



# Reverse Engineering of Complex Shape Part

## Diplomová práce

*Studijní program:* N2301 – Mechanical Engineering  
*Studijní obor:* 2302T010 – Machines and Equipment Design

*Autor práce:* **Pradeep Vempala**  
*Vedoucí práce:* Ing. Petr Keller, Ph.D.





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Faculty of Mechanical Engineering ■

# Reverse Engineering of Complex Shape Part

## Master thesis

*Study programme:* N2301 – Mechanical Engineering  
*Study branch:* 2302T010 – Machines and Equipment Design  
*Author:* **Pradeep Vempala**  
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## DIPLOMA THESIS ASSIGNMENT

(PROJECT, ART WORK, ART PERFORMANCE)

First name and surname: **Pradeep Vempala**  
Study program: **N2301 Mechanical Engineering**  
Identification number: **S15000603**  
Specialization: **Machines and Equipment Design**  
Topic name: **Reverse Engineering of Complex Shape Part**  
Assigning department: **Department of Manufacturing Systems and Automation**

### R u l e s   f o r   e l a b o r a t i o n :

The main aim of thesis is the design and realization of methodological process for reverse engineering of complex shape part. The work will include individual process steps of RE, ie. optical 3D digitalization of real model, creation of 3D part model, generating NC program and manufacture of part on CNC machining centre.

Recommended methods of elaboration:

1. Become familiar with the laboratory equipment needed to implement the practical part of work (non-contact 3D scanner Atos II 400, SW for RE and CAM, CNC machining centre Mazak Integrex).
2. Make research of possibilities CAD / CAM applications to work with the STL model (NC program creation based on data from 3D scanners) and to conduct a survey of software for reverse engineering (ie. SW for transformation of polygonal mesh to model suitable for CAD / CAM applications).
3. Suggest a procedure for RE of parts and practically implement this (to perform a 3D scan of the original part, to create an NC program of digitized part, product to manufacture on a CNC machine tool).
4. Evaluate individual steps of RE process, to compare the produced part to the original model - to perform shape inspection.
5. Assessment of the results and conclusion.

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(scope of dissertation): **approx. 55 pages**

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[1] ZHANG, S. **Handbook of 3D Machine Vision: Optical Metrology and Imaging**. Boca Raton: CRC Press, 2013. ISBN: 978-1-4398-7219-2.

[2] GOM MbH. **Inspection: V8 Manual Basic**. Braunschweig (Germany): GOM MbH, 2014.

[3] GOM MbH. **Atos V7 - Hardware: User manual**. Braunschweig (Germany): GOM MbH, 2010.

[4] **Help for SW Geomagic Studio and Design X**. 3D software support centre [online]. Information on: <http://support1.geomagic.com/>

[5] **EdgeCAM User Guide**. Edgcam documentation [online]. Information on: <http://help.edgcam.com/>

[6] YAMAZAKI MAZAK CORPORATION. **Integrex IV**. Japan: Yamazaki Mazak corp., 2005.

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Liberec, dated: 1 November 2016

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**TOPIC:** Reverse Engineering of complex shape part

**ABSTRACT:** This thesis deals with the creation of the original part model using the method of reverse engineering. The work includes the digitizing of the selected part by using ATOS scanner. After scanning the part, the collected data is transferred to obtain the mesh in general CAD surface using Geomagic X design software. Model consists of faces are then converted into complete 3D solid model. Then the solid model is served as the initial data for creating the machining data in Edgecam program and then create an NC program of digitized part for manufactured on the CNC machine tool. The intention is to describe and show the example of a process for producing a prototype model of the product and possibility to increase the quality.

**Key words:** 3D digitizing, ATOS scanner, Geomagic Design X, prototype, GOM inspect.

**TÉMA:** Reverzní inženýrství komplexní tvarové součásti

**ABSTRAKT:** Tato práce se zabývá tvorbou originálního modelu metodou reverzního inženýrství. Součástí práce je digitalizace zvolené součásti pomocí skeneru ATOS. Po skenování jsou data přenesena do návrhového softwaru Geomagic X pro vytvoření obecného CAD povrchu pomocí naskenované sítě. Pak se jako základní údaje slouží k vytvoření modelu obrábění v programu Edgecam a následně k vytvoření NC programu digitalizované části pro CNC obráběcí stroj. Cílem je popsat a ilustrovat model prototypového produktu a schopnost zlepšovat jeho kvalitu.

