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MARIBOR

Coordinate Measuring Machine (CMM) in part modification

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Maribor, 2021

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Signed Ikesh Maharjan, am the author of the diploma thesis titled *Coordinate Measuring Machine (CMM) in part modification,* which I wrote under the mentorship of mag. Jože Ravničan, uni.dipl.ing.str..

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GRATITUDE

I owe my immense gratitude to my mentor mag. Jože Ravničan who helped me through all my academic years as well as in the quality of my research for the diploma thesis. He has been an absolute example of a fine, understanding, and great professor.

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Last but not least, I want to show my sincere respect to my parents who always believed in me and pushed me towards success.

SUMMARY

To summarize my diploma thesis, It is all about the complication and its solution in the part modification project with the help of a 3D (CMM) measurement system. The main vision of this research is to produce precise modified parts maintaining the required quality to minimize the reclamation and scrap management.

Talking about the primary purpose of the research, the company receives a sufficient number of part modification projects for Mercedes trucks (Unimog and Zetros) throughout the year. It includes small to big spare parts which we modify with heavy stamping, laser cuts, and bending machines. Thus, the main goal is to improve those parts which help us assemble in further processes. On the other hand, it minimizes the reclamation and the cost of production.

The basic research method, used for this project were the primary and secondary research. Since this is my own experience in the related field, the main source of this project was the primary research facing real-time problems and its solution. The secondary research methods like books, articles, and online data were mostly used for the theoretical presentation in the research. It includes an introduction and present condition of the company, description, and use of CMM machine, reverse engineering, geometric precision of the parts to minimize further complication. The experimental part includes the ongoing modification process, implementation of the new plan and system, Measurement programming, and new clampers designed for 3D measurement. CMM is a very crucial device or machine in the manufacturing process of the company. This machine is way more reliable for reverse engineering, digital measurement, CAD comparison, etc. Regarding the modification project, documentation with the 3D measurement report of the modified part within the given tolerance level is very important in order to receive the final payment or complete the project.

With this research, We minimize the measuring time of the part and anticipate the better quality of the parts and reclamation to be reduced by at least 40%. Also, control the production cost with fewer scraps and easier assembly thus, less time consumed.

Key words: Quality, Measurement, Economy, DFA, CAD, RPS

POVZETEK

Koordinatni merilni stroj (CMM) pri spreminjanju delov

Če povzamem svojo diplomsko nalogo, gre za zaplet in njegovo rešitev pri projektu spreminjanja delov s pomočjo 3D merilnega sistema (CMM). Glavna vizija te raziskave je izdelava natančnih modificiranih delov, ki ohranjajo zahtevano kakovost, da bi se zmanjšala reklamacija in ravnanje z odpadnim materialom.

V zvezi s primarnim namenom raziskave je treba poudariti, da podjetje skozi vse leto prejema zadostno število projektov modifikacije delov za tovornjake Mercedes (Unimog in Zetros). Vključuje majhne in velike rezervne dele, ki jih modificiramo s težkimi stroji za štancanje, laserskim rezanjem in upogibanjem. Tako je glavni cilj izboljšati tiste dele, ki nam pomagajo pri sestavljanju v nadaljnjih postopkih. Po drugi strani pa se s tem zmanjšujeta predelava in stroški proizvodnje.

Osnovni raziskovalni metodi, uporabljeni pri tem projektu, sta bili primarna in sekundarna raziskava. Ker gre za moje lastne izkušnje na sorodnem področju, je bil glavni vir tega projekta primarna raziskava, ki se je soočala s problemi v realnem času in njihovimi rešitvami. Sekundarne raziskovalne metode, kot so knjige, članki in spletni podatki, so bile večinoma uporabljene za teoretično predstavitev v raziskavi. Ta vključuje uvod in sedanje stanje podjetja, opis in uporabo stroja CMM, obratno inženirstvo, geometrijsko natančnost delov za zmanjšanje nadaljnjih zapletov. Eksperimentalni del vključuje tekoči postopek spreminjanja, izvajanje novega načrta in sistema, programiranje meritev in nova prijemala, zasnovana za 3D-meritve. CMM je zelo pomembna naprava ali stroj v proizvodnem procesu podjetja. Ta stroj je veliko bolj zanesljiv za obratno inženirstvo, digitalno merjenje, primerjavo CAD itd. V zvezi s projektom modifikacije je dokumentacija s poročilom o 3D-meritvah modificiranega dela v okviru dane tolerance zelo pomembna za prejem končnega plačila ali dokončanje projekta.

S to raziskavo zmanjšamo čas merjenja dela in pričakujemo boljšo kakovost delov ter zmanjšanje reklamacij za vsaj 40 %. Prav tako bomo nadzorovali proizvodne stroške z manjšim številom ostankov in lažjim sestavljanjem, s čimer bomo porabili manj časa.

Ključne besede: *Kakovost, merjenje, gospodarstvo, DFA, CAD, RPS*

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DFA - Design for assembly

CAD - Computer - aided design

RPS - Reference point system

1. INTRODUCTION

Tthis diploma thesis explains the whole process used in the company for the part modification projects, allocates the problem in making precise spare parts and assembling them using Coordinate Measurement Machine. For the prolific clarification, a simple spare part Fender from Mercedes – Unimog truck was taken. For the mentioned part, BNM D.o.o made an agreement with Wagon Automotive Nagold GmbH to be modified as needed in January 2021. Since this is a new modification on a very old work project, numerous problems were faced. Although it was just to make a few new holes and cuttings. The prime problem was that the Company didn't have any kind of clamper or fixture neither for laser cuts nor 3D measurement. Before this modification, all the process was done by press machines through heavy stamping. Therefore, this research is about how the problem was solved and how CMM played its role to get the precise parts, improve quality, reduce processing time in production and assembly in similar modified parts. For this project, CMM by Thome Prazision (Made in Germany) is being used which is operated by a computer software named Rational DMIS. CMM is a very sensitive machine, so the recommended lab temperature is 20 degrees and operating humidity must be 40% - 70%. After the successful attempt with this project, the company is looking forward to applying this research method in upcoming related projects.

1.1 Description of the area and definition of the problem

CMM is a very crucial device or machine in the manufacturing process of the company. This machine is way more reliable for reverse engineering, digital measurement, CAD comparison, etc. Regarding the modification project, documentation with the 3D measurement report of the modified part within the given tolerance is very important in order to receive the final payment or complete the project. Plus, it is easier with the assembly if our parts are the same as those with the CAD model. Therefore, going through the systematic way with CMM helps in an enormous way to the company.

Working on this project, a lot of problems were faced from the beginning on. In earlier years, there were no complicated modifications. Most of it was just to make the change on the stamping die. But now, since processing like bending machines and CNC (laser cuts) were used, the following problems were faced:

- No proper fixture: The Unimog is a very old project in this company. Fixtures were provided only for the assembly. All the processes for spare parts were done by heavy stamping. Lack of clampers or fixtures for laser cut as well as CMM was the major problem.
- Irregular laser cut: At the beginning phase, numerous parts were cut irregularly from the laser. It was all because of improper placement of the part or too tight fixture. Several days of trial and error processes were done. Hence, the maximum number of scraps.
- Long processing time: Several methods were used to prepare the fixture that could be used in CMM. It took a significant amount of time to get to the final desired part.
- Assembling problem: Even though we made the desired part according to the CAD model, different problems occurred during its installation because the fixtures in the assembly unit were changed a lot of times by workers in between these years.
- Unsatisfied Customer: As it took a long time to make the parts ready and installed on the truck and also we couldn't prepare the documentation in a desired period of time, the customer was not happy.

Taking these issues into the account, Using the proper lean tools and with the help of CMM, the processing cost and time can be reduced with the better quality of the parts.

The diploma thesis used the fender part of Unimog truck to explain the problems and their solutions in detail. The theme of this research is to make all the modified parts exactly as demanded by the customer and minimizing the problems in its quality and installation with proper utilization of CMM.

1.2 Purpose, objectives, and basic claims

After the completion of the first modification project, we figured out and listed the complication faced in between. Then the responsible team concluded, CMM can play a major role in solving these problems.

The purpose and objectives of the CMM in part modification project are explained below:

- Minimizing the scrap or production cost: The few new parts from the first production can be measured with the CMM and compared with the CAD model. If the part is under the tolerance treshold, only the serial production can be started to avoid the scrap and minimize the cost.

- Quality spare parts: 3D measurement of our product will lead to the higher quality of the parts. The parts can be prepared to CAD model given by the customer. The geometric precision will be accurate.
- Easier in assembly: When the parts are exactly as needed, it is much easier to assemble. Production units face rare problems to fit it in.
- Self-development of required fixtures: Generally, if customers can't provide the fixtures for measurement or laser cut, the Company can prepare it on its own. The 3D measurement of the self-designed fixture can be done in the company accordingly.
- Precise laser cut: As we are able to develop the clampers and fixtures on our own, the laser cuts will be much more accurate. The deviation for the same position in the part will be minimum.
- Regulation of reverse engineering: Sometimes, the problems regarding the existing checking fixtures or assembling fixtures can be faced with no data history. In such case, with the help of CMM, reverse engineering can be operated to solve the problem.
- Reduce processing time: As we can make precise laser cut, quality part according to CAD model and make assembly easier, the reduction of the processing and 3D measuring time can be achieved.
- Customer satisfaction: If the projects are finished within the given time with demanded quality, the customer is well satisfied. Thus, less or no reclamation is received. An increase in the number of reclamations after the modified parts were installed was a big issue after the completion of the project.

With the experience from the earlier projects, the importance of CMM in part modification is clean and clear. Hence the following assumptions can be made:

- The geometric precision and quality of the parts will be improved.
- The proper regulation of reverse engineering in the required work area.
- The minimum number of reclamation and customer satisfaction.
- Self-development of the fixtures for measurement.

- Minimizes the scrap and production cost.
- Significant decrease in 3D measuring time.

1.3 Assumptions and restrictions

The assumptions for this diploma thesis are enlisted below:

- Deduction of production cost.
- Improve in geometric precision of the product.
- The minimum number of reclamation.
- Self-development of the CMM fixtures.
- Regulation of reverse engineering.
- Measurement time minimized.

