to carry out additional evaluation at a later point
New situation: saving raw data for additional evaluations

Rejecting raw data constituted the biggest problem for the additional evaluation which provided a crucial point for this master thesis. Being equipped with these data would ease the evaluation of every single detail.

Conclusion
The new situation should help the operator and outsider to easily read the measurement note and see which actions are necessary to take. The only disadvantage is the missing figure of the average diameter of the track. This could be compared with an evaluation of the raw data in an excel file, or with this third aspect of the old situation, or by reprogramming the evaluation program.

5.5 Data preparation

A requirement for doing a statistical evaluation is to bring the old data into a new form with which it is then possible to copy and paste them into the statistical tool. The original data have to be split up so that every single figure is in a separate box. The fields for comments also need to be separated and brought in a form which enables the evaluation in the statistical program. Initial evaluation showed that just two figures (one for the smallest and one for the biggest deviation of roundness) are not sufficient because it lacks information concerning the locations of these figures. Therefore, it is required to carry out an additional evaluation of the existing measurement notes. Because old trial data were not always completely up to date, it was necessary to compare all the old data sheets with the actual lists and complete missing data. Some tests were conducted using a different forming process, a previously treated plate or just manufactured by manual mode. Therefore, it is vital to sort out the experiment data beforehand.

5.5.1 Old trial list

Versuchsnummer	Datum des Versuches	Auftragsnummer	Abmessungen	Postennummer	Miba Materialnummer	Best-Nr.	Ringgewicht	Herstelldatum	Nutzstreifen Nr.	Materialbreite	Verfahrweg Schieber	oberer Schieber	unterer Schieber	Beschichtung unterer Schieber	Beschichtung oberer Schieber	Dorn Höhe/Breite	oberer Schieber = Führungsleiste?	unterer Schieber = Führungsleiste?	Kante Schieber	Geschwindigkeit in %	Platinenlänge	Position der Pl.	DA	Rundheit Teil 1 Zeiss mit Aufwurf	Rundheit Teil 2 Zeiss mit Aufwurf	Rundheit Teil 3 Zeiss mit Aufwurf	Ölart	sonstige Bemerkungen	sonstige Bemerkungen	Programm Name
195	KW17	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,50/28,55	28,50/28,55	keine	keine	51,4/51,6	ja	nein	nicht poliert	60%	181,35 +-0,05	ölnuten mittig zum Dorn	57,535	0,214/0,239	0,194/0,217	0,189/0,217	OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15
196	KW17	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,6	28,6	keine	keine	51,4/51,6	ja	nein	nicht poliert	60%	181,35 +-0,05	ölnuten mittig zum Dorn	57,503	0,158/0,170	0,162/0,172	0,160/0,171	OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert) oberer,	dafzylv186-30.03.15
197	KW17	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,6/28,65	28,6/28,65	keine	keine	51,4/51,6	ja	nein	nicht poliert	60%	181,35 +-0,05	ölnuten mittig zum Dorn	57,492	0,129/0,130	0,123/0,132	0,127/0,131	OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv189-02.04.15
198	KW17	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,5/28,55	28,5/28,55	keine	keine	51,3/51,5	ja	nein	nicht poliert	60%	unterschiedlich	ölnuten mittig zum Dorn					OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15
199	KW19	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,5/28,55	28,5/28,55	keine	keine	51,2/51,4	ja	nein	nicht poliert	60%	181,55 +-0,05	ölnuten mittig zum Dorn	57,316	0,133/0,137	0,131/0,142	0,132/0,133	OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15
200	KW19	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,5/28,55	28,5/28,55	keine	keine	51,2/51,4	ja	nein	nicht poliert	60%	unterschiedlich	ölnuten mittig zum Dorn					OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15
201	KW19	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,5/28,55	28,5/28,55	keine	keine	51,2/51,4	ja	nein	nicht poliert	60%	181,15 +-0,05	ölnuten mittig zum Dorn	57,323	0,178/0,180	0,170/0,168	0,167/0,169	OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15
202	KW19	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,5/28,55	28,5/28,55	keine	keine	51,2/51,4	ja	nein	nicht poliert	60%	181,45 +-0,05	ölnuten mittig zum Dorn	57,332	0,134/0,148	0,128/0,136	0,151/0,143	OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15
203	KW20	Wasserstrahlgeschnitten, nicht mehr nachvollziehbar									laut Programm	28,5/28,55	28,5/28,55	keine	keine	51,2/51,4	ja	nein	nicht poliert	60%	181,55 +-0,05	ölnuten mittig zum Dorn	57,315	0,152 / 0,123	0,136 / 0,141	0,127 / 0,104	OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15
204	KW20	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,5/28,55	28,5/28,55	keine	keine	51,2/51,5	ja	nein	nicht poliert	60%	181,50 +-0,05	ölnuten mittig zum Dorn	57,423	0,127 / 0,149	0,130 / 0,128	0,125 / 0,130	OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15
205	KW20	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,5/28,55	28,5/28,55	keine	keine	51,3/51,5	ja	nein	nicht poliert	60%	181,50 +-0,05	ölnuten mittig zum Dorn	57,452	0,175 / 0,181	0,162 / 0,183	0,165 / 0,183	OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15
206	KW20	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,5/28,55	28,5/28,55	keine	keine	51,2/51,5	ja	nein	nicht poliert	60%	181,50 +-0,05	ölnuten mittig zum Dorn					OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15
207	KW20	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,5/28,55	28,5/28,55	keine	keine	51,2/51,5	ja	nein	nicht poliert	60%	181,50 +-0,05	ölnuten mittig zum Dorn	57,414	0,136 / 0,138	0,141 / 0,145	0,133 / 0,153	OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15
208	KW20	80142859-01	2,85x50	Q-9364 I	130014572	2000160178G1-WS	177kg	27.08.2014	2A	50	laut Programm	28,5/28,55	28,5/28,55	keine	keine	51,2/51,5	ja	nein	nicht poliert	60%	181,50 +-0,05	ölnuten mittig zum Dorn					OMV Gear HST 100	Zylindrischer Platine mit Ölnuten und Ölloch, umgeformt auf eine zylindrische Buchse.	Linker Schieber im Bereich des Clinch ausgenommen (Ausnehmung poliert), spezielle	dafzylv194-17.04.15

Table 5.3: Old trial data (Michael Riesenhuber 2016)

5.5.2 Additional analysis

It is unavoidable for the statistical evaluation to find and create an additional evaluation process which monitors more areas. This provides the possibility to evaluate and compare different areas of the bushing and makes it possible for the statistic tool to define areas which are affected by the selected influencing factors. To avoid unnecessary work, the trial list is filtered before doing the extra analysis as is explained in Chapter 5.5.3.

The first step is dividing the measurement note from Figure 5.9 into different areas. For that, a transparent sheet is designed for the additional measurement points (like Figure 5.14 shows). The tolerance area of the bushing is split into twelve small sections, six in the positive direction and six in the negative one. Numbers from one to fifteen mark the areas which are evaluated separately. The focus lies on the measurement note of the bottom side (as we can see in Figure 5.9) since the difference between the bottom and the top side is just the bending of the mandrel as explained before in Chapter 5.4. Below one can see the numbers and their location on the bushing.

Position:

1. Bottom bending, area of the first big kink on the bottom
2. Right bending approximately 45° from bottom bending
3. Right edge of the bottom forming slider
4. Buckling between top and bottom slider right side
5. Right edge of the top forming slider
6. Left bending approximately 45° from bottom bending
7. Left edge of the bottom forming slider
8. Buckling between top and bottom slider left side
9. Left edge of the top forming slider
10. Maximal value from area of 30° before the left top side
11. Minimal value of the left top side
12. Maximal value of the left top side
13. Minimal value of the right top side
14. Maximal value of the right top side
15. Maximal value from area of 30° before the right top side
16. Peak quantity counts the peaks in the marked section

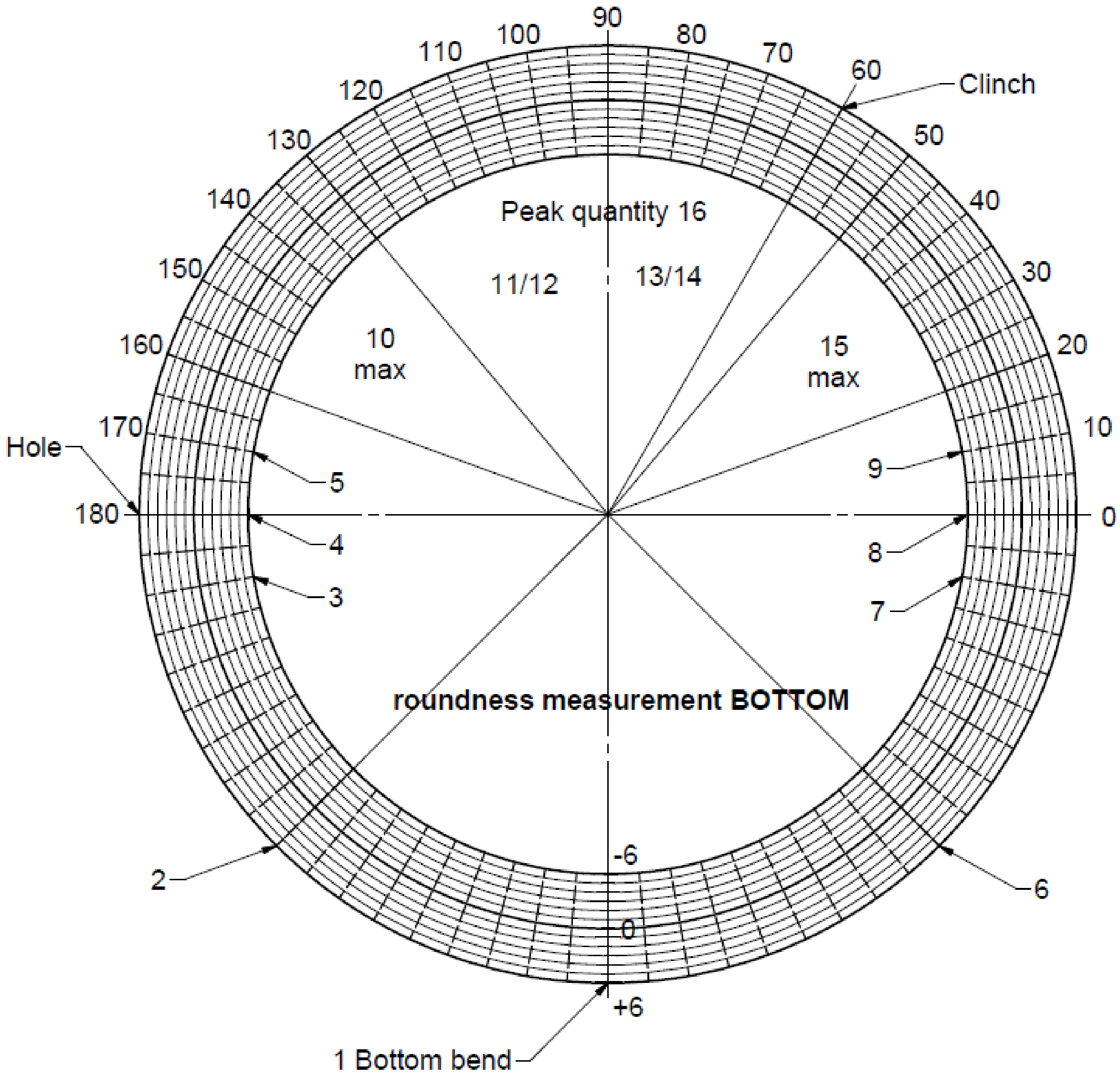


Figure 5.14: Transparent sheet for additional evaluation (Michael Riesenhuber 2016)

The transparent sheet is put on the original measurement note from the bottom side and aligned with the main contour elements from the bushing. Point 1 shows the position from the center of the bushing bulging aligned with the zero axis of the foil. Afterwards each position is evaluated separately and noted in the Table 5.4. For Point 1 In this case the evaluated value for position eight is +1.

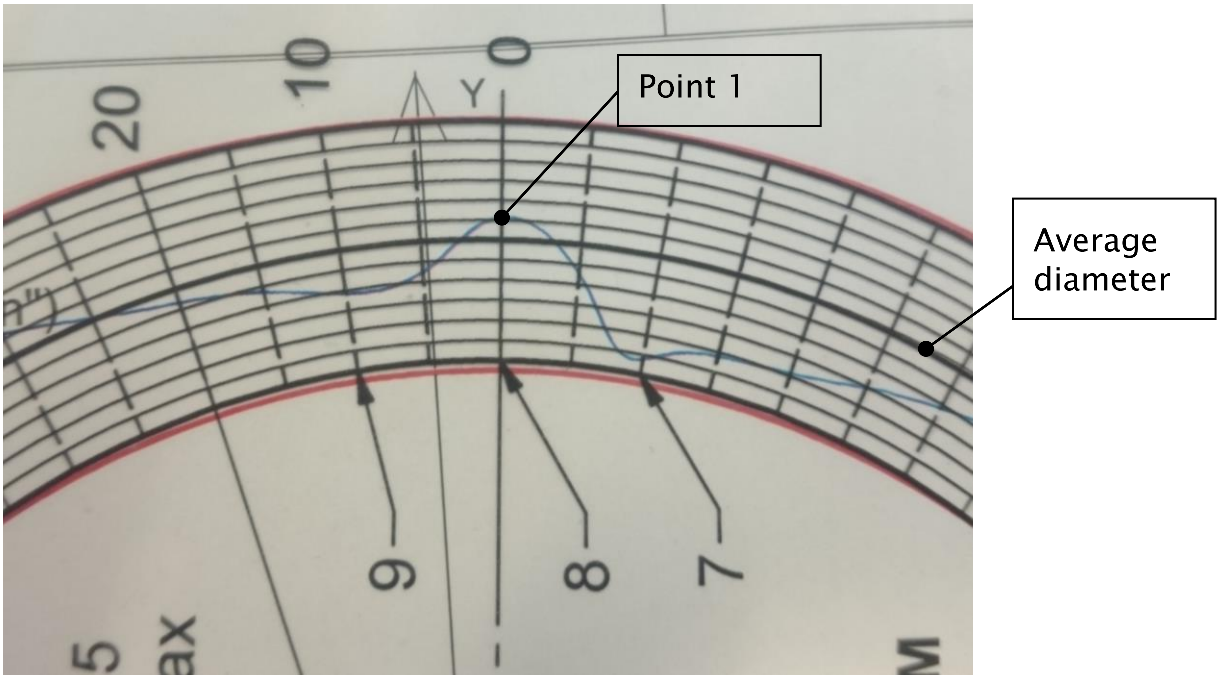


Figure 5.15: Orientation of transparent sheet on printed pdf (Michael Riesenhuber 2016)

In order to enable replication of the evaluation the scale is split into twelve equal parts. The center is the average diameter and the deviation into the center is marked with minus in one and with plus in the other side as we can see in Figure 5.16. In this case the position 1 Bottom bend is evaluated with +5.

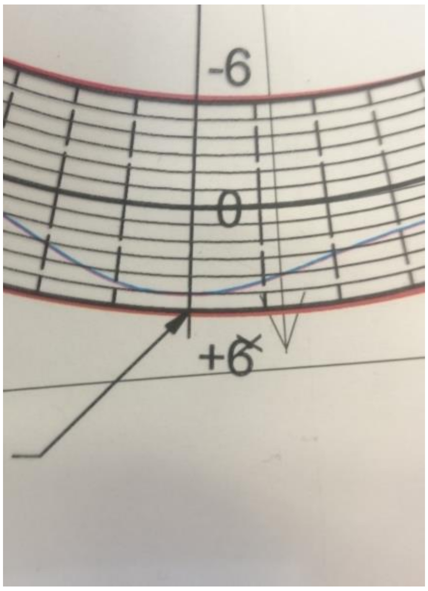


Figure 5.16: Evaluation scale at 1 Bottom bend (Michael Riesenhuber 2016)

Table 5.4: Additional evaluation of measure notes (Michael Riesenhuber 2016)

T-Number	**roundness (exact) [mm]**	**diameter bottom [mm]**	**diameter top [mm]**	**Position 1**	**Position 2**	**Position 3**	**Position 4**	**Position 5**	**Position 6**	**Position 7**	**Position 8**	**Position 9**	**Position 10**	**Position 11**	**Position 12**	**Position 13**	**Position 14**	**Position 15**	**peak quant.**
229	0,244	57,462	57,458	7	0	-7	-2	-6	0	-7	-2	-4	0	0	5	1	7	3	4
230	0,177	57,381	57,369	5	-1	-5	0	-3	-1	-5	1	-2	1	0	4	-2	5	2	4
231	0,182	57,461	57,454	6	-2	-5	-2	-6	-1	-6	0	-4	-1	-2	3	-2	5	1	4
232	0,184	57,369	57,367	5	-1	-6	0	-4	0	-6	0	-2	0	-1	3	-2	5	2	4
233	0,191	57,405	57,376	6	0	-6	0	-5	-1	-6	1	-2	-3	-3	3	-1	6	2	3
234	0,175	57,484	57,451	5	-1	-5	-2	-5	0	-5	-3	-4	-1	-2	3	-2	5	2	4
235	0,178	57,463	57,428	5	-1	-4	-1	-5	-2	-5	0	-4	-2	-3	2	-1	5	2	3
236	0,178	57,382	57,362	5	-2	-6	0	-4	-1	-5	1	-2	1	0	4	-1	5	2	4
238	0,153	57,351	57,321	5	-2	-5	0	-3	-1	-5	1	-2	1	-1	4	-3	4	2	4
239	0,180	57,375	57,353	5	-2	-5	0	-4	-1	-5	1	-2	1	0	4	-2	5	2	4
240	0,166	57,373	57,346	5	-2	-5	0	-3	-1	-5	1	-2	2	0	4	-3	5	1	4
241	0,185	57,378	57,351	6	-2	-6	-1	-4	-1	-6	0	-3	2	0	5	-2	5	1	4
243	0,164	57,350	57,355	5	-2	-5	0	-4	-1	-5	0	-3	1	-1	4	-1	5	1	4
245	0,157	57,342	57,337	5	-2	-4	1	-4	-1	-5	0	-4	1	-2	4	-2	4	1	4
247	0,179	57,365	57,356	5	-2	-5	1	-5	-1	-5	0	-4	0	-2	4	-2	5	1	4
248	0,164	57,359	57,349	5	-3	-4	-1	-5	-1	-4	-1	-5	1	-2	4	-2	5	1	4
249	0,127	57,350	57,348	4	-2	-4	0	-4	-2	-3	0	-4	1	0	4	-3	3	1	4
257	0,128	57,334	57,304	4	-3	-4	1	-4	-1	-1	2	-3	1	0	4	-3	3	0	4
258	0,128	57,352	57,340	4	-3	-3	1	-4	-2	-3	0	-4	1	0	4	-3	3	0	4
259	0,122	57,346	57,333	3	-3	-3	0	-3	-2	-2	0	-4	0	-1	4	-3	3	1	4
260	0,119	57,344	57,343	3	-3	-3	0	-3	-2	-2	0	-3	1	0	3	-3	3	1	4
263	0,136	57,350	57,334	3	-3	-3	0	-3	-3	-3	0	-4	1	-3	4	-4	4	1	4
264	0,154	57,367	57,357	4	-3	-3	1	-3	-2	-3	-1	-4	2	-4	4	-4	4	0	4

Evaluation showed that there are a few bends in the area from 10 to 15. It is necessary to evaluate each one separately because each bend could stem from another influencing factor or slider. Therefore, the maximum and minimum figures of the peaks and the associated angles are documented to gain more data for the statistical evaluation as Table 5.5 shows. In Table 5.4 the evaluation of the measurement notes is done with the transparent sheet.