**Klíčová slova:** Digitalizace 3D, skener ATOS, Geomagic Design X, prototyp, kontrola GOM.

# Contents

<b>1</b>	<b>Introduction.....</b>	<b>12</b>
1.1	The aim of the work: .....	12
<b>2</b>	<b>Literature Review .....</b>	<b>13</b>
2.1	Reverse Engineering.....	13
2.1.1	Need for Reverse Engineering .....	13
2.2	Product Development by CAD Integrated RE concepts .....	13
2.2.1	Reverse Engineering services.....	14
2.3	Product development approach .....	14
2.3.1	Conventional approach.....	14
2.4	Uses of reverse engineering.....	14
2.4.1	Engineering .....	14
2.4.2	In design .....	14
2.4.3	In medicine.....	14
2.4.4	Automatically generated surfaces .....	15
2.4.5	Interfaced surfaces .....	15
2.4.6	Manual modelling .....	15
2.5	Applications of reverse engineering .....	16
<b>3</b>	<b>Introduction to ATOS II system.....</b>	<b>17</b>
3.1	General explanation for ATOS scanner .....	18
3.1.1	Adjustment and calibration of the device.....	19
3.2	Types of 3Ddigitization.....	20
3.2.1	Contact type digitizing .....	20
3.2.2	Non-contact type digitizing.....	20
3.3	Preparing parts for measurements .....	21
3.3.1	Rules for placing the reference points.....	21



3.4	Principle of scanner .....	22
3.4.1	Advantages and disadvantages of optical digitizing[16] .....	23
3.5	Optical 3D digitizing .....	23
<b>4</b>	<b>GEOMAGIC DESIGN X .....</b>	<b>25</b>
4.1	Functions of GEOMAGIC DESIGN X .....	25
4.1.1	Scan to data .....	25
4.1.2	Scan to surfaces .....	25
4.1.3	Scan to mesh .....	26
4.2	Power of 3D Scanner .....	26
4.3	Applications of Geomagic Design X .....	27
4.3.1	Industrial design and manufacturing .....	27
4.3.2	Healthcare .....	27
4.3.3	Cultural heritage .....	27
4.3.4	Survey .....	27
<b>5</b>	<b>Reading and editing data in GEOMAGIC DESIGN X .....</b>	<b>28</b>
5.1	Retrieve data in GEOMAGIC Design X .....	28
5.1.1	Region group .....	28
5.1.2	3D sketch .....	29
5.1.3	Extract contour curves .....	30
5.1.4	Construct patch network .....	30
5.1.5	Shuffle patch groups .....	31
5.1.6	Fit surface patches .....	31
5.1.7	Trim surfaces .....	32
5.1.8	Boolean operation .....	33
5.1.9	Extrude .....	33
5.1.10	Fillet .....	34

5.2	Final 3D model .....	34
<b>6</b>	<b>Edgecam.....</b>	<b>35</b>
6.1	Workflow of Edgecam .....	35
6.2	Edgecam applications .....	36
6.2.1	Edgecam Mill Turn .....	36
6.2.2	Edgecam Milling .....	36
6.2.3	Edgecam turning .....	37
6.2.4	Edgecam feature based manufacturing .....	37
<b>7</b>	<b>Practical part.....</b>	<b>38</b>
7.1	NC programming for machining parts .....	38
7.2	Preparation procedure for the formation of a machining cycle .....	38
7.3	Selection of the machined part and protected area .....	39
7.4	Preliminary instructions for machining parts .....	39
7.4.1	Creating the blank .....	40
7.4.2	Selection of the tools: .....	40
7.5	Turning operation .....	41
7.5.1	Orientation: Axial.....	41
7.5.2	Toolstore .....	42
7.6	Roughing and profiling: A mill with a diameter of 16mm.....	42
7.6.1	Check allowance .....	43
7.6.2	Pitch toolpath .....	44
7.6.3	Depth of cut.....	44
7.6.4	Cut increment .....	44
7.6.5	Tool control.....	44
<b>8</b>	<b>Five-axis machining cycle.....</b>	<b>46</b>
8.1	Procedure for five-axis machining .....	47

8.1.1	Machining left cavities .....	47
8.1.2	Items for defining five-axis cycle .....	48
8.2	Relative to the cut direction.....	48
8.3	Simulation and tool path verification .....	50
8.4	Generating NC code .....	51
8.4.1	Production of the CNC machine .....	51
8.4.2	Adjustment of tool length.....	52
8.4.3	Preparation for machining.....	52
<b>9</b>	<b>GOM INSPECT .....</b>	<b>53</b>
9.1	Parameter inspection .....	53
9.2	Editing mesh.....	53
9.2.1	Mesh processing.....	53
9.3	Report .....	54
9.4	Virtual measuring room (VMR).....	54
9.5	Properties of GOM Inspect.....	54
9.6	Comparison between the Actual and Nominal parts using GOM Inspect software. ....	55
9.6.1	Surface Comparison .....	55
9.6.2	Deviation Label.....	56
9.6.3	Sectional view .....	57
<b>10</b>	<b>Conclusion .....</b>	<b>58</b>