The restrictions for this diploma thesis are mentioned below:

- Organizational confidential to CAD model and other data.
- A limited sample of survey.

1.4 Used research methods

The research method used in this diploma thesis is the primary research and secondary research explained below:

Primary Research:

Being a trainee for around 800 hours and now as a responsible employee in the company, the primary research is considered to be the main source of this diploma thesis. The survey in the related work station and visual inspection helped to collect the necessary information in order to get the whole concept. The experts, experienced colleagues, and engineers are regarded as the primary source of reference and information.

Secondary Research:

Similarly, online research, academic books, and journals are taken as the secondary research method to get detailed knowledge about the CMM machine and its use in part modification.

2 THEORETICAL ANALYSIS

This section includes the general description of the company, the elements, and the procedures used in this diploma thesis.

2.1 Company Description

BNM Automobilska Industrija, a Maribor-based company with extensive history to its origin and specializes in the sheet metal forming process. The company develops the desired product of good quality by heavy stamping in order to supply the customers with reasonable price and put a healthy competition in the sheet metal forming industry.

It is located in Tezno, Maribor, Slovenia, an industrial zone with more than 60 years of experience in the metal industry. Until 1996, buses and trucks with brand TAM were manufactured in this place. BNM supply its product mostly to Germany, Austria, Croatia, and Italy. The company works for known brand names like Mercedes, BMW, Jaguar, KTM, Kawasaki, Honda, etc. Genuine customers for the company are Wagon, SW-Motech, KTM, and Magna.

This company is well equipped with six big press machines and nine medium and small size press machines, 2D and 3D laser, 2D and 3D measurement machines, bending machines, welding robots, spot welding, and bolt welding and manual welding machines, etc. Most of the work processes are manual here. Only a few working areas are introduced according to Industry 4.0.

For product development, design, and installation of automotive-related products, the company is ISO/TS 16949:2009 certified. For welding standardization, it is DIN EN 15085 CL1 certified.

Employees working here are professionally trained and very important assets to the company. Approximately 200 employees are working, where experienced workers and young, energetic employees go hand to hand to give the better result. The company is divided into different departments to complete the task responsibly. They are the administrative Unit, product development, plan and technology, quality, logistic, production unit, and maintenance. The company has the goal to be one of the top automobile spare parts suppliers all around the world. BNM supplies the product at a reasonable and cheap price than other competitors. That is the main reason why its demand is rising with time. Mostly, German automotive companies are very much interested to put their trust in and give new projects. (The company, n.d.)

2.2 Coordinate Measuring Machine (CMM)

In general terms, Coordinate Measuring Machine (CMM) is a crucial tool or machine operated to measure the dimensions of the work piece with coordinate technology. The dimension contains X, Y, and Z-axis indicated for height, width, and depth. It plays a key role to maintain the flow of the manufacturing process. In the serial production of prototypes or spare parts, physical dimensions and geometric accuracy are very important. Mistake in these things and threaten the whole production process. For this reason, a high tolerance measurement machine was invented. The traditional method is mostly based on a manual inspection where the quality is highly dependent on the skill of the person. CMM can measure parts that are complicated to measure with other measuring machines with high accuracy.

2.2.1 Types of CMM

Based on the mechanism, there are two types of CMMs:

- Contact Mechanism (Touch probes)
- Camera or Laser Mechanism

Other basic types of CMMs are mentioned and explained below:

- Bridge CMMs:

This is the most popular measurement machine of all kinds because it is available at an affordable and reasonable price due to its low manufacturing cost. Bridge CMM provides the micrometer-precise measurement. It is used for medium size components.

- Cantilever CMMs:

Cantilever CMM is specially projected for the small workpiece. It is different from a bridge because the head is attached only to one side of the rigid base.

- Gantry CMMs:

Gantry CMM is the best choice for the huge and heavy parts that need high precision. It has open access to the measuring area and is not easily damaged.

- Horizontal CMMs:

It is a much less accurate measuring machine compared to others but it is a good choice to measure the bigger parts. (McMillion, 2021)

2.2.2 Components:

- Probe
- Granite table
- Fixture
- Air compressor
- Software
- Joystick

2.2.3 Advantages:

- Refined parts are obtained
- Accuracy and precision to the variety of geometry is delivered
- Durability
- Better speed for the repeatedly measured parts than the traditional method
- Maintains flow of production

2.2.4 Disadvantages:

- Expensive
- Need of qualified operator
- Calibration on a regular basis

- Measurement stability
- Responsiveness
- Soft parts could lead to damage

2.2.5 Use of CMM in the automotive industry:

- Saves time and money:

  To any manufacturing company, CMM will have a big save on time and money. The visual inspection for all the products can consume a lot of time and manpower. Once the machine is programmed, we just need to fix the position of the part with the machine which then makes the rest on its own. Manual measurement takes a lot of time than on the other hand. At start it might take adequate time for programming but later it can be done in a limited amount of time.

- Less operators needed:

  For bigger companies, if the measurements are done by manual machines, it will take a lot of manpower to complete the task. But for CMM, very little manpower can take over all the related works. Operator and programmer can be the same person and also work as efficiently.

- Quality improvement:

  As we discussed earlier, CMM improves the quality of the product significantly. We can easily find the errors and mistakes done in the whole manufacturing process in a short time and can be corrected immediately which results in the upgrade of the products quality. It helps to keep the products below tolerance treshold level which results the satisfaction o the customers satisfaction. If it is utilized properly, automotive manufacturing companies will have less reclamation regarding the problems.

- Maintains flow of the production:

  The production does not need to be stopped for the measurement of the product. The initial parts can be measured and checked during the proceedure. If it is good enough, the production can carry on. Then, during more short pauses, more samples can be checked without disturbing the flow of production.

- Less setup time:

  CMM does not need a long setup time. As it is repreprogrammed, the operator can just make the accurate positioning and start the measurement. It is a very quick measurement process. (Huang, 2021)

2.3 Steps to work on CMM:

Precaution

- Stylus calibration
- Handling precautions
- Maintenance and calibration
- CMM training

Measurement

- Coordinate and alignment
- Set coordinates
- Measuring dimension and 3d features
- 3D report

Programming

2.4 Preparation of 3D measurement report:

3D measurement report indicates the exact quality of your product. The geometrical precision, shapes, cutting, and dimensions should be clearly illustrated whether they are under the given tolerance or not. If the dimensions are out of tolerance, it is shown with red color and if it is below the uper tolerance treshold the reports are green. All the details, measured date, operator, measurement unit, part number, tolerance, and all three dimensions should be clearly seen in the report. This will make the report overview easier. The reports can be prepared in Microsoft word, excel or pdf format according to the requirement of the customers. The reports show all the mentioned dimentions, points and shapes in three dimension that will help to make the correction in further process.

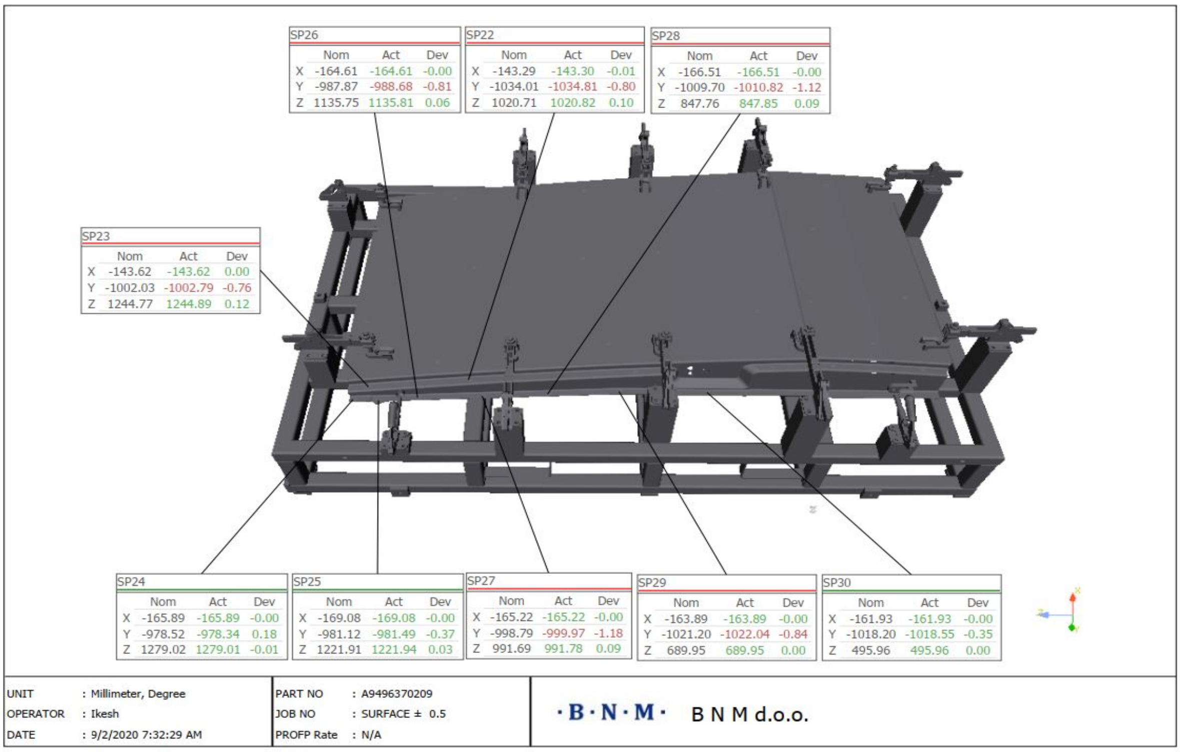


Fig 1Sample of a 3D measurement report

Source: (Own Source)

2.5 Reverse engineering:

Reverse engineering is the process where the workpiece is deconstructed to extract the detailed information or specification to prepare the prototype or rework the same piece. It is also known as back-engineering. The process gives you the whole idea of how it was designed so that it can be recreated. Generally, it is like breaking down the part into its components to understand it, to build a copy, or to improve it. (Schwartz, 2001)

Reverse engineering includes the following process:

- Original:

  The first step is to identify and analyze the original part. Check for the components used in the part and get the hint to start with measurement.

- 3D scan:

The second step is to measure every single detail in the workpiece to get the most information possible. The more information you get with the measurement, the easier it will be with the further process.