Table 5.5: Additional evaluation with peaks of measure notes (Michael Riesenhuber 2016)

	Peak 1				Peak 2				Peak 3				Peak 4				Peak 5	
T-Number	Peak1 max	Peak1 max angl.	Peak1 min	Peak1 min angl.	Peak2 max	Peak2 max angl.	Peak2 min	Peak2 min angl.	Peak3 max	Peak3 max angl.	Peak3 min	Peak3 min angl.	Peak4 max	Peak4 max angl.	Peak4 min	Peak4 min angl.	Peak5 max	Peak5 max angl.
229	3	45	1	53	7	62	0	70	7	83	3	100	5	110	0	133	1	143
230	2	45	0	55	5	63	-2	72	5	85	2	100	4	113	0	135	1	145
231	1	40	-1	55	5	63	-2	72	4	83	-1	100	3	112	-3	135	-1	145
232	2	45	0	55	5	63	-2	72	4	85	1	100	3	112	-1	135	0	145
233	2	47	1	55	6	63	-1	70	5	83	-1	100	3	112	-3	140	-3	145
234	2	48	0	58	5	67	-2	75	5	87	-1	102	3	112	-2	137	-1	145
235	2	35	0	53	5	60	-1	68	4	82	-1	97	3	110	-3	137	-2	145
236	2	45	-1	55	5	63	-2	72	5	85	2	100	4	112	0	135	0	145
238	2	33	-1	55	4	62	-3	70	4	83	0	98	4	110	-1	135	1	145
239	2	35	-1	57	5	63	-2	72	6	85	1	100	4	112	0	135	1	145
240	2	33	-1	55	5	62	-3	70	5	84	1	97	5	112	0	133	2	145
241	2	35	-1	55	6	63	-2	71	6	85	0	98	5	112	0	135	2	145
243	1	35	-1	55	5	63	-2	71	5	85	1	97	4	112	-1	135	1	145
245	1	40	-1	55	5	62	-2	70	4	82	0	95	4	110	-2	135	1	145
247	2	40	0	53	5	62	-2	70	5	82	0	97	4	112	-2	135	1	145
248	1	43	-1	55	5	62	-2	71	4	85	1	95	4	110	-2	135	1	145
249	1	40	-3	53	3	60	-4	70	3	83	1	94	4	110	0	128	1	145
257	0	40	-3	50	2	60	-4	67	3	83	0	93	4	110	0	125	1	147
258	0	40	-2	52	3	60	-3	68	3	83	0	95	4	110	-1	130	1	145
259	0	40	-2	52	3	60	-3	68	3	82	0	95	4	110	-2	133	0	147
260	1	40	-2	52	3	60	-4	68	3	83	0	95	3	112	0	130	1	150
263	1	40	-3	50	4	60	-4	68	3	82	-3	95	4	112	-2	137	1	150
264	1	37	-3	50	4	60	-4	68	4	82	-5	95	5	112	-2	130	2	150

To facilitate comparability the measured positions are based on the diameter and so the absolute value of the point is calculated as seen in Table 5.6. For the calculation the diameter is divided by two plus the number of the ring multiplied by 0,2/12 (dividing the tolerance of 0,2 into 12 equal circles).

Table 5.6: Additional evaluation relative and absolute (Michael Riesenhuber 2016)

							Peak 1							Radius Peak 1	
T-Number	roundness (exact) [mm]	diameter bottom [mm]	diameter top [mm]	Position 1	Position 2	Position 3	Peak1 max	Peak1 max angl.	Peak1 min	Peak1 min angl.	Radius Position 1 [mm]	Radius Position 2 [mm]	Radius Position 3 [mm]	Radius Peak 1 max [mm]	Radius Peak 1 min [mm]
229	0,244	57,462	57,458	7	0	-7	3	45	1	53	28,8477	28,7310	28,6143	28,7810	28,7477
230	0,177	57,381	57,369	5	-1	-5	2	45	0	55	28,7738	28,6738	28,6072	28,7238	28,6905
231	0,182	57,461	57,454	6	-2	-5	1	40	-1	55	28,8305	28,6972	28,6472	28,7472	28,7138
232	0,184	57,369	57,367	5	-1	-6	2	45	0	55	28,7678	28,6678	28,5845	28,7178	28,6845
233	0,191	57,405	57,376	6	0	-6	2	47	1	55	28,8025	28,7025	28,6025	28,7358	28,7192
234	0,175	57,484	57,451	5	-1	-5	2	48	0	58	28,8253	28,7253	28,6587	28,7753	28,7420
235	0,178	57,463	57,428	5	-1	-4	2	35	0	53	28,8148	28,7148	28,6648	28,7648	28,7315
236	0,178	57,382	57,362	5	-2	-6	2	45	-1	55	28,7743	28,6577	28,5910	28,7243	28,6743
238	0,153	57,351	57,321	5	-2	-5	2	33	-1	55	28,7588	28,6422	28,5922	28,7088	28,6588
239	0,180	57,375	57,353	5	-2	-5	2	35	-1	57	28,7708	28,6542	28,6042	28,7208	28,6708
240	0,166	57,373	57,346	5	-2	-5	2	33	-1	55	28,7698	28,6532	28,6032	28,7198	28,6698
241	0,185	57,378	57,351	6	-2	-6	2	35	-1	55	28,7890	28,6557	28,5890	28,7223	28,6723
243	0,164	57,350	57,355	5	-2	-5	1	35	-1	55	28,7583	28,6417	28,5917	28,6917	28,6583
245	0,157	57,342	57,337	5	-2	-4	1	40	-1	55	28,7543	28,6377	28,6043	28,6877	28,6543
247	0,179	57,365	57,356	5	-2	-5	2	40	0	53	28,7658	28,6492	28,5992	28,7158	28,6825
248	0,164	57,359	57,349	5	-3	-4	1	43	-1	55	28,7628	28,6295	28,6128	28,6962	28,6628
249	0,127	57,350	57,348	4	-2	-4	1	40	-3	53	28,7417	28,6417	28,6083	28,6917	28,6250
257	0,128	57,334	57,304	4	-3	-4	0	40	-3	50	28,7337	28,6170	28,6003	28,6670	28,6170
258	0,128	57,352	57,340	4	-3	-3	0	40	-2	52	28,7427	28,6260	28,6260	28,6760	28,6427
259	0,122	57,346	57,333	3	-3	-3	0	40	-2	52	28,7230	28,6230	28,6230	28,6730	28,6397
260	0,119	57,344	57,343	3	-3	-3	1	40	-2	52	28,7220	28,6220	28,6220	28,6887	28,6387
263	0,136	57,350	57,334	3	-3	-3	1	40	-3	50	28,7250	28,6250	28,6250	28,6917	28,6250
264	0,154	57,367	57,357	4	-3	-3	1	37	-3	50	28,7502	28,6335	28,6335	28,7002	28,6335

5.5.3 Filter of old trial data

The trial data for this master thesis consist of data from the old experiments combined with those from the new additional evaluation. Because each single test previously conducted cannot be reevaluated, the experiment list is filtered according to some criteria.

The first measure is to list the test runs from the last one back to the first one, because the documentation and the tests improved over time. The documentation at the beginning of the project was not the same as it was at the end, so it would be much more difficult to compare the results of the roundness and all the other quality criteria.

The data received from the old experiments consist of 298 positions for 264 experiments, since more than one test was done for some of the positions. Experiments included, for example, varying the plate length or varying the plate attributes.

So, all in all, there was the original list of 298 tests with variation of nearly every factor. Unfortunately, for some experiments results for the roundness and the diameter measurement were not saved, so not every evaluation can be carried out a

second time. This was the case for 42 experiments, since measurement data are not available any more.
The variety of the forming process concerned 9 experiments. This is also not informative for the roundness evaluation because variation of the forming process changes too much to do a correct evaluation. Variations in this case included, for example, testing different sliders or attaching adhesive tape to some geometry points of the slider.
Another problem for making a repeatable evaluation is the forming speed of the truck bushing line. Some of the experiments were done with manual control, which leads to a gap of information, since manual control can vary the machine speed widely. It is up to the operator how fast he is spinning the control wheel. This circumstance affected 53 examples and, thus, reduced the number of those experiments for which it made sense to be evaluated a second time.
Moreover, some of the tests were done for another customer. The difference did not only lie in the customer it was also the plate geometry, the whole die and the forming process, which also made these experiments not meaningful for this evaluation. These particular kinds of bushings were produced three times. After taking all those aspects into account there were data from 191 experiments left for a second evaluation.
Another factor which prevented the comparability of the tests was the use of a pre-treated material. The pretreatment affected 6 positions on the list, which leaves 185 positions and 151 individual experiments on the final list.
This is an extensive number of tryouts, which leads to a great number of positions for which to do the additional validation with the transparent sheet as illustrated in Chapter 5.5.2. To achieve the best result evaluation started at the last experiment and went back in time. This filtering procedure led to 91 data sets which can be used afterwards for the Minitab evaluation.

Table 5.7: Filtering reasons (Michael Riesenhuber 2016)

Filter reason	**Sum of positions**	**298**
Second evaluation not possible		-42
Variety of forming process		-9
Forming speed		-53
Different customer		-3
Pretreatment of blank		-6
Additional evaluation		-94
	End sum	**91**

List of experiment number:

Table 5.8: List of evaluated experiments (Michael Riesenhuber 2016)

143	145	146	147	148
149	158	166	167	168
169	172	173	174	175
176	177	178	179	180
181	182	183	184	185
186	188	189	190	194
195	196	197	199	200 12x
201	202	204	205	207
209	210	211	212	213
214	215	219	220	221
222	223	224	225	226
227	228	229	230	231
232	233	234	235	236
238	239	240	241	243
245	247	248	249	257
258	259	260	263	264

5.6 Statistical evaluation

For the statistical evaluation it is necessary to define a statistic program which has the ability to evaluate the given raw data. In this master thesis the used statistics program is Minitab.
Since the result can just be as good as the inserted data are, it is crucial to know where the data came from and if the data are correct. It is also necessary to check the accuracy of the values to reduce the risk of incorrect data. In order to generate the best outcome of the statistical evaluation a correlation analysis is done first. In this analysis the red line describes the sequence of the mean value. The second step is to create a time graph to see how the behavior might have changed over time. For evaluation and determination of the significance level a one-way ANOVA is done. With this ANOVA the main levers are detected and documented for further evaluations.

5.6.1 Correlation analysis

The additional evaluation of the 91 data sets gives a lot of new data points. To check the correlation between the new evaluation and the old results of the roundness evaluation the "Total absolute sum" and the "Roundness" are compared. The Total absolute sum is a calculated value which sums up every single measurement point from the new additional measurement.

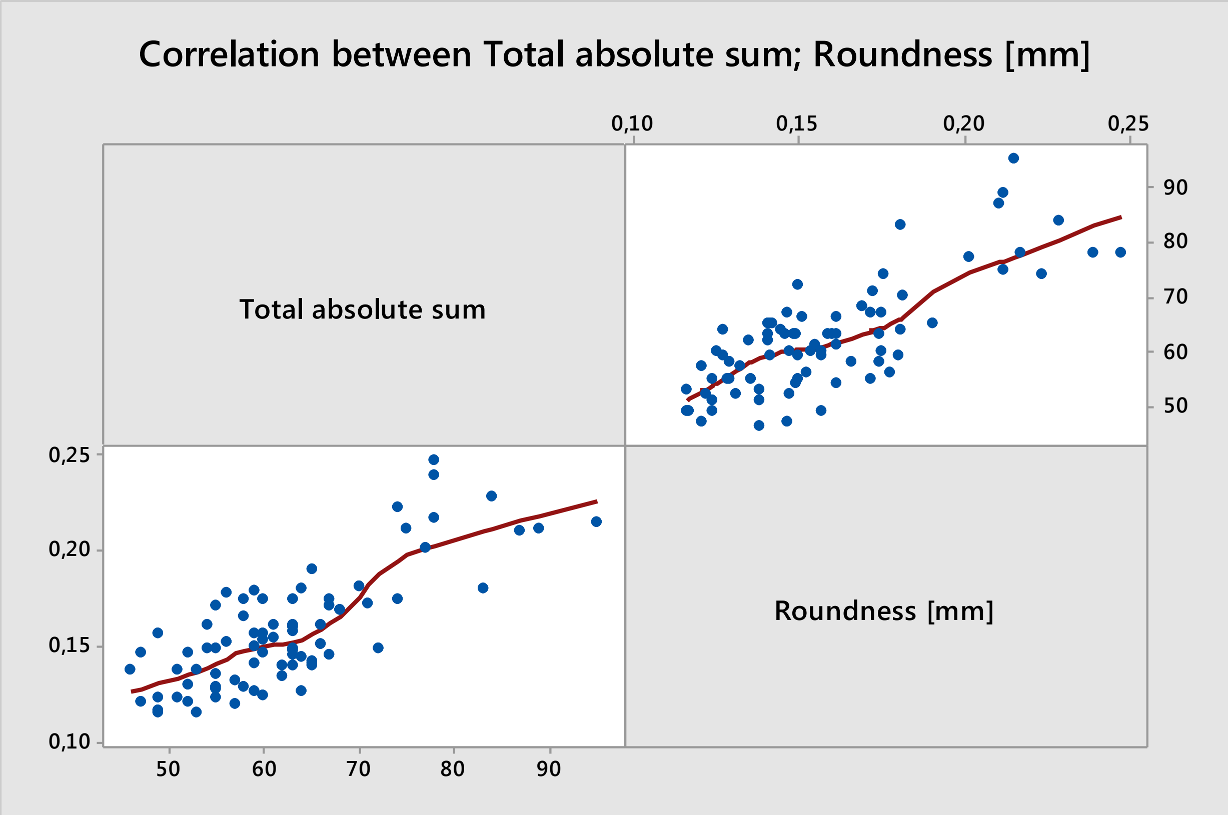


Figure 5.17: Correlation between Total absolute sum and Roundness (Michael Riesenhuber 2016)

As expected, the correlation between total absolute sum and the roundness is very strong. This means the roundness is affected by the total sum. If a factor will be found which could minimize the total absolute sum, we will have a lever for the roundness. The red lines in the figures show the sequence of the mean values again.

Correlation of Total absolute sum and Sum Clinch

The “Sum Clinch” is a specific area of 0 to 180 degrees at the clinch. It is selected because in this area there are a few bends and so the five main peaks in the area of 0 to 180 degrees (see Figure 5.14) are summed up. As seen in Figure 5.18 the absolute sum and the sum clinch correlate. The reason for that is that the peaks in the clinch area are essential for the Total absolute sum and they are also part of the calculation.

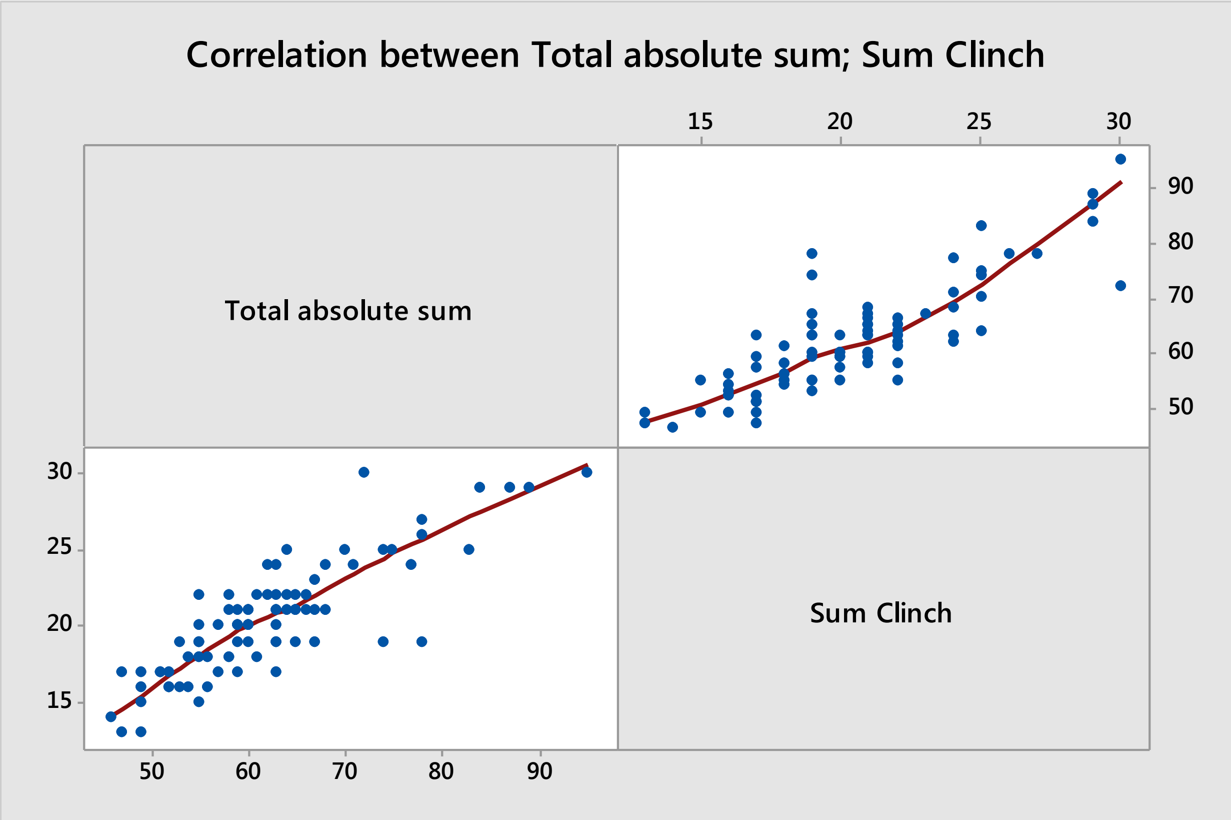


Figure 5.18: Correlation Total absolute sum and Sum Clinch (Michael Riesenhuber 2016)

Correlation Gap mandrel/slider and position distance of 3+7 and 5+9

Another correlation analysis is done between the gap of mandrel and slider and the position distance of position 3 and 7 and the position of 5 and 9 (for positions see Figure 5.14). This evaluation is done because it seemed apparent that the gap between the mandrel and the slider considerably influences the areas where the top and the bottom slider approach each other. The reason why it seemed obvious is the fact that the gap between slider and mandrel is about 2,7mm at times, but the thickness of the raw material is about 2,87mm and so it is unavoidable to generate problem areas. This circumstance can be seen in Figure 5.19, if the gap is too small the difference value from 3+7 and 5+9 is very great.

