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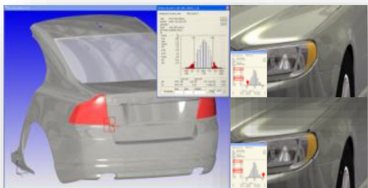
Variation Simulation & Visualization



Geometry Assurance Integration in Current Development Process at Volvo Group Truck Technology

Master's Thesis in Production Engineering

AMRUTH SABBISETTI

Department of Product and Production Development
Division of Product Development
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Cover:
A figure of product realization loop

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Abstract

In a real world scenario, nothing is nominal like the digital CAD model. All manufacturing processes are affected by variation. Reducing variation has become a big challenge for companies and they are striving hard to achieve it. When products are manufactured, no two products look same, but they look similar. In a few cases functional and aesthetical requirements will not be satisfied. The variation in the final product is stemming from part variation and variation in the assembly process. The geometrical part variation occurs in the part's shape and size due to change or variability in material, tools, operators, environment and process. The assembly process results in variation due to variation in the contact between parts and assembly fixtures.

Avoiding variation completely is rather difficult and expensive. But there are methods and tools that are aimed for reducing variation and more importantly reducing the effects of variation. The method or work that is aimed at decreasing geometrical variation and its effects is called geometry assurance.

The project is a collaboration between Semcon, Volvo GTT and Wingquist Laboratory. The purpose of the project is to understand the current procedures of geometry assurance at power train engineering at Volvo GTT. A new geometry assurance process for Volvo GTT is to be created based upon interviews with Cab engineering department in Volvo GTT and Volvo Cars Corporation. The suggested method is formulated based upon the interviews that were conducted with persons concerned with Geometry Assurance in Volvo Cars Corporation and Volvo GTT. The benefits of variation simulation in the software RD&T are understood by analyzing a case study. The economic benefits for using geometry assurance are stated out from interviews. In addition, the effects of geometry assurance on suppliers and buyer relationship are studied.

In conclusion, the thesis states that there is no clear current working procedure for geometry assurance at power train engineering at Volvo GTT. A new method for the geometry assurance procedure is formulated based on interviews from Cab engineering at Volvo GTT and Volvo Cars Corporation. Variation simulation is performed on a subassembly from Volvo GTT, using RD&T and the benefits of using this tool are stated.

Keywords: Geometry Assurance, Variation simulation, Variation

Preface

This master thesis is performed as the completion of M.Sc. in Production Engineering at Department of Product and Production Development, Chalmers University of Technology. This master thesis is a collaboration between Semcon, Volvo Group Truck Technology and Wingquist Laboratory. The work has been performed at Department of Product Design Engineering, Semcon.

The master thesis is titled as 'Geometry Assurance Integration in Current Development Process at Volvo Group Truck Technology'.

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Gothenburg, June 2015

Amruth Sabbisetti

List of abbreviations

GTT	Group Truck Technology
VCC	Volvo Cars Corporation
CE	Cabin Engineering
PE	Powertrain Engineering
MP	Measure Point
GAE	Geometry Assurance Engineer
PD	Product Development
RSS	Root sum square
GSU	Geometry System Developer
GE	Geometry Engineer
PPAP	Production Part for Approval Process
WC	Worst Case
MC	Monte Carlo

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1 Introduction

The project is carried out in collaboration between Semcon, Volvo GTT and Wingquist Laboratory. This chapter explains the purpose, objectives and main goals of the project.

1.1 Purpose

The purpose of the project is to understand the current procedures for geometry assurance at Powertrain Engineering at Volvo GTT. A new method or process is to be created based on the current geometry assurance processes of CAB engineering department, Volvo GTT and Volvo Cars Corporation. The benefits of variation simulation in RD&T are to be understood by analyzing a case study. Economic gains for using geometry assurance are to be calculated. In addition, supplier and buyer relationship are to be studied and required improvements are to be suggested.

1.2 Objectives

The main objective of the project is to suggest a process for geometry assurance at Powertrain Engineering Department to Volvo GTT. Initially, the current procedure of geometry assurance that is currently undertaken at Powertrain Department of Volvo GTT is analyzed. In order to make the complete process, information is collected based on interviews from the experts of CAB Engineering Department, Volvo GTT and Volvo Cars Corporation. Economic gains of implementing geometry assurance in the current development process will be stated. Another part of the project is to analyze a case study from Volvo GTT using variation simulation in RD&T and investigate potential benefits of using this tool in geometry assurance.

1.3 Goals

The project main goal is to build a geometry assurance process for Powertrain engineering Volvo GTT. The proposed process should include detailed procedures to be followed in concept, verification and production phases. The responsible roles are needed to be prioritized in each step of the process.

The case study needed to be analyzed using variation simulation in RD&T and use of this tool in geometry assurance process should be mentioned. Economic gains of geometry assurance process are to be calculated. Supplier and buyer relationships are to be studied in relation with geometry assurance process.

1.4 Volvo Group Truck Technology

The Volvo Group is one of the world's leading manufacturer of trucks, buses and construction equipment and drive systems for boats and motors for industrial use. The majority of group's technology development takes place within Volvo GTT [1].

As every company wants to satisfy their customers with their high-quality products and stand out in market competition, the Power Train Engineering department is planning to implement Geometry Assurance process like CAB Engineering department.

1.5 Semcon

Semcon is a global company, active in the areas of engineering services and product information with specialist teams that meet customer requirements [2]. The Geometry and integration team is a group which is mostly concerned in working with areas of Robust Design and Geometry Assurance at Semcon [2]. For carrying out this project, required support is provided by Semcon in understanding RD&T.

1.6 Wingquist Laboratory

Wingquist Laboratory is an internationally competitive competence center for multidisciplinary research within the field of efficient product realization [3].

Wingquist Laboratory applies deep knowledge within its defined research areas on new research challenges emerged from the effective and efficient development of product families with a high level of commonality with respect to components, knowledge and manufacturing [3].

1.7 Outline

Chapter 1 describes purpose, objectives, and goals which provides information about companies that are involved in the project.

Chapter 2 explains the product realization loop, essential information regarding geometry assurance and RD&T. This chapter presents good information about variation simulation and types of analysis that can be performed in geometry assurance.

Chapter 3 presents the methodology, explains about the how the results of case study are attained and the strategies that are applied in formulating process maps of geometry assurance from interviews.

Chapter 4 includes the introduction to the case study and the results of various analyses that are performed on the case study.

Chapter 5 gives information about the results from case study and presents new design.

Chapter 6 describes the current working method at Powertrain Volvo GTT.

Chapter 7 provides the description of geometry assurance which includes state of the art of geometry assurance, problems in the current situation of geometry assurance at Powertrain Volvo GTT and finally the reasons for implementation of geometry assurance at Volvo GTT.

Chapter 8 presents the suggested geometry assurance process which is formulated by VCC and CAB Volvo GTT. Here, detailed descriptions of suggested process maps are provided.

Chapter 9 explains the impact of supplier-buyer relation using geometry assurance.

Chapter 10 explains the gap study between current situation of geometry assurance and suggested geometry assurance process at Volvo GTT. Here, a detailed description of gap study for all the three phases are given.

Chapter 11 includes conclusions, results, recommendations and suggestions of future work.

2 Theory

2.1 Product realization loop

The Product realization loop which deals with the different phases in developing a product. The loop comprises of the concept, verification and production phase. Here in figure 1, the loop is described from a geometry assurance perspective.

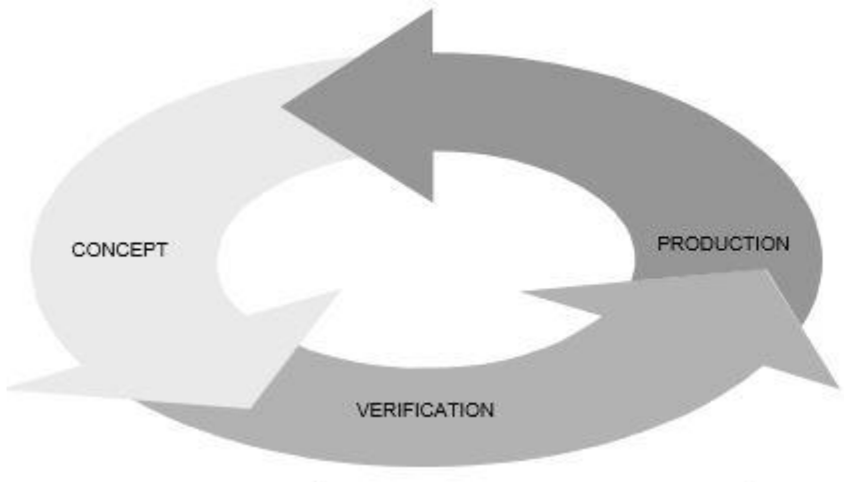

Figure 1: Product Realization Loop [4]

2.1.1 Concept phase

In the concept phase, a various number of concepts are evaluated, compared and optimized to withstand the effect of manufacturing variation and tested virtually against available production data [5]. In this stage, the concepts of product and production are developed [4]. The work starts from the frame of reference with an overview or an idea related to robust design. Locating schemes turns out to be the most prominent activity that is considered in this phase and it's going to be a control factor for obtaining a robust design. Here, the concept is optimized with respect to robustness and verified against assumed production system by statistical tolerance analysis. The visual appearance of the product is optimized and part tolerances are allocated [4].

2.1.2 Verification/Industrialization phase

In verification /industrialization phase, the product and production systems are physically tested and verified [4]. Here, product and production systems are verified and errors are adjusted and they are prepared for full production. A reduced number of suggested concepts are verified using physical prototypes and test series [8].

2.1.3. Production phase

In this phase, the start of production takes place. The most important thing is to monitor the production process in order to quickly detect disturbances and increased variation. Important activity here is to gather data, in order to monitor the process and to send data to future development processes.

2.2. Variation

It is the imperfection seen in actual as-produced parts, contrasted against the perfect model created in CAD and seen in drawings [6]. In the context of design and specification, tolerances on the drawing set the limits of allowed variation. In the context of tolerance analysis and tolerance stack-ups, variation must be considered from a specification point of view as well as measured value point of view [6].

There are many factors that will contribute to variation.

Here figure 2 describes sources of variation that will cause a huge impact on assembly.

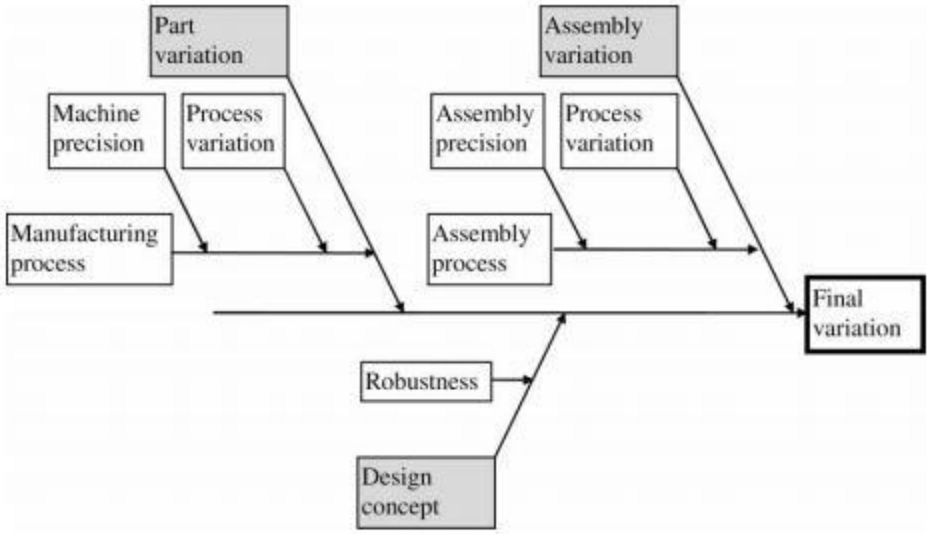

Figure 2: Geometrical variation contributors [7]

2.3. Sources of variation

2.3.1. Manufacturing process limitations (Process capability)

Most of the manufacturing process have requirements on parameters like precision and accuracy. Tighter tolerances are achievable, but at increased cost due to the extra [6].

In order to maintain this capability of the machinery or equipment, there are several factors and requirements that are to be handled and that are to be taken care of.

These are the things like to set the machinery level, clean, no distractions to working mechanisms, no damage in the working components, the factors like humidity, temperature are to be observed to keep them maintain within specified limits. Another most important thing is to keep maintaining the machinery properly.

2.3.2. Tool wear

This is another factor that causes variation. Tools like drills, dies and cutting tools will wear as they have been used for a quite a long time. The reason for this to happen is friction and interaction with the workpiece. When the tool use has increased, this will reduce the size and they becomes dull.

2.3.3. Operator error and operator bias

Operator error includes various aspects like improper handling of raw material, improper handling of clamping of tools and improper sequence of operations etc. [6] This kind of improper things can be controlled by proper training, turnover of personnel.

Operator bias includes different effects like ergonomics and human factors like whether the person responsible is left or right handed, short or tall, weak or strong etc. The primary concern in performing mechanical tolerance analysis is the variations in the size and form of raw material, sheet thickness and angle between the surface acting etc.

2.3.4. Ambient working conditions

Factors like temperature, humidity, cleanliness, vibration effects the ambiance of the final product.

These factors highly affect the process and these factors should be maintained within specified limit to make sure that process goes smoothly. The things like cooling systems and lubricants should be considered to keep the machines in optimal conditions.

Processing machinery may be neglected, and preventive maintenance may be lacking. Hence the precision and accuracy possible when the machine was new, or properly maintained, is lost over time [6].

2.3.5. Assembly process variation

The assembly process can have a profound effect on assembly variation. It is very important that the designer understands the assembly process. The sequence of assembly operations has a huge effect on the relationship between the features on assembled parts. Assembly shift is one of the largest contributors in tolerance stack ups where parts are assembled and located by fasteners passing through holes in mating parts.

2.4. Geometry assurance and robust design

The method or work that is aiming for decreasing geometrical variation and its effects is called geometry assurance [5]. The most prominent phase in the geometry assurance process is the concept phase. It is highly important to choose a good concept, a concept insensitive to variation. A robust concept suppresses variation in the input parameters while a concept sensitive to variation amplifies the incoming variation instead [5]. The robustness of the concept is to some extent determined by the shape of the included parts and other characteristics [5].

The robust design methodology is to create a design which is insensitive to the existing sources of variation without elimination of these sources [8]. The word robust is used to describe the products and processes that are insensitive to different kind of disturbances. Locating schemes play a key role in choosing a robust design concept.