- Data process:

  Then, you collect all the data and save it in your system or prepare the reports that can help the technologists or engineers. You can clearly see the deviation in this process.

- Engineer:

  After the data process, the data is passed to the engineer, and the required model or design is extracted for the lost information or new prototype.

- Prototype:

  Finally, the prototype of the workpiece is designed according to the original part.

2.5.1 Advantages:

- Retrieve the lost information (or if manufacturers no longer make the part)
- Fixing the problems in the work piece
- Easier in making prototypes
- Cost control
- Analyze the competitor's product

2.5.2 Disadvantages:

- Misuse of copyright products
- Need of specialized knowledge
- Long process (Anderson, 2019)

2.6 Advance Measurement system:

In this generation of advanced measurement system, its technology and work speed is vastly increased. Without a doubt, measurement systems have made a big step in development in the past few years. Some of the recent technologies are:

- High-performance imaging for reliable engine block inspection
- Laser scanners
- High precision surface inspection
- 5g sensors
- Ultra-high accuracy
- Automated visual inspections (metrologynews, 2019)

2.7 Quality over quantity:

Generally, Quality can be defined as the tool to determine the characteristic of the product to meet the customer requirements. It helps to maintain a healthy relationship with the customer. The standard of any company can be straight determined by their product. So, for any manufacturing company, good quality should be the top priority.

Quality management in the automobile industry not only makes consistent deliveries and guarantees the standard specified but prevents work fatalities as well. That's why automotive industries all over the world train their employees on the basis of manufacturing quality standards. It is encompassed in IATF16949 in accordance with ISO 9001. (Widjaya, 2020)

In BNM, we consider quality over quantity. The quantity and the quality of the deliveries are not the main concern of ours, the main goal is to achieve the desired quality when exporting. 3D measurements contribute a big role in maintaining this environment. CMM is one of the main components to maintain the quality of the product in this company. One of the lean tools used to maintain the quality here is Ishikawa or fishbone diagram. It helps to figure the reasons for the problems and deviation within the process. It prioritizes the main causes to develop in-depth joint brainstorming discussions. (Trout, n.d.)

To figure the different problems in process of the part modification and maintain good quality, the following fishbone diagram was used. With this research, we focus on the problems regarding the machines and quality.

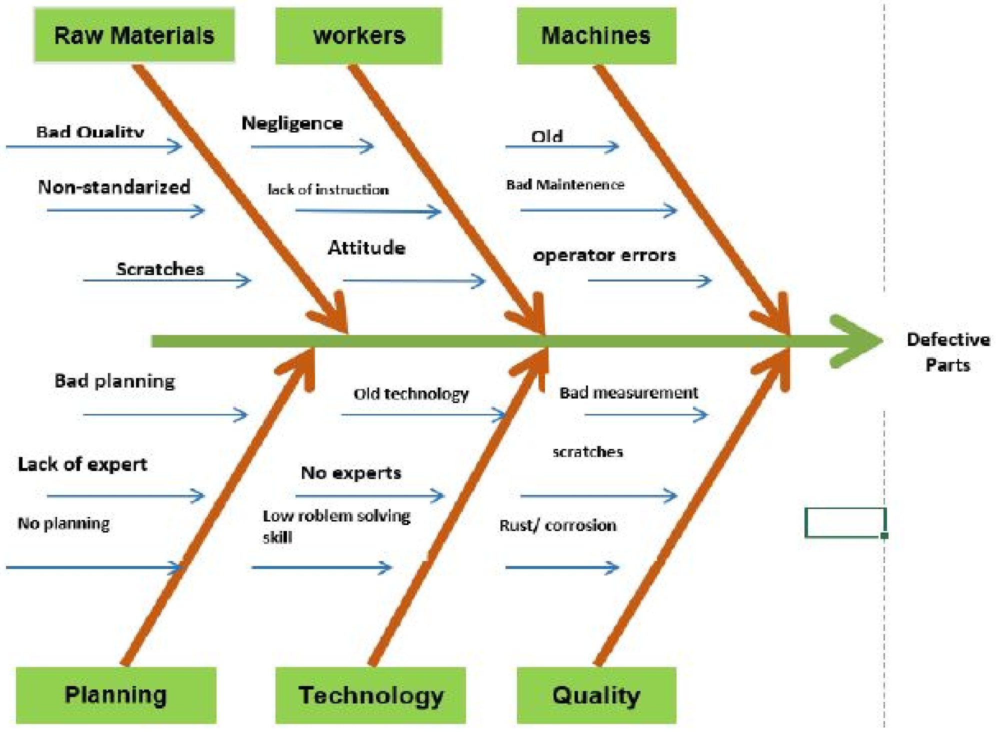


Fig 2 Fishbone diagram showing the problems and causes in the production process.

Source: (Own source)

3. EXPERIMENTAL ANALYSIS:

3.1 Workpiece details:

Part modification projects are one of the most profit-generating works in this company. Every year, multiple series of spare parts are to be modified. Some of them are with big changes but most of the time it is to modify the simple things like adding or removing holes, change in cuttings, bending, or different geometric shapes on the existing parts.

Among them, the fender part for the Unimog truck was taken as the workpiece. This part has been produced in the company for more than 10 years. In one of the recent modification projects, this part was enlisted to be added few holes in very complicated positions.

The main theme of this thesis is to design a fixture that helps to position and align the part to start the measurement. The newly designed fixture can measure both the left and right parts at the same time. It will save a significant amount of time and improve the remarkable quality of the product. In case fixture functions exactly the way it is supposed to be and helps in project, same procedure can be applied on other modified parts too.

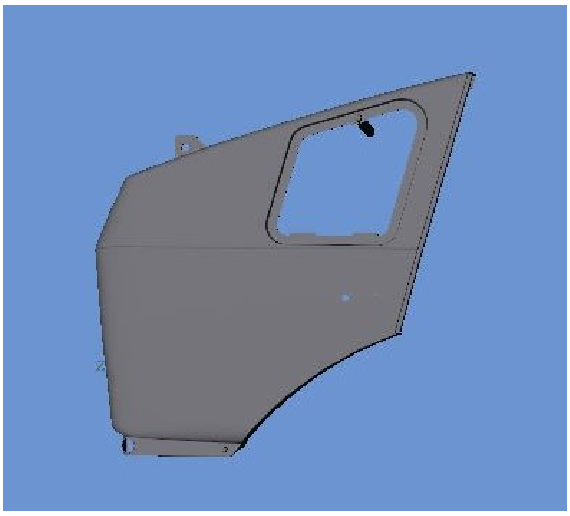


Fig 3 Right side of the fender.

Source: Own Source

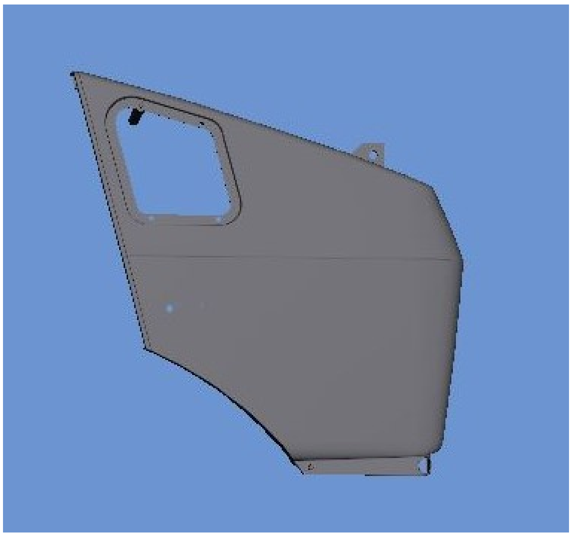


Fig 4 Left side of the fender.

Source: Own Source

Table 1 Modification description table of the work piece.

Change No.	**BNM Ident**	**Name**	**Change**	**Operation**	**Note**	**Activity**	**Responsibity**	**Time**
UAS 180/20	5990140	A4256270309 A4256270409 Fender left-right	4 holes added	3D	Component change	Measurement (left and right)	R.lah	KW2
						Sampling (left and right)	S. Cizerl	KW2
						Preparation for the assembly	Z. Slamberger	KW2
						Preparation for the line	Z. Slamberger	KW2

Source: Own source

3.2 Existing Procedure:

The mentioned workpiece is built and assembled in Unimog trucks for a long time. Initially, the part is formed with deep drawing from the press machine. The required shape and some crucial cutting are made here. After that, the part is forwarded for the laser cut where the new changes (the holes) are made.

The first few parts are inspected and sent for 3D measurement before the serial production starts. The CMM measures and compare the part with the CAD model to check the position of the holes, cuttings, and surface points. If the 3D reports are below the tolerance treshold, the process continues. The measurement reports are also sent to the customers as proof that we have included the desired change and the parts are good to be installed.

3.3 Flaws in the process:

The whole process seems easy but there are unseen problems that can be fixed to save the whole processing or measuring time and benefit the company in many ways. Some of the problems from the current condition are mentioned below:

- ***Unavailability of measuring fixture:***

  As mentioned earlier, Unimog trucks are one of the oldest projects in the company. Before the modification, the parts were prepared just by the press machines and just normal measurement with manual checking fixture and visual inspection was enough. Since we put in some extra work at CNC and make the changes, 3D measurement is essential for the project. Unfortunately, a fixture or clamping device was not provided. Due to this, the project is challenging and complicated.

- ***The complication in positioning before measurement:***

  To start a 3D measurement, setting a good position of the workpiece is a must. The position placed at the initial phase of preparation of programming is very important because every time you measure the same workpiece in the future, first you have to place it in the same position. Different components like magnets, clampers, fixtures can be used for this. It is much easier if the part has at least one flat surface. This will help us to align with one axis among three X, Y, and Z-axis. The remaining two axes can be featured with other cuttings or surfaces around.

With this fender, we don't have any flat surface to consider any one of the axes which makes things more complicated. The magnets are used for the alignment but it takes a very long time (several hours) just to make a good position. In the worst-case scenario, the whole new programme has to be prepared. And, making a new programme in every production batch is a total waste of time. It directly affects and results in the prolongation of the whole process.