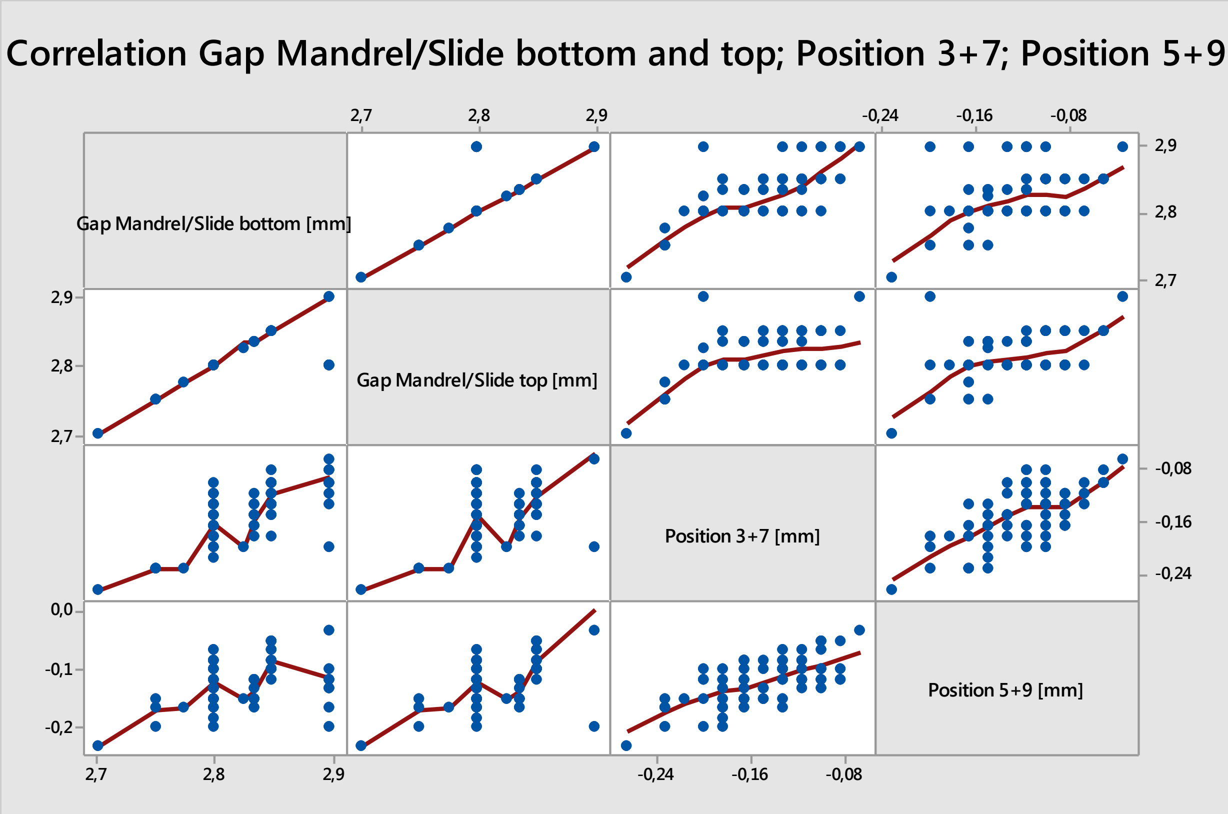


Figure 5.19: Gap Mandrel/Slide and Position 3+7/5+9 (Michael Riesenhuber 2016)

Plate length and Sum Clinch

The correlation analysis of the plate length and the sum clinch should show whether these two variables correlate. As Figure 5.20 demonstrates, there is a loose connection between these two characteristics, but this effect could also stem from some other aspects which are not considered in this analysis. It seemed that when the plate length is bigger the sum clinch gets smaller. This could be a possible realistic effect created by the geometry of the sliders and the inside space.

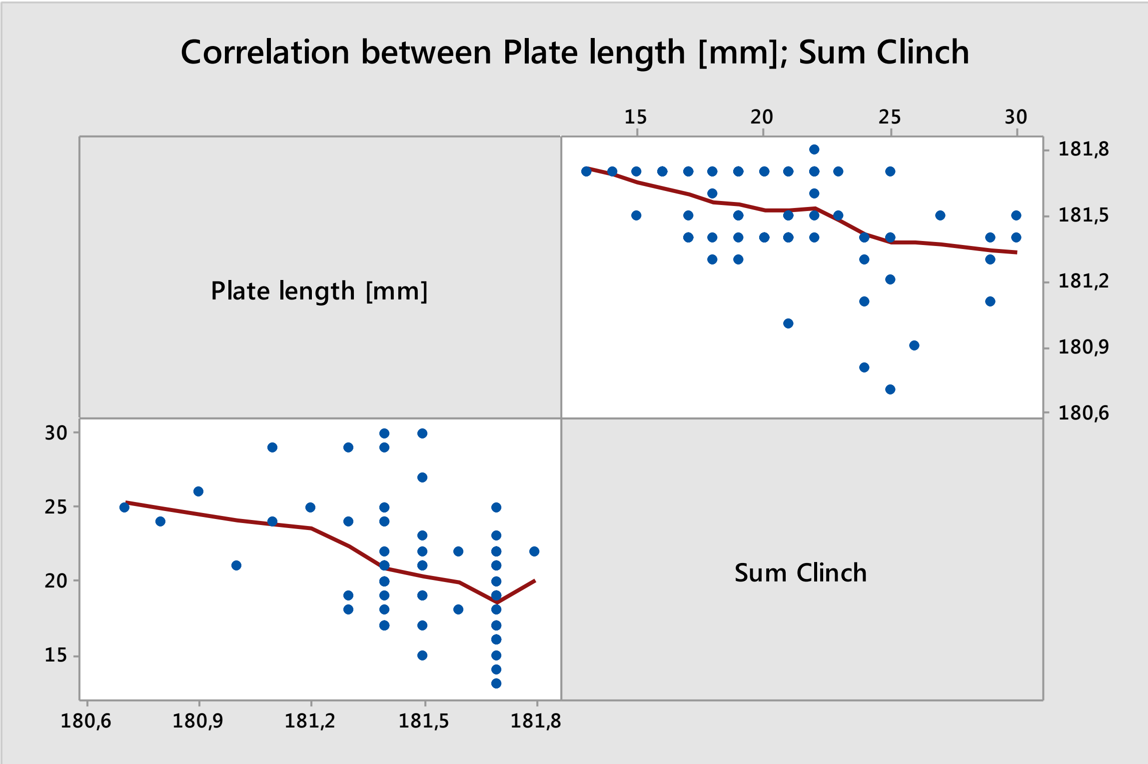


Figure 5.20: Correlation of Plate length and Sum Clinch (Michael Riesenhuber 2016)

5.6.2 Time series graph comparison

To give an overview of the time, a graph is created which shows the roundness, total absolute sum, sum clinch and the outer diameter of the evaluated experiments. Index one is describing the experiments conducted long ago and index 91 is the latest test.

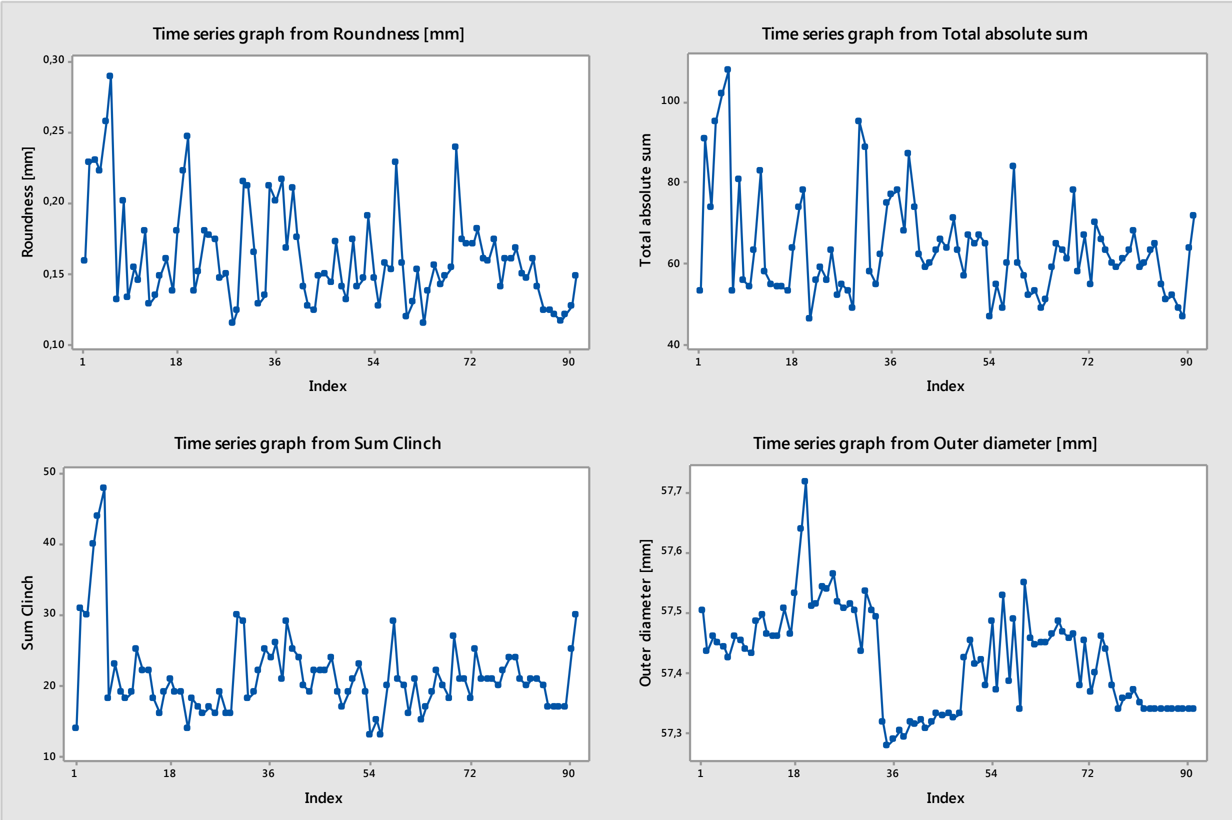


Figure 5.21: Time series graph arrangement (Michael Riesenhuber 2016)

Over time the roundness can be observed to improve in all four graphs, but still there is no significant development. Frequent outliers could be the result of a flawed experiment or could also be of statistical nature.

5.6.3 Variance analysis one-way ANOVA

For the statistical evaluation the one-way ANOVA (analysis of variance) was chosen. It is a technique to compare means of three or more samples using only numerical data. The ANOVA tests the null hypotheses of samples drawn from populations with the same mean values. If the null hypothesis is rejected it means that at least one mean value is different. The test of the hypothesis is done with the level of significance of $\alpha=0,05$.

Table 5.9: Method of one-way ANOVA (Michael Riesenhuber 2016)

Method:	
Null hypothesis:	all mean values are equal
Alternative hypothesis:	at least one mean value is different
Level of significance:	$\alpha=0,05$

Significance level p-value:
This is the level of significance between two criteria. The critical level is 0,05, which means that if the significance level is above the value of 0,05 the null hypothesis has to be rejected. Then it can be stated that the alternative hypothesis is significant.

F-value: the higher the value the better
An F-Test can be any statistical test, in which the test statistic has an F-distribution under the null hypothesis. F-Test is mostly used when comparing different statistical models that were suitable for a data set. This way one can identify the model that fits the population from which the data were sampled best.

Geometry and roundness

To get meaningful results from the experiments the tests are divided into two different geometries: contoured and cylindrical. There are a few problems with the evaluation of the diverse geometries, because only ten experiments were carried out with the contoured one. Moreover, the deviation of the roundness is also significant for the contoured bushings. Figure 5.22 shows the considerable deviation and the difference between the cylindrical and the contoured bushings. As a consequence, the focus for the rest of the evaluation is laid on the cylindrical geometry.

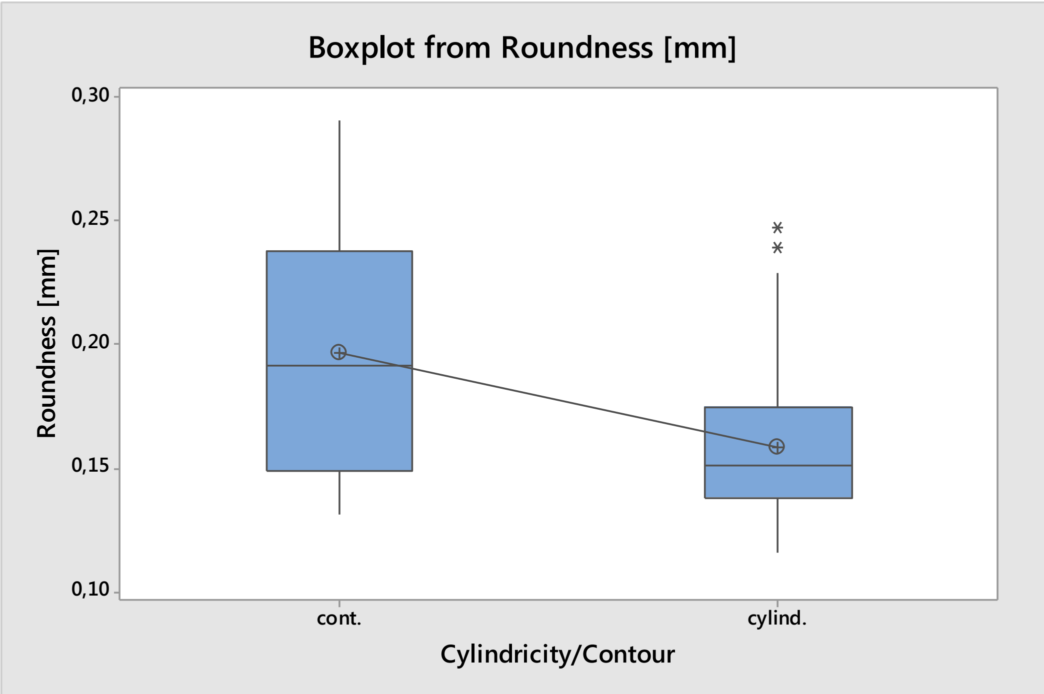


Figure 5.22: Boxplot geometry and roundness (Michael Riesenhuber 2016)

Table 5.10: Boxplot geometry and roundness (Michael Riesenhuber 2016)

Geometry and roundness	
Geometry	**Piece**
Contoured	10
Cylindrical	81
Sum	**91**
Variable	**value**
F-value	11,12
p-value	0,001

Gap mandrel and slider

Very obvious areas of the bushings are the bulges on the left and also on the right side. The describing points of the additional evaluation are three, four, five, seven, eight and nine. The bushing has a material thickness of about 2,87mm per side. If the gap between the mandrel and the slider is smaller than the blade, the material is crushed between slider and mandrel. This leads to a deformation in the areas mentioned and sometimes to creating the maximum and minimum value of the whole bushing. Unfortunately, results are not as clear as expected. Reasons could include documentation mistakes or the small amount of some test dimensions.

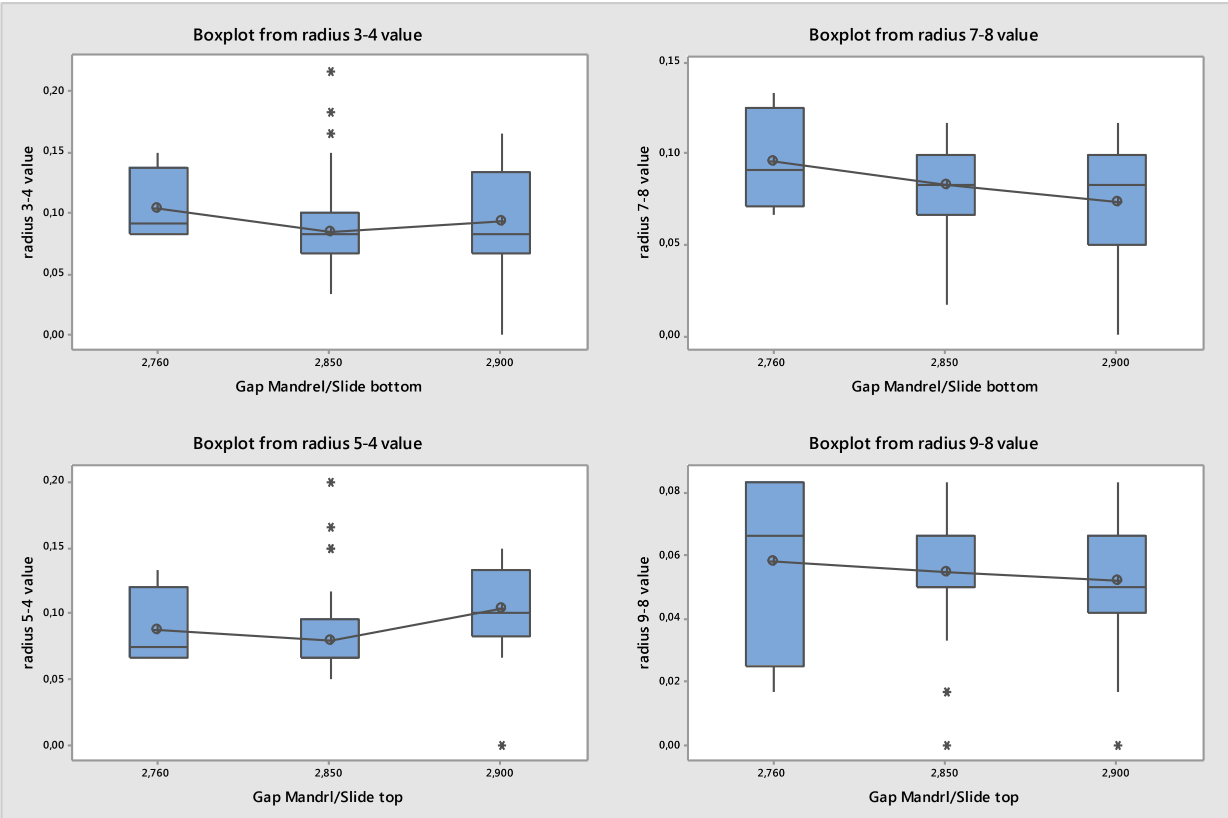


Figure 5.23: Boxplot gap mandrel and slider bottom and top (Michael Riesenhuber 2016)

For 7-8 value and 9-8 value one can observe continuous improvement when the gap increases. This can also be seen in the p-values in Table 5.11 and Table 5.12.