2.5. RD&T (Robust design and Tolerancing)

RD&T (Robust Design & Tolerancing) is a tool for statistical variation simulation that allows manufacturing and assembly deformations of the product to be simulated and visualized long before any physical prototypes are being made [9]. Different design concepts can thereby be analyzed and compared and quality of decisions can be improved. It supports geometry assurance process in all its phases, from early design/styling to pre-production and production. A strong focus is on making the product concept robust to manufacturing variation and to be able to predict final variation in the products and critical dimensions [9].

2.6. Locating schemes

Locating schemes have an important role while positioning or fixating the part. Locating schemes are usually in focus in initial phase of the development of a concept. This is the central concept of geometry assurance. Locating schemes are used in optimizing the robustness, there are also various practical factors that affect the choice of positioning system or locating scheme.

The general principle for choosing the locating points is to spread the locators or locating points as much as possible over the geometrical surface in order to obtain the most robust solution. In many situations, it is not that easy to obtain the best way to do it. A rigid part has six degrees of freedom; three rotations and three translations. For a rigid part, six points are used to position or locate it. These points are called locators. These locators are realized in the fixtures by pins with corresponding holes or slots in parts and with clamps [5].

The principle is called as 3-2-1 locating scheme. The primary points A1, A2 and A3 represents a plane as shown in figure 3 and these three points lock the geometry in space in two rotations (Rotation in X, RX, and Rotation in Y, RY) and one translation (Translation in Z, TZ). The secondary points B1 and B2 represent a line and lock the translation (Translation in Y, TY, and Rotation in Z, RZ). The tertiary point C1 represents a point and locks the geometry in space in one translation (Translation in X, TX) [5].

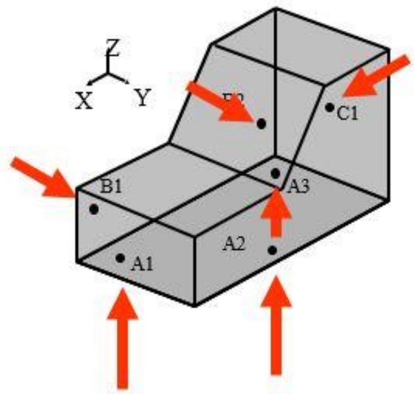

Figure 3: 3-2-1 Locating Scheme [5]

For a non-rigid part, additional points can be added to support the part to avoid a deformation of the part due to gravity or other forces during assembly. These points are called support points. These points can be of any arbitrary number [5]. For a non-rigid part the principle of locating schemes which are handled here is the N-2-1 locating scheme. Here, N represents a number of support points.

There are different kind of locating schemes. These are classified into orthogonal and non-orthogonal directions [10]. In total RD&T provides twelve different types of locating schemes. They are used in different industrial situations, 3-2-1, 3-point, 2-point, 6 directions, 3 directions, and 6 directions local, 6 surfaces, 6 surfaces local, subsystem, Flex and high points [10].

2.6. Tolerances

A tolerance defines as the maximum deviation from nominal specification within which a part is acceptable for its intended purpose [5]. Tolerances play a key role in design variation simulation activities. A tolerance may include the location, size, form, or orientation of the feature as applicable [5].

Sufficient accuracy and precision are two main factors controlling the validity of a simulation model in imitating the real world problem [11].

Tolerances are usually defined by an Upper Specification Limit (USL) and by a Lower Specification Limit (LSL) [12]. Apart from locating schemes, tolerances are going to highly affect the geometrical outcome of the assembly. In the most earliest or beginning phase of product development, the locating schemes can be optimized with respect to the geometrical robustness without incurring any extra or additional costs.

To obtain a good geometrical outcome of the product tight tolerances can be used, but with tight tolerances the production cost will be high. It's better to avoid choosing tight tolerances.

There are methods that are developed in relation to design tasks of geometric tolerancing. These are classified into the following methods.

- **Tolerance specification:** For each feature, a set of tolerance types is then chosen in order to limit variation with respect to its nominal geometry and to datum features [12].
- **Tolerance allocation:** Numerical values are set for all specified tolerances by either adjustment (i.e., refinement of initial empirical values) or optimization (i.e., minimization of a cost function subject to manufacturing constraints) [12].
- **Tolerance analysis:** Whenever required within tolerance allocation procedure, design requirements are verified through the calculation of geometric entities such as gaps, angles, and dimensions involving different parts of the assembly [12].

RD&T can be used for specifying various tolerances at required points in order to generate or check variation. There are different types of tolerances that are used in this variation simulation software. These are used based on given specifications and for different purposes. Different types of tolerances are linear tolerance, circular tolerance, circular position tolerance, spherical tolerance, cubic tolerance, clearance tolerance, clearance, float tolerance and clearance contact tolerance. These tolerances are set in the specified points with a specification limit and a capability index.

Here are the tolerances that are mostly used in performing analysis of the case study.

2.6.1. Linear tolerance

Among the tolerances mentioned, the most frequently used tolerance is the linear tolerance. This can be used to generate a variation in a specific direction in space [10]. This is used for position tolerances of a model, surface profile tolerance and flatness tolerances [10].

2.6.2. Circular tolerance

This type of tolerance is used to model position and diameter tolerance of holes and pins [10]. This kind of tolerances are used for generating variation for circular zones in required areas of assembly [10].

2.6.3. Circular positional tolerance

This is another kind of tolerance used to model a position of a point on a plane [10]. A hole position can be considered as an example.

2.7. Measures

Measure is a critical dimension that is used to measure a critical point while performing analysis in variation simulation [10]. While performing variation simulation analysis, depending on specific requirements, appropriate measures need to be chosen. There are different measures in RD&T. Different measures are used for different purposes and here are few examples of measures, Point-self, Point- Point, Line-Self, Line-Line, Circle-Circle, Circle-Circle, Max pin etc [10].

In analyzing the case study, Point-self measure is used. It is used to analyze the point variation relative to its nominal position in space [10].

2.8. Process Capability

The ability of a process to produce units with dimensions within the tolerance limits is called its capability. It is highly important to observe that a capability measure can only be interpreted if the process is stable. Determining process capability is one of the easiest way to control production quality statistically and prediction of production capability within a batch [13].

Process capability have been proposed in the manufacturing industries and service industries in order to provide certain numerical measures on whether a certain process is capable of reproducing items within specification limits which are preset in the industry [14]. The capability indices essentially compares the predefined manufacturing specifications with the actual production performance [14]. The most commonly used measure of process capability is $C_{p.}$

$$C_p = \frac{USL - LSL}{6\sigma} \text{ [14]}$$

Where USL and LSL are the upper and lower specification limits. σ is the process standard deviation [14].

2.9. Tolerance stack-up methods

2.9.1. Worst case method

In this method of tolerancing, all dimensions are assumed to be at their worst conditions. The worst case technique guarantees assembly and function of finished products regardless of which components are used in assembly, as long as the components are within their specification limits [5].

2.9.2. Root sum square method

In reality, the probability that all dimensions contributing to the final result of an assembly will be at their worst case conditions is very low. Instead, most of the dimensions are distributed close to their mean values. In statistical tolerancing, the possible values for a dimension of a component are described by the distribution function for the dimension in question. Using the root sum square method, and different modifications of the RSS method, all component dimensions are assumed to follow a normal distribution [5].

2.9.3. Monte Carlo simulation

Monte Carlo method performs the prediction of the final variation of an assembly by using a random number generator that selects values for each tolerance parameter, based on the type of statistical distribution assigned by the designer. Monte Carlo simulation is said to be exact but time-consuming while the deterministic methods sometimes lack accuracy, are somewhat complicated to use, but are usually not as computer-expensive as the Monte Carlo method [5].

2.10. Stability analysis

Stability analysis is used to find robust locating schemes. Stability analysis is used to evaluate or analyze the geometrical robustness of the concept. This helps in understanding the introduction of variation into components by the locators and the effects caused by this variation. By varying each locating point with a small increment, one at a time, the change in output may be determined in the X, Y, Z directions separately for a number of output points, representing the geometry [4]. The RSS value for all points, represents the sum of variation in each point caused by variation in six locating points, can be visualized by color coding [4].

The color coding of variation amplifications shows how the variation will propagate from the locators (the inputs) to critical areas of part or assembly [4]. By performing this kind of analysis in the early phase, different kind of locating schemes can be compared and evaluated and the best solution can be chosen in the early phase of product realization cycle.

2.11. Statistical variation simulation

The main objective of variation simulation is to be able to predict the geometrical behavior of a sub-assembly or of an assembled product as soon as possible in the concept phase of the product realization cycle. This kind of tolerance stack up or tolerance chain calculations are considered under sections like variation analysis, variation simulation or tolerance analysis [5]. There are different tools that are available on the market for performing variation simulation and most of them run on the basis of Monte Carlo simulations. In this project, RD&T software has been used and different kind of analyses have been used on a subassembly to check out the factors like the stability of solution, variation analysis and contributors affecting the assembly.

The inputs to a variation simulation consists of digital 3d models of designed parts that are to be assembled and the information including relevant tolerances and the locating schemes are required. High levels of accuracy are necessary for variation simulation and in order to make it possible to replace prototypes and physical testing. The use of simulations will help to reduce the lead times. Moreover, it also importance from a sustainability point of view. Hereby, accurate simulation results not only lead to the increase of virtual tools but also help in reducing scrap rate, the risk of failures and wrong judgements. A reduction in scrap rate will also help in gaining sustainability in both economic and ecological aspects.

The output are parameters like mean, range, variation, standard deviation and capability measures. In order to determine the quality level for a product that is sent into production, the key factor variation in the product must be depicted. This kind of analyses are performed to analyze the stack up calculations and to predict variation in the assemblies before building the first prototype and sending it into further production. This Monte Carlo simulation method generates a number of parameters for all the input parameters defined as per the distribution and the output parameters are being generated and builds up distributions based upon the critical product dimensions.

Variation simulation analysis utilizes a virtually built assembly model with all defined locating schemes together with all distributions of input parameters. In order to obtain the desired output, the distributions for all the expected parts are defined as well as the locating schemes for the parts. The product dimensions that are to be measured are defined as one point on each part along with a measuring direction. Based on the number of Monte Carlo iterations, the simulation calculates the mean, range, capability measures etc.

2.12. Contribution analysis

Contribution analysis is the final stage of variation simulation. This is performed to predict or calculate the relative importance of each input with respect to output. It means for a critical dimension, the input parameters can be ranked and their contribution can be determined [5]. This analysis helps to find the tolerances that are highly contributing to the result and that are to be reduced. This shows highly contributing tolerances and based on one's requirement that particular tolerance can be tightened or can be loosened based on the requirement.

3 Methodology

3.1 Literature studies

The project comprises of two different phases. One phase of the project is to analyze a case study by using variation simulation in RD&T the another phase is to formulate a process for geometry assurance at Powertrain Volvo GTT. Literature studies are carried out to understand the concepts of variation simulation and various activities in different phases of geometry assurance.

3.1.2 Case study in RD&T

Various practice exercises are carried out with support from Semcon and Wingquist Laboratory to understand variation simulation and the working environment of RD&T. These exercises are performed to get hands on experience of RD&T.

3.1.3 Results and analysis of case study in RD&T

Variation simulation is to be performed on a sub-assembly of the Powertrain from Volvo GTT using CAT tool RD&T. The task is to measure the variation at an end point of a pipe in X, Y and Z directions. Results are stated by performing variation and contribution analyses. Required tolerances and a new design are suggested. Finally, the benefits of using variation simulation in geometry assurance are stated.

3.2 Interviews on current product development process and current situation of geometry assurance in Powertrain Volvo GTT

To understand the current development process and current situation of geometry assurance of Powertrain Volvo GTT, a series of interviews were conducted with the responsible persons in this particular area of expertise. To understand the current situation of geometry assurance, a questionnaire has been prepared and was sent to the concerned managers before the interview.

3.2.1 Interviews on geometry assurance process from cab engineering, Volvo GTT and Volvo Cars Corporation

Volvo Cars Corporation and CAB Engineering of Volvo GTT are using the standardized process of geometry assurance. In order to make a new suggestion of process to Powertrain Volvo GTT a series of interviews are carried in order to collect the information from both the companies.

3.2.2 Final processes for concept, verification & production phases for Powertrain Volvo GTT

This phase of the project includes quite a lot of brainstorming activity. A huge amount of information regarding all the three phases of geometry assurance has been collected from VCC and CE, VGTT. A final process has been formulated after analyzing the collected information.

3.2.3 Conclusion and results

In this phase, conclusions and results are stated. The results and conclusions are presented to advisors from university and to the companies. A report is also documented stating all the results and conclusions. The below mentioned figure 4 shows the sequence of activities that are performed.

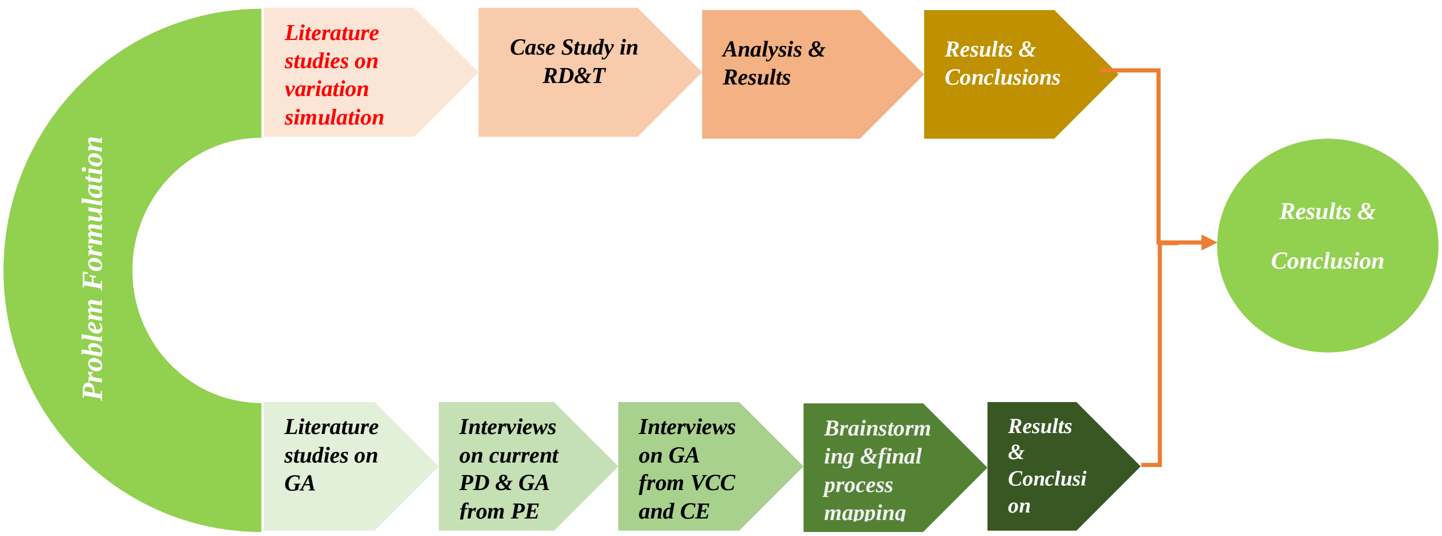

Figure 4: Methodology

4 Case study using RD&T

4.1 Introduction to case study from Volvo GTT

The case study is to analyze the variation at the end point of a pipe from an assembly in X, Y and Z directions using variation simulation in RD&T. The specification limits are not provided by Volvo GTT, as they have no clear understanding of pipe behavior in the whole assembly. The below mentioned figure 5 demonstrates various components in the sub assembly. Appendix-2 describes the individual parts in detail.