**3D** - Three dimensional

**ATOS** – Advanced Sensor Topometric

**CAD** – Computer Aided Design

**STEP** - Standard for the Exchange of the product data

**Solid** – 3D digitizing part

**NC** – Numerical control

**CNC** – Computer Numerical Control

**STL** – Standard Triangulation Language

**CAM** - Computer Aided Manufacturing

## **1 Introduction**

In the recent year's importance for the digitalization of parts which are used in the mechanical system has dramatically increased. Job requirement is to produce complex shape parts by the existing components. For producing this model, we use some modern methods of 3D digitizing, in that it is necessary to show how it is possible to achieve a result. It is not always that easy to reconcile with the desired quality production capabilities, so it is suggested here, to what extent we can achieve the resulting requirements. ATOS scanner is used to scan the part. Data is required to get into the digital form in order to produce a model. With the help of this data we can obtain the surface by using GEOMAGIC X design software. It offers optical method in productive, leading to obtain the data directly from the scanned original part. The production model is oriented according to the requirements of the output quality of the reproduction model. Another method is implemented chip technology in CNC turning-milling centre Mazak Integrex 100-IV. Production is possible to perform in 5-axis cycle. This method is versatile in terms of materials, but the accuracy is limited by the used tools, software and data preparation is very time consuming. Work will focus on obtaining data from a cast model, where the part should be machined in a way to approach its original form. To what extent that we met expectations is described below.

### **1.1 The aim of the work:**

The aim of this work is to perform the reverse engineering on complex shape parts. The main objective is to design technological process for the production of this part on the five-axis turning-milling centre Mazak Integrex 100-IV.

## **2 Literature Review**

### **2.1 Reverse Engineering**

Reverse engineering is the process of duplicating the existing objects, components, or products without any documentation, drawings or computer model is called reverse engineering. Generally, it is used to recreate the same or similar objects which are exists in the real world. The original manufacturer of a product is no longer exists, but the customer needs that product, if the documentation of that has been lost or not existed, but if we have that product with a bad features even though it will be helpful to designed it.[3, 4]

#### **2.1.1 Need for Reverse Engineering**

- The original manufacture of the product is not exit or no longer produces a product.[4]
- There is inadequate documentation of the product.[5]
- The original manufacturer was no longer exit, but the customer wants the product.
- The original CAD model is not sufficient to support the modification.
- For analysing the good and bad features of the competitor's product.
- The original supplier is not willing to provide the additional information regarding the parts.[3]
- The original supplier is not willing to provide the additional information regarding the parts.[3]

### **2.2 Product Development by CAD Integrated RE concepts**

Reverse engineering of mechanical parts involves acquiring three-dimensional data in point cloud using laser scanning or computer tomography (CT). Geometry of this part in terms of surface points is the first step to create parametric patches. Polymesh is created from point cloud using reverse engineering software. [3]

## **2.2.1 Reverse Engineering services**

- Contact and non-contact scanning.
- Deviation analysis of physical part with CAD model.
- Dimensional inspection and validation.[3]

## **2.3 Product development approach**

Product development begins with the need and identified on the basis of customers or market demand. Product development involves either ‘conventional approach or ‘non-conventional approach’. Both the approaches go through the design process followed by manufacturing process.[6, 7]

### **2.3.1 Conventional approach**

Product development approach deals with the customer’s specification and passes through the traditional design process to produce final product. It shows the traditional design methodology as well as Reverse Engineering process.[7]

When the goal is to reengineer or to optimize the existing parts /moulds/tools without any CAD database, reverse engineering design approach is adopted. This approach starts with mock-up and passes through the reverse engineering design process, for the improvement in product design.[4, 7]

## **2.4 Uses of reverse engineering**

### **2.4.1 Engineering**

It may be used every time in digital 3D model of manufactured components. For example: restoration or creation of drawings, for inspection of parts by comparing it to the CAD model, for updating the CAD model, etc.[8]

### **2.4.2 In design**

The designer creates a clay model and needs to digitise it. This procedure is also often used in designing a vehicle body.[4]

### **2.4.3 In medicine**

It is used for designing implants and for art (creating copies), etc.