Gap mandrel/slide bottom

Table 5.11: Gap mandrel/slider bottom (Michael Riesenhuber 2016)

radius 3-4 value		radius 7-8 value	
Length	**Piece**	**Length**	**Piece**
2,76	4	2,76	4
2,85	52	2,85	52
2,90	25	2,90	25
Sum	**81**	**Sum**	**81**
Variable	**value**	**Variable**	**value**
F-value	0,75	F-value	2,00
p-value	0,474	p-value	0,142

Gap mandrel/slide top

Table 5.12: Gap mandrel/slider top (Michael Riesenhuber 2016)

radius 5-4 value		radius 9-8 value	
Length	**Piece**	**Length**	**Piece**
2,76	4	2,76	4
2,85	60	2,85	60
2,90	17	2,90	17
Sum	**81**	**Sum**	**81**
Variable	**value**	**Variable**	**value**
F-value	3,54	F-value	0,32
p-value	0,034	p-value	0,737

Roundness and gap mandrel

The correlation analysis between gap mandrel/slide bottom and roundness shows the same results as assumed in Figure 5.19. If the gap between the bottom slider and the mandrel widens, the roundness also improves. This fact is caused by the thickness of the blade of about 2,87mm.

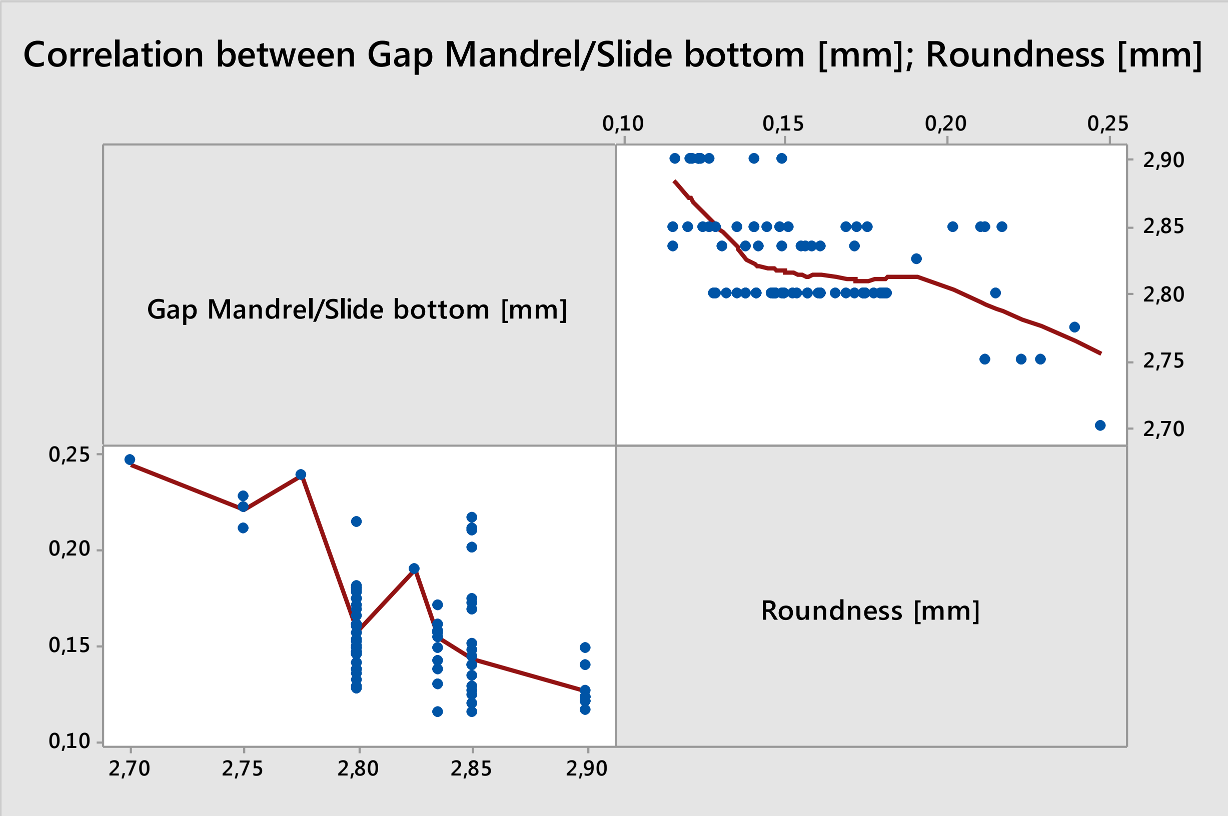


Figure 5.24: Correlation gap mandrel/slider bottom and roundness (Michael Riesenhuber 2016)

The distribution of the number of experiments is not uniform and this could also lead to a poor result in the evaluation. To minimize the risk of failure because of the small amount of experiments some tests are combined. Still, it reflects the fact that crushing the material leads to bends in specific areas.

To determine whether the gap between the mandrel and the bottom/top slider influences the roundness a boxplot is created. While there are more aspects that have influence on the roundness, it is obvious that the roundness is consistently improving when the gap between the mandrel and the slider expands until 2,9mm. This sounds plausible if the fact of squeezing the plate is considered.

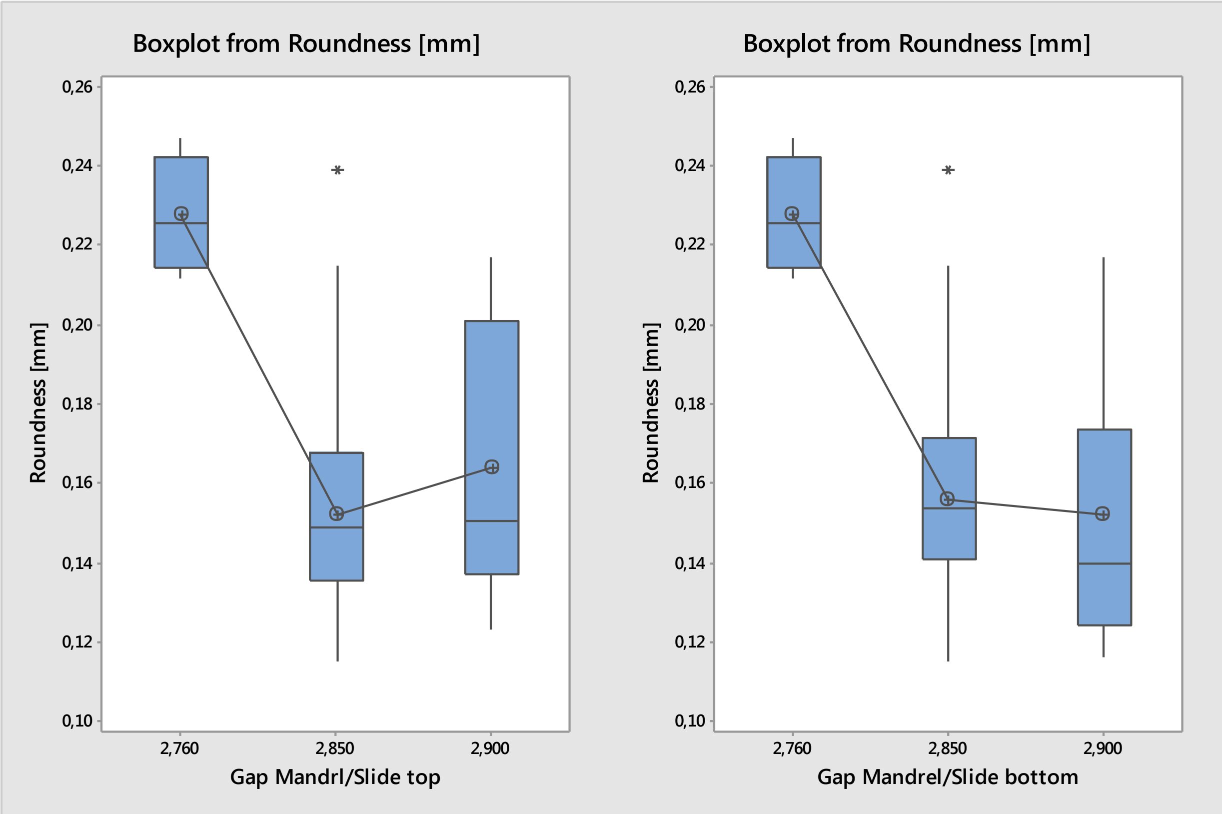


Figure 5.25: Boxplot roundness and gap mandrel (Michael Riesenhuber 2016)

Table 5.13: Roundness and gap mandrel (Michael Riesenhuber 2016)

Roundness and Mandrel/Slide bottom		**Roundness and Mandrel/Slide top**	
Length	**Piece**	**Length**	**Piece**
2,76	4	2,76	4
2,85	52	2,85	60
2,90	25	2,90	17
Sum	**81**	**Sum**	**81**
Variable	**value**	**Variable**	**value**
F-value	14,73	F-value	16,45
p-value	0,000	p-value	0,000

Outer diameter and plate length

First, a correlation analysis is made to see the relation between the plate length and the outer diameter. Again, the bad distribution of the experiments proves to create problems, but it generally seemed that if the plate is longer, the diameter is also bigger.

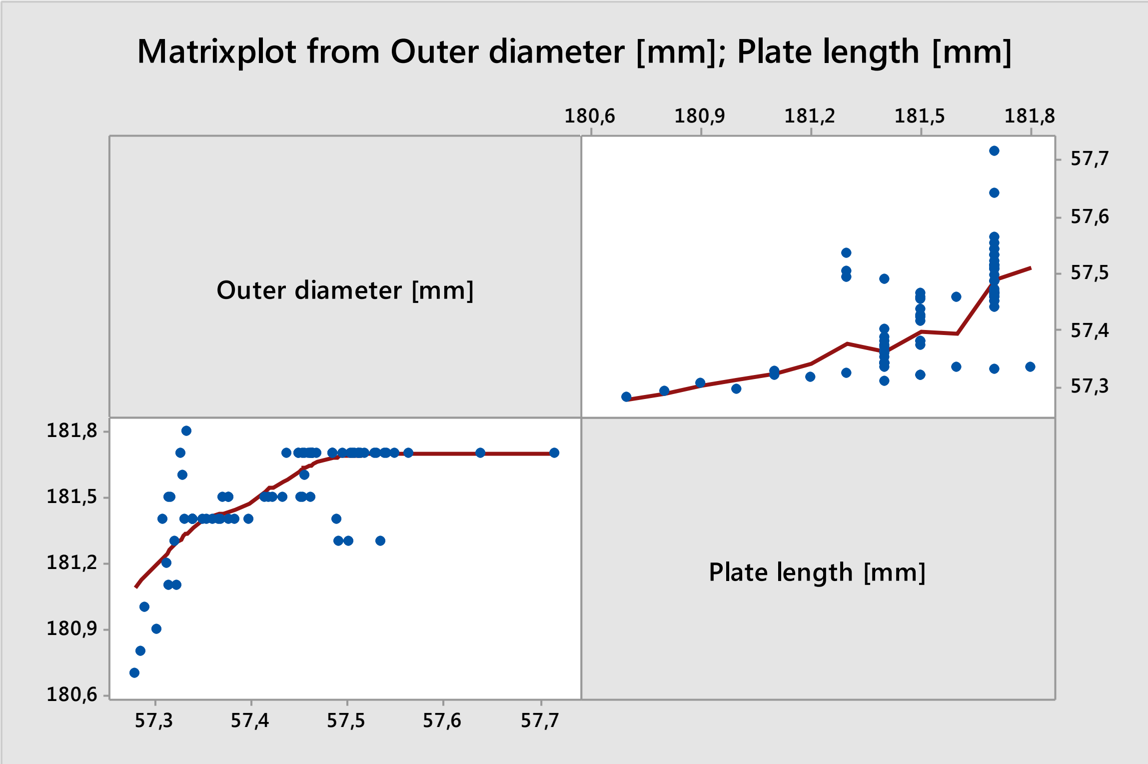


Figure 5.26: Matrix plot outer diameter and plate length (Michael Riesenhuber 2016)

The definition of the diameter of the formed bushing is not fixed, so it is up to the following process to decide which oversize is necessary. The finished outer diameter is between 57,1mm and 57,14mm, so the diameter for the raw bushing is approximated with 57,35mm. To reach this diameter a plate length of 181,4mm was defined as a standard because experiments showed the best results. The cross-section dimension depends not just on the plate length, it is also subject to much more influences. The main factor is the slider geometries. While these sliders are the key form giving parts, it is not just the geometry but also the moving distance and the forming speed (Figure 5.30) of the sliders which influence the form.

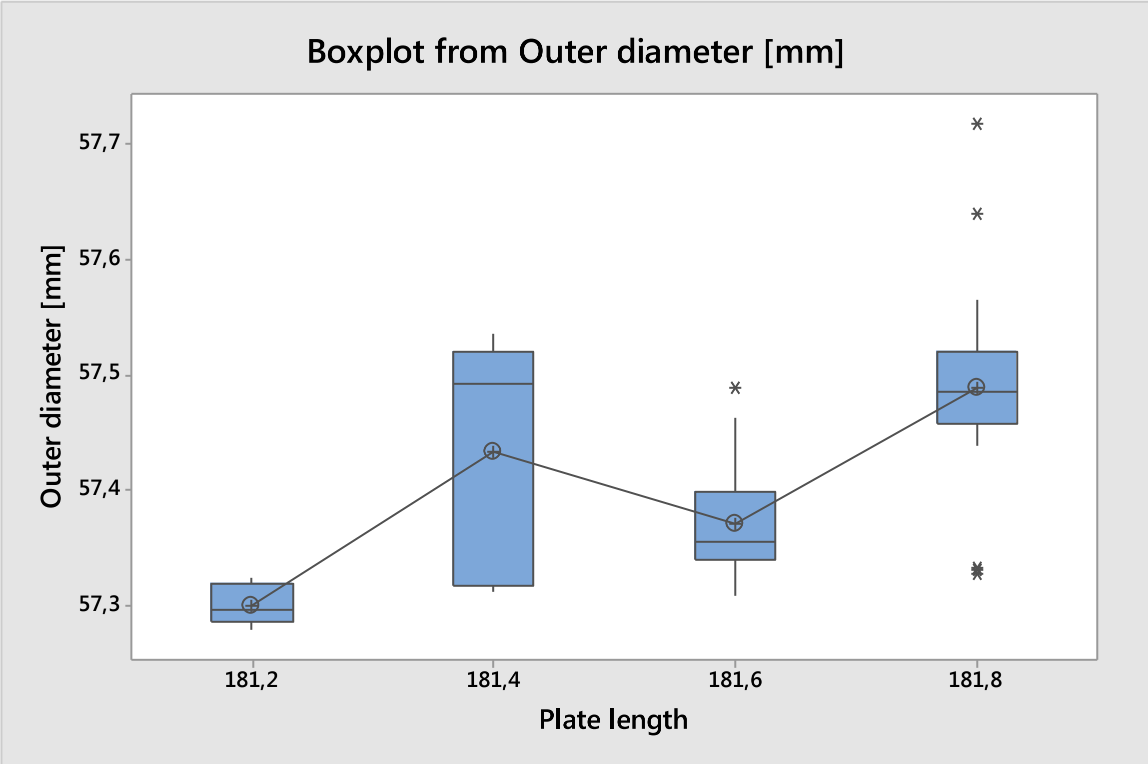


Figure 5.27: Boxplot outer diameter and plate length (Michael Riesenhuber 2016)

Table 5.14: Outer diameter and plate length (Michael Riesenhuber 2016)

Outer diameter and plate length	
Length	**Piece**
181,2	6
181,4	5
181,6	35
181,8	35
Sum	**81**
Variable	**value**
F-value	28,09
p-value	0,000

In this case the p-value of 0,000 provides the information that the significance is rather high between plate length and outer diameter; this means that the null hypothesis is not rejected. Since the distribution of the experiments is not perfect, it is approximated by summing up some length values.

Roundness and plate length

To determine the significance level between roundness and plate length another boxplot with one-way ANOVA is created. The p-value of 0,011 is a sign for a great significance. If the value is below 0,05 the null hypothesis is significant. This means that the length of the plate has a significant influence on the roundness of the bushing. This fact could result from closing the space of the sliders.