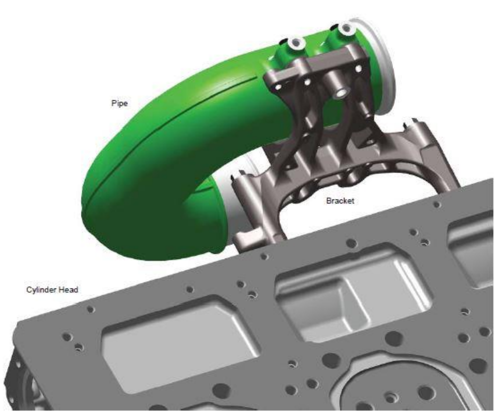

Figure 5: Components in Sub-Assembly Pipe, Bracket and Cylinder head.

4.2 Critical measure

The figure 6, shows the critical measure that is to be measured in the sub-assembly. As mentioned in section 2.7, RD&T comprises of different types of measures. Here, Point-self measure is chosen based on current requirement to analyze the variation of the pipe. The point-self measure is represented by the point 'MP' which is to be analyzed in X, Y and Z directions.

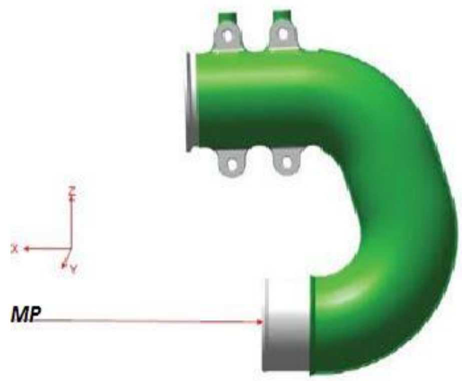

Figure 6: Showing the critical measure

4.3 Locating schemes for the case study

As mentioned in section 2.7, locating schemes should be chosen in such a way that the locators are to be spread on the surface, to increase the robustness of geometry.

This particular sub-assembly includes pipe, bracket and cylinder head. Here see in figure 7, 3-2-1 locating scheme is chosen for locking the cylinder head and bracket. The locating frames which are in yellow color from the below mentioned figure represents 3-2-1 locating scheme. Here, the cylinder head acts as target part and bracket acts as local part. Once the locators are chosen, the bracket is assembled to the cylinder head.

Local part frame is the set of six points that are used to lock six degrees of freedom for the part [10]. The target part frame is the six mating points that corresponds to the local part frame [10].

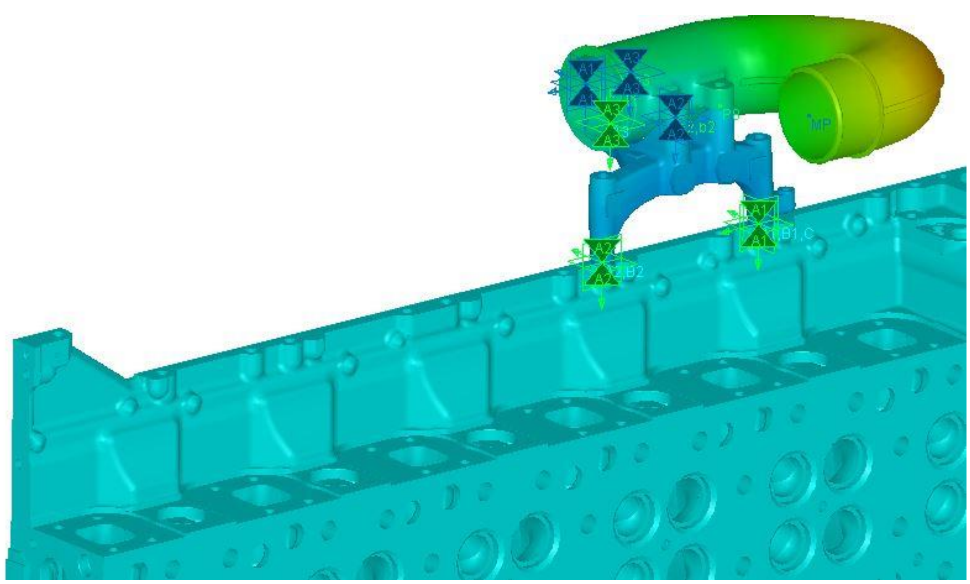

Figure 7: 3-2-1 Locating scheme to lock bracket in cylinder head.

While assembling the pipe and the bracket, 6-directions locating scheme has been chosen. 6-directions locating scheme works on the same principle as a 3-2-1 locating scheme. The additional thing that the user gets to choose the in 6-directions locating scheme is directions based on requirements while fixating the parts.

Here, the explanation is regarding the 6-directional locating scheme acting between pipe and bracket, shown in figure 7. In this locating scheme, pipe acts as a local part while the bracket acts as the target part. From the above figure 7, the points A1, A2, A3 are locking the translation of pipe in Z direction and rotation in X and Y direction. The points B1 and B2 are locking the pipe in translation in X direction and rotation in the Z direction. The point C locks the translation in Y direction. The locating frames acting between pipe and bracket which represents blue-grey color represents 6-directional locating scheme.

Once the locating schemes are assigned, the parts are assembled using an option called 'assemble' in RD&T. If the parts are not assembled in a desired manner then the process is repeated until the requirement is achieved. If assembly comes out in a desired manner, then stability analysis is performed to check the robustness of chosen concept. In figure 8, the actual design of slot holes in the pipe is described and figure 9 represents actual design of circular holes in the bracket.

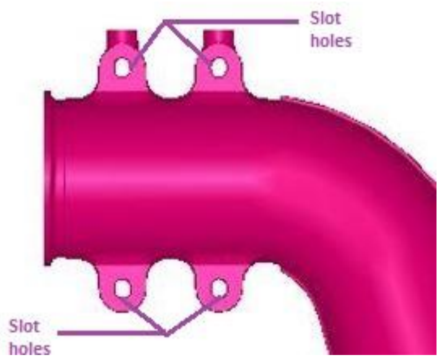

Figure 8: Actual design of slot holes in pipe.

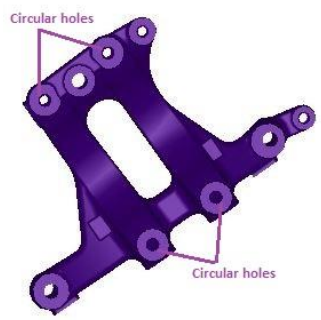

Figure 9: Actual design of circular holes in bracket

4.4 Stability analysis for case study

A stability analysis is performed to check the geometrical robustness of the concept. A set of locators are analyzed and the appropriate sequence of locators has been chosen. The figure 10 shown below illustrates the stability analysis.

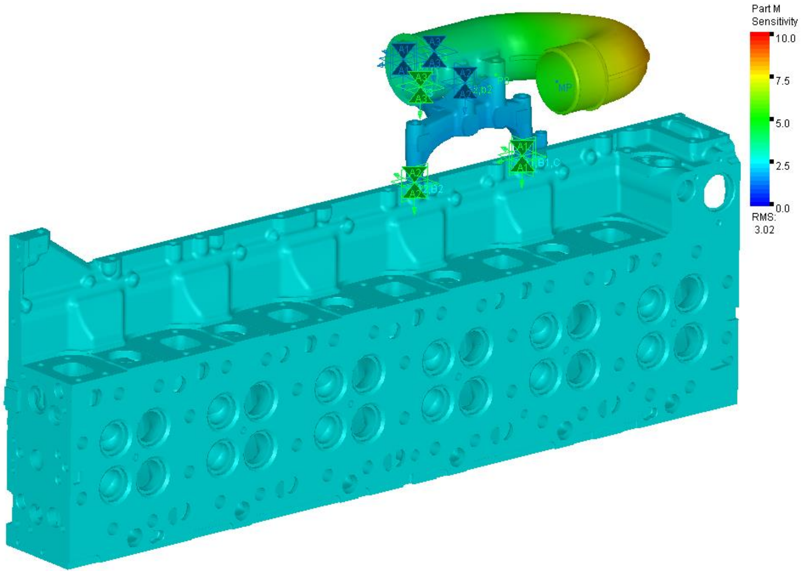

Figure 10: Stability analysis.

4.5 Variation analysis for case study

Once the robust solution is chosen, variation analysis can be performed on the assembly. From the engineering drawing, required tolerances along with respective directions are assigned in RD&T. This is performed in order to predict the variation of a point-self measure in the assembly. In this case study, variation analysis is done to evaluate a point 'MP' in X, Y and Z directions. As specification limits are not provided from Powertrain Volvo GTT, one has to look for six sigma limit rather than capability measures. Here, variation analysis is performed for 1 million Monte Carlo iterations. The below mentioned figures 8, 9 and 10 represent variation analysis in X, Y and Z directions.

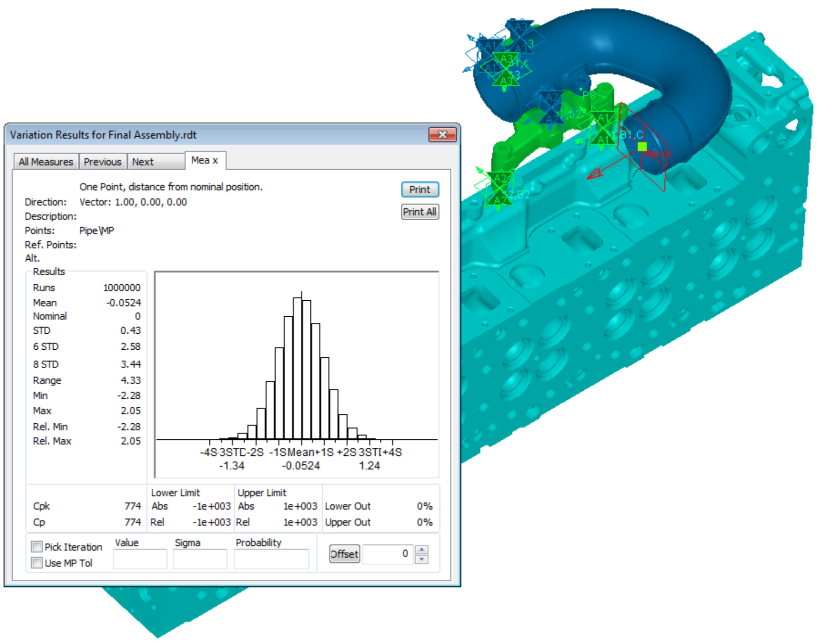

Figure 8: Measure point MP variation in X direction.

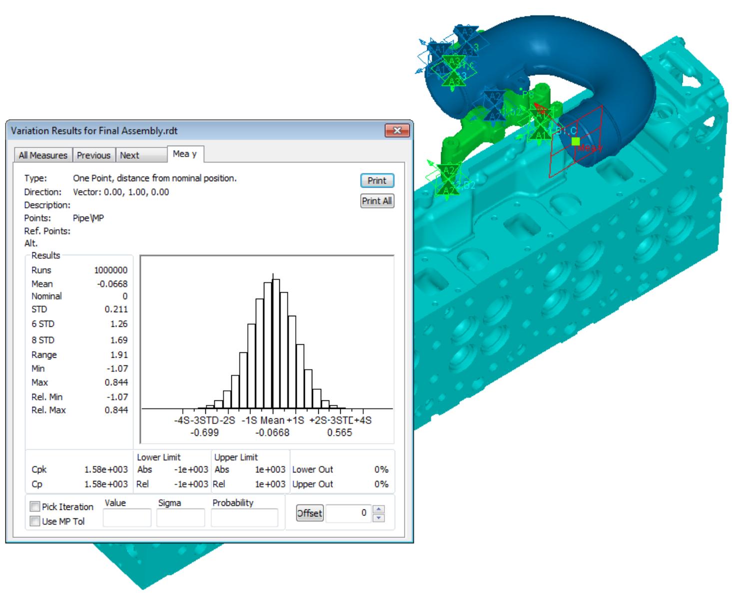

Figure 9: Measure point MP variation in Y direction.

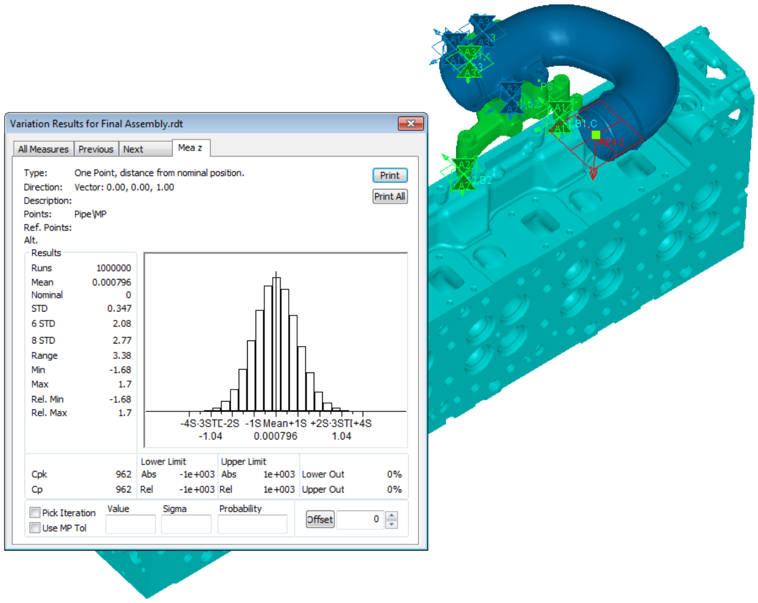

Figure 10: Measure point MP variation in Z direction.