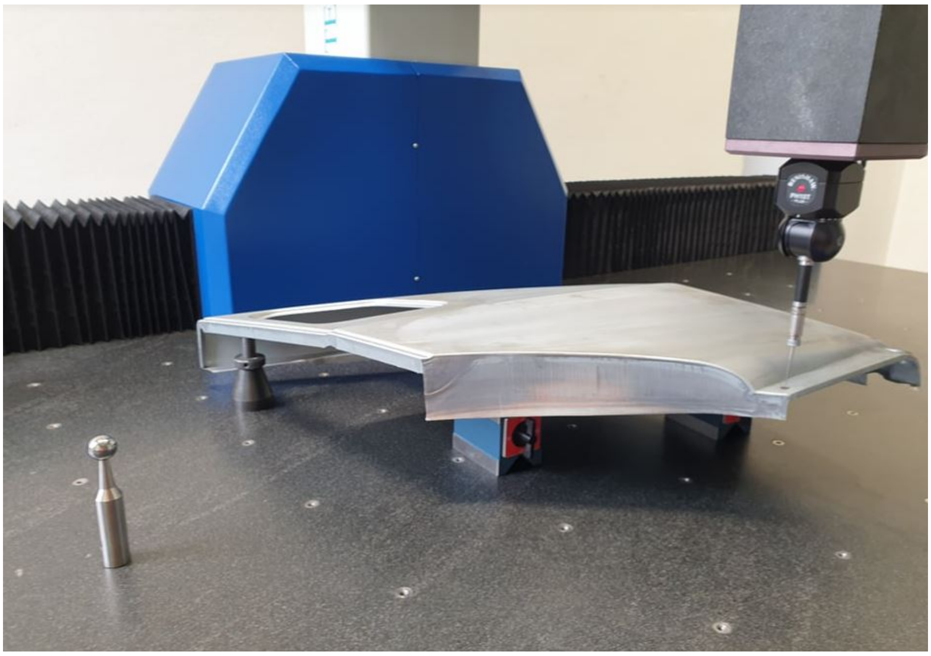


Fig 5 Positioning with the magnets.

Source: Own source

- ***Extensive measuring time:***

  Generally, it takes 15-20 minutes to make a 3D measurement of one simple part. Similarly, the programming time takes from one to several hours depending on the complexity of the part. It could be a disaster if you don't have the measuring fixtures of the work piece for the preparation of the CMM report. Right positioning of the part might take a very long time and will be hard to put it in the same position in the next measurement.

Also, the workpiece fender has two sides, left and right. That means, whatever the time for the measurement of one side is, the total measuring time is going to be doubled or or even more. The CMM can measure only one part at a time. The machine is big enough to measure both sides at the same time but the programmes for each part are different. With the new design fixture, we can program and measure both the right and left sides at the same time with more precision and accuracy. This will save an adequate amount of time.

- ***A high number of damaged parts:***

  When the production unit has to wait too long for the measurement report, sometimes they continue working without the verification from the quality department in order to save on time. This issue was faced before and as a result, the parts were not below the tolerance trehsold and the company had to throw away all the produced parts. When the proper measurement is made in time, critical mistakes can be prevented. The related employees would be notified to make the correction.

  Installation of the damaged parts will cost us a higher number of reclamation. The company has to either fix the problem on its own or pay the fixing cost and time to the customer depending on the complexity of the problem.

- ***Measurement error:***

  CMM needs perfect layout points as a reference to measure the whole part. When the workpiece is measured in incorrect positions it creates the wrong layout point and once the reference is not accurate the entire measurement is useless. The part can be measured in a way to see, if the precision will fluctuate. The report may show the products are good but not in reality. In this case, the further process is carried out and the real mistakes can only be seen after the installation of part in the truck cabin. This is a serious problem and hard to fix.

  To figure out and analyze the exact condition of the current situation, five sample pieces at a different time from the same production batch were measured. The outcomes are displayed in the table below:

Table 2 Description of the current condition.

No. of workpiece	**Part below tolerance**	**Positioning time (In minutes)**	**Total measuring time for both left and right**
1.	75%	45	120 minutes
2.	80%	35	90 minutes
3.	78%	30	100 minutes
4.	90%	40	85 minutes
5.	85%	50	90 minutes
Average (∑fx/n)	81.6	50	97 minutes

Source: Own source.

3.4 Areas to be improved:

As presented above, we have some critical areas to be improved. The most interesting thing is that those are simple things thus easily neglected. We have different loopholes in the whole production procedure. Fixing every single mistake or inaccuracy would be impossible. Therefore, a simple idea to design a new measuring fixture was developed that can make a remarkable change in this project and the company.

The newly designed fixture for the CMM machine will save an enormous amount of time to measure the workpiece in the coming days and increase the quality of the product. The areas considered to be improved are:

- Quality of product: Quality is the most essential factor to be focused while working for the big automotive company like Mercedes (Diamler). The minor deviation on the spare part will result in compensating the reclamation and huge loss. Our company is trying its best to install only good work piece on the Unimog truck. Yet, sometimes we face the technical issues that complicates the employees to maintain the standard of required quality in the process.

- CNC (Laser cuts): The key process in this modification project is the three dimensional laser cuts as we have to input the different required cutting shapes after heavy stamping on the press machines. Most of the changes or modifications are carried out in this work station. It would be very expensive to modify the pressing dies for simple changes. The precision consistency in CNC is very low. The part produced are different in every serial production which result big complication in assembly. This is the main reason why the designed fixture is so important for the given project. The production can be carried out only after the proper measurement with CMM and approval given.
- Assembly: The Unimog trucks is being produced in this company for a long time (around ten years). The checking fixtures, assembling fixtures are customized time and time again according to the already faced problems in the working period. In some work stations, it gets hard to assemble the perfect parts (Exactly same as in 3D model). The fixtures are customized many times to resolve the occured problem. In the upcoming year, the company is optimistic about automatization of the truck assembly. Hence, the accurate parts and fixture seem essential. Spending millions on buying robots for automatization without the perfect spare parts seems quite challenging.
- Measurement process: Working on this project, we have very limited amount of time to measure all the produced work piece. Numerous model of small and big parts are produced every day seraily and if one simple measurement takes much time, the whole production process is then messed up. This project is just an example on how we can improve the whole measurement process in coming days with proper planning, necessary fixtures and equipment. The company now owns one gantry coordinate measuring machine with two arms. Its main purpose is to measure the whole truck cabin after it is completed and ready for delivery. In conclusion, the proper measurement process for the spare parts and whole cabin should be prime focus with better plan, fixtures and equipments.

3.5 Tools used in improvement process:

3.5.1 Thome 3D machine:

Thome prazision is a Germany-based company for coordinate measurement technology. For this project, the TETA model of its kind is used which is available in the company. It is a high-precision operator-friendly machine that can measure small to large workpieces. The measuring range of the machine is:

Length: 265cm

Breadth: 100cm

Height: 80cm

The machine is featured with Renishaw probe heads with extreme flexibility for every kind of workpiece. It is controlled by Reinshaw CNC control and a one-hand joystick. A calibration ball with a diameter of 25mm is installed for probe calibration. Thome 3D machine is verified by Geometrical product specification ISO 10360-2: MPEe = 2.2 + L / 350, MPEp = 2.5 µm (with probe TP20), MPEe = 1.9 + L / 350, MPEp = 1.9 µm (with probe TP200 and SP25). (Thome Prazision, n.d.)

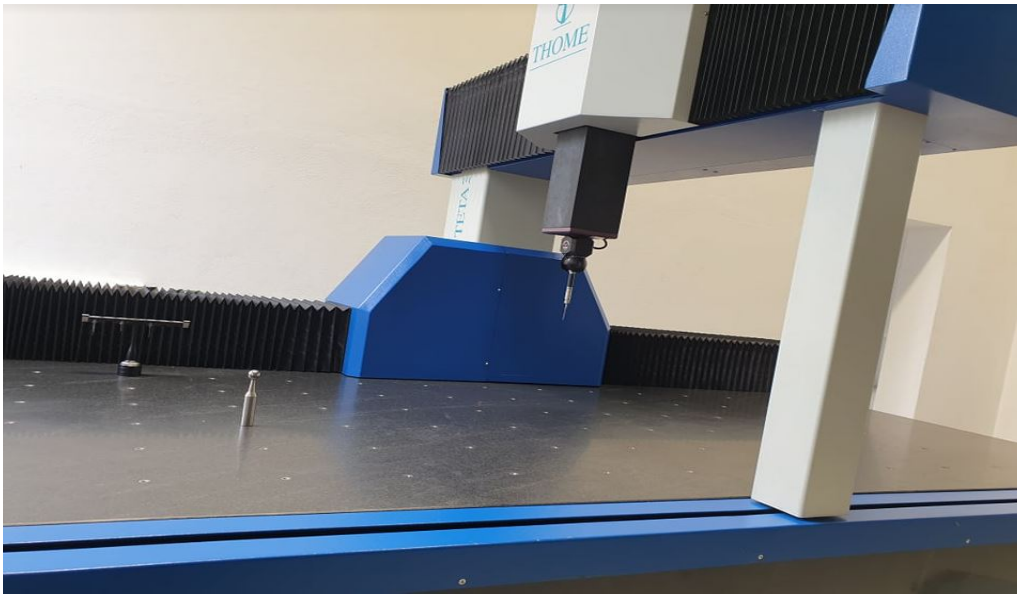


Fig 6 Coordinate measuring machine used in the project.

Source: Own source.

3.5.2 Rational Dmis software:

This is an automatic intelligent CMM software that is easy to use with any level of programming knowledge. It operates on powerful functions with a rapid programming model based on CAD graphic objects. The software can programme from simple geometric shapes to complex gears, pipes analysis, aero-engine blades, laser scanning modules, etc. Providing a rich diversity of output reports. For this research, version 6.5 is used. (World Metrology, n.d.)