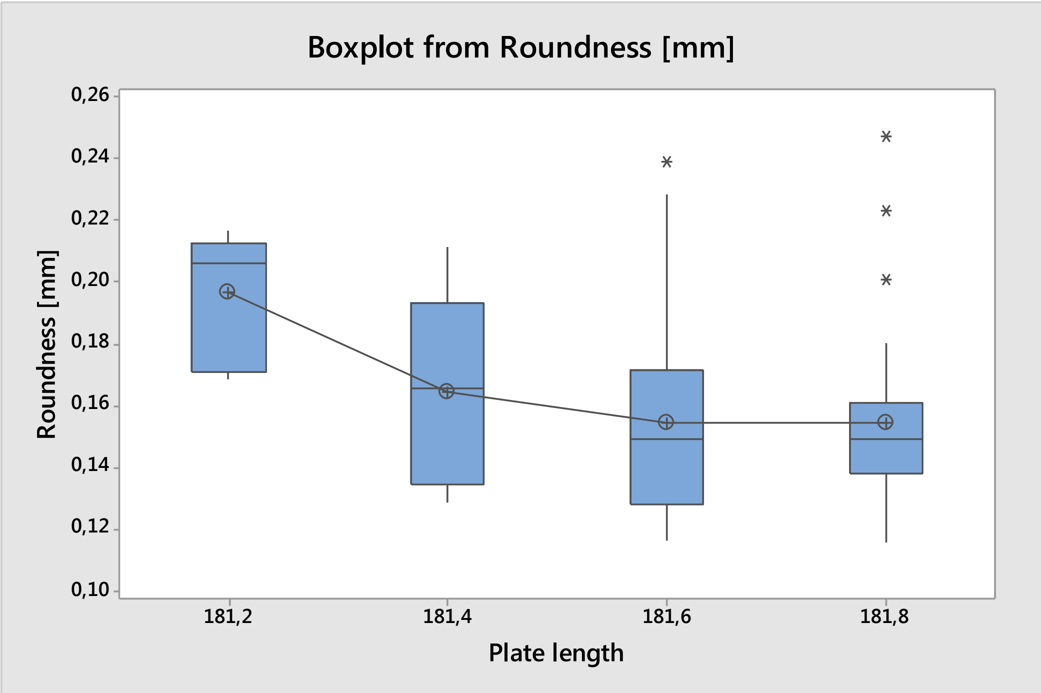


Figure 5.28: Boxplot roundness and plate length (Michael Riesenhuber 2016)

Table 5.15: Roundness and plate length (Michael Riesenhuber 2016)

Roundness and Plate length	
Length	**Piece**
181,2	6
181,4	5
181,6	35
181,8	35
Sum	**81**
Variable	**value**
F-value	4,00
p-value	0,011

Roundness and Tool surface

Some tests were done with different surface quality of the sliders. The standard version is not polished; however, to reduce the abrasion a few tests were carried out with polished sliders. It seemed that the polished sliders achieved better results and the p-value of 0,039 shows us it is significant. This might also stem from other experiments or other influencing factors. The boxplot in Figure 5.29 is representing the roundness and the surface quality. In fact, a higher surface quality normally leads to a higher quality of the product and also to less abrasion and, therefore, to less contamination in the forming unit.

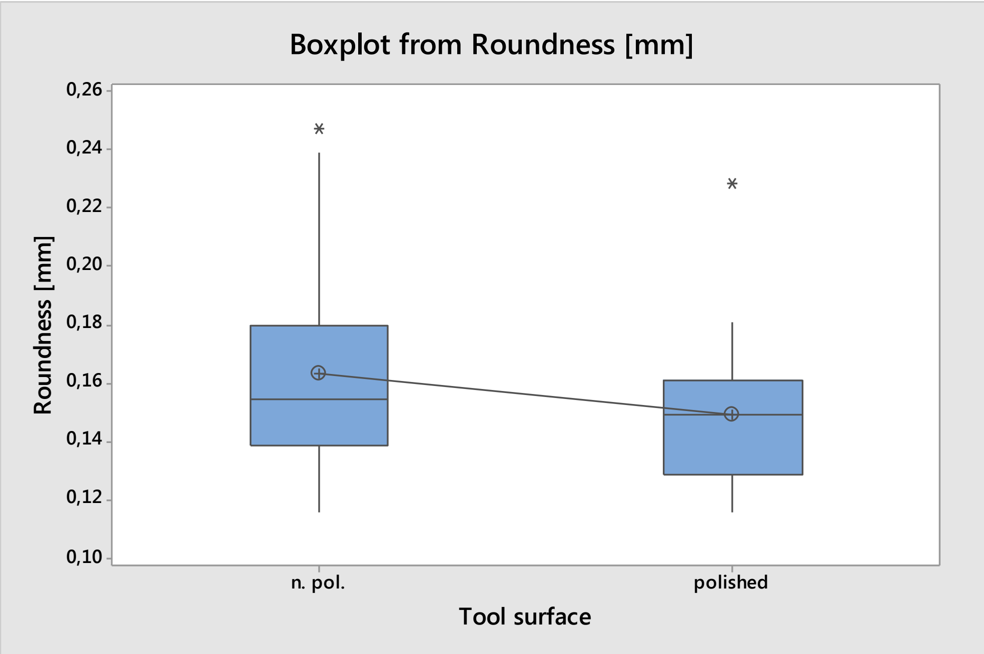


Figure 5.29: Boxplot tool surface and roundness (Michael Riesenhuber 2016)

Table 5.16: Tool surface and roundness (Michael Riesenhuber 2016)

Tool surface and roundness	
Surface	**Piece**
Polished	52
Not polished	29
Sum	**81**
Variable	**value**
F-value	4,43
p-value	0,039

Roundness and forming speed

The whole system could be operated in manual mode with the operator spinning a wheel and, thus, moving the active axes with the speed depending on the operator’s rotating speed. In the automatic mode the operator selects a particular speed, for example, 25 rounds per minute of shaft rotation and, then, he can regulate the speed by changing the percentage of the shaft rotation. The first tests revealed a big difference whether the bushings were produced in manual or in automatic mode. Investigation of forming speed (as seen in Figure 5.30) shows there is no significant difference between automated forming at different speed. This hypothesis is also confirmed by the p-value of 0,891.

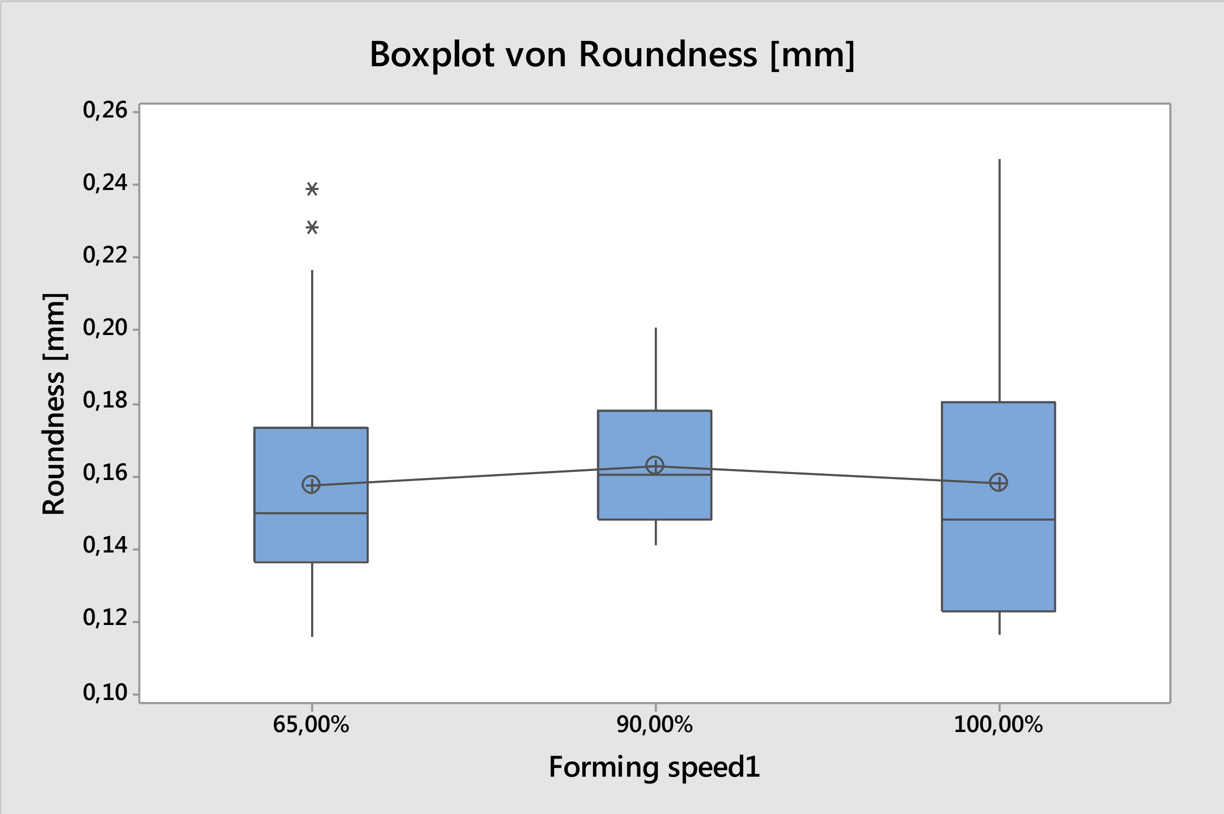


Figure 5.30: Boxplot roundness and forming speed 25U/min (Michael Riesenhuber 2016)

The speed of the sliders and the presses depend on the rotation – in this case 25U/min – and the angle and distance of each single slider or press. To compare the forming speed a calculation is done which can be seen in Table 5.17 below. This table includes the moving axis, the angle of the movement and the related distance.

Table 5.17: Calculation of forming speed (Michael Riesenhuber 2016)

	Forming speed	**25 U/min**			
	Angle	**Distance**	**Distance/Angle**	**m/sec**	**m/min**
A3 Prägen	60	15,9	0,264	0,040	2,378
A4 Presse	40	7,5	0,188	0,028	1,688
A5 ob	53	102,9	1,942	0,291	17,474
A6 re	40	75,8	1,895	0,284	17,055
A7 un	20	28,2	1,411	0,212	12,699
A8 li	40	69,6	1,740	0,261	15,660

Table 5.18: Roundness and forming speed (Michael Riesenhuber 2016)

Roundness and forming speed	
Forming speed	**Piece**
65%	57
90%	10
100%	14
Sum	**81**
Variable	**value**
F-value	0,12
p-value	0,891

Boxplot roundness and oil groove

Serial production showed a distance between the two oil grooves on the plate which was too wide. This geometry failure leads to problems at the milling process and, additionally, the tolerance was also not centered. The distance between the oil grooves is determined by the punch, because it is impossible to do adjustments in any other way without influencing other geometry details. To solve this issue the punch forming the oil grooves was redesigned and the distance between the two grooves was reduced. In the boxplot it appears as if this change had a positive influence on the roundness, as does the p-value of 0,003. However, one has to consider the amount of just seven experiments carried out using the new design and also the continuous improvement of the whole roundness over time. If the improvement of the roundness is not monitored, it definitely has a positive effect on the groove distance and tolerance, making it an upgrade for the process stability.

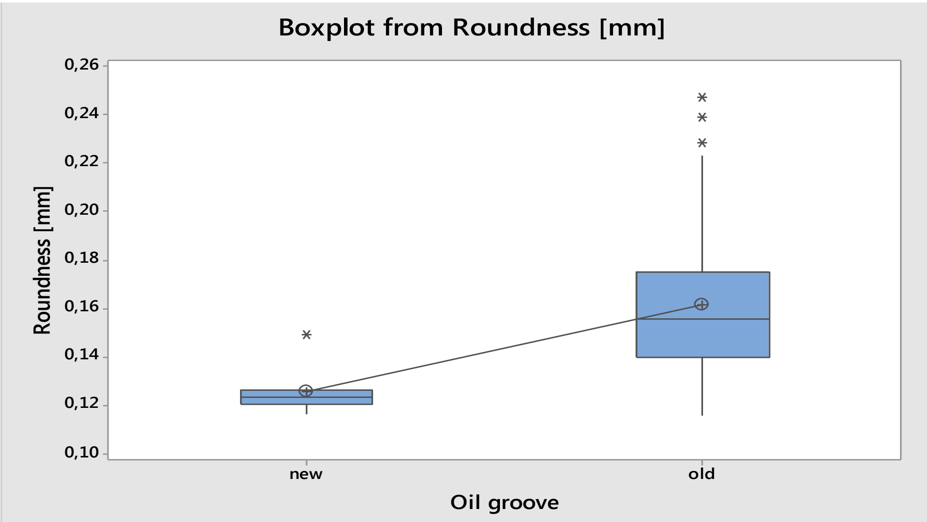


Figure 5.31: Boxplot roundness and oil groove (Michael Riesenhuber 2016)

Table 5.19: Roundness and oil groove (Michael Riesenhuber 2016)

Roundness and oil groove	
Oil groove	**Piece**
new	7
old	74
Sum	**81**
Variable	**value**
F-value	9,75
p-value	0,003

Roundness and position dent

The difference between these two experiments is just the position dent which was introduced to support the operator at the milling machine to make sure the bushing is positioned in the correct way. The influence on the measured areas is insignificant for the roundness as seen in the p-value of 0,299, but this could also result from badly selected measuring tracks and does not provide a clear answer to whether the position dent has an influence or not. The main influence of the position dent is namely in the border areas, but these are not measured.

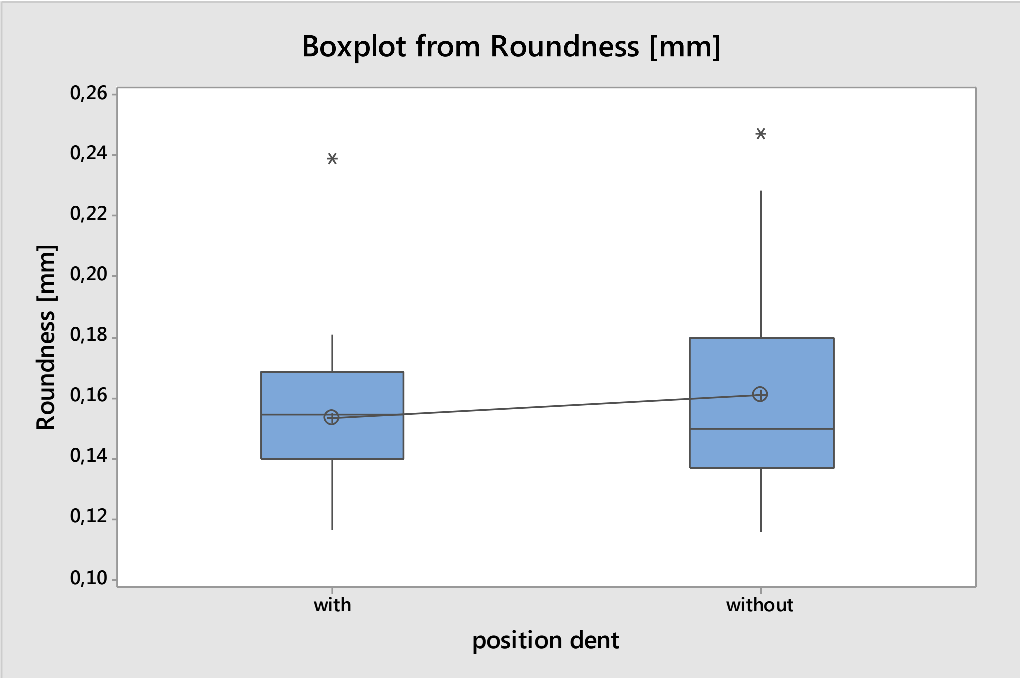


Figure 5.32: Boxplot from roundness and position dent (Michael Riesenhuber 2016)

Table 5.20: Roundness and position dent (Michael Riesenhuber 2016)

Roundness and position dent	
Position dent	**Piece**
With (position dent)	53
Without (position dent)	28
Sum	**81**
Variable	**value**
F-value	1,09
p-value	0,299

5.6.4 Reference samples

Great roundness differences between the experiments exist. There could be a few factors which are responsible for these varying results. The main influence is exerted by changing a variable factor. But an obvious change of the influencing factors is not the only possibility to affect results of the roundness evaluation. A great variance of the roundness could also arise from unknown factors or the machine reliability itself. To figure out how strong this unidentified influence is, 20 sample pieces are collected during one production process. The pieces are picked discontinuously to generate results as reliable as possible. For these reference samples a quantity of 20 pieces was chosen, because it is sufficient to gain all the necessary information. They were collected in one day and, therefore, not every factor is considered. Still, this gives an idea of how the machine varies during one day production.

Time graph from roundness top/bottom side

The first part of analyzing the reference samples is to create a time graph from the roundness on the top and on the bottom side. An improvement of the roundness bottom can be witnessed at around bushing six. To detect the origin of the improvement a boxplot is produced. It may be somewhat confusing that the improvement is just on the bottom and not on the top side too, but this might derive from a bending of the mandrel during the forming process. Changes during the reference samples are just done for the position of the press unit 1.

Bushing 2 +0,1mm and Bushing 8 -0,15mm

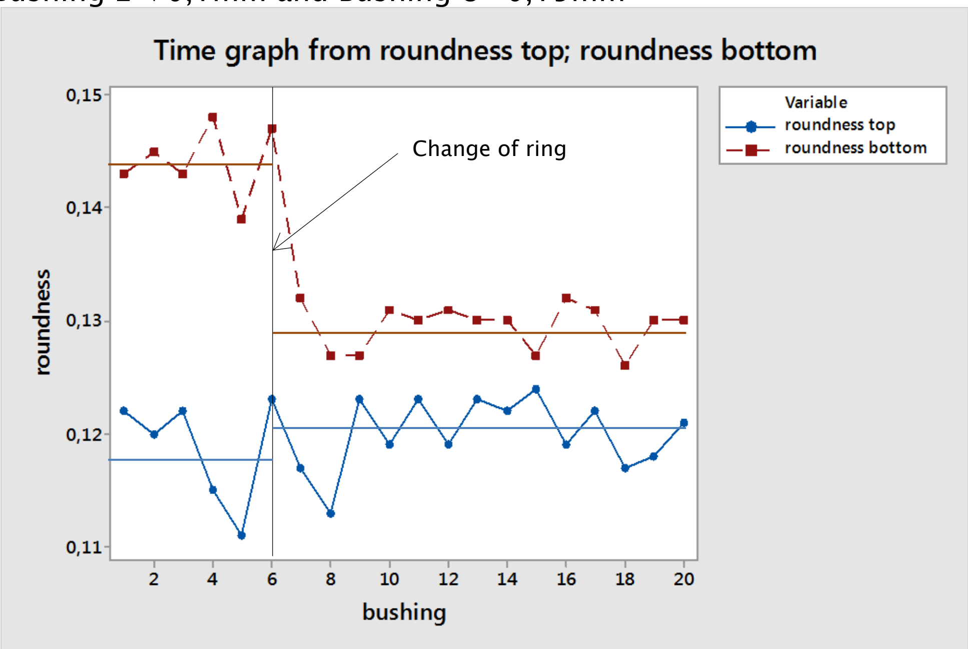


Figure 5.33: Time graph from roundness top/bottom side (Michael Riesenhuber 2016)

Time graph from diameter top/bottom

The sixth bushing shows a greater diameter, which might originate from the change of the ring done at bushing number six. Bushing number 20 also has a bigger outer diameter. A reason for that could be the end of the ring and the loosening of the metal strip or some other unknown factors.