4.6. Contribution analysis for case study

This is the final step in variation simulation. Contribution analysis is used to calculate the relative importance of each input on the output [5]. The major contributors to variation in a critical measure can be found in the contribution analysis. By actually analyzing the percentage level of contribution, the tolerance can either be tighten or loosen depending on specific requirements. By performing this analysis, a decision can be made to optimize the respective tolerances or designs considering requirement. The figures 11, 12 and 13 represents results of contribution analysis in X, Y and Z directions.

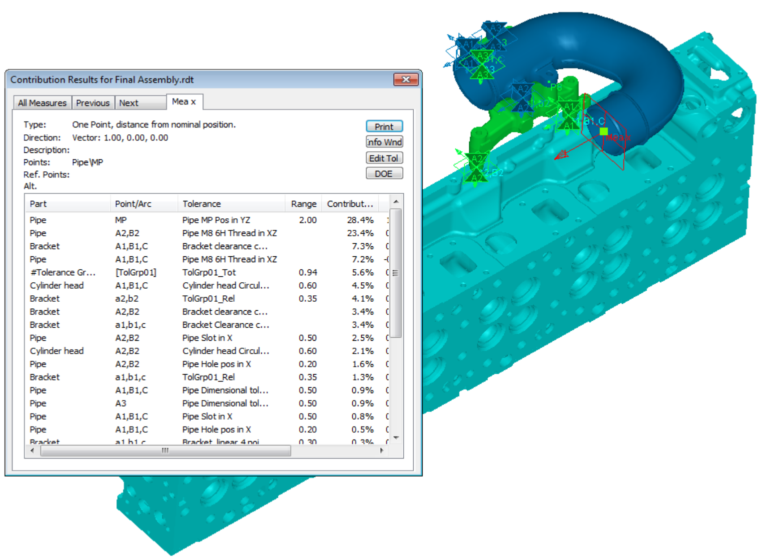

Figure 11: Contribution analysis in X direction.

Figure 12 and 13 demonstrates the contribution analysis performed in Y and Z directions.

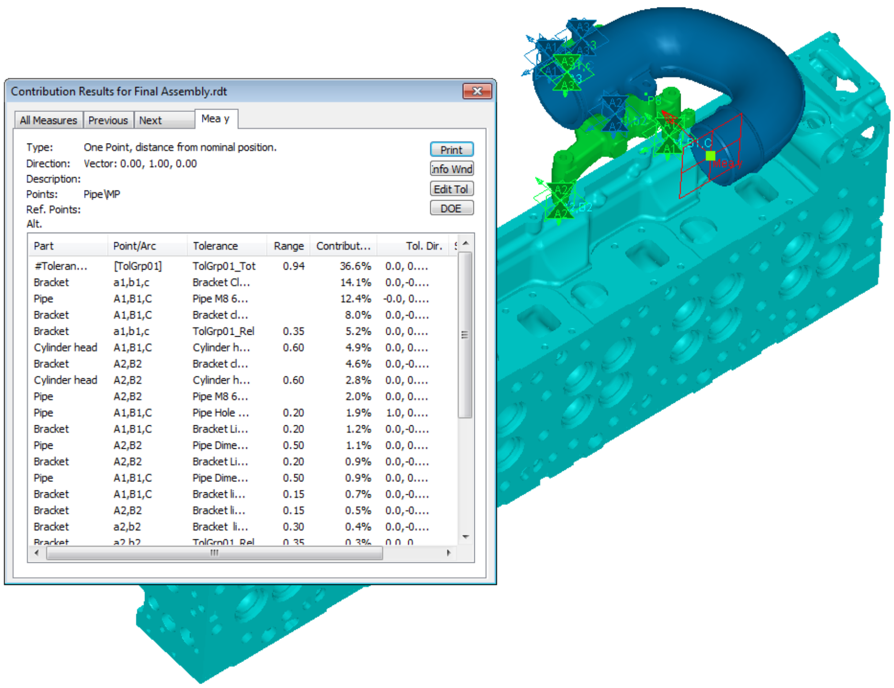

Figure 12: Contribution analysis in Y direction.

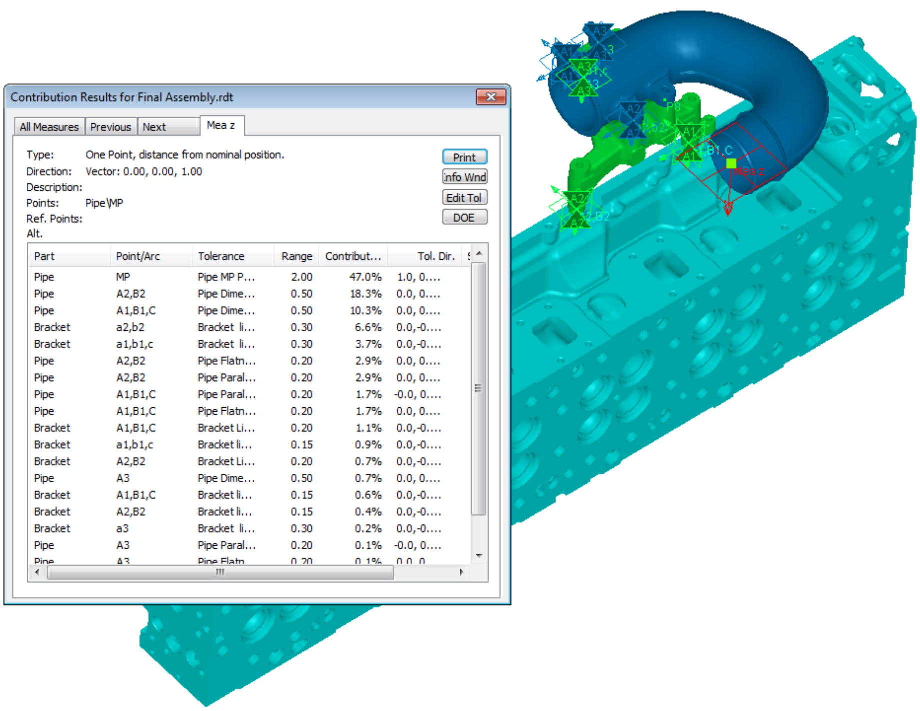

Figure 13: Contribution analysis in Z direction.

5 A new suggestion for the case study

A new design suggestion for the pipe has been made based on major contributors that are obtained from analyses of the case study. In the actual design, pipe includes four slot holes as shown in the figure 8. The bracket includes four circular holes in the actual design as illustrated in figure 9. Bracket acts as a target part while the pipe acts as local part. From the design, there are more chances of variation as four slot holes are locked by four circular holes. Here, slot holes are used by Volvo GTT to ensure the best fit between bracket and pipe.

In order to make a robust assembly, a new design is suggested. In the new design, the points A1, B1, C on the pipe has been suggested by a circular hole that completely fits the hole of a bracket. This hole is chosen to be a tightened hole because in this circular hole all the three points are acting in such a way that it locks movement in three directions. A slot hole has been chosen for point A2, B2 in pipe. This is chosen for best fit and to allow the variation to act in Y direction otherwise the design becomes completely constrained. The figure 15 illustrates the points A3 and P5 are chosen to be oversized holes. These point helps to manage variation in X and Y directions. Suppose, if the chosen design with all the circular holes are tightened, this works well for performing analysis virtually. Speaking about reality, the solution with all circular tighten holes will not work out as it becomes over constraint. The new analysis, a design solution with a completely tightened hole A1, B1, C which completely locks with bracket and a slot hole and two oversized holes works well considering both virtual and reality aspects. The figure 15 describes the newly suggested design for the case study.

The actual design includes linear tolerances acting in X and Y directions on all slot holes. While considering new design, tolerances changes are to be made accordingly the new design. In the new design, circular position tolerances are chosen for points A1, B1, C and A3. While considering tolerances that are to be assigned to the slot hole, linear tolerances are assigned that acts in X and Y directions. Based on contribution analysis from the actual design, a new tolerance change has been made. A circular position tolerance in the end point of pipe acts as a major contributor in X, Y and Z directions. In the original design, the tolerance acting at this particular point according to the drawing is '2mm', which is acting at the point measure 'MP'.

A new tolerance suggestion of '1mm' is chosen at that particular point MP. Variation and contribution analyses are performed once after modifying the tolerances to know the results. The below mentioned figure 14 describes linear tolerances and circular tolerances which are going to act in the new design.

From the analysis, a tolerance suggestion of '1' makes a reasonable solution. As mentioned earlier, as the specification limits are not assigned as they are not provided by Volvo GTT. To understand the behavior one has to compare the results taking 6 sigma limits as reference. Comparing both the processes the new design has given good results and contributions on the particular circular positional tolerance are drastically brought down. From overall conclusion of results, the new design which is suggested is comparatively good. This case study helps one to understand the benefits of variation simulation in the concept phase of geometry assurance.

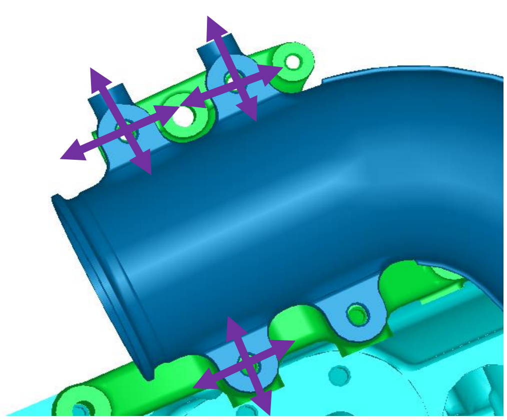

Figure 14: Linear tolerances in actual design

The below figure 15 describes the new suggested design and tolerances acting in the suggested design of pipe.

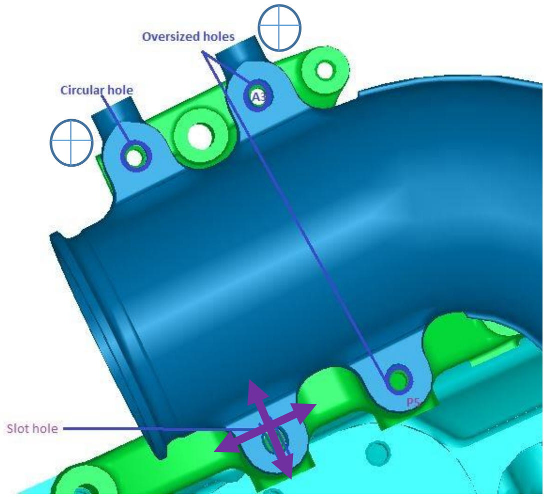

Figure 15: New suggested design with new assigned tolerances

5.1. Results of variation analysis for suggested design

Here, variation analysis is performed with 1 million iterations. No specification limit has been provided. In order to understand the improvement for the newly suggested design, one has to look into 6-sigma limits or 6 STD (Standard deviations) to get clear understanding about the behavior of the point MP in pipe. Below, figures 16, 17 and 18 describes variation analyses for the suggested design in X, Y and Z directions.