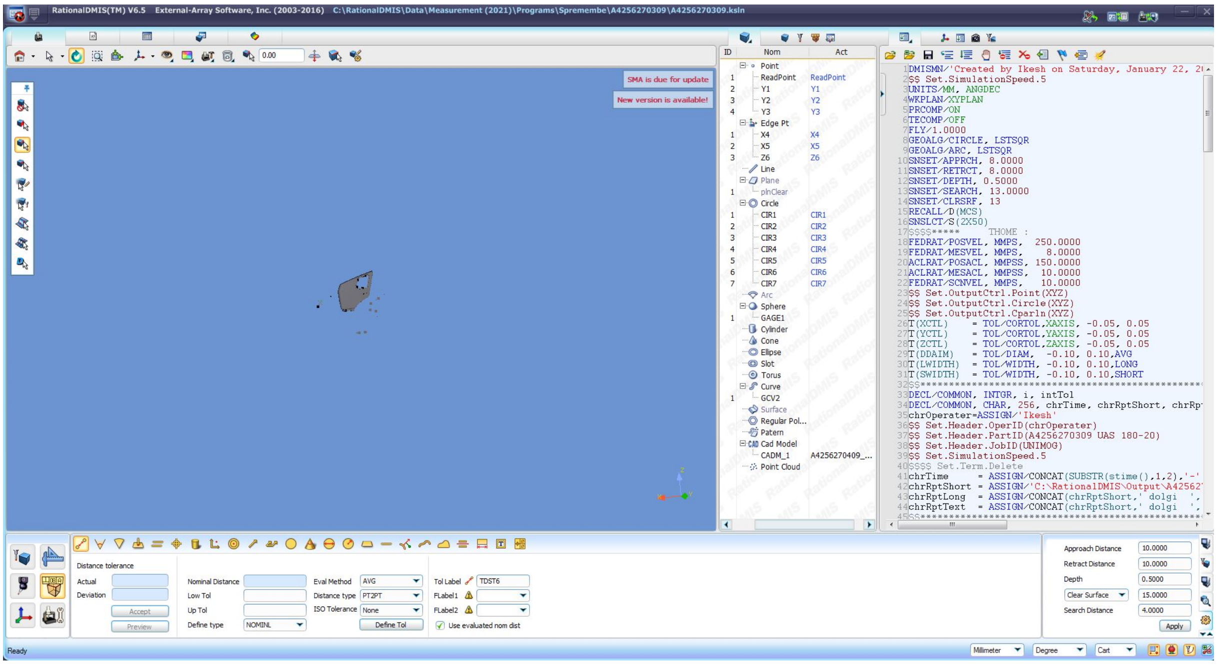


Fig 7 Software used in the project.

Source: Own source.

3.5.3 The fender part of Unimog:

The selected part is a very commonly used workpiece in any automobile industry. Basically, it functions as the wheel frame in vehicles that is used to prevent the splashing of dirt, sand, water by rotating the wheels. In this diploma thesis, we take both left and right sides as a workpiece to be measured at once with the same programme and same fixture. At first, 10 samples of the fender will be measured and compared when results are known . Once the parts are below the tolerence trehsold according to the 3D model, further process is made.

Fig 8 Fender part used as the workpiece in the project.

Source: Own source.

3.5.4 Positioning fixture:

The new design measuring fixture is the main component in the whole process of improvement of this research. This fixture will help us to measure the fender of both sides at once. It is very easy to install and position the workpiece for measurement on this. The leftovers elements from other projects were used to make this fixture. Only the magnetic holding pins were bought. The effectiveness of this fixture was very high on the given workpiece. The total weight of the fixture is 30kg whereas the dimension was (144*50*21)cm. The four magnetic pins of 18cm with a diameter of 20mm were used for holding and making the right position of the fender. The top of the pin got a smaller diameter (9mm) that fits perfectly into the holes of the work piece. The sheet metal of 4mm with the required shape was used on both sides of the fixture to maintain the stability of the part. The square iron pipes joined by mag welding 135 are the base of the entire fixture. In addition, the thick plane metal of 6mm was installed at the bottom to make the good base of the fixture. After the installation, it is checked with a seismometer to see the vibration on the workpiece.

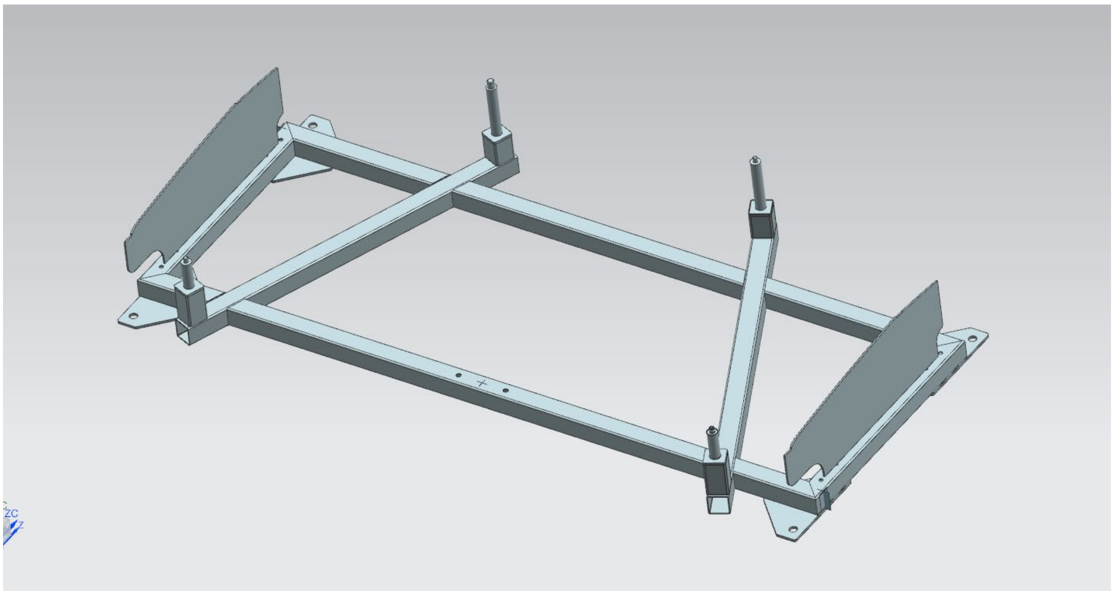


Fig 9 A newly designed fixture for the workpiece.

Source: Own source.

3.6 Measuring technique:

In order to get the fast and accurate measurement following steps or techniques were used:

3.6.1 Alignment:

For every part to be measured in this CMM machine, the proper alignment and positioning play a vital role. This specific workpiece (fender) will be positioned and aligned along with the newly designed measuring fixture. When measured with this fixture, the length can be considered as X-axis. Firstly, we put at least two screws in the screw holes that are on the machine. It will help in making the lengthy part (the iron bar in the fixture) fixed and steady. Once we are aligned with at least one axis, the machine can easily locate the coordinates for the whole part after correct programming. It might take two to a maximum of three rounds of locating processes in programming to read the exact position of the part. As the original part is already simulated with the new fixture, just proper alignment with the measuring fixture is enough.

3.6.2 Layout points (Reference):

The layout points are the most sensitive part while preparing the 3D measurements. The whole accuracy and precision of the report are determined by the layout points that you use as the reference. The machine compares the workpiece to the CAD model according to your reference i.e, layout points.

In most cases, the layout points are provided by customers themselves because not random geometric shapes, cuttings, or surfaces can be considered as good ones. These points must be 100% correct and accurate so that the machine can create the coordinates of the work piece according to it

On our workpiece, we use a 3-2-1 reference system with two circles and three surface points from the same plane for layout points. Three surface points will create an imaginary plane (for X-axis), one circle representing two-axis (Y and Z axis) and another circle for Y-axis again. Two coordinates from the Y-axis will create an imaginary line and Z-axis is just for one point. In this way, with the help of a plane, a line, and a point, the coordinate for the whole part is generated for the measurement of our part fender.

3.6.3 Programming:

After measuring the two successful rounds of the layout points, the exact position of the part is read by the machine. Now we create the measuring path according to our wishes. The programming process for our workpiece is created to reduce the significant amount of measuring time. Following steps are applied in it:

- Surface points: Good surface points determines the quality of the plane areas in the workpiece as well as the different complex shapes made from all kind of procedure. The required angle of the probe can be selected to measure complicated spots. On our workpiece, we are taking 30 surface points on each side (60 points in total) to make sure that the entire shape of our part is below the tolerance treshold compared to the CAD model.

- Edge points: Similarly, when the surface points are done, we pick the cuttings made in the part to measure. The cuttings are especially from deep drawing and some are made with lasers.
- Overall geometrical shapes and dimensions: After all the surface points and edge points are measured, we move to the remaining geometrical shapes. For this part, we only have a circle to be measure. So, we measure the four newly added circles and few old circles. Then, we can also include the distances, angle between planes, perpendicularity, parallelism, etc according to the requirement from the customer.

There are various things to consider while preparing the CMM programme. In our part, The approach and retract distance can be 8mm each. The search distance, clear surface, and depth for the measurement were 10mm, 13mm, and 0.5mm respectively.

3.6.4 Measurement and reports:

The actual quality of the spare part produced and used by the company is determined by the 3D measurement report. For every production batch, the company needs to measure few sample pieces in a different interval of time and send it to the customer. It builds up a strong relationship with the customers because we are proving to them the workpiece is below the tolerance trehsoldaccording to their needs.

The measurement report includes all the surface points – shapes, edge points – cuttings, and different geometrical shapes and requirements. Generally, the customer provides the CTQs (Critical Points) with the 2D sketch which is the most important to be included in the measurement report.

For our workpiece, the critical points were the four new holes added from the laser. So, after finishing all the regular measurements (surface points, edge points, and remaining geometric shapes), we move to these circles. The position of the circles is checked with all three axes and the diameter is measured. The given tolerance for the circles is + 0.50 and -0.50 for the position. Likewise, +0.20 and -0.10 for the diameter. As per demand, the distance between circles was also included in the report. If the measurement is not below the tolerance treshold, the correction is made and the process repeats until we get the good part.

Table 3 Tolerence tabel as per standard Mercedes Benz Norm 11012-20.