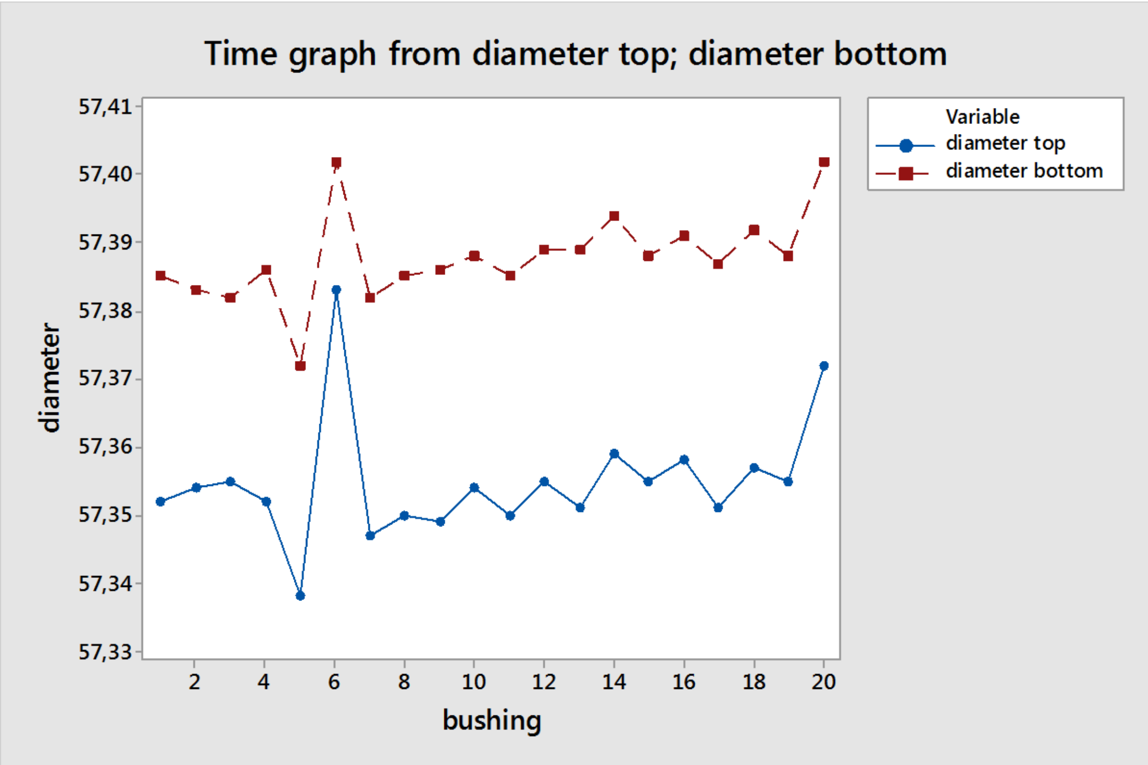


Figure 5.34: Time graph diameter top/bottom (Michael Riesenhuber 2016)

Boxplot from roundness bottom/top and old/new ring

To identify the cause of the improvement at bushing six, a boxplot from the roundness evaluation and the ring is created. The ring was changed during production because the old one was used up. With the new ring the quality of the roundness is much better than before. This could either stem from a different material and, therefore, different material properties, or just from machine related factors which were not known at the moment. In order to do a detailed evaluation of the machine capability, the sample size would need to be much bigger. However, for the purpose of getting a rough feeling for the truck bushing line this test is adequate.

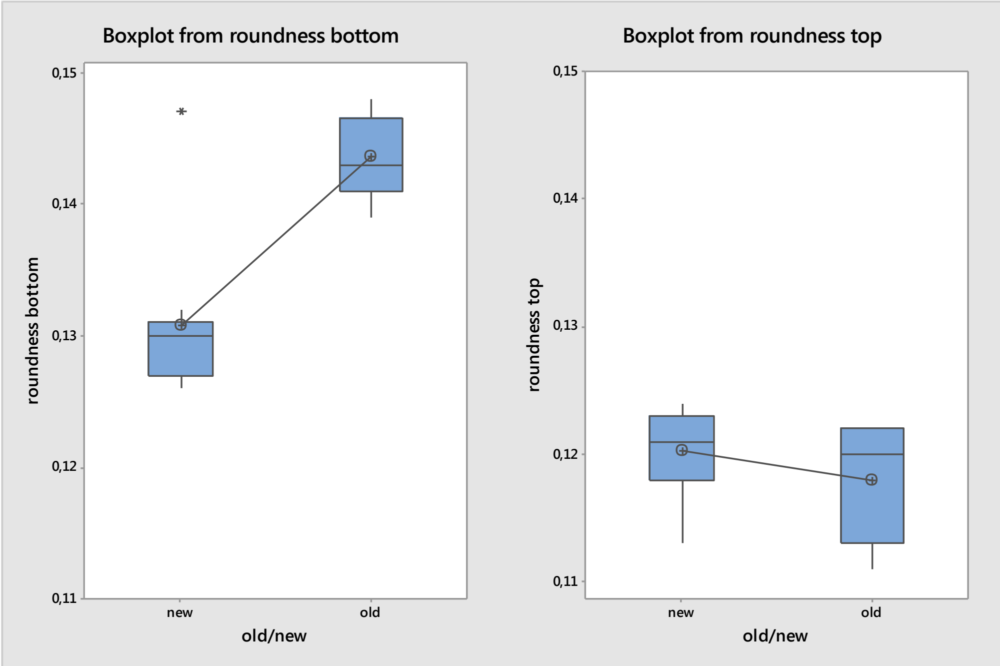


Figure 5.35: Boxplot from roundness bottom/top and old/new ring (Michael Riesenhuber 2016)

In these two plots there is a difference between the old and the new ring and also concerning the roundness between bottom and top. The designation “old” and “new ring” does not mean any quality difference such as another production or any other variance. It was referred to the change of the ring, because the old one had to be replaced. The significance level of the roundness bottom is much higher than the level of the roundness top. In fact, they should be nearly equal for such an evaluation, but the difference might derive from the mandrel clearance.

Table 5.21: Roundness and ring (Michael Riesenhuber 2016)

Roundness bottom and ring old/new		**Roundness top and ring old/new**	
Ring	**Piece**	**Ring**	**Piece**
old	5	old	5
new	15	new	15
Sum	**20**	**Sum**	**20**
Variable	**value**	**Variable**	**value**
F-value	29,55	F-value	1,43
p-value	0,000	p-value	0,247

Boxplot from diameter bottom/top and old/new ring

For visualizing the diameter and the change of the ring a boxplot is created. According to the p-value, significance is just on the bottom side and not on the top side. But as already mentioned, normally results should be rather similar for such an evaluation.

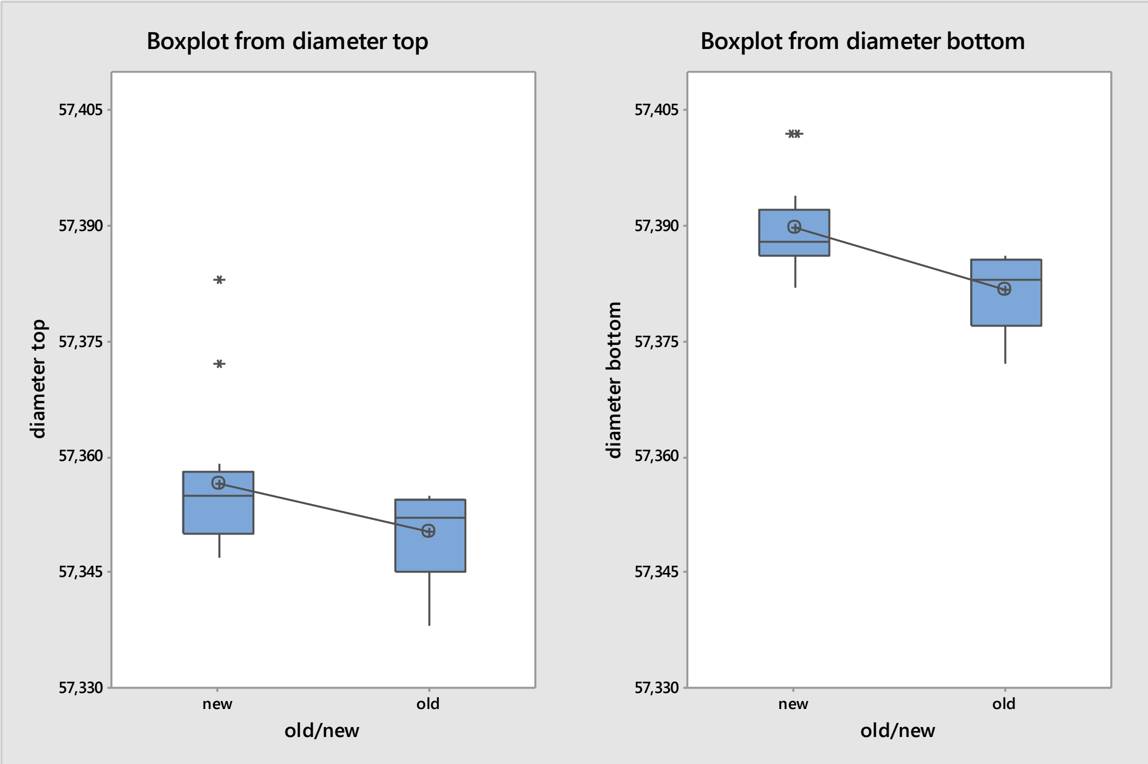


Figure 5.36: Boxplot from diameter bottom/top and old/new ring (Michael Riesenhuber 2016)

Table 5.22: Diameter bottom/top and old/new ring (Michael Riesenhuber 2016)

Diameter top and old/new ring		Diameter bottom and old/new ring	
Attribute	**Piece**	**Attribute**	**Piece**
old	5	old	5
new	15	new	15
Sum	**20**	**Sum**	**20**
Variable	**value**	**Variable**	**value**
F-value	1,79	F-value	7,86
p-value	0,197	p-value	0,012

Boxplot roundness top and bottom

This boxplot has the aim to visualize the difference between the roundness top and the roundness bottom. Bending and moving the mandrel in the center has the effect displayed in Figure 5.37. If the result between top and bottom is to be fairly similar in the future, one cannot avoid fixing the mandrel in its initial position since otherwise it is not possible to achieve small tolerances.

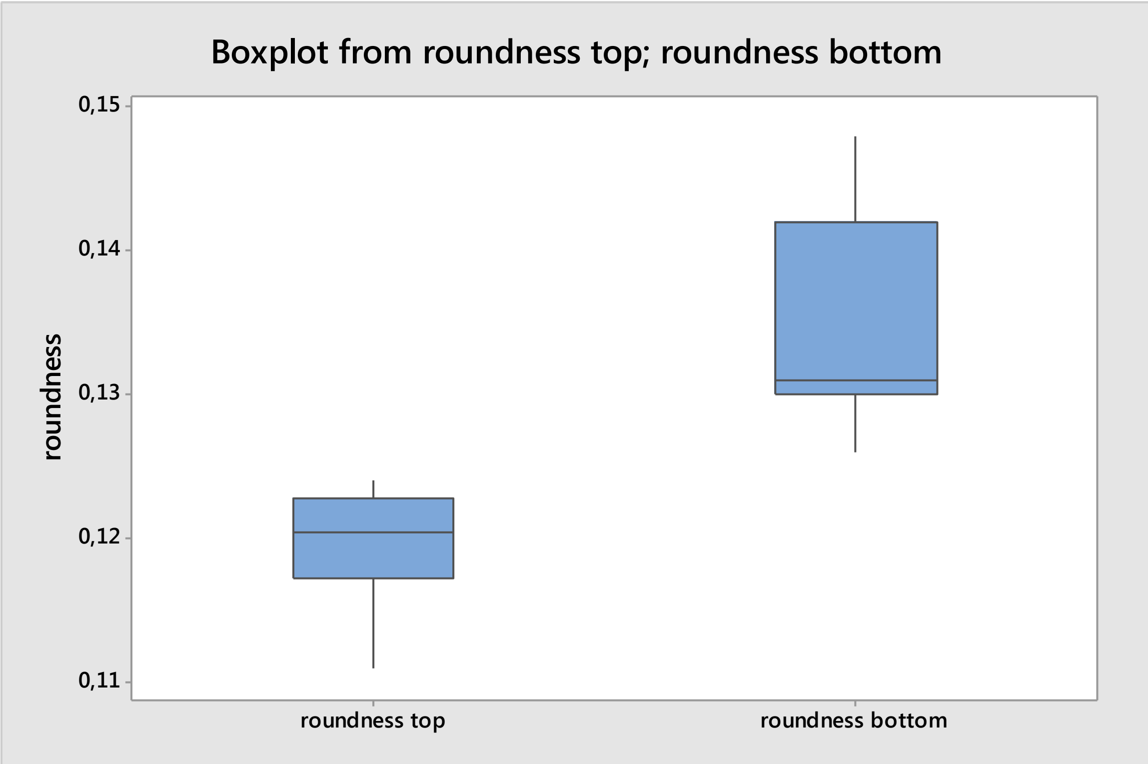


Figure 5.37: Boxplot roundness top and bottom (Michael Riesenhuber 2016)

5.6.5 Conclusion of statistical evaluation

The aim of the statistical evaluation is to ascertain where the main influences originate from and which levers are responsible for which quality criteria. Filtering the data was necessary to generate useful results, but this reduced the amount of useable experiments drastically.

Evaluation of the trial data

The first analysis discovered a lack of saved information. Unfortunately, digital measurement data are not available anymore and noted information just regard the roundness (highest peak minus lowest peak) and the diameter of the bushing. To fill these information gaps an additional evaluation method was created. A transparent sheet was designed to obtain more information from the stored measurement pdfs.

With these supplementary figures it was possible to evaluate specific areas of the bushing. Because the measurement data had a different reference diameter, it was not easy to compare different bushings. Statistical evaluation with Minitab did not show all relevant influencing factors, since the focus of documentation was not a DoE and some data were not complete. The received outcome facilitates doing a DoE in the future, because the main factors are shown in this thesis with the one-way ANOVA. These main factors include plate length, surface quality, slider geometry and the gap between slider and mandrel.
The information gaps are documented and prepared for further projects. With all the detailed information it should be possible to do an evaluation in the future. For a correct statistical evaluation and to determine the influencing factors it is essential to do a design of experiment (DoE). Chapter 5.8.4 illustrates how such a DoE has to be prepared and what process steps have to be taken. Finally, a systematical test sequence is important for a reliable result.

Evaluation of the reference samples
Although the number of reference samples was not very large, it managed to show the difference between two charges. After the first ring was consumed, the second one was loaded and the roundness evaluation showed a difference between the first six bushings and the rest. This leads to the assumption that the behavior of the material must have changed. To determine the material influences further investigations are necessary. Another positive outcome was the small deviation of the bushing line. During one day production the quality of the bushings hardly varies.

5.7 Information lack

In the process of conducting this master thesis it became apparent that the distinct lack of information prevents evaluations to be done afterwards. With the given documentation and information it is not possible to retrace a certain experiment. If there happens to be any quality problems or complications with the process itself, one cannot reconstruct previously done tryouts. Knowledge gained from this experience lies in the necessity to document the information gaps and fill them as effectively as possible.

5.7.1 Measurement

Measurement is one of the most important things for a statistical evaluation. If the measured data are incomplete, wrong, or the false information was extracted, it is not possible to do a correct evaluation afterwards.

Measurement data
Bushings are measured with the Zeiss coordinate measuring machine after the forming process. The generated graphical analyses were saved as pdf files in a specific folder, but the related raw data from the 3d machine were rejected. The raw data from the measuring tracks of the Zeiss machine include all the relevant data for the bushing. This means the documentation of about 850 points describing the outer contour. If these raw data are still available at a later point, it is rather easy to do every evaluation which is needed. These data enable to select just a specific area of the bushing or determine every specific peak. Only noting the roundness, however, is definitely too little to work with, because it gives no information about the location of the extreme values. There is no evaluation of geometry details like clinch, label or others.

Measuring tracks
The definition of the measuring process with the measurement tracks concerns attributes which are located on the bushing. It is possible that the tracks are not placed in the critical zones. This entails loss of information because the measurement note compared to another bushing might have looked better than it really was. The clinch area is also not covered with the selected tracks, so there is no information about the clinch quality and the performance after grinding.

Documentation of plate geometry
The documentation of the plate geometry only includes the length of the plate but no information about the attributes. There is a lack of information concerning the position of the oil groove, the depth or other attributes.

Measuring device for plate geometry
Geometry details on the blank are checked with a caliper and a depth gauge. Chapter 5.4.2 describes the measuring procedure, which has a lot of error sources. Results strongly depend on the operator and a great variation of the values is common.

5.7.2 Documentation of the experiments

Extensive documentation was done for the experiments but there are a few factors missing which would be relevant in order to trace an old status. If the slider geometries are not known, it is not possible to have a uniform starting position. For a complete documentation it is also essential to note the travel distances and angles of the sliders and the presses.

5.7.3 Geometry data of dies

Because all the changes for dies and sliders were done at DIETZ Company, in fact all the drawings and expertise were located at DIETZ and not at Miba. This fact leads to problems for modifications because Miba did not always have the correct information about the actually used geometry details. If some changes were done, DIETZ sometimes happened to also lack the correct drawings of the used geometries. Longer waiting time and additional rework were the consequences, which again resulted in loss of time and increased costs if a certain, not updated part was ordered.

5.7.4 Material properties

The act of determining and evaluating influencing factors revealed a great number of aspects that are responsible for the quality of the end product. One of these factors is the material properties, which surely have an influence; however, the factor is not known exactly.

5.8 Close information gaps

Information gaps are crucial to locate and eliminate because otherwise it is nearly impossible to achieve the required quality in a short time. Long development time raises the costs of a project and can lead to losing the contract in the worst case. The minimization and elimination of these gaps is decisive for success. With detailed documentation it is easier to determine the cause of an error.

5.8.1 Measurement

Additional measuring track

Currently the measuring tracks are placed at the center with a distance between each other of about 15mm. These tracks were selected during tests and they should not touch the attribute elements on the bushing surface. They were placed close to the label, but there was no investigation whether this is the critical path.