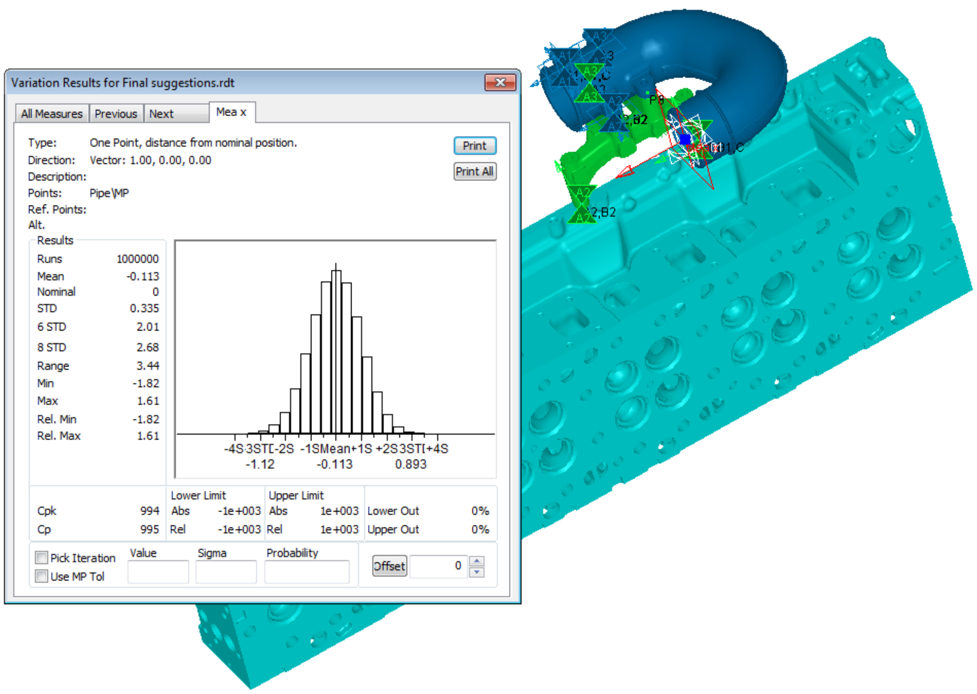

Figure 16: Variation in the point MP in X direction for the suggested design

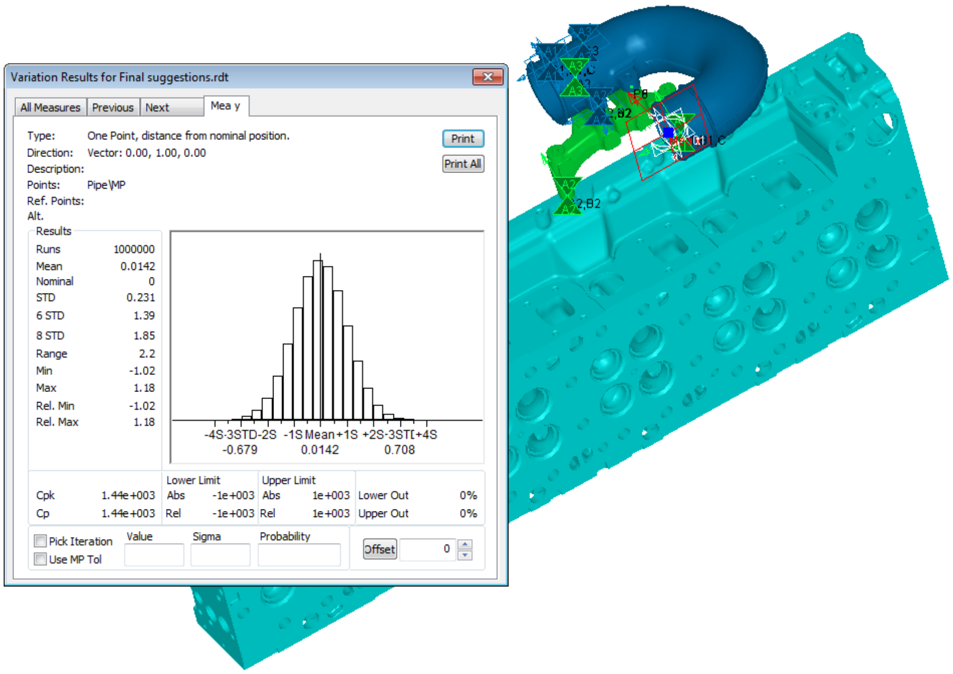

Figure 17: Variation in the point MP in Y direction for the suggested design

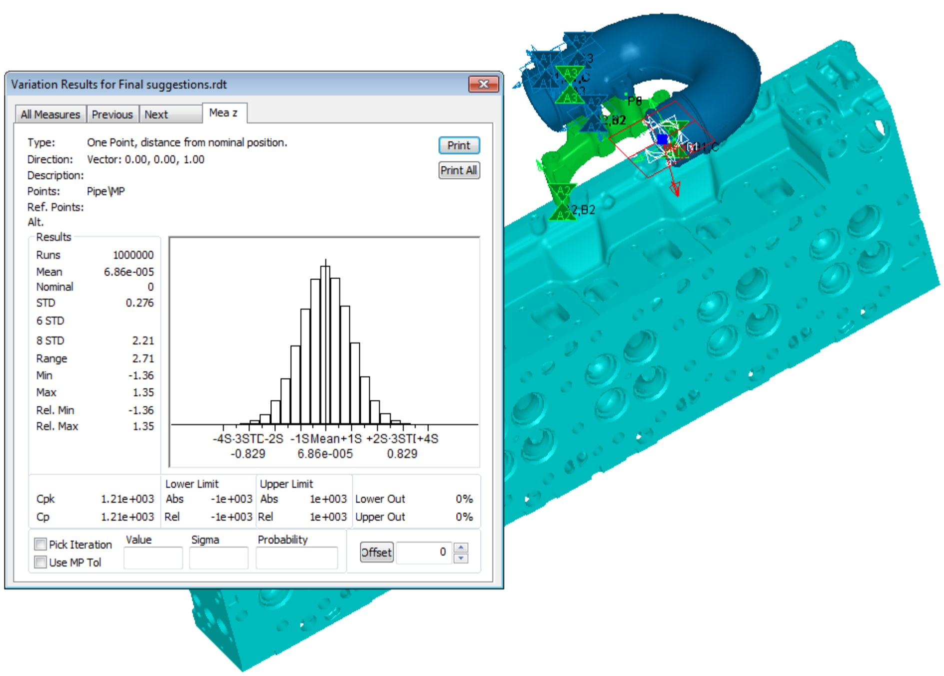

Figure 18: Variation in the point MP in Z direction for the suggested design.

5.2 Contribution analysis for new suggested design

In the new suggested design, the contributors that are having a high impact in the actual design are drastically dropped down in the new suggested design. Below, the figures 19, 20 and 21 describes contribution analyses for the suggested design in X, Y and Z directions.

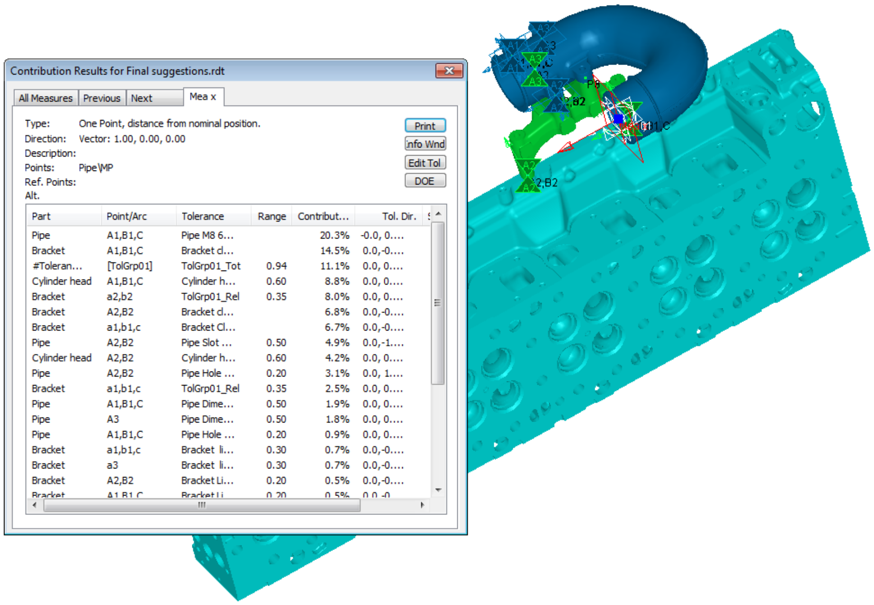

Figure 19: Contribution analysis for the suggested design in X direction

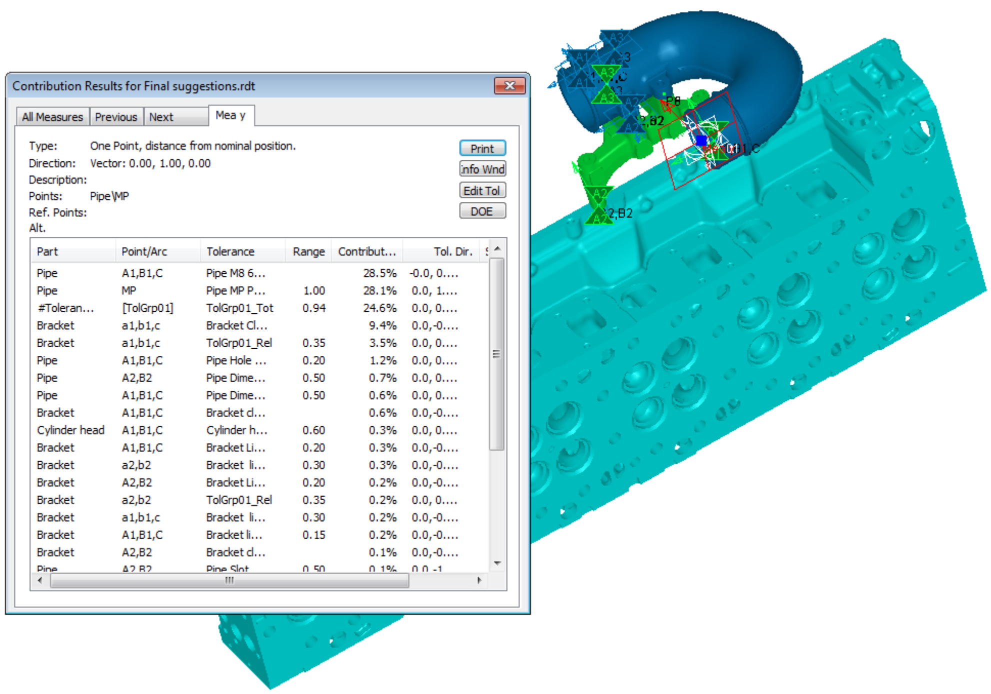

Figure 20: Contribution analysis for the suggested design in Y direction

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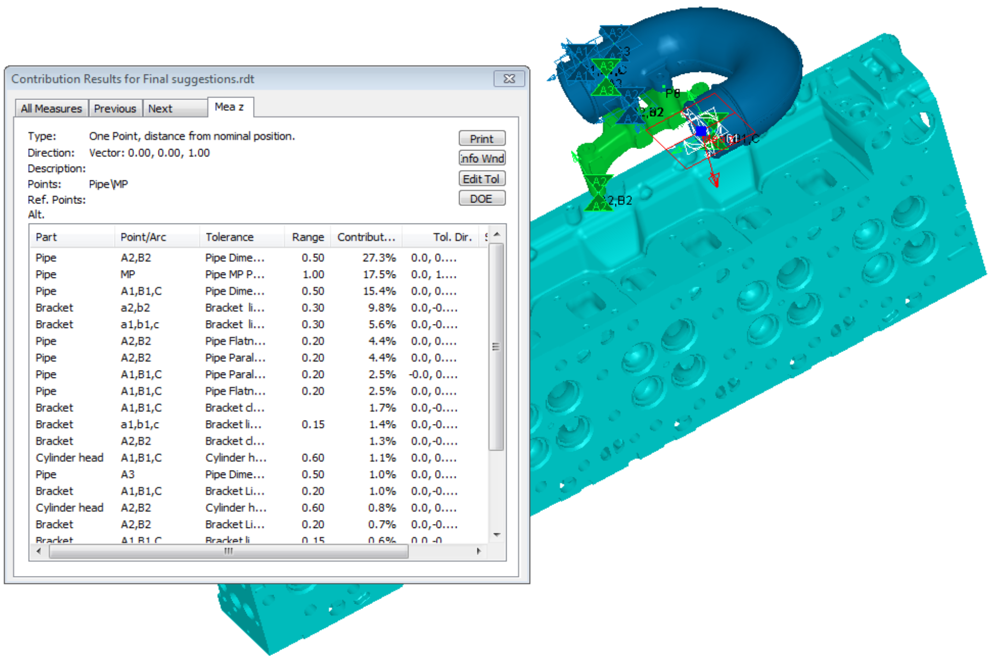


Figure 21: Contribution analysis for suggested design in Z direction

6. Current development process at Powertrain engineering at Volvo GTT

As a part of this thesis, another task is to study and understand the current development process at Powertrain engineering, Volvo GTT. Information has been gathered based on interviews with concerned managers in the current development process at Powertrain engineering Volvo GTT. To understand the current working method, a questionnaire has been prepared and was sent to the concerned managers before the interview.

The current development process consists of six stages in the product development cycle. It is a six gated process which includes gates from pre-study until the launch of the product. Each gate in the process has specific objectives to be satisfied before proceeding to the next successive stage. According to Volvo GTT standards, each gate needs to satisfy environmental, quality and safety objectives. The process is used to indicate a certain focus of work that is undergoing in the project. The gates in the process can be either added or combined or deleted in such a way it fulfills the requirements of the project.

The process is like a sequential or linear way of working. Follow-up of activities practically during the process is difficult. Project gates are used to make sure to know what is completed and what is yet to be completed in the project. An illustration of the gates that are in the process is given in figure 22.

6.1. Gates in current development process at Powertrain engineering at Volvo GTT

Pre-study

The main objective of the pre-study is to evaluate the ideas of the projects. It also includes consideration of efficiently allocating required resources to make sure that the best ideas can be implemented. The scope of the project is defined by balancing project targets, development requirements and alternative solutions [15].

Concept study

Here the concept is chosen through a process of market research, environmental impact assessments, and the business case [15]. Activities like evaluation of concepts, selection of concept and requirement settings are done in this phase [16].

Detailed development

This is an applied research phase, which includes the technical feasibility study [15]. Here detailed development and documentation of solutions take place [16].

Final development

The development phase includes building, verifying, and validating of the product solution. Here the market, aftermarket, manufacturing and assembly solutions need to be refined by concluding feasibility studies [15]. A brief building, testing and refinement of product and process occur [16].

Industrialization

In the industrialization and commercialization phase the industrial system has to be installed, prepared and verified to enable production [15].

Follow up

This phase deals with product launching and aftermarket products

Figure 22: Current development process at Powertrain Volvo GTT [15]

The process is moreover a kind of reactive problem solving. The people concerned with the activities act accordingly to the problem that pops up during the process. There is no proper communication between designers, manufacturing engineers and production units. Based on the situation, engineers who are concerned about activities in production get back to designers when they come across various problems during production.

7 Analysis of geometry assurance at Powertrain Volvo GTT

7.1 Current situation of geometry assurance at Powertrain engineering at Volvo GTT

Interviews are carried out in Powertrain engineering department at Volvo GTT. From the analysis, Volvo GTT has no systematic procedure of geometry assurance in the current development process. The department has an unclear structure of working with geometry assurance.

In the department, the primary focus is on functional requirements. The objective of an implementation of geometry assurance is to reduce pressure and air leakages, to increase the efficiency of the system. In the department, a bottom-up approach is followed for defining tolerances. In allocating tolerances, engineers experience and knowledge are used to set tolerance limits and choose locating points rather than following virtual verification techniques.

Powertrain Volvo GTT has very few engineers currently working with tolerance issues. They are mostly using tools like CTOL and Excel for performing tolerance calculations and on complex situations they use RD&T for performing tolerance stack up calculations. In most of tolerance calculations, worst case method and root sum square methods are being used. The figure 23 below mentioned shows the current situation of geometry assurance in Powertrain Volvo GTT.

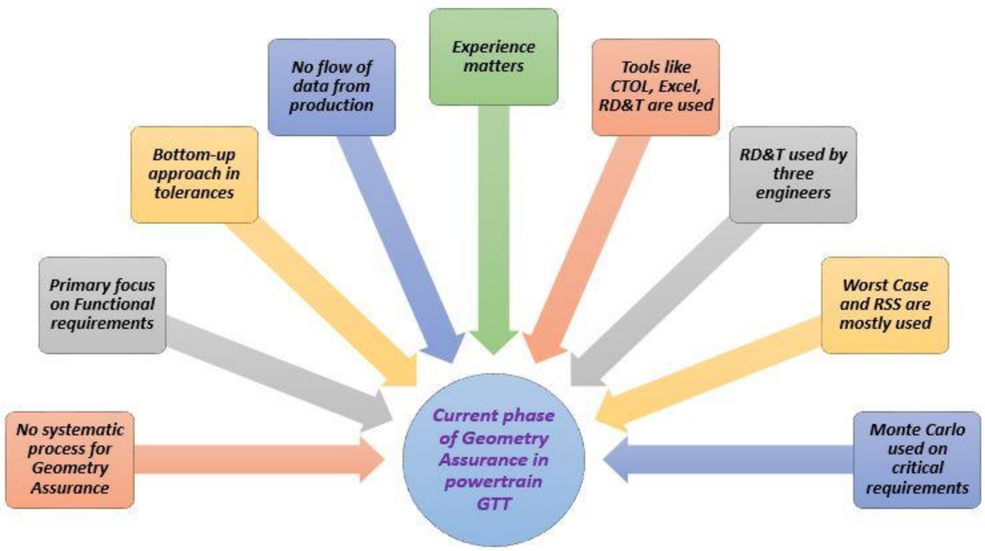


Figure 23: Current situation of Geometry Assurance at Powertrain Volvo GTT

7.2 Problems in current situation of geometry assurance at PE department at Volvo GTT

The PE department at Volvo GTT is looking for an implementation of geometry assurance. Here are a few problems found from the interview analysis.