There are several ways of transformation;[8]

#### **2.4.4 Automatically generated surfaces**

- The program generates the four sided patches on the surface of the polygonal network which represent the shape of the model and creates a volume model when the whole polygonal network is covered.[8]
- Artwork cannot be created by any of the available modelling elements such as extrusion, pattern, rotation, etc.
- The advantage of this processing method is speed. The disadvantages of the model created in such a way.
- The subsequent model shape adjustment may not be easy.
- This method is convenient in this case, where you want to get the model into a CAD system and the machine, or where the model serves as the basis for the construction.

#### **2.4.5 Interfaced surfaces**

- Model is divided into individual segments according to their curvature.
- A selected type of the surface is then interface through these areas.
- This software provides with the possibility to interface these areas with the surface type, shaped surfaces, plane, cylinders, cone, and extrusion sphere, extrusion at an angle, rotation, drawing, and patterning.

#### **2.4.6 Manual modelling**

- Scanned data are remodelled into a parametric model by using the same principle as in the CAD systems.
- The whole modelling process is under constant precision monitoring, since it is possible to show the deviation of the created body in comparison to the scanned data.
- This method is more demanding than the method of generating four-sided surfaces on the model surfaces. Since the method is more time-demanding, it is also more expensive. [8]



## **2.5 Applications of reverse engineering**

The reason for reverse engineering is to compress product development times. In the intensively competitive global market, manufactures are constantly seeking new ways to shorten the time to market the new product. [2, 3]

By using reverse engineering, a three-dimensional product or model can be quickly captured in digital form, re-modelled, and exported for rapid prototype or rapid manufacturing.[3]

Reverse Engineering will provides the solution to the problem because the physical model is the source of information to the CAD model. This is also referred as the part-to-CAD process.

### 3 Introduction to ATOS II system

ATOS system is an optical measurement system whose measurement process is based on the principles of optical triangulation, photometry and fringe projection. It is used in various industries such as construction, manufacturing, quality control, design, etc. The ATOS system can ensure fast and easy digitisation of the measured objects with the relatively high resolution and precision. The most important part of the system is the optical 3d-scanner itself which is consisting of a projector. Each configured sensors defines the size of the 3D area in which the measured object will be scanned- so called measurement volume.[9]



Figure 1. Optical scanner ATOS II [2]

ATOS II 400 optical scanner	
weight	5,200 g
Dimensions	490*260*170 mm
Time of 1 scan	1 second
Measured volume	700*560*560 mm 250*200*200 mm 55*40*33 mm
Number of points in one can	Up to 1,400,00
Point density	0.04-0.18-0.5 mm
Measurement accuracy	Approx.30 $\mu$ m

Table 1 Parameters of ATOS scanner[10]

ATOS provides dimensional measurement data and analysis of industrial components, i.e. sheet metal parts, tools, moulds, turbine blades, castings etc. Instead of measuring individual point or by laser, ATOS captures all the geometry and surface components into dense cloud and polygon.[11]

ATOS is the broadest use of the system in the areas of CAD, CAM and FEM, where it is necessary for the measurement of real objects and their comparison with the virtual model.

The entire device is designed so that the operator puts the minimal requirements users. Handling sensitive device around the head of the subject is very easy.

Since the object is located on the adjustable tripod. Also, there is no need to scan the object after regular sections (e.g.:  $20^0$ ), but it is enough to create the irregular images and makes auxiliary software brands will assess its position.

The scanner is supplemented by computer-controlled rotary table. It finds the application in repeating of the same parts. [11]

### **3.1 General explanation for ATOS scanner**

ATOS core system mainly consists of 3 main elements, the left camera, the right camera and the projector in the middle. The definition of the object left and right results from the sensor view. The left camera and the right camera are calibrated relatively each other. This means that the angle in- between the cameras is known, therefore you may have called them as stereo cameras. The angle in-between the cameras results in a distance from the sensor to the point at which the camera rays meet. This distance is called measuring distance. At the measuring distance, the stereo cameras span a three-dimensional area. This area is called measuring volume, in which 3D points can be computed. The size of the measuring volume depends on the sensor type. The sensor projects fringes onto the measuring objects. This measuring process is captured by the 2 cameras and will result in the 3D coordinates of the camera image pixels. The resolution of the stereo cameras depends on the sensor type, but the results up to 5 million points per scan. You will get the 3D data information from those areas which were visible for the sensors. In this data are captured only for the areas which are visible for both the cameras simultaneously and are within the measurement volume. In order to capture the object entirely, more scans from different positions of

the objects are necessary. However, if you take another measurement, there is no information about the correct orientation of these measurements. Reference points are placed automatically to combine the different scans together in one common coordinates system. As soon as the measurements are taken, the ATOS system determines the position of the reference points in the 3D space and the distance between the reference points.