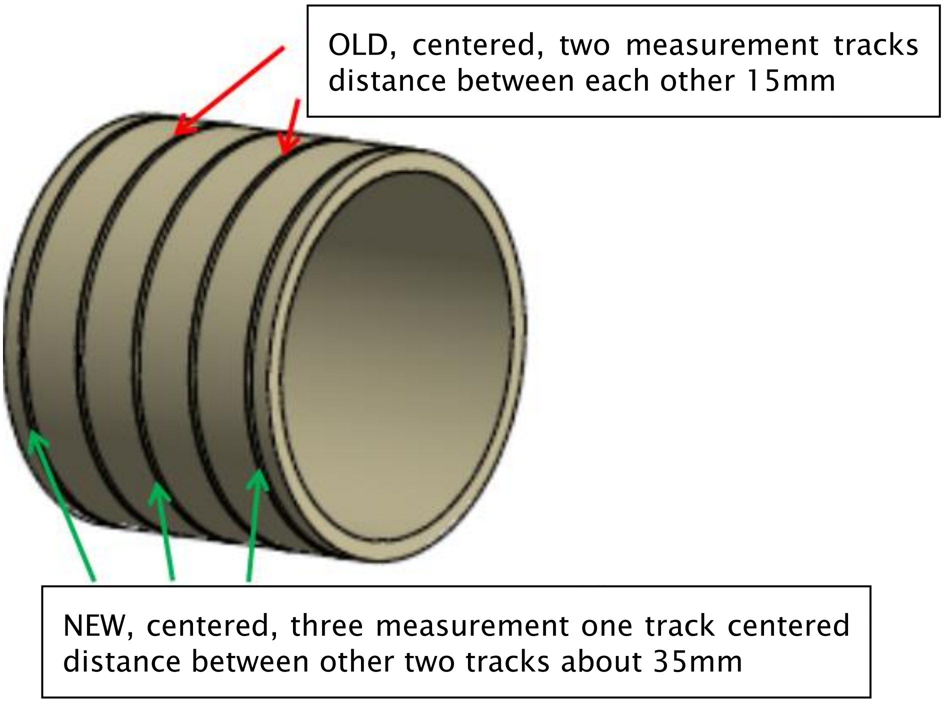


Figure 5.38: Bushing with old and new measuring tracks (Michael Riesenhuber 2016)

To extract more information from the bushing, it would be necessary to optimize the paths of the measurement tracks. Optimization here does not mean to find the tracks with the best roundness, but to locate the critical paths and transfer the tracks to it. A first concept would add a third measurement track in the middle of the bushing. This path should monitor the clinch and its critical zones. Investigation showed problems during grinding in the clinch zone because the surface was not clean after the last grinding step. With the additional track it should be possible to determine a tolerance field and check this continuously. The paths of the original tracks could also be moved to the outside of the bushing. Critical zones could be determined during simulation with FEM or during practical tests. This does not provide better results in roundness, but it gives more information about the real quality of the bushing.

Change of measurement analysis

To improve the readability and the comparability of the measurement analysis some changes have to be done. The main changes are explained in detail in Chapter 5.4. They should show the operator the real variance of the surface based on the basic diameter and centered by the real bushing. Transformations from the orientation of the bushing make adjustments easier for the operator.

Documentation of Zeiss raw data

It is vital to save the Zeiss raw data because these data document the whole bushing form and include the entire measured points of the bushing. The points are described with the coordinates X-axis, Y-axis and Z-axis.

Table 5.23: Zeiss raw data example (Michael Riesenhuber 2016)

XACT	YACT	ZACT
0.000	-28.779	15.200
-0.151	-28.777	15.200

This is symbolical and shows just two points. Normally one track of a bushing is described by about 1200 points.

Automated in-line measuring

During serial production the bushing is not permanently checked for its quality. The presses and sliders lack measuring systems that monitor the quality. This means that there is absolutely no check whether the bushing and the attributes are in the correct position and whether they have the expected depth. To obtain the missing information and ensure the required quality of the product, an automated in-line measuring system could be implemented to the truck bushing line. In this system the outer diameter, the roundness and the position and quality of some attributes could be determined. Trevista optical is a possibility like other optical systems to do an in-line control of the serial production. This does not just help minimizing the amount of scrap parts; it also serves to monitor and document the machine’s capability.

Install Additional measurement system

If an in-line quality check is not practicable, there is also the possibility to install some other measuring systems. One could be an optical or laser system to check the plate length. The length is essential for the quality of the finished bushing but varies very easily. Normally the gripper feed is responsible for the plate length, but it could also differ because of the big distance between gripper feed and clinch cutting. With an optical system there is also the possibility to check geometry details of the blade.

During production the metal strip sometimes reared up. That originated from geometry failures, contaminations or other effects and results in defects and time consuming repair work. To prevent such a rearing up of the stripe the installation of a laser or magnetic sensor would be an option.

Documentation of plate geometry

In order to enable replication of the plate geometry for claims or quality problems it is necessary to document all relevant geometry data of the board. Therefore, a measurement sheet in qstat (quality program) has to be prepared and all previously defined values have to be checked carefully. This allows an evaluation to be done afterwards and also has a big advantage for handling claims.

Measuring device for plate geometry

To minimize this source of error an additional measuring tool is needed. The best solution would be an in-line device which checks all the relevant dimensions digitally. Another possibility would be using a marking gauge with additional measuring equipment to position the blank.

5.8.2 Documentation

The formerly common documentation method creates a lack of information. To fill these gaps some positions are added to the documentation sheet. With these additional positions it should be possible to reconstruct each experiment at a later point in time. Therefore, it is necessary to attach the drawing number to the sliders and all the relevant parts of the dies. This facilitates replacing such marked die parts. Noting the traveling distance of the forming unit and the presses is required. For each experiment all relevant drawing numbers have to be noted in the documentation sheet.

Table 5.24: Documentation old and new compared (Michael Riesenhuber 2016)

Old documentation	New documentation
Trial related	**Trial related**
Trial number	Trial number
Customer	
Date of the experiment	Date of the experiment
Material related	**Material related**
Order number	Batch number
Stripe geometry	Ring number
Batch number	
Miba material number	
Ring weight	
Production date of the material	

Forming unit	Forming unit
Slider top diameter	Slider drawing number
Slider bottom diameter	
Slider top coating	
Slider bottom coating	
Mandrel height and width	Mandrel drawing number
Slider guide top/bottom	
Edge of slider	
Forming oil	Forming oil
Plate position in forming unit	Plate position in forming unit
	Traveling distance and angle of sliders
Process related	**Process related**
Machine speed	Machine speed
Diameter bushing	Diameter bushing
Roundness bushing	Roundness bushing
Comments	Program name
Program name	Which changes are done?
	Why is the change done?
	Is an improvement achieved?
Plate geometry	**Plate geometry (qstat)**
Plate length	Plate length
	Plate width
	Position of oil groove 1
	Position of oil groove 2
	Depth of oil groove 1
	Depth of oil groove 2
	Position of hole
	Position dent
	Thickness total
	Thickness ratio steel/bearing material
Press related	**Press related**
	Clinch cutter drawing number
	Traveling distance and angle of presses
	Oil groove stamper drawing number
	Cutting related drawing numbers

Reading machine related data

The program has to be saved with a meaningful name in order to be able to be read afterwards. In this program all machine and forming unit related data are saved. Travelling distances and angles of the moving motions are written down by hand with the new documentation sheet, because the operator needs it for adjustment work. However, it is also possible to read the program data at the machine.

5.8.3 Geometry data of dies

To improve the adjusting process all the know-how and geometric information of the dies and sliders need to be switched to Miba. It is also a great advantage to have the last version of the drawings at one's disposal. This shortens the respond time for small adjustments because these can be done right in the company. To have the drawings in the building is also important if anything happened to the supplier, for example, because of their economic situation or other unplanned actions.

5.8.4 Structured testing process

In order to achieve an improved process one needs to do a structured modification of the influencing factors. If the experiments are not structured, it could lead to wrong conclusions. It is very important to vary just one factor because otherwise the real reason for the modification could not be pinpointed. Moreover, the documentation of the reason why a modification is done and the result of the modification are essential, too. If a design of experiment (DoE) will be done in the future, a structured testing process is vital. The method of doing a DoE is described in detail in Chapter 2.3.2.

5.8.5 Additional evaluation with excel

With the raw data of the Zeiss 3d measurement machine (as explained in Chapter 5.8.1) it is possible to do additional evaluations with excel, for example. To obtain more information from the measurement note a excel file was created which allows the user to evaluate a few defined areas of the bushing. This file makes it possible to check the roundness of the bushing without the clinch, just the clinch or every single slider. Now it is possible to do more and different evaluations and to check specific geometry criteria.

Versuchsnummer NEU:	22	Einlesen zweier Versuche			
Versuchsnummer ALT:	11				
		Vollkreis	Ohne Clinch	Bereich 3	Bereich 4
	Winkel	0 bis 360	8 bis 350	220 bis 250	100 bis 150
	Groß	0	8	220	100
	Klein	360	350	250	150
Versuch NEU gegen Ausnehmung					
	Durchmesser	57,3863871	57,3855502	57,3898275	57,3780101
	Rundheit	0,22972086	0,2096947	0,03737031	0,04360559
	Punkte im Durchschnitt	65%	67%	100%	97%
Versuch ALT gegen Ausnehmung					
	Durchmesser	57,460758	57,4605666	57,4614619	57,4378227
	Rundheit	0,32397903	0,32397903	0,04318717	0,07802029
	Punkte im Durchschnitt	27%	27%	92%	56%
Versuch NEU bei Ausnehmung					
	Durchmesser	57,3921657	57,3903266	57,3941278	57,3803845
	Rundheit	0,22268761	0,18374422	0,03221522	0,03965281
	Punkte im Durchschnitt	66%	68%	100%	99%
Versuch ALT bei Ausnehmung					
	Durchmesser	57,3850797	57,3860758	57,4297437	57,3465127
	Rundheit	0,16654207	0,16654207	0,05587653	0,05168534
	Punkte im Durchschnitt	32%	33%	72%	92%

		Rundheit		Durchmesser		Pkt. Im Durchschnitt	
		gegen Ausnehmung	bei Ausnehmung	gegen Ausnehmung	bei Ausnehmung	gegen Ausnehmung	bei Ausnehmung
Vollkreis	Versuch 22	0,230	0,223	57,386	57,392	65%	66%
	Versuch 11	0,324	0,167	57,461	57,385	27%	32%
	NEU vs. ALT	0,094	-0,056	0,074	-0,007	38%	34%
Ohne Clinch	Versuch 22	0,210	0,184	57,386	57,390	67%	68%
	Versuch 11	0,324	0,167	57,461	57,386	27%	33%
	NEU vs. ALT	0,114	-0,017	0,075	-0,004	40%	34%
Bereich 3	Versuch 22	0,037	0,032	57,390	57,394	100%	100%
	Versuch 11	0,043	0,056	57,461	57,430	92%	72%
	NEU vs. ALT	0,006	0,024	0,072	0,036	8%	28%
Bereich 4	Versuch 22	0,044	0,040	57,378	57,380	97%	99%
	Versuch 11	0,078	0,052	57,438	57,347	56%	92%
	NEU vs. ALT	0,034	0,012	0,060	-0,034	41%	7%

Figure 5.39: Additional excel evaluation (Michael Riesenhuber 2016)

First, the experiment number will be selected and afterwards its raw data can be read. The file compares two experiments and shows the different previously selected areas. With this file it is simple to evaluate the bushing regardless of the clinch since the clinch is mostly the bad area of the bushing, although it is not clear whether the clinch area influences the grinding process significantly.

5.8.6 Material properties

At the moment the correlation between the material, its properties and the end product is not known. For a better understanding of the process it could be helpful to monitor the material related to the end product. With the documented properties it should be possible to understand the forming behavior in a better way. Therefore, it seemed unavoidable to spend time doing investigation of the material to improve the bushing quality. It would also be interesting to analyze the production, the slitting and the coiling of the raw material.

Material specification

It seemed that the material specification has tolerances that are too high and this could allow property distribution in the raw material. Different material properties could result in different forming behaviors.

Goal of material test

The aim of the material property evaluation should be a better understanding of the influence exercised by the material. In the best case it could be possible to adjust the bushing line just with the material property data from the incoming good inspection.

5.8.7 Data management

Collecting all the mentioned information leads to a big data volume. To avoid data garbage it is very important to check which data are really necessary to save. In the development phase in particular all the data need to be saved for the improving process. For a process analysis and detecting the standard deviation it is essential to have all the relevant data. If the process is analyzed and the influencing factors are detected, it suffices to just save the relevant geometry and machine data and the values which cannot be controlled or monitored easily. So the huge data volume is just collected for the ramp-up and the understanding of the process. Once the process is clear and controlled the saved data could be reduced.

5.9 Cause and effect diagram

In many technical applications it is very hard to determine the origin of a failure. Therefore, a structured cause and effect diagram is generated to make it easier to detect the failure and its root cause. Designing such a diagram proves difficult, because the process and all the process related steps are very complex. The main influencing factor that may seem obvious does not always need to be the actual cause for failure. The complexity of the process requires the operator to always think about all the other factors which could possibly have an influence on the failure, too. They have to consider the fact that adjusting one factor could lead to a negative result in any other section. Therefore, a cause and effect diagram is created to support the operator to define the root cause.
The yellow fields mark the quality criteria and give the starting point for troubleshooting. Following the lines and the influencing factors, which are marked blue, should guide the user through the factors and their causes. Figure 5.40 gives an overview of all known factors with all known correlations. Continuous improving is required to generate a tool which can be applied by and support affected persons. The diagram is constructed according to the main sub processes

- Raw material:
  describes the properties and the behavior of the raw material, the material is delivered by an extern vendor

- Coil welding/grouting:
  Coil joining is necessary to be produced with an endless ring; otherwise loading of every single ring is required

- Cutting:
  this describes all the cutting tasks which are done in the truck bushing line

- Gripper feed:
  is the process step which is mainly responsible for the plate length and the transport of the strip through the process

- Hydraulic press unit 1:
  in the hydraulic press unit 1 the rough cut and the coining of the oil grooves are located

- Design of die:
  this describes all relevant information of the die, some geometry elements could vary depending on the application

- Measurement errors:
  depending on the operator and the measurement equipment the results can vary

- Control unit:
  it is responsible for the machine and forming unit related data such as traveling distances and angles of motion

- Hydraulic oil:
  the hydraulic oil can vary in viscosity, temperature and age; it is a undefined factor which could be influenced by temperature, moisture etc.

- Contamination:
  could come from abrasion, wear, contamination from outside or any mechanical stress

- Periphery:
  the outer limits or edge of an object or area; periphery covers blank oiler, decoiler, strip straightener, bushing output etc.

- Forming unit:
  the forming unit is the last step in the truck bushing line and has the biggest influence on the quality of the end product.

5.9.1 Cause and effect diagram overview

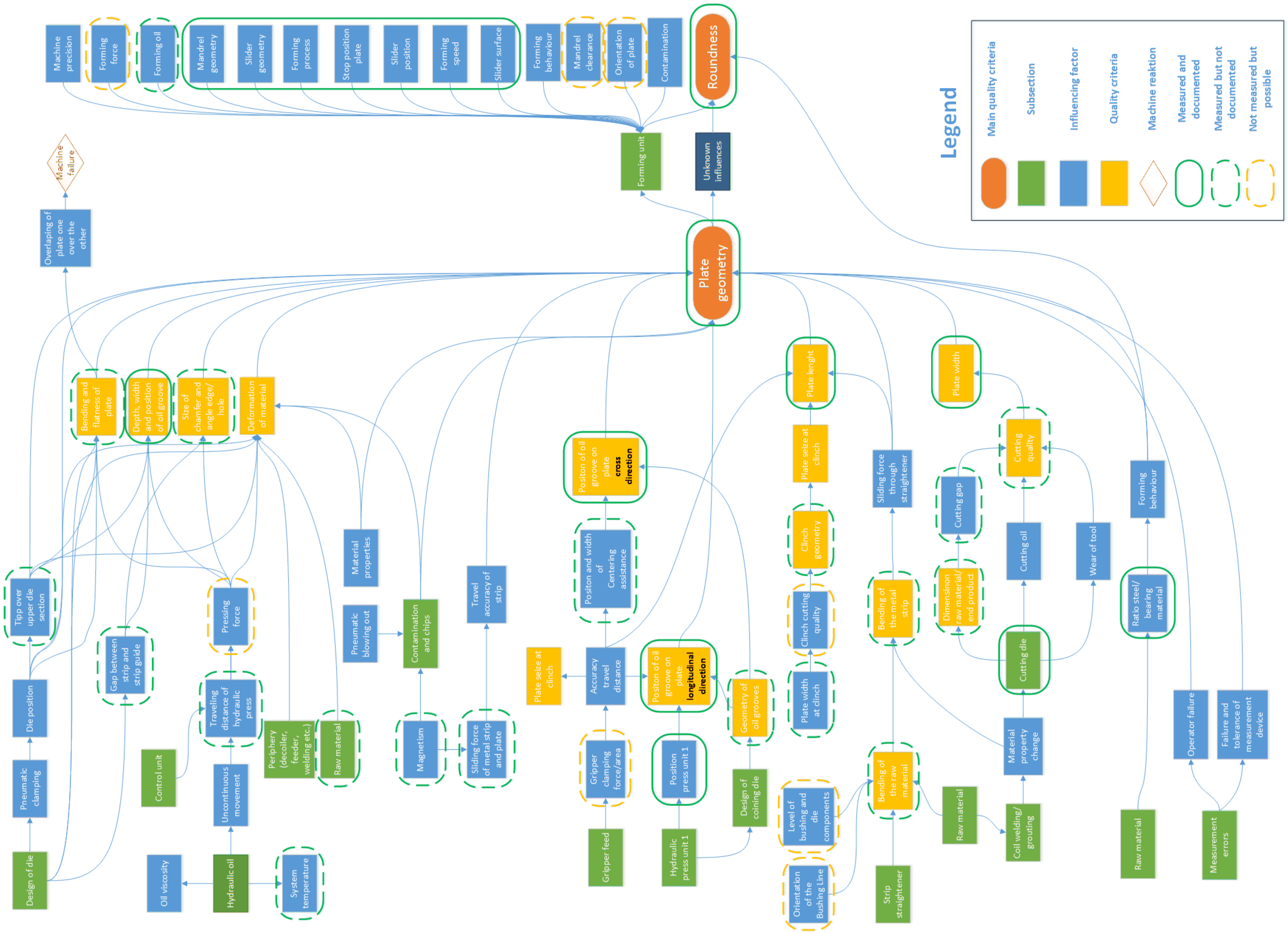


Figure 5.40: Cause and effect diagram overview (Michael Riesenhuber 2016)

5.9.2 Usage of the cause and effect diagram

The Figure 5.41 illustrates how the cause and effect diagram is used. In this particular case shown below, the roundness of a bushing is not within the tolerance field. To find out where the failure derives from a specific part of the diagram was selected. The selected part of the diagram is chosen because first investigation showed a problem with the plate length (red circle). Next step is to follow the lines back to the root cause (red lines). In this special case the reason for the wrong plate length is determined by the clamping force of the gripper feed.