- Awareness among the engineers should be brought explaining the importance of geometry assurance and its activities.
- Designers aren’t aware of the importance of tolerances and datum targets.
- Responsible people have improper understanding of the reason behind assigning tolerances.
- No standardized work or systematic way of working with calculations are carried out in the current phase.
- Many of the engineers in the department have no proper education of how to perform tolerance calculations using RD&T and it is learned by themselves.
- They have insufficient manpower for carrying out these kind of analyses in product development or concept phase.
- The current systems have no feedback from production to design make required changes.

- Suppliers are not ready to share production data, measurement data and their method of working in the organization.
- There is no common global database where suppliers can share data and the designers can check whether the design meets production requirements or not.

7.3 Importance of geometry assurance implementation in Powertrain Volvo GTT

Every company desires to produce products of high quality and strives hard to reach customer expectations. In order to satisfy product functional requirements and produce products with high quality, PE department has an interest of implementing geometry assurance process in their organization. Currently in the organization there are problems with assembly and tolerance issues.

Here are reasons for implementation of geometry assurance process at Volvo GTT:

- Many of the working team have no complete understanding about the reasons for assigning tolerances and about reasonable tolerance levels.
- To bring awareness, importance of tolerances and to set them reasonably.
- To perform tolerance calculations virtually and to assign them after analyzing in variation simulation tools.
- To satisfy functional requirements of Powertrain and to attain the best possible quality.
- To shorten lead time from start of project to product on the market.
- To reduce the number of physical prototypes and to encourage virtual verification of prototypes.
- To reduce redoing/rework of activities.
- To reduce scrap rate.
- To improve communication among design, manufacturing and production departments so they can work collectively and make common decisions while building new concepts.
- To choose the best manufacturing process virtually before going to production.
- To reduce lead time and manufacturing costs by choosing the best sequence of operations before initiation of production.
- To have a global database for production and supplier data to share information and deviations from nominal.
- To improve and strengthen relationships with suppliers by understanding their working procedures and sharing the production data.
- To choose a robust design and better positioning systems by verification using variation simulation during concept development.
- To make manufacturing engineers involved in the beginning of the concepts to setting datum targets and requirements.

8 Suggested geometry assurance process formulated from Volvo Cars and Volvo Cab Engineering, Volvo GTT

8.1 Suggested process of geometry assurance for Powertrain Volvo GTT

The new process is formulated based on interviews from VCC and CE, Volvo GTT. The new suggested process of geometry assurance includes concept, verification, and production phase. A new database is added during production phase where all the production sites and suppliers globally can share their production and measurement data which is accessible to every employee of the organization. Here, database helps the organization for using the information for future purpose activities while developing new concepts. This helps in improving proper communication between designers, manufacturing, production and suppliers. By having proper understanding and usage of data, designers can bridge the gap between virtual verification and reality. Here, figure 24 represents the suggested geometry assurance process including the people responsible for activities.

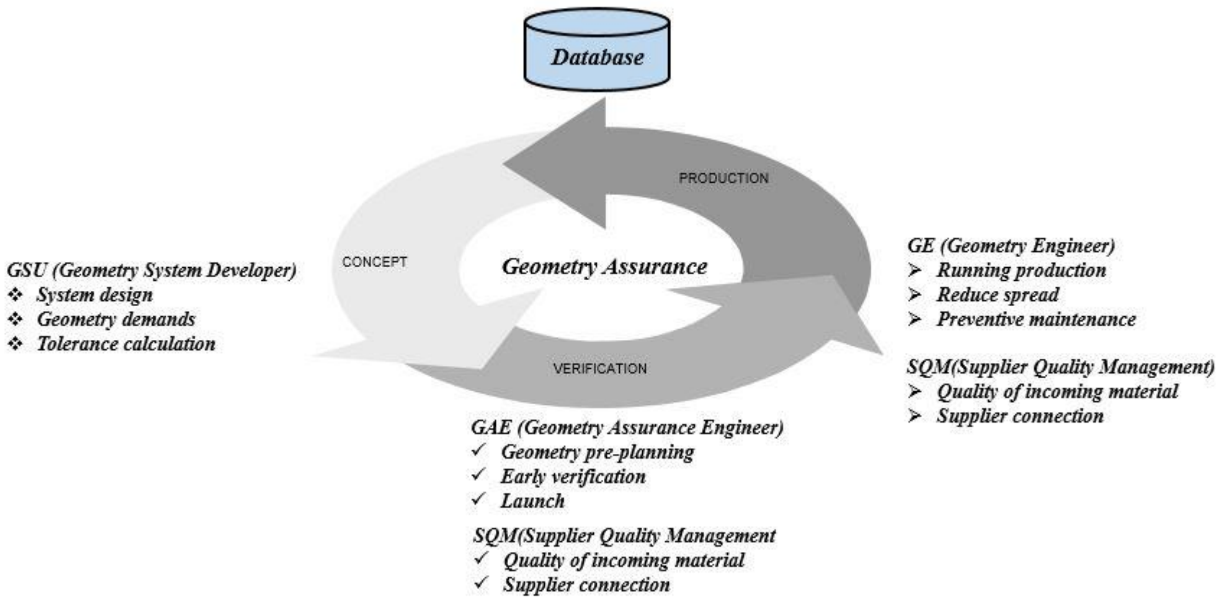


Figure 24: Suggested geometry assurance process with people responsible for activities

Each phase of the geometry assurance process is assigned with different people with specific responsibilities. A geometry system developer (GSU) is the responsible person for carrying activities in concept phase. A GSU acts as an active player from beginning of concept until the end of the product development activities. GSU is responsible for performing tolerance calculations and allocating them. He plays a major role in setting geometry demands and for setting targets for system design.

Once the final system description is attained, the GSU will pass it on to verification or industrialization phase. A geometry assurance engineer (GAE) is responsible for the activities in this particular phase. He takes charge of activities from the beginning of industrialization phase. GAE is responsible for geometry pre-planning, early verification and the launch of the product. After performing the required activities in the verification phase, the information and responsibilities are transferred to the geometry engineer (GE) in the production phase. He is responsible for taking care of running production, preventive maintenance and for reducing spread.

Supplier quality manager takes interference once after concept has been developed. He involves in both verification and production activities. He ensures the quality of incoming material and maintaining proper connections with the suppliers.

8.2. Detailed description of new suggested process for concept phase in geometry assurance

Concept phase

Every company has research and development team for generating new concepts. The company has to reach their customer goals and expectations, while maintaining specific company's objectives and limitations in order to make the product go for production. This activity includes responsible people to carry out a sequence of activities during the process. A detailed process map has been formulated using the information gathered from interviews. For the complete process map, look at Appendix-3. In the detailed process map, the process shapes in orange color or the shapes that are presented towards the right of the process chart indicate the concerned people assigned with responsible activities. The middle column includes a sequence of activities during the concept phase. The process shapes towards left side of the chart which are represented in green color act as input to the activities.

Summarized requirement

For developing a product, a company has certain prerequisite requirements and objectives that are needed to be attained and should reach the customer expectations. In order to sort out the specific requirements, the requirement owner takes the responsibility of framing out prerequisite requirements and concerned geometry quality requirements. Geometry quality requirements are collected from statistical analysis of data and measurement data of parts from production/suppliers.

Once the requirements are compiled by the requirement owner, a summarized requirement is created with cost perspective as a priority. A summarized requirement is going to be updated as functional requirement and geometrical requirement documents. GSU will play an active role during the entire process of concept phase.

Prioritization of critical components

In this phase, the GSU and the project management team take the initiative of prioritizing critical components. Usually, an assembly consists of many complex components. Here prioritization is made on how a particular component is going to show impact on other components.

Definition of datum target for the concepts developed

In defining datum targets, a team of GSU's, manufacturing engineers and designers will play an active role in making an appropriate decision. Datum targets are defined based on the company's production system standards. Involving manufacturing engineer in this phase is going to be an added advantage. Here the the most important things regarding the manufacturing process and availability of fixtures are undergone. There can be chances of adopting the design based on the availability of existing fixtures which is very beneficial from a financial perspective. In deciding upon manufacturing processes in this phase helps in having a proper understanding between designers and manufacturing engineers.

Robust analysis and concept selection

This is one of the most important steps in the whole geometry assurance process. Here robustness analysis is performed on defined datum targets on various concepts which are developed in previous steps. Robustness and concept selection are made by analyzing parts in a variation simulation tool. The GSU is the responsible person for performing robustness analysis. A 3d variation simulation tools needs to be used in order to carry out the robustness analysis.

Definition of pre-tolerance for critical components

In this particular phase, pre-tolerances are assigned for previously prioritized components. The GSU and the perceived quality department are responsible for assigning pre tolerances.

A Pre-tolerance is assigned based on statistical analysis of data, measurement data of parts from production/suppliers in previous projects and updated functional requirements by perceived quality.

A selection of suppliers is also going to act in this particular phase. Pre-tolerances are assigned based upon the data from selected suppliers. Tolerance requirement is said to be obtained from this pre-tolerance document with defined datum targets.

System description

This document contains pre-tolerance document with defined target/locators and tolerance requirements. The GSU is the responsible person for making out system description.

Tolerance calculation

This is another important stage of concept phase where tolerance stack up calculations are performed and analyzed. The GSU is the responsible person for performing tolerance calculations. Here calculations are performed using 3d variation simulation software.

Initially tolerance calculations are performed. If the calculations satisfy the tolerance requirements then the results are concluded and summarized. If the calculations don't satisfy the tolerance requirements, then changes are made accordingly with considering the change of material/process/concept/requirements. Required changes are made by requirement owner taking necessary feedback from GSU.

Analysis report

GSU is the responsible person for developing an analysis report. This particular document includes results from the tolerance calculation. The report comprises results from contribution analysis, and predicted variation.

Reviewed system description

The analysis report is reviewed by a component designer and a GSU together. Here the drawing is started with an isoview and agreed referencing system.

Final system description

Here the final system description will be developed by the GSU. If the production is in-house this final description will be delivered to industrialization or verification phase.

If the production is not in the company it will be passed on to the supplier. Once after the document is handed over to the suppliers, no modifications can be made in design or developed concept. The supplier has to take their own responsibility in solving the issues.

8.3. Detailed description of new suggested process for verification or industrialization phase in geometry assurance

Geometry assurance engineer (GAE) is the responsible for geometry assurance activities in the verification phase. Here verification of prototypes, physical testing, and trimming of the production process and inspection preparation activities are carried out actively in this particular phase. Once the final system description is completed in the concept phase, it will be passed on to the verification phase. Here the motive and goal of this phase is to analyze the parts virtually. For the complete process map look at Appendix-4.

Inspection point preparation

In this phase, 3D models of parts, 3D models of fixtures with station data and simulation reports are going to act as input for inspection point preparation. Inspection engineers takes over the responsibility to carry out the activity. Inspection point preparation will be carried out on product inspection points, inspection points for assembly and fixtures and inspection point for manufacturing.

Critical areas are identified and cluster analysis can be performed in order to reduce the number of inspection points. Offline path planning and optimization of inspection robots and CMM's are used in this activity.

Verification of parts in nominal setting

In verification process, the company chooses either virtual or physical methods of testing prototypes. These days' companies are performing both physical and virtual verification to understand the gap between two methods.

If the company follows physical verification, then physical verification of parts in nominal setting are performed by pre-matching with part-coordination fixtures. In this process, the physical components supplied by supplier or in-house production are pre-matched together and testing will be performed to check whether the parts mate or not. The parameters like capability measures, target values, and tolerance values are measured in this particular stage. Manufacturing geometry takes care of operations in this particular phase.

If the final calculations reach or satisfy the requirements then the measurement point document will be updated. Once after satisfying requirements this will be updated in PPAP (Production parts approval process) stating the final measurement drawing and final demand.

If the calculations couldn't reach the requirements, then physical trimming by modification in design or process with respect to target setting is done. This process is repeated until the calculations reach the product requirements.

In the case of virtual verification of prototypes, the parts are scanned using manufacturing and assembly parameters. After scanning, a method called virtual matching is performed. In the virtual matching process, the parts will be analyzed virtually to see whether the parts meet the geometry demand or not. If the parts match the geometry demand they will be updated in measurement point drawing.

If the parts don't satisfy requirements, virtual trimming is performed by adjusting the existing design or the process with respect to target setting. This process will be repeated until it satisfies the requirements. After reaching requirement it will be updated in measurement point document and will be sent to PPAP document along with measurement point drawing and final demand.

8.4 Detailed description of new suggested process for production phase in geometry assurance

Once after PPAP document is prepared along with measurement point document with final demands, the document is moved from verification to the production phase. Geometry engineer (GE) is responsible for geometry assurance activities in the entire production phase. For the complete process map look at Appendix-5.

In the production phase, the parts are measured to make sure that products produced are within specification limits. The measurement data for the parts are stored for future purposes. This data can be used for new development of products or to track out geometry defects during production.

The parts are measured during production. The measurement is done using a Coordinate-Measuring Machine (CMM), following a predefined program of measurement. Measurements can be performed either by contact through a probe or be performed without contact, by a laser scanner. In this phase both the parts and assemblies are measured, whereas incoming parts are measured by the supplier and the data is delivered to the home company.

A measurement can be performed on all surface parts, or it can be done on pre-defined important features (may be partly measured) to reduce cost.

Apart from part measurements, tool measurements are performed to make sure that production fixtures and tools have required geometrical specifications. This kind of measurement is performed by portable laser tracker equipment and it is repeatedly performed during running production.

Measurement is carried out on all parts and incoming material during production. Here CMM's are used for in-line measurements to check the assembly variation.

As soon as PPAP is transferred to the production phase, initiation of production is taken by the production engineer. Once the production starts, a deviation report along with inspection measurement data is prepared by geometry engineer. From the generated report, inspection data from the produced product is used together with a virtual product model to analyze product error from fixtures and locators that have generated an error. This analysis is carried out by the production engineer and the geometry engineer.

Inspection data that is gathered from a product is used together with a virtual product model to analyze whether the product error originates from assembly fixtures and if so, to decide fixture and locators that have generated error.

Once after the analysis, root cause analysis is said to be performed. In the complete phase, root cause analysis is the main activity performed to check variation and deviation in complex geometry data to take actions for adjustable parameters. This analysis helps in finding errors in locators, fixtures and assembly stations. This activity is carried out wholly by geometry engineer. From root cause analysis, an adjustment is made on detected root cause and adjustments and production data will be reported to the database.