### **3.1.1 Adjustment and calibration of the device**

- 1) Calibration of the device is necessary to adjust before each measurement; some steps are performed prior to each measurement, others after changing the optics. [12]
- 2) All the settings and control of the scanning process is performed directly by means of GOM ATOS professional software. [13]
- 3) According to our software we have to fit the cameras and projectors with a suitable lens and selecting the optics.
- 4) Adjusting the recommended measuring distance from the calibration etalon
- 5) Adjusting auxiliary laser, 'pointer' we can see in figures. Further sensor settings only when needed. Projected focus adjustment- focusing on both cameras, setting aperture of both cameras. All the functions are accessed from the toolbar; we can use the guide showing upon choosing the desired function.
- 6) Calibration of the device by means of calibration etalon can be performed by means of a guide, lies in scanning approximately 20 images of the etalon from the given positions.

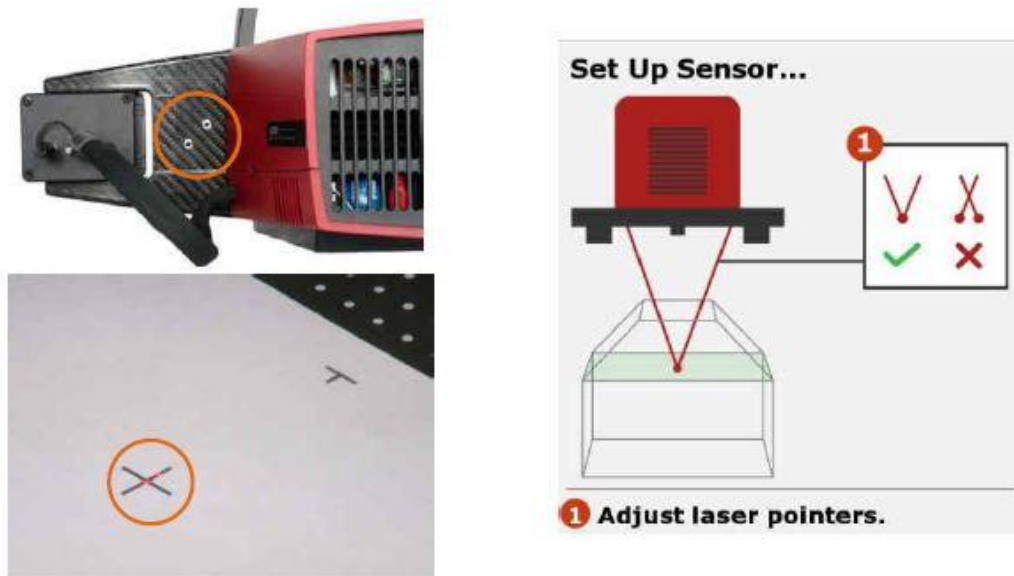


Figure 2. Auxiliary laser pointer[12]

### 3.2 Types of 3D digitization

- Contact
- Non-contact

#### 3.2.1 Contact type digitizing

- We have studied about two types of contact machines; one is coordinate measuring machine and measuring arm. [12][14]
- It is very accurate measurements and scanning, but quite slow- hundred points per minute, problem with compute of coordinates when the ball end of touch probe is used. [12]

#### 3.2.2 Non-contact type digitizing

- Optical scanners- these machines use laser for measuring. We have studied about two kinds of optical scanners; those are ATOS and Rev-scan.[14]
- It is very quick and quite accurate scanning and measurements, but the problem lies in measuring the surface.
- Glossy surfaces or transparent components usually cannot be scanned directly.
- Problems with some complicated shapes (deep holes and ribs etc.)