Allgemeintoleranzen nach General Tolerances acc. to		MBN 11012-20 ③
Symbol	Toleranz/-Art/-Wert Tolerance/-type/-value	Bedeutung / Meaning
⊖	0	Bezugsstellen nach Datum Targets according MBN 11012-1
⌓	⌓ 1 X Y Z	Flaechenformtoleranz fuer umgeformte Flaechen Surface tolerance for formed surfaces
⌒	⌒ 2 X Y Z	Linienformtoleranz fuer geschnittene Kanten Line tolerances for cut edges
⌖	⌖ 1 X Y Z	Positionstoleranz fuer Loecher Position tolerance for holes
⌖	⌖ 0.4 X Y Z	Positionstoleranz Bezugsloecher (Bezugselemente) fuer die nicht fixierte Raumrichtung Position tolerance for locating holes (reference elements) of the not defined direction of space
ϕ	+0.2 -0.1	Lochdurchmesser allg. bzw. Formkontur Hole diameter general resp. shape
ϕ	±0.1	Durchmessertoleranz Bezugsloecher und Bezugsbohrungen Tolerance of diameter for locating holes and datum holes
	+2	Biegeradien Bending radii
	+0.3	Zulaessiger Stanzgrat Permissible burr height

Source: www.diamler.com

3.7 Procedure to design and implementation of the desired fixture:

3.7.1 Fixture design and development:

As the real problem regarding the measurement time was acknowledged, design and development processes were discussed in the working team. Making the high-efficiency fixture with low cost that can make a quick measurement was the main purpose. The best way to make it possible was with the help of a scientific manufacturing approach and the DFA (Design for assembly) methodology. DFA refers to using the minimum number of components in designing for easier assembly with saving the working time. This method was used for the following advantages:

- To make a quick design.
- To use the minimum components.
- To make it impossible to install parts incorrectly.
- To optimize the tolerances. (fastradius, n.d.)

The measurement fixture was designed by experienced 3D designers in the company on Catia V5 and simulated. The description of the components used in its development are as follows:

Table 4 Component description for a new fixture.

Component Name	Component number	Material	Function
Magnetic Pins (x4)	1	Magnetic high strength steel	Fix the workpiece in a proper position.
Zinc coated sheet metal – 3mm (x2)	2		Provides required stability to height.
Square tubes (x6)	3	Iron	The base for all other components.
Thick metal plate (x4)	4	Iron	Balance the whole measurement fixture.

Source: Own source

Most of these components are already available in the company. The main idea to create this fixture was gained from one of the older projects from Magna. They had a similar kind of measuring fixture. We tried to make the prototype with a bit upgraded version.

The development of the fixture was started by cutting the components into specific dimensions. After that, the components were taken for the welding procedure. It was welded by some of the most experienced welders available in the company. To prevent the expansivity of the material due to excessive heat during welding, the linear thermal expansion was calculated and implemented accordingly. (mewelding, n.d.)

$$\Delta L = \alpha L \Delta T$$

Where,

ΔL = Change in length

ΔT = Change in time

αL = Coefficient of linear expansivity

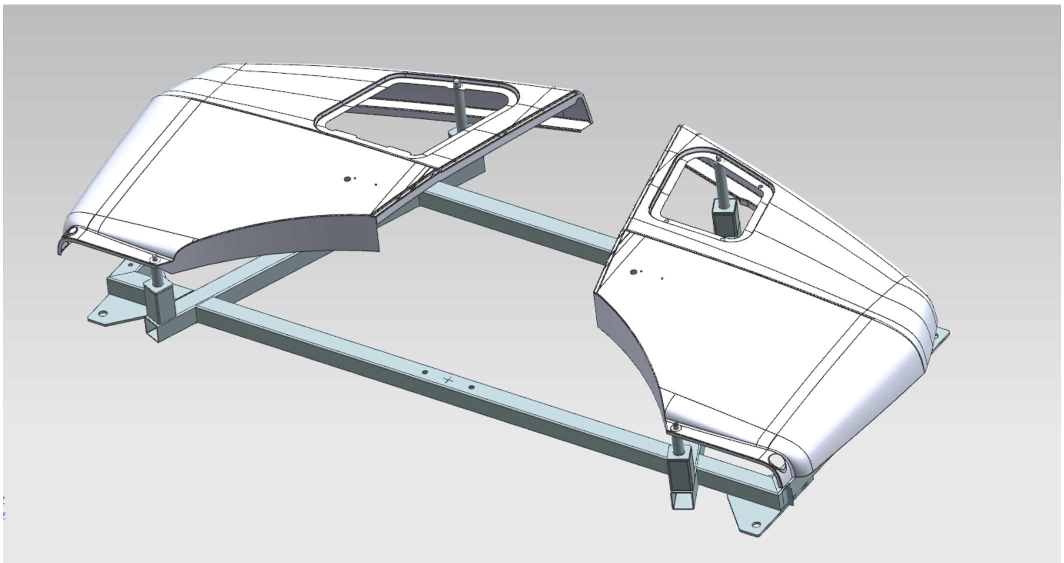


Fig 10 3D model of both side fender along with new fixture.

Source: Own source

3.7.2 Measure and check by CMM:

When the 3D model of fixture is prepared and developed into the physical part through a different process, the precision and accuracy of the fixture need to be checked. The fixture should be designed with minimum tolerance possible. If the dimension is not measured and made according to the model the whole measurement process will be a failure. The base of the fixture was made very carefully to make it error-free and can be used as the RPS (reference points) or zero points for measurement. It was aligned with two normal screws and three rounds of RPS points were programmed and measured to get perfect reference points. After that, the machine created the coordinates for the workpiece according to the CAD model.

In the first measurement, all the dimensions looked fine but the position of the magnetic pins was totally out. The pins were bent because of excessive heat during welding. Without the perfect position of those pins, the fixture was useless for the measurement process. The welding engineers from the company helped the team to fix the problem. Different techniques were implied to prevent the expansion during welding.

Then we reworked the fixture, two magnetic pins were good after rework but another two had to be changed. So, we used some extra clamping to prevent bending from excessive heat. Later the fixture was measure five times in different positions and the report was accepted. Finally, the newly designed fixture was below the tolerance treshold we wanted and ready to be used.

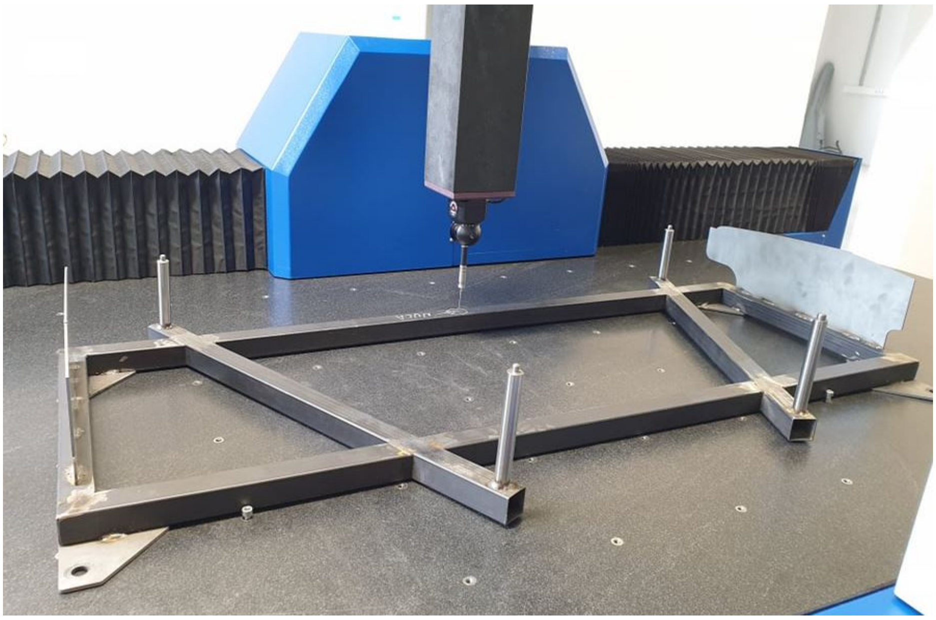


Fig 11 3D measurement of fixture

Source: Own source

3.7.3 Trial and error with workpiece:

The new fixture for the measurement was designed and prepared in two weeks. 3D measurements are also done and assumed to be under the given tolerance. The further step was to install the part on the fixture and try measuring it. The workpiece fits perfectly on the fixture thus the complication regarding positioning and alignment was solved. It took approximately 10 minutes to install both sides of the fender on it and make the alignment.

Now, the main part is to prepare a suitable programme to get an accurate measurement report. The reference points were taken from the fixture which we explained to be fine in the topic (3.6.2).

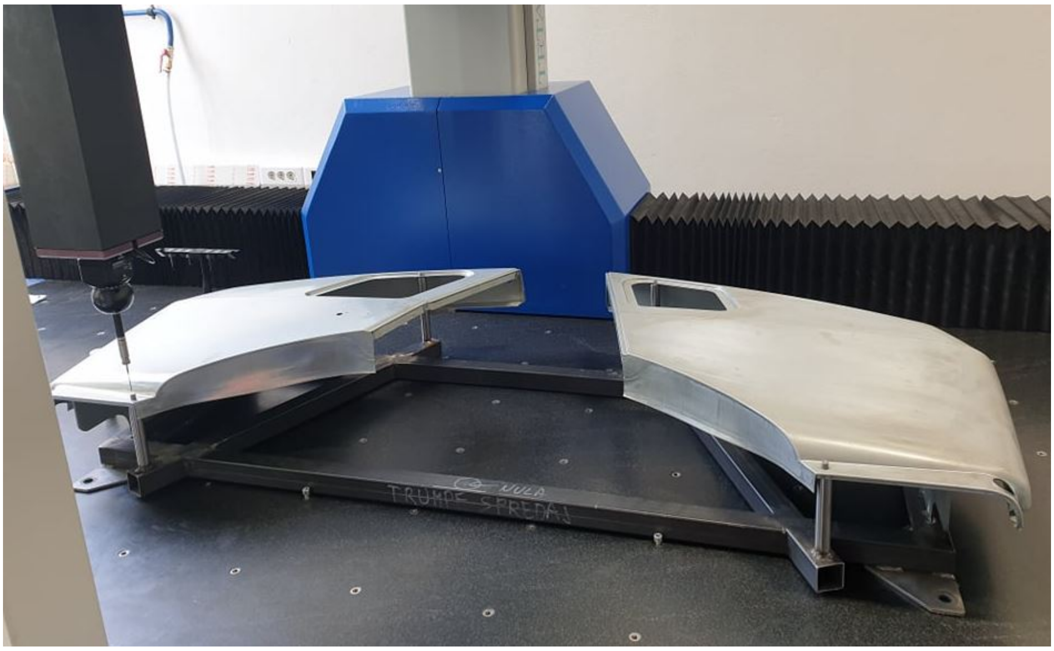


Fig 12 Attempt to the 3D measurement of the fender with a new fixture.