9 Impact of supplier and buyer relationship before and after using geometry assurance in current development process

9.1 Supplier and buyer relation is current product development process at Volvo GTT

Volvo Group has suppliers globally and the suppliers have to satisfy different objectives in order to become a supplier. Suppliers have to satisfy quality, environmental and safety objectives in order to be a supplier to Volvo Group. Volvo Group has a broad spectrum of supplier quality management capability and systems where production capabilities can be evaluated. They have an evaluation on supplier performance rating zero, poor, excellent and fully meeting expectations.

The purpose with the model is to

- Initially to make available a standard basis for evaluation of existing and potential suppliers.
- The model helps in making fact-based decision making.
- Helps to know more about the supplier and deepen the knowledge of their way of working.
- Aids as an improvement tool for developing suppliers and supplier structure.
- Share information about a supplier to the Volvo group.

Supplier evaluation criteria include aspects like company profile, management, environment, quality, logistic, after-market, competence, product development, finance, productivity, sourcing etc. Suppliers will be evaluated in all the mentioned aspects and ranking are assigned. Supplier is chosen based on their performance.

In the current development process, there is no common database where the suppliers can share data. Currently, suppliers are not showing interest in sharing data and their current working procedures. In the current process, there is a difficulty of choosing the freeze gates. Sometimes negotiations take place even after setting contract with the supplier.

9.2 Supplier and buyer relationship in new suggested geometry assurance process

In the new suggested geometry assurance process, supplier and buyer relationship will be strengthened when compared to the old process. By using the database, supplier choice can be made at the beginning of the concept phase based on requirements. This is a possibility to strengthen the relationship as the supplier shares their data and working procedures. So the buyer can have a clear understanding about the working procedure of suppliers.

Here, buyer can have a chance of making or preparing designs based on the previously used database or agreements. Depending upon the requirements, suppliers have to satisfy different objectives in order to be a supplier for Volvo Group.

In the old process they have no reporting of data to database and no sharing of working procedures are done. In the new process, the buyers have to pay for the measuring and reporting of data. The negotiation have to take place while the final system description is going to be handed out to the supplier.

10 Gap Study between current situation of GA and suggested GA process at Powertrain Volvo GTT

The gap between current and new suggested geometry assurance process is very high in all the phases of geometry assurance.

10.1. Gap study for the concept phase

The PE department, Volvo GTT has quite many things that are to be implemented. The following activities need to be focused upon.

Supplier interference and freeze gate

In the new suggested GA process, supplier choice will be made while developing a concept. A separate supplier freeze gate has been established where once final system description is handed to suppliers there will be no design modifications in the process.

Production data input database

In the new process, there is a chance of using production data and supplier data while developing new concepts. By using this data, the designers can modify the tolerances based on the behavior in production. This database can be used to know or understand the gap between virtual world and reality.

Variation simulation and choosing a robust solution

In the new suggested GA process, variation simulation is performed using RD&T in the concept phase. Variation simulation and robustness analysis are important things that play a key role in the entire geometry assurance process.

Check paragraph 8.2 for further information.

Cross functional team

A cross-functional team will be acting from the beginning of the concept phase to make a summarized requirement from the statistical analysis of data, quality, and functional requirements and prerequisite requirements. A cross-functional team includes manufacturing engineer, designers, GSU, perceived quality, component engineer etc.

10.2 Gap study for Powertrain Volvo GTT in verification phase

The gap between new suggested GA and the current process is very large. There are many things that are to be implemented. Currently, the company is practicing physical verification in the complete industrial process.

In the new suggested process the entire manufacturing or verification phase is going to be completely virtual. Here virtual verification is carried out to reduce costly prototypes and to perform testing before they are manufactured.

In the current process, there is no proper authority responsible for geometry assurance activities. Whereas in the new suggested process GAE takes care of the activities in complete phase.

From the beginning of the verification phase, the supplier quality engineer takes care of the quality of incoming material and maintains proper connection with suppliers.

In the current situation, they are choosing tools based on the previous projects experience or knowledge. They are not performing any virtual verification for selecting manufacturing processes. In the new process of geometry assurance, almost everything is performed virtually and selection of process and tools are based on virtual tools.

In the current process, they are going for physical matching and physical trimming of activities and no virtual verification is carried out in adjusting or modifying locators. In the newly suggested process, the suggested adjustment of locators are based on virtual matching. This is performed in parallel with normal physical matching. This virtual matching technique helps in gaining knowledge during development process itself. Check 8.3.

In the current process, they have offline part programming and use different physical tools measure parts. The CMM's are running at a very slow pace. Now Volvo GTT is transforming to CMM's which are going to be more efficient and more precise and accurate. In the new process, they have an inspection engineer handling inspection point preparation and inspection point reduction where he optimizes the program and makes sure that work will be done in an efficient way.

10.3 Gap study for Powertrain Volvo GTT in production phase

In the current process, they have no proper measuring system and no database where the suppliers or the production units can report or update the measured data. None of them is assigned for geometry assurance activities in production phase in the current situation. Root cause analysis which is highly important in this particular phase is not performed and it requires a start in today's production.

In new phase, GE is responsible for taking care of GA activities. An inspection database is installed, root cause analysis is performed. A database has been arranged to store the measured data in production. Check 8.4.

11 Conclusion

From the interviews and the overall analysis of the gap study and the results provided within thesis, Volvo GTT can get a basis for future implementation of a new geometry assurance process. The process map explains the sequence of activities, tools that are required and the responsible people for every activity.

In order to implement geometry assurance, proper awareness should be brought among employees in the organization. Proper training should be provided to responsible people to handle and use the tools in an effective manner.

A proper database needs to be installed in order to maintain proper communication and understanding among all responsible people in geometry assurance activities. It helps to maintain a proper relationship with suppliers and the company can have a good understanding of the working procedures of the suppliers.

In the beginning of the implementation might be difficult as it includes many people concerned with different activities. By proper follow-up of the geometry assurance process and by utilizing the tools better results can be achieved.

Variation simulation should be used in the concept phase of the product realization process, it is also important to perform robustness analysis in the concept phase.

12 Discussion

During the time for the project, a huge interest and lot of time were invested towards geometry assurance and its activities. From my personal opinion and understanding with the current development process of Volvo GTT, geometry assurance is something Volvo GTT needs to prioritize to produce high quality products and to be competent as a world class company. Considering previous years, the main focus of industries was to produce products with high performance. Today, the focus is to achieve high quality products using fast processing techniques to lower manufacturing costs while providing products with high performance. In order to meet these high requirements, extra attention needs to be paid for producing stable products which can withstand variation. This thesis can be a useful suggestion for integration of geometry assurance in the current development process at Volvo GTT.

As mentioned, the initial action of the company is to introduce variation simulation in order to reach the final stage of a complete geometry assurance process. As the use of variation simulation today is quite small, it will take time for implementing it in a fulfilled manner. Necessary actions and support should be provided by Volvo GTT for learning and using a new tool.

In the thesis, a step wise geometry assurance process along with responsible people with assigned activities has been formulated. A gap study is also formulated which helps the concerned department of Volvo GTT to understand the current situation and things that are needed to be implemented.

Interviews are taken from concerned managers to understand the current situation of geometry assurance process from Powertrain Volvo GTT and working of geometry assurance process from VCC and CAB engineering Volvo GTT.

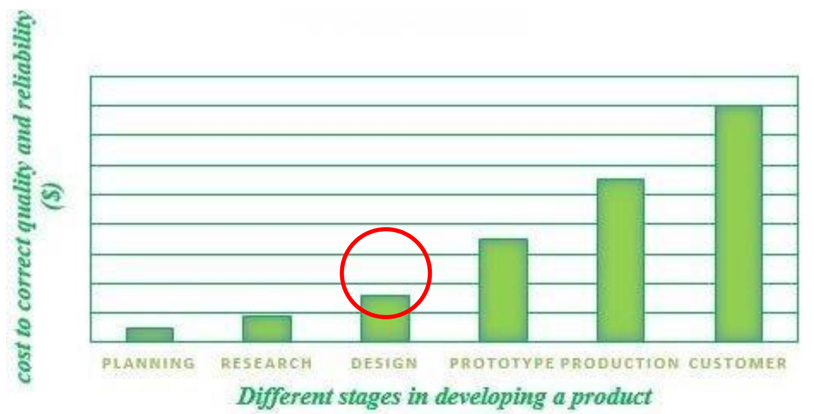


Figure 25: Impact of opportunity of defects in different stages of developing a product.

Detecting or visualizing of defects during the development of concept phase is very hard, but if once detected they can be fixed easily as it is in early development phase. Usually, defects found after the development of the complete process are very expensive to fix even if spotted. From this understanding, if it is possible to fix or eliminate defects in the early stage of the concept phase, these will be cheaper to fix than fixing them at the end. The case study performed in the thesis helps one to predict the defects in the early phase of concept development. The figure mentioned above helps to understand the impact of defects in the product cycle. The above mentioned figure 25 demonstrates design stage has the highest opportunity of detecting defects from different stages of developing a product.

Variation simulation and stability analysis are the most important tools in the geometry assurance process. Variation simulation can be of biggest advantage to find robust solutions and to be able to make adjustments of tolerances before going into production. It is easy to make changes and visualize the result in RD&T. The case study analysis that has been performed in the thesis helps to understand the working of variation simulation and its benefits.

Appendix-1

Interview Questions:

Geometry Assurance:

1. Why do you use geometry assurance process?
2. What are the phases and activities that use in geometry assurance loop or product realization loop?
3. What is the difference you found before and after implementing geometry assurance?
4. From how many years are you using geometry assurance process?
5. Are you looking for any improvements in the current process or do you feel it's going well?
6. If you think something missing, what will help in optimizing the process?
7. Do you think geometry assurance is going to affect cost and quality of the product?
8. Does the geometry assurance activities affect the lead time of the product?
9. How does the geometry assurance process affects the cost and how do you calculate it?
10. By fixing the tolerance and geometry variations in the product development phase, do you think the product needs less time for verification and pre-production phase?
11. Can I know the approximate percentage or value of the increase in the quality of product and approximate cost reduced based on your experience and company statistics?
12. By using geometry assurance process, do you think you get some special status in the market?
13. What do you usually do in verification or in pre-production phase?
14. How do you keep track of production process?
15. What do you do if the production process is not in control?
16. How do you calculate economic gains (cost, quality) of the product?
17. Do you have any particular methodology for calculating them?
18. Do you think the costs are based on tolerances? What are the factors that help in reducing cost?

Requirements

1. How do you work with tolerance requirements (being built from the top down or bottom up)?
2. How the designer decides on the right tolerance limit for the supplier?
3. How is the discussion between design and production with regard to requirements the tolerances?
4. What requirements do you have on manufacturability and how do you evaluate the concept against it?
5. Do you have any requirements on the interface from the customer regarding allowable variations?
6. What happens if the customer changes their requirement during the process?
7. How late in the process, is it possible for the customer to change their demands?
    - How frequently tend requirements change?
    - How is the new requirements verified?
8. When the product development process starts, do you break down the requirements to component level?

Locating points

1. Is locating points / datums defined so that others in the process can make use of the same points? What? Why / why not?
2. What kind of locating schemes you use mostly during your work?

Tolerance Analysis / Stack-Up

1. What are your support for setting tolerances (experience, tools, suppliers, etc.)?
2. How do you work with tolerance analysis / stack-up's?
3. How do you prioritize the measurements/dimensions to be analyzed (security, reliability, customer satisfaction, etc.)?
4. What methods do you use (WC, RSS, MC or something else)?
5. Do you use Six Sigma as a goal to assure quality?
6. How do you take into account production requirements when you do your tolerance analysis?
7. Does the tolerance analysis is performed everywhere or only on specific product requirements?
8. How far you use worst case and Root sum square method?
9. How do you allocate tolerances in such a way it has quality and reduce the cost?
10. How do you manage cost with regarding tolerance?
11. How much tolerance can you expect from nominal?
12. Do you have any cost versus tolerance data for the component?
13. How do you stack up tolerances without hampering functionality?

Database management system

1. Is there a database that keeps track of production data and data from the simulation?
2. How do you use the stored data for deciding the tolerance limit and locating points for the product developed in future?
3. Does the root cause analysis data from the process control is sent as a feedback to the team of designers for continuous improvement?
4. Do you have any "white book" that stores and verifies that it produced consistent with what has been simulated?

In-house part manufacturing

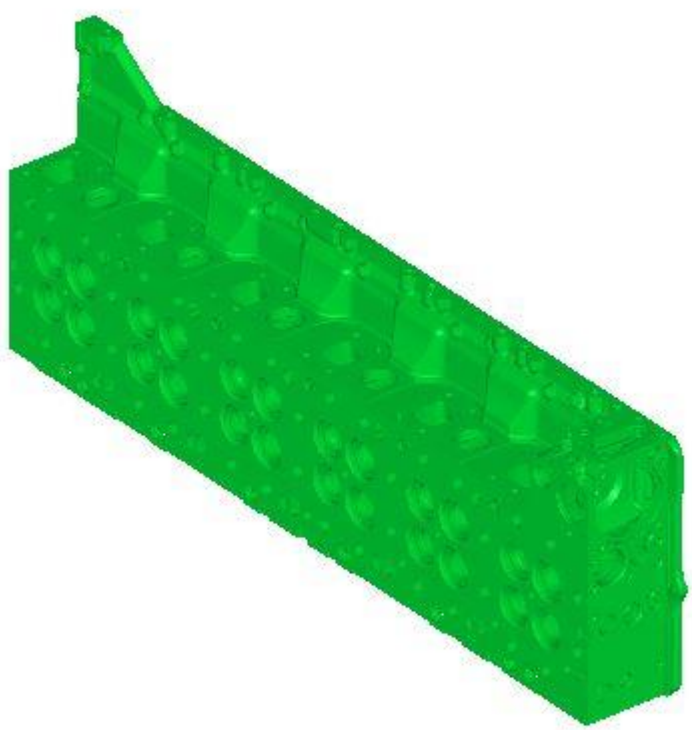
1. What are the inputs given for manufacturing process design for the parts produced in-house?
2. How the fixtures are designed to retain the geometry of the product?
3. What are the steps taken to fix if the datum target or tolerance level defined by the designers couldn't be realised in manufacturing process?
4. Is manufacturing engineering requirement such as process constraints and tool constraints is provided to product design team to ensure quality?
5. How the fixture variation and tool variation which affects the overall product variation are considered while designing the process?
6. How the assembly sequence are decided to retain the overall geometry of the product?
7. Do you perform different assembly sequence (Virtually or physically) to choose the sequence which reduces the variation from assembly of the product?
8. What are the process optimization steps taken to reduce the variation in fixture and tool?
9. Is there any virtual simulation tools which are used to predict the variation?