### 3.3 Preparing parts for measurements

- Modification of surface by means of anti-reflection coating, because the part which I choose is transparent and shiny.
- Placing reference points.[14]
- After placing the reference point we must clean.
- Mounting the scanned part to a measurement table. [11]

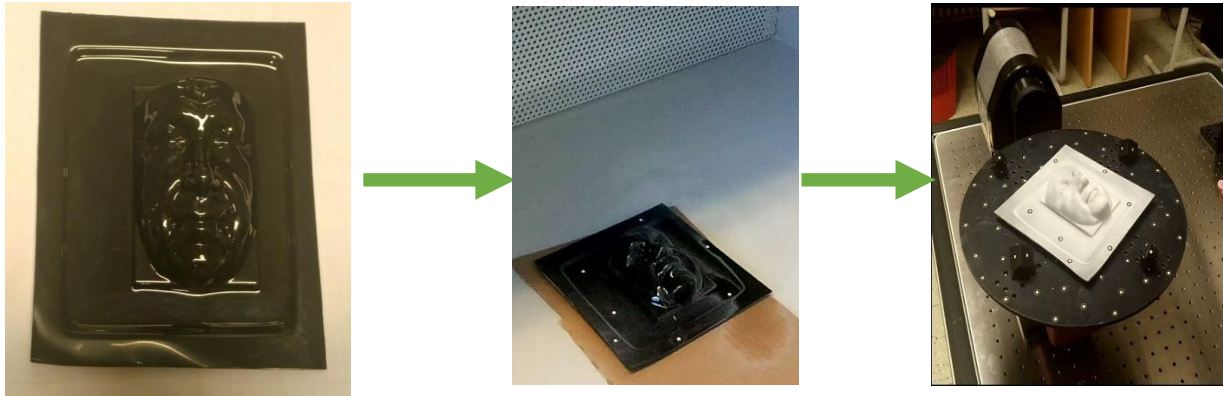


Figure 3. Preparation for measurement

#### 3.3.1 Rules for placing the reference points

- On flat or slightly curved surfaces. [11]
- We cannot place the points too close to the edges – issue of filling the opening.
- Reference should be appropriately distributed throughout the whole length, width and height of the measurement volume.[13]
- Use as many reference points for the given measurement volume, so that sensor can reliably identify at least three reference points from the previous measurements.
- Do not place reference points in straight line.
- If we want to scan the part from both the sides, we need to place at least three reference points around the part to connect the partial measurement series.
- When scanning the flat surfaces, we do not place the points directly on the opposite spot (risk of point substitution = transformation errors).

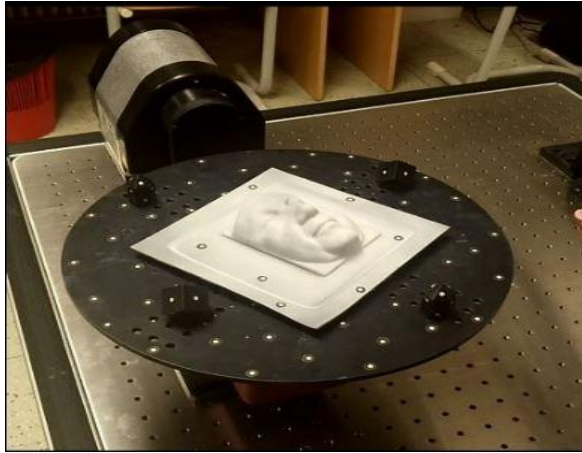


Figure 4. Reference points

### 3.4 Principle of scanner

Using the projector and shutter are projected on the surface strips lights. They are then deformed into the surface shapes of the object. Thus 'illuminated' component surface is then scanned through the two CCD cameras. Penultimate steps that ensure the software are calculating the spatial coordinates of individual points using complex algorithms. Rarely scanner needs only one shot to get the sufficient information to the component surface, so that the scanner is supplemented by computer-controlled rotary table. Later it finds the scanning components with which it is necessary to obtain all the information about part. The condition is to have two consecutive frames at least four recurring points.[15]



Figure 5. Projection of strips lights

### 3.4.1 Advantages and disadvantages of optical digitizing[16]

Benefits	Drawbacks
Quick measurements even for complex shapes	Problem with some measuring surfaces (often required for surface finish; reflection)
We can scan the three-dimensional model	Difficult measurements of deep cavities and holes etc.
We can export data in various formats.	Sensitive to ambient light
Flexibility(one device can measure the object from few millimetres to several meters	
Independent results for rigid components, the weight and temperature can be measured e.g. Soft materials	
Ability to measure fragile or historical valuable objects without contact	

### 3.5 Optical 3D digitizing

The ATOS system is depending on the triangulation principle. The sensor unit projects deal with different patterns on the object that to be measured and observe them with two cameras, based on the optical transformation equations, the computer automatically measure the 3D coordinates for each camera pixel with high precision. Depends on the camera resolution, a point cloud of up to 4 million surfaces points can results for each individual measurement.[17]

To digitize an object, several individual measurements from various views are required. Transformation of global coordinate system can be done automatically by means of reference points. So that we can observe the digitization processes continuously on the



screen. Each individual completes the building up of the 3D model of the object to be scanned. Finally, at the end of the digitizing process, a high - resolution polygon mesh of surface completely describe the object. [17]