Source: Own source

The tolerance level for the reference points was as minimum as possible (+0.05, - 0.05 for points and +0.10, -0.10 for diameter).

3.7.4 Implementation:

After all the designing, measurement, and trial process was done for the new fixture, finally, it was first implemented for one production batch. The initial two pieces of both sides have proceeded for the measurement. The total measurement time was improved exactly it was supposed to be. The precision of the part was better and measurement reports were much more reliable. The same process was repeated four times in one production batch and the result was gratified. The whole new system was introduced and explained to the related department (plan and production, technology and quality department). The result was time-saving and profitable for the company. Hence, it was implemented.

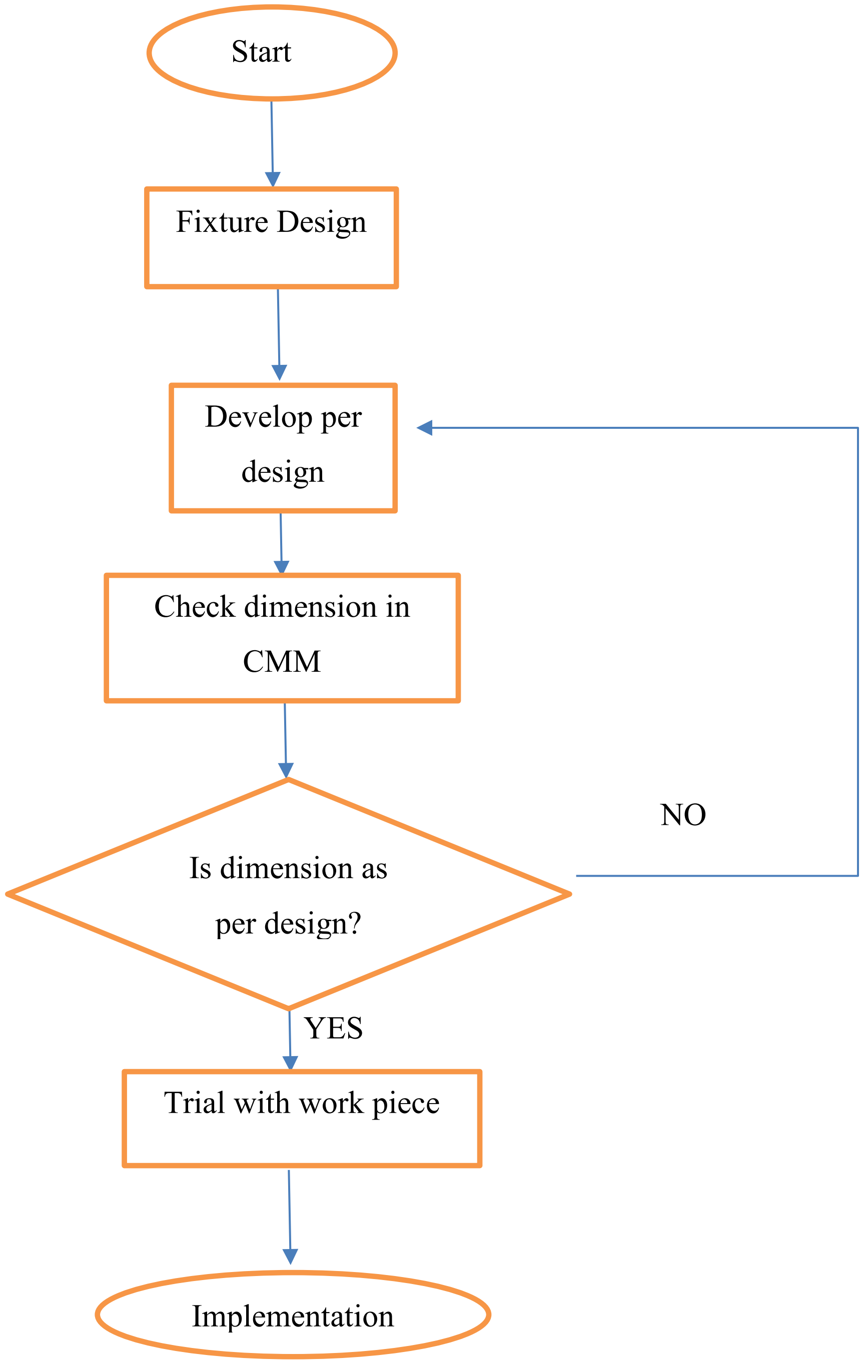


Fig 13 Flow chart of fixiture developement

Source: Own source

4. OUTCOMES:

4.1 Parts under tolerance are easier to correct:

When the workpiece was measured on a new fixture, the measurement process was found to be more productive. The main purpose of preparing a 3D report for any workpiece is to compare the physical part with the CAD model designed by customers and figure out any deviation. If the produced parts are out of tolerance on the measurement report, a correction needs to be made accordingly. With the fixture, the reports are more accurate than the ones without a fixture. A single measurement is enough to find out the problem. Multiple measurements were needed to make the accurate correction in the laser before this fixture was introduced.

Since the correction process gets easier, the quality of the parts is automatically improved. The workpiece was found to be below the given tolerance treshold. Good parts resulted positively in the whole production process. The assembly of the part became much effortless. Extra works during assembly like drilling and hammering that used to be carried out on this very part do not exist anymore. The reclamation related to this part is very rare after this process.

4.2 Possibility in other workpieces:

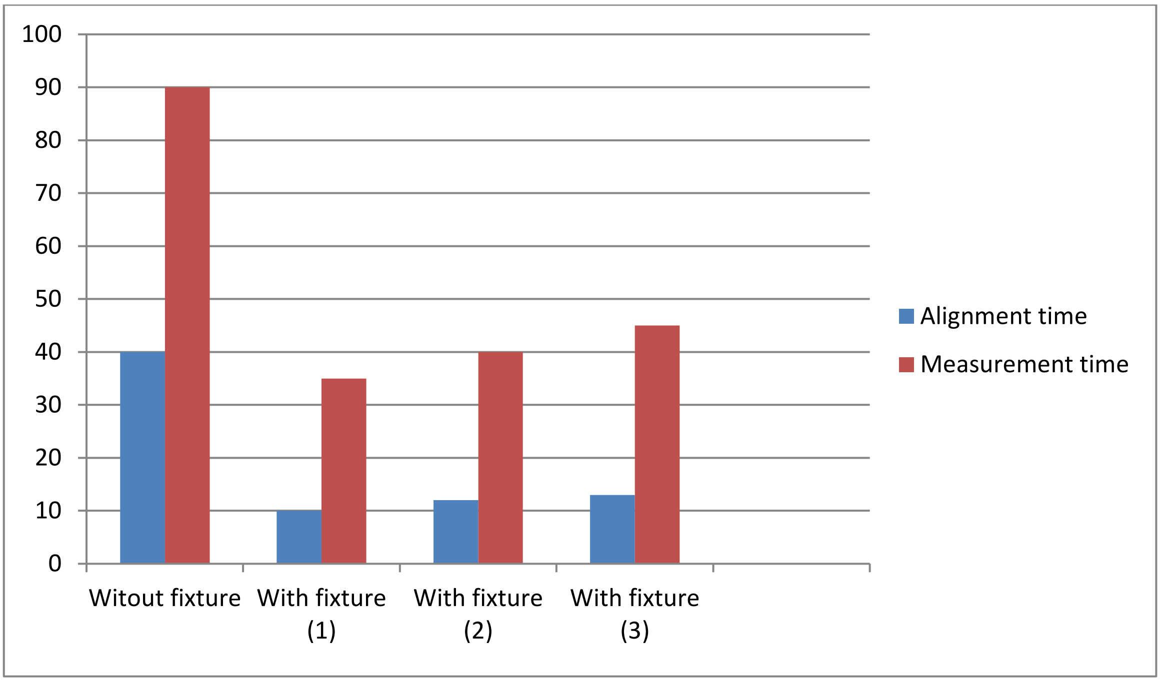
The company receives an adequate number of part modification projects from customers (Wagon) every year. Complication remains the same in many workpieces. In most cases, the fixtures are unavailable for both 3D laser and measurement. The whole process literally takes more time, more waste of material, and degrades the quality overall.

Therefore, once we are successful with this project, it would be a lot easier to apply the same solution with other workpieces. Measuring left and right sides separately consume a double amount of time while designing fixtures that can measure both at the same time will save a lot of time. The company has enough workforces to design, make and implement the desired fixture for the betterment of the company. The whole production process can be improved to a different new level with this simple solution of the new fixture.

4.3 Quick alignment and measurement:

The alignment and measurement were found to be much easier, convenient, and faster compared to the existing condition. The total time needed to make the perfect position for measurement was deducted up to 75% percent after the implementation of the new fixture. The straight iron bar fixed with the screws had easily set the position of the fixture with both parts on it. And the magnetic part holding tubes makes it stable for the perfect measurement. The installation of the fender on the fixture was very easier. An operator can do it all on its own. It takes approximately 8-12 minutes to put the part on and make the required position.

Measuring the left and right sides separately was a total waste of time. The CMM machine had enough big space and yet the workpieces were measured separately with different measurement programming while we can do it all at once with better performance. When workpieces were measured together, it saved more than 60% of the existing time in the whole measurement process. Therefore, a massive amount of time was rescued which was the main theme of this diploma thesis.