Appendix -2

Figures of 3d modeled parts from Case Study

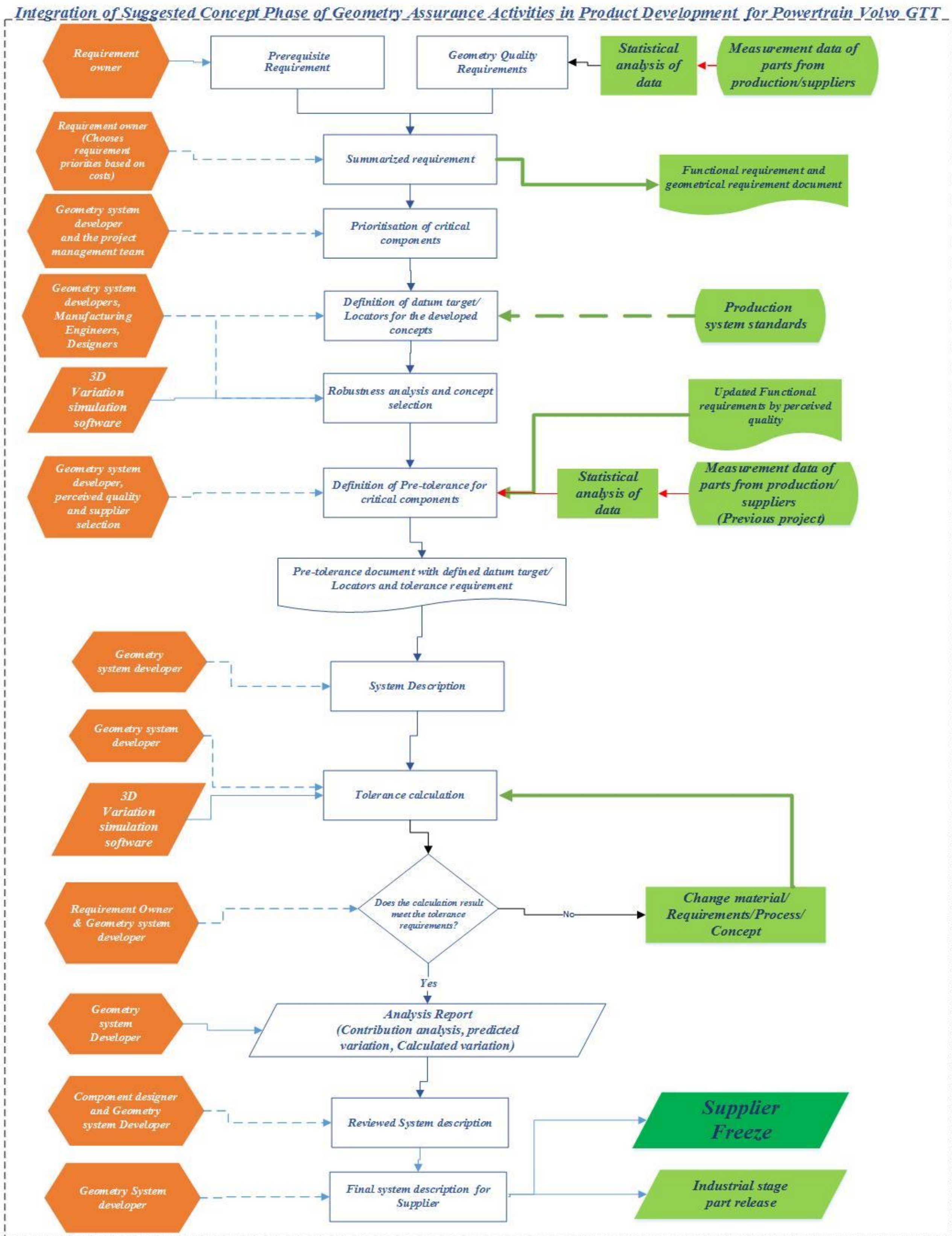
Pipe

Bracket

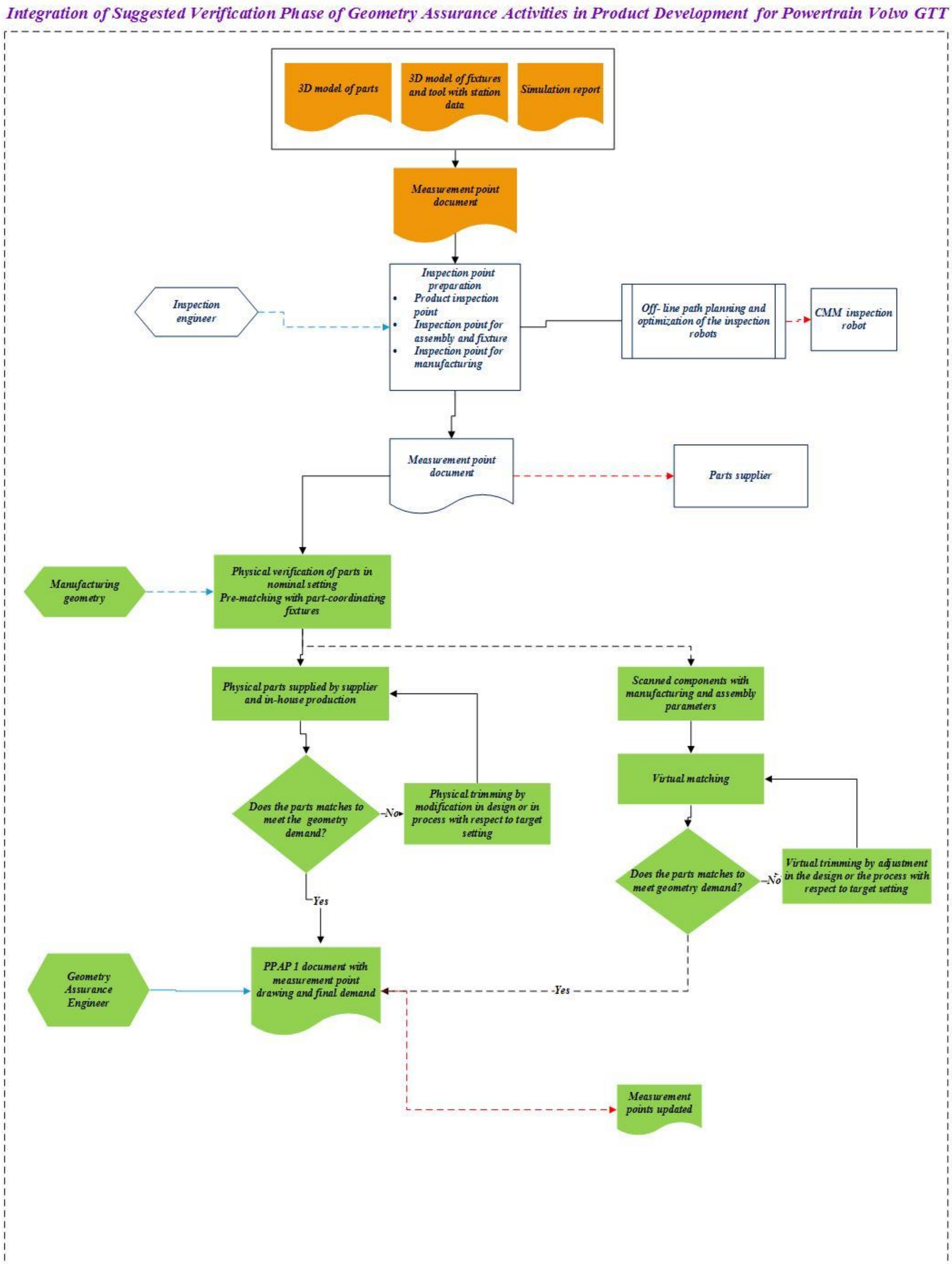


Cylinder head

Appendix-3

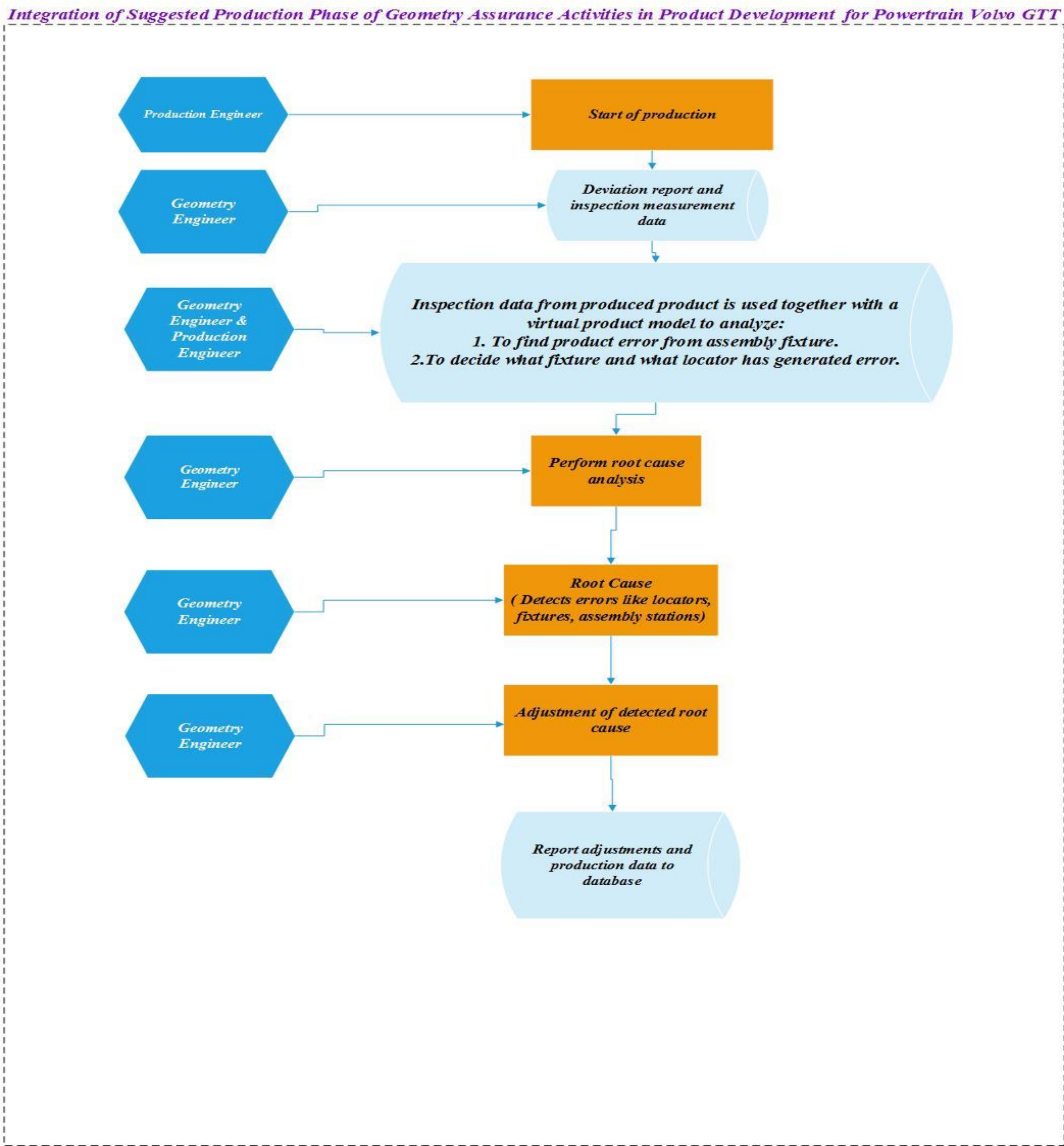

Integration of Suggested Concept Phase of Geometry Assurance Activities in Product Development for Powertrain Volvo GTT
Requirement owner
Prerequisite Requirement
Geometry Quality Requirements
Statistical analysis of data
Measurement data of parts from production/suppliers
Requirement owner (Chooses requirement priorities based on costs)
Summarized requirement
Functional requirement and geometrical requirement document
Geometry system developer and the project management team
Prioritisation of critical components
Geometry system developers, Manufacturing Engineers, Designers
Definition of datum target/ Locators for the developed concepts
Production system standards
3D Variation simulation software
Robustness analysis and concept selection
Updated Functional requirements by perceived quality
Geometry system developer, perceived quality and supplier selection
Definition of Pre-tolerance for critical components
Statistical analysis of data
Measurement data of parts from production/ suppliers (Previous project)
Pre-tolerance document with defined datum target/ Locators and tolerance requirement
Geometry system developer
System Description
Geometry system developer
3D Variation simulation software
Tolerance calculation
Requirement Owner & Geometry system developer
Does the calculation result meet the tolerance requirements?
No
Change material/ Requirements/Process/ Concept
Yes
Geometry system Developer
Analysis Report (Contribution analysis, predicted variation, Calculated variation)
Component designer and Geometry system Developer
Reviewed System description
Supplier Freeze
Geometry System developer
Final system description for Supplier
Industrial stage part release

Appendix -4



Integration of Suggested Verification Phase of Geometry Assurance Activities in Product Development for Powertrain Volvo GTT
3D model of parts
3D model of fixtures and tool with station data
Simulation report
Measurement point document
Inspection point preparation
• Product inspection point
• Inspection point for assembly and fixture
• Inspection point for manufacturing
Inspection engineer
Off- line path planning and optimization of the inspection robots
CMM inspection robot
Measurement point document
Parts supplier
Manufacturing geometry
Physical verification of parts in nominal setting
Pre-matching with part-coordinating fixtures
Physical parts supplied by supplier and in-house production
Scanned components with manufacturing and assembly parameters
Does the parts matches to meet the geometry demand?
No
Physical trimming by modification in design or in process with respect to target setting
Virtual matching
Does the parts matches to meet geometry demand?
No
Virtual trimming by adjustment in the design or the process with respect to target setting
Yes
Geometry Assurance Engineer
PPAP 1 document with measurement point drawing and final demand
Yes
Measurement points updated

Appendix-5



Integration of Suggested Production Phase of Geometry Assurance Activities in Product Development for Powertrain Volvo GTT
Production Engineer
Start of production
Geometry Engineer
Deviation report and inspection measurement data
Geometry Engineer & Production Engineer
Inspection data from produced product is used together with a virtual product model to analyze:
1. To find product error from assembly fixture.
2.To decide what fixture and what locator has generated error.
Geometry Engineer
Perform root cause analysis
Geometry Engineer
Root Cause
(Detects errors like locators, fixtures, assembly stations)
Geometry Engineer
Adjustment of detected root cause
Report adjustments and production data to database

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