It could, however, also come from the clinch cutter geometry or the sliding force of the strip through the dies. Experience and carefulness of the operator is crucial for the success of failure detection.

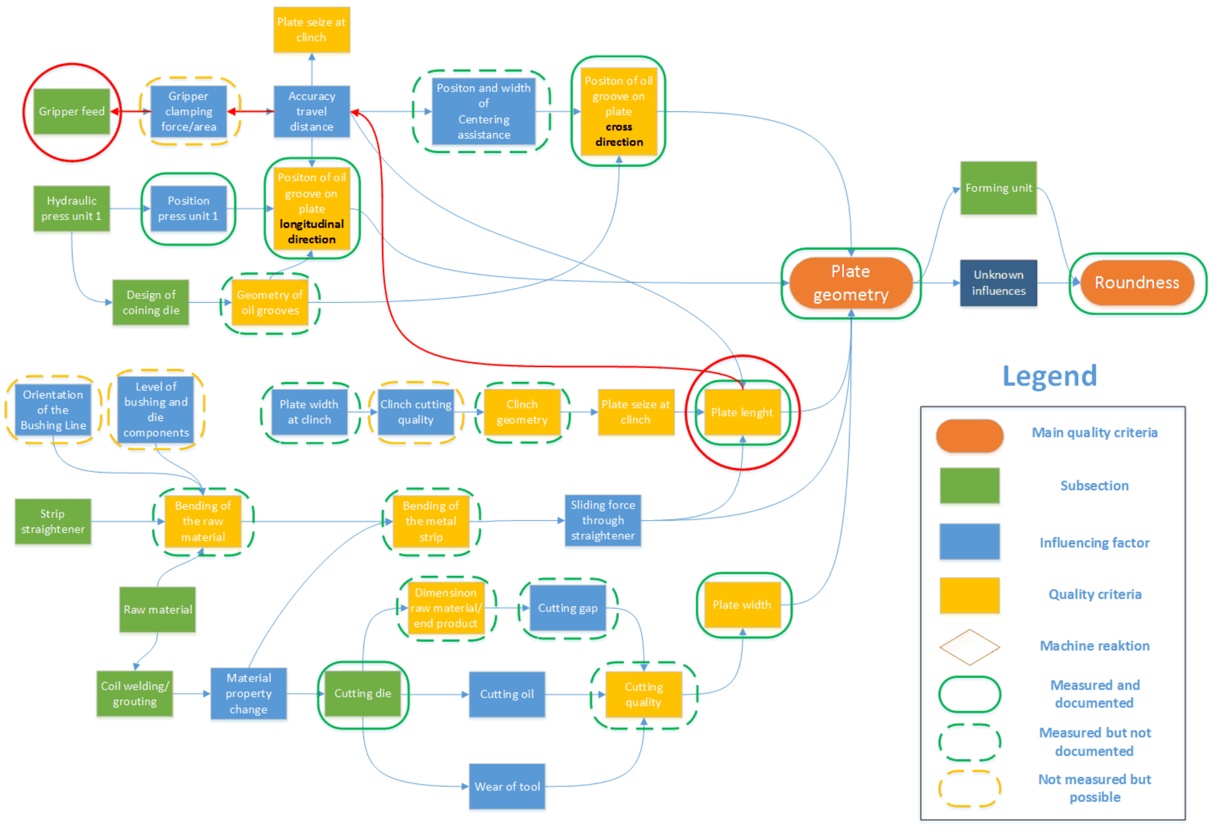


Figure 5.41: Usage of cause and effect diagram (Michael Riesenhuber 2016)

5.9.3 Forming unit

The forming unit is the last step in the truck bushing line and has the biggest influence on the quality of the finished bushing. It is the subsection where the main levers are assumed. Adjusting work is monitored just in the roundness evaluation. There are a lot of influencing factors which can be adjusted during the tuning tasks.

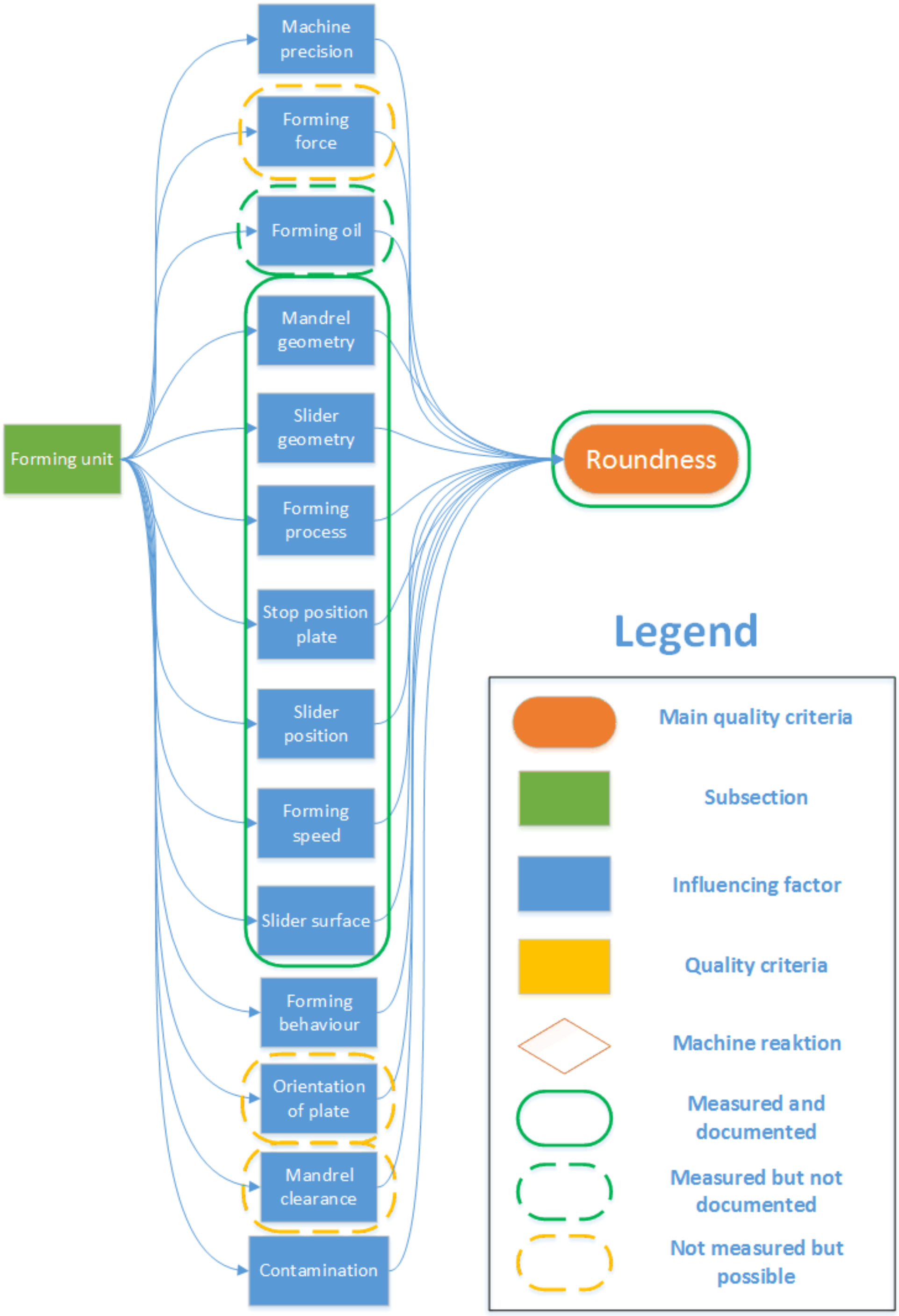


Figure 5.42: Forming unit (Michael Riesenhuber 2016)

5.10 Improvements emerged through master thesis

The insight of this master thesis is the lack of information and documentation failures. Nevertheless, some developments and improvements are implemented. It is a starting situation for doing a DoE and for a better understanding of the process because some factors are detected and noted. This list shows an overview of the enhanced processes:

- Showing information gaps
- Documentation of plate geometry via qstat
- Installation of sensors against rearing up of the metal strip
- Positioning die with dowel pin
- Installation of drawing standard
- Reading machine related data
- Introducing simulation support
- Establishing project meetings
- New measurement evaluation and documentation
- Additional evaluation with excel
- Cause and effect diagram
- Improving ideas for new projects

5.11 New projects

If a new project request is received, it is important for the success of the task to follow some steps to reach the set goal. The sequence could vary from job to job depending on the geometry and the gained knowledge from the previously done projects.

Basic rules

At the start of a new project one needs to follow some basic rules. Without this rules it is much harder or even impossible to achieve success.

- Before starting a project or improvement make sure you know what the aim is and set a clear, measurable goal
- Ascertain that the project related persons can communicate and cooperate in frequent meetings
- Describe a project plan and discuss the approach
- Define clearly documented mile stones and important project steps
- Create a concept for the time schedule
- Make sure that the time schedule is achievable when interacting with related departments

- Control and customize the time and project schedule if necessary
- Hold continuous meetings with decision-makers for a coordinated approach
- Discuss all changes in an expert group
- Write down every idea to make sure no idea or improvement gets lost (To Do list for improvements)
- Inform everybody involved in the project about changes
- Work as a project team
- Use experts, knowledge carrier, software tools etc. if necessary and possible
- Do not vary in serial production

Process steps

- Receiving the project
- Doing a finite element analysis of the product
- Checking feasibility of the project
- Checking the geometry of the bushing and define the necessary production steps
- Completing documentation in the early stages
- Determination of the bushing diameter and the plate length
- Determination of the relevant geometry data
- Determination of the tolerances according to the subsequent machining
- Determination of the product related main influencing criteria
- Brainstorming and documentation (for understanding the process) of all influencing criteria
- FEM: Doing the experimental design with finite element and evaluating them
- FEM: Creating a DoE (Design of Experiment)
- FEM: Varying the main influencing criteria according to the DoE
- FEM: Determination of the optimal geometry and the optimal factor settings
- Ordering and setting-up the defined tools
- First test production and optimization of the process
- Doing a DoE in reality to reach the center of the tolerance field if necessary
- Defining a status quo as a base, all improvements based on the status quo
- Checking results if possible in advance with finite element if improvements are necessary
- Completing documentation of the improvements (Why? Who? Improving? etc.)
- Making sure every experiment is reproducible in each detail

Important documentation notes

For continuous improvement it is necessary to have a complete documentation of the experiments and the received results. To go back in time to a specific point it is important to document all the process related data such as structured in Table 5.24.

FEM (Finite Element Method)

To reduce the process development costs one can use the power of a simulation tool. It is helpful to simulate the process in advance since this can reduce the risk of failures. It is also a tool to support the designer during the construction phase. Finite element method should not just be applied in the construction or development phase, it should also support the improving process. FEM was not used at Miba in the past but its implementation has already started. One should be aware of the power of the simulation but also of the difficulties, especially for a multicomponent material. Normally, the material properties are known of the single materials and not the combination of two or more materials. It could be a helpful tool for coarse tuning, but surely has problems with fine tuning at the moment.

DoE (Design of experiment)

For the development and improving processes a DoE could be the best way to reach the tolerance field. A DoE uses a structured testing procedure to receive a lot of information with just a few experiments. This statistic tool reduces the costs, the required time and also shows the engineer the lever they have to adjust.

Different production processes

If a project will be started, it makes sense to think about different production processes. One should start with determining the required tolerances of the finished product, then select the right machining operation for the application and check the feasibility of the different machining possibilities. If there are problems with machining tolerances, one should check potential solutions. Reviving old ideas may be effective since they might work in another application.

Brainstorming

The power of brainstorming sessions should be used in every stage to generate as many ideas as possible. Carefully adhering to the brainstorming rules avoids killing potential ideas too early. Brainstorming can produce a lot of ideas and the combination of different ones could potentially deliver the best result.

Schedule for possible new projects

For new projects the best approach is to follow a previously defined timeline. The timeline has to be adapted continuously according to the gained knowledge. To ensure a close cooperation between the technicians and the project team a first guideline is created. It is vital to make sure this guideline is followed and the meetings are held. This guideline is just a first approach for new projects and has to be applied, adapted and improved continuously.

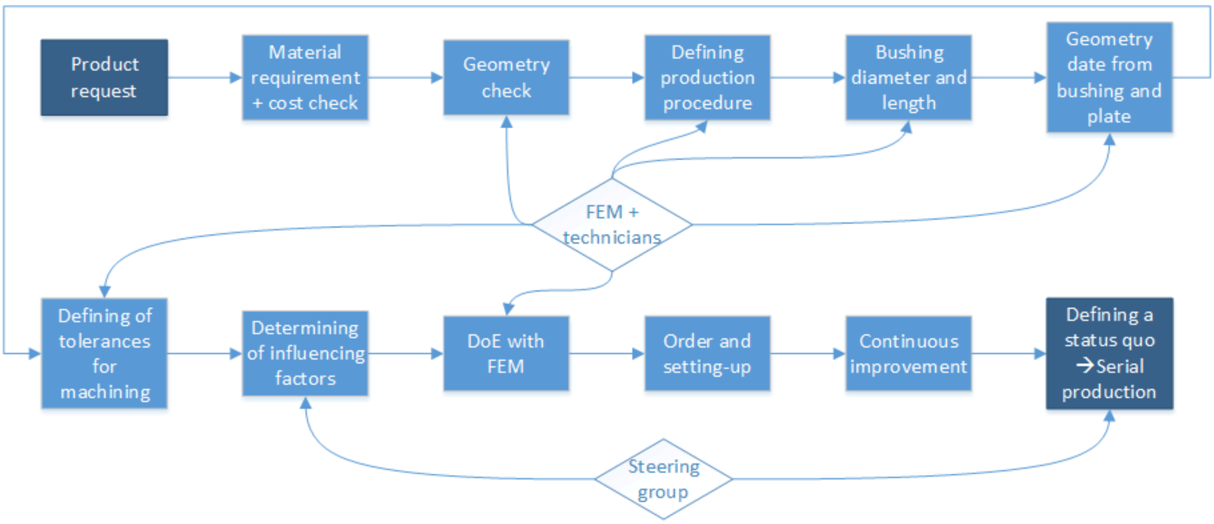


Figure 5.43: Schedule for possible new projects (Michael Riesenhuber 2016)

Schedule for possible modifications

If it is required to do some modifications, it is also very important to follow a defined schedule to avoid unnecessary mistakes. With this schedule the close cooperation between operator, project team, technicians and all related persons should lead to a positive outcome in a short time. The schedule itself depends on the project and its complexity and needs customization if required.

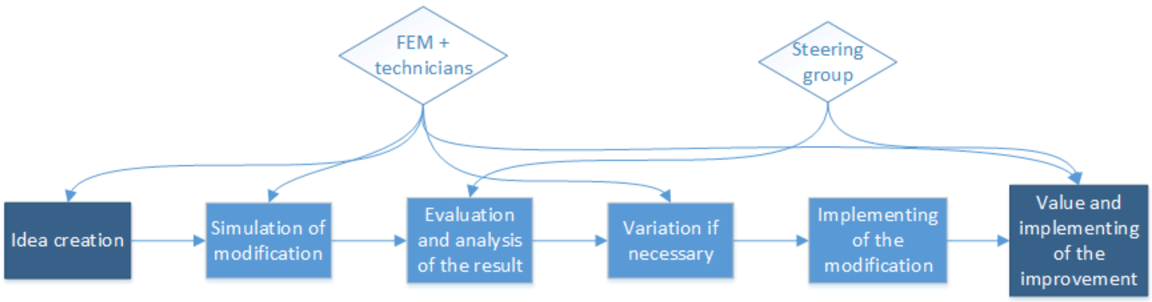


Figure 5.44: Schedule for possible modifications (Michael Riesenhuber 2016)

6 New bending sequence

The old forming sequence with four sliders prevented possibilities to further improve the quality of the end product. In cooperation with external experts a new forming concept was generated to enhance the quality of the bushing. The new sequence is a forming process with more forming sliders, a mandrel positioner, a plate holder and a plate loader.

Advantage of the new system

The roundness should be improved with the usage of more cylinders and sliders. Orientations of the cylinders are selected to minimize buckles and shape deviations as best as possible. Different settings could be applied with the higher amount of sliders. Flexibility for new projects is ensured with the possibility to move the cylinders nearly 360° and to vary the number of cylinders.
The positioning slider for the mandrel should protect it against unintended movement. This should minimize the difference between the two or more measurement tracks.

Sequence

Loading the plate → clamping with clamper → tip sliders moving upwards and steering sliders describe the movement → prebending left and right → removing the prebending mandrel → form giving movement of the prebending slider right → closing the clinch → ejection of bushing with prebending mandrel

7 Summary and Outlook

The analysis of old trial data shows some correlations between the geometry of the sliders and the quality of the bushing. Identifying the correlations was only possible by following a new analysis procedure which was done with a transparent sheet. A great amount of variations of the influencing criteria were done without a precise plan and this may sometimes lead to misinterpretations. A disadvantage for the statistical evaluation was the poor distribution of experiments over the adjustment range. However, as a result of this thesis the documentation gaps are noted and adapted for the new forming sequence. One of the biggest improvements provides the new measurement analysis, which definitely simplifies the adjustment work and enables outsiders to read the Zeiss evaluation. The cause and effect diagram is also a new possibility for persons involved to understand the process and the linked influences. Although the thesis did not yield the expected results of detecting every single influencing factor and the exact related quality criteria, it still revealed problems of documentation and also showed the main factors which could be the basis for a future DoE.

The next step for the truck bushing line is conducting an investigation of the process capability to figure out how robust the process is. This is the first step to guarantee bushings with a constant quality. In order to ensure the quality it is required to determine tolerances for the roundness, outer diameter, quality of the surface and contact area of the bushing. Checking these quality criteria could be done using the Zeiss in combination with additional excel files, but it is required to adapt the files and exactly define the limit values.
Rough designs for new products could be done by trial and error but supported with a simulation tool. For fine adjustments a DoE is unavoidable. To use such a statistical tool it is very important to have a structured testing procedure where the factors vary in a defined way (testing sequence from DoE).
Since there is no control of the machines movements, there is also no alarm signal when the hydraulics does not move according to the defined way. To avoid geometrical defects it would be helpful to install an inline measurement system or, at least, to implement an end point control.
For the whole bushing production the tolerances should be determined, because with defined tolerances the additional processes might be changed. Additional processes are necessary to fulfill the requirements, but the requirements are not exactly defined. It could also be helpful to think outside the box, because another grinding technique, for example, could lead to an improvement in the throughput time.

List of Figures

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List of Literature

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