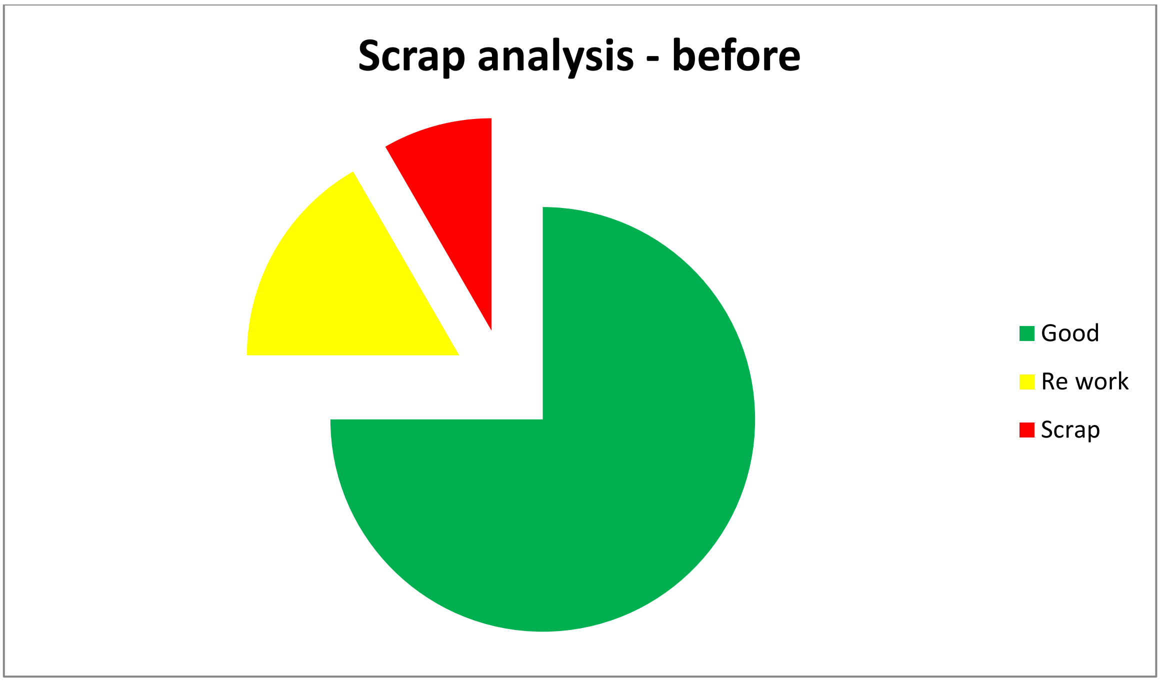
Graph 1 Time comparison graph.

Source: Own source

The above bar graph shows the time needed to make alignment and measurement of the work piece with/without a fixture. The red color indicates the measurement time and the blue color indicates the time for alignment and positioning. The time is calculated for both left and right sides together. The measurement was made for three different samples with the new fixture and the result is clearly seen in the graph.

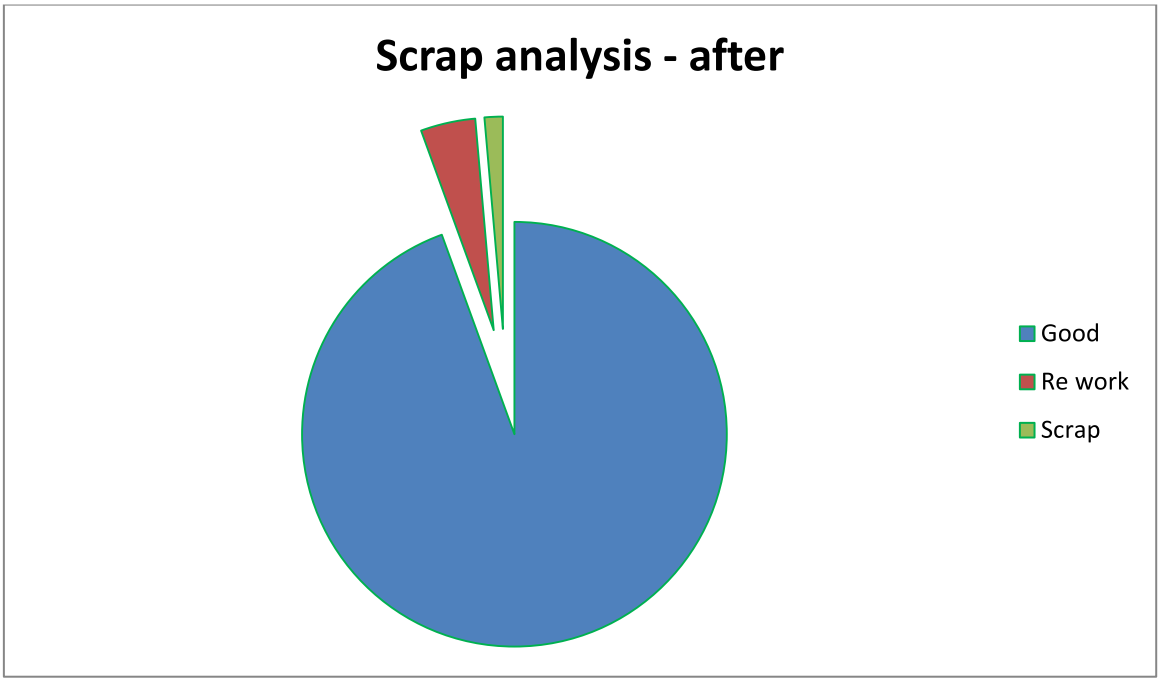
4.3.1 Minimum Scraps:

As the measurements were more precise and accurate than before, the correction process became fast with minimum scraps. The measurements reports for both sides were delivered to the related department within a limited amount of time. In such a case, production can be immediately stopped if correction is needed. The production carried out without overviewing the report results in a high number of waste workpieces. Before this, the production unit has to wait for too long so sometimes they continue making parts without the measurements. The scrap analysis for the workpiece is compared below:



Graph 2 Scrap analysis graph before using fixture.

Source: Own source



Graph 3 Scrap analysis graph after using fixture.

Source: Own source

In above graphs, the difference between the number of scraps before and after the implementation of the new fixture is explained. The efficiency of the production process was improved with the minimum number of waste pieces and better quality.

4.4 Economical:

Converting the specific design into a physical component might stay on hold for a long time if the preparation cost is high. Most of the companies like the idea of the new designs but think twice about making it due to its expenses. In our case, most of the components were already there at the company. The raw materials used design was simple. Square shape iron rods (leftover from other projects), Holding wall (thick sheet metal) and magnetic pin were the basic raw materials used in the fixture. We only had to buy the magnetic pin that is used to fix the position of the fender to make the whole fixture. The welding, measurements, assembly, and designs were all done in the company. The total cost for making the fixture was just 400 euro and made in one week.

4.5 Advanced upgrade:

Yes, this research delivers a wide range of problem-solving in the CMM measurement procedure, but we have an advanced option too. A 3D scanner is one of the advanced technologies in the measurement sector. The thing is, it's too expensive to buy, test, or make the measurement. Just one measurement costs from 100-1000 euros depending on the size and details of measurement. The measurement requirements and quantity are really high in this company. Renting or few times measurement is not enough so, buying a new 3D scanner could be one meaningful and productive decision in the coming days. This will help a lot to improve the quality of the products as well as any sort of work piece that could be easily measured without any complications.

4.6 Drawbacks:

- Confidential to CAD model and limited data available:

The model of the designed fixture must be approved by the customer with the proof that no provided data of the work piece have been misused and implemented only for the improvement of the quality products. The several agreements are to be made with customer for this project.

- Results in incorrect measurement if a work piece is not loaded properly:

In the initial step of the measurement, the operator should be very cautious with the positioning of the work piece. Minor positioning or measuring mistake will cost huge loss in mass production because if the reference points are not taken carefully, the results or reports can be totally different from the actual part. It might show the parts out of tolerance even if it's good or might show good enough when not.

- Could be a bit complicated for a new operator:

As the programming and operating for the measurement of this work piece is done by same person, it may not look like complicated. But in further days, if the operator is replaced and new employee has to do the same task, it could be challenging.

5. CONCLUSION:

As explained above, this research paper concludes the prime role of Coordinate measuring machine (CMM) in part modification projects. The complication faced during the whole measurement process is transparent in this diploma thesis. The main idea was to design a fixture with minimum cost in such a way that it would be much easier and quicker to make 3D measurements of the workpiece (Fender) resulting in a better production process and quality in a given project.

Primary research and secondary research were introduced as the main strategy for this diploma thesis. As a responsible employee in the company, the thesis is more based on primary research. Visual inspection, the guide from experienced colleagues, information, and data from senior engineers were used to make it more effective. The secondary research methods like journals, academic books, online research, etc. were used to clarify in detail the theoretical part.

The hypothesis expected from this research is that the measurement time of the workpiece will be minimized significantly resulting in the control in production cost. Making corrections in the 3D laser is going to be much faster and easier with less scrap and better-quality products. The smart move can be assumed making both left and right measurements at the same time.

Once the idea popped up inside my mind, it was immediately shared with co-workers and the process took the place very quickly. The old process of measurement was outdated, very slow and not accurate which was hurting the company's production directly as well as the assembly of the workpiece. Due to the unavailability of measuring fixtures, the positioning time was unacceptably long (at least 30 minutes). On top of that, the left and right sides of the parts were measured separately which was gratuitous because there was enough space on CMM to measure both parts at once if proper fixture and the programming is made for its measurement. The raw materials used in preparing the fixture were the leftovers parts from other projects except for the magnetic holding pin. So, the preparation cost was as low as it could get.

When the measurement was successful with the new fixture, the result was remarkable. The positioning time of the workpiece on CMM shortened by approximately 75%. It was so easy to make the perfect position for measurement because the length of the fixture can be aligned with help of just two normal screws. On the other hand, a new measurement programme was made to measure both sides of the work piece at once. As mentioned before, this was a tricky move in the entire research. More than 60% of the measurement time was saved. 3D reports can be prepared faster, and corrections can be made in a short amount of time if needed. If not, the production continues to the next step. The quality of the parts was improved with fitting right below the mentioned tolerance treshold from the customer. There was much less scrap pieces during the procedure than before. This helped to control the production cost of the part. Visual inspection was made in the assembly unit, where it was noted that extra work like hammering and drilling was not needed anymore as the fender was made with high rpecision. As a result, there was not much – almost no reclamation of this very part afterward.

Therefore, properly managed CMM programming and measurement procedure can play a crucial role in part modification projects and many other projects of this nature, carried out in the company. The scope of this diploma thesis is wide in the automobile industry as it helps to save an adequate amount of work time, improves the quality of the product, controls the production cost and thus achieves the company's goal.

6. SOURCES & LITERATURE

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