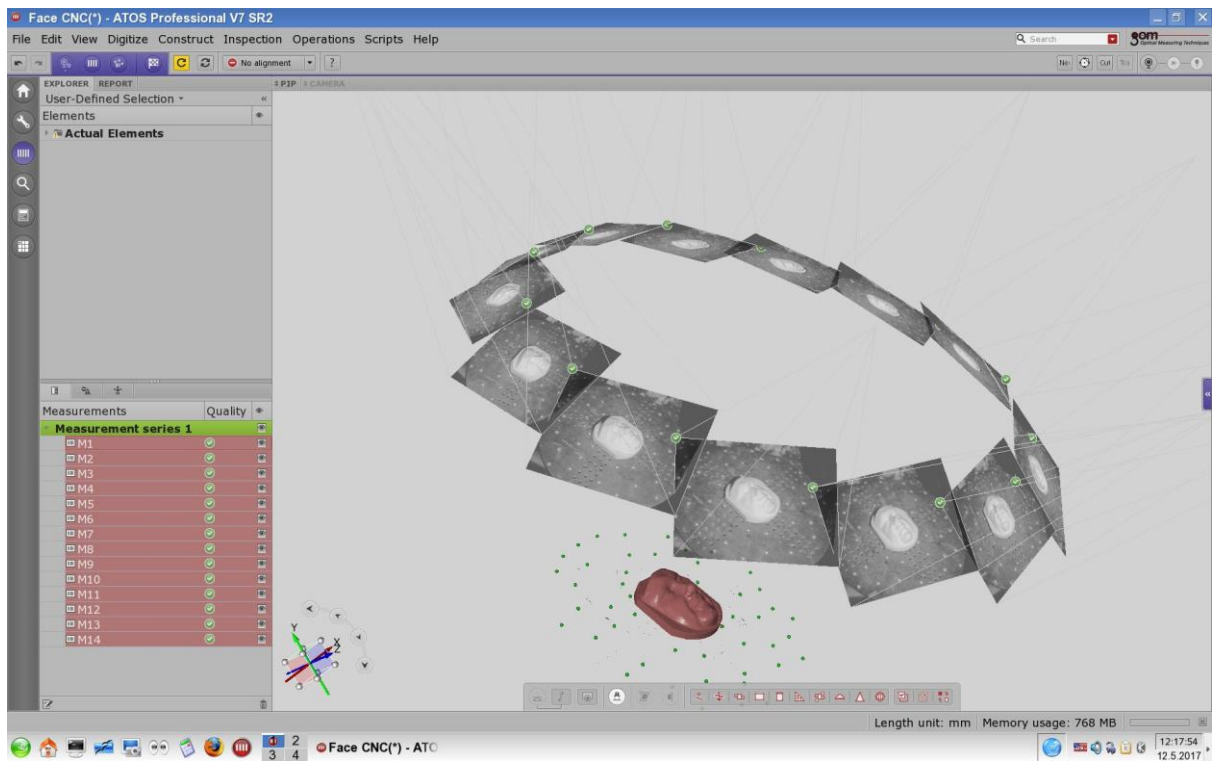


Figure 6. Part digitizing

Sufficient number of scans can be performed on the part from all sides. From that we can create the new measurement series. As shown in above figure 6.

## 4 GEOMAGIC DESIGN X

“Geomagic Design X is the industry’s most comprehensive reverse engineering software that combines history – based CAD design with 3D scan data processing. So that you can create the feature – based models with editable solid surfaces that can be compatible with your existing CAD software”. [18]

### 4.1 Functions of GEOMAGIC DESIGN X

#### 4.1.1 Scan to data

CAD model is suitable for manufacturing; therefore, Geomagic Design X employs the straightforward workflow that is today well-known for solid modelling process. Instead of modelling from scratches, Geomagic Design X feature wizards and some other automatic tools helps to build the features directly from 3D scan data.[19]

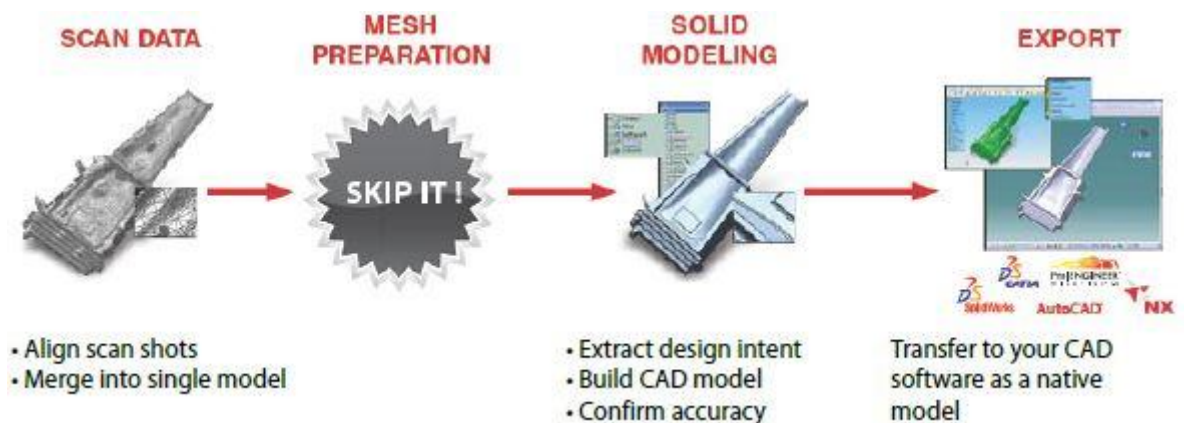


Figure 7. Scan to data process [19]

#### 4.1.2 Scan to surfaces

Geomagic Design X can also support NURBS surface fitting, when you need a copy of what you have scanned, and don’t need to edit the model. It is the most powerful software for automatic surfacing technology can do all the work, or the network surface can be created manually.[19]



Figure 8. Scan to surface process[19]

#### 4.1.3 Scan to mesh

For archiving, animation, measurements, 3D printing and other polygon-based applications, Geomagic Design X includes a full suite of mesh processing tools. With the Mesh Buildup Wizard™, you can step through the entire scan alignment, merge and mesh optimization process with just a few clicks.[19]

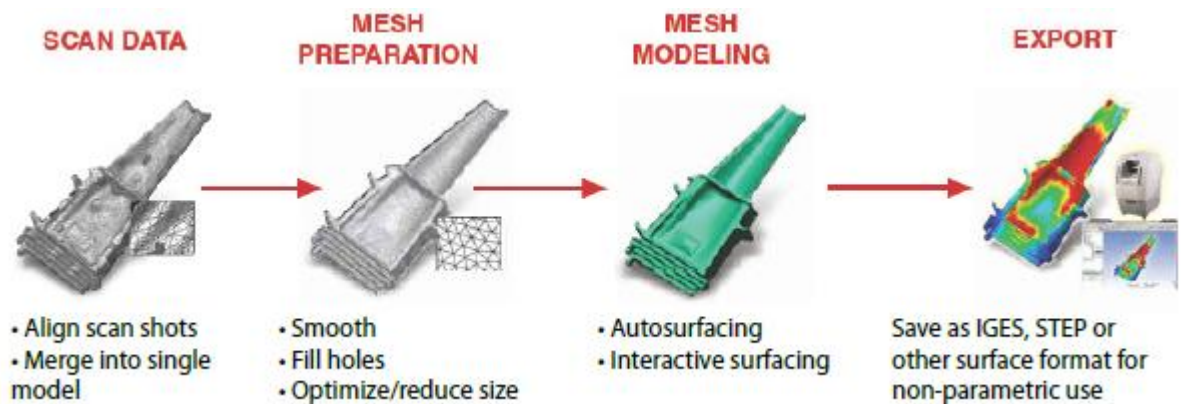


Figure 9. Scan to mesh process[19]

#### 4.2 Power of 3D Scanner

3D scanner is a device that captures data from real object or environment as 3D shape data. The collected information is then converted into digital data. 3D scan data is a set of points. A point represents a location of real object that contains X, Y, Z coordinates. Numerous points can be used for describing the real object.

A point set is also known as a point cloud can be converted into digital model into operations and used in various industrial fields.[19]

### **4.3 Applications of Geomagic Design X**

#### **4.3.1 Industrial design and manufacturing**

Developing the new products and taking the measurements of the objects with complex geometry of workflow in manufacturing facilities. You can use the 3D scanners to capture the data very quickly from any small mechanical component, with astonishing accuracy. The resulting 3D model can be exported to a variety of CAD & CAM programs. [3]

#### **4.3.2 Healthcare**

Designing customized prosthetic and orthotic device can require a real precision and must pay close attention to the patient's individual anatomy. These are successfully used to produce quick and accurate scans of the body. [3]

#### **4.3.3 Cultural heritage**

Cultural heritage domain also uses cutting-edge 3D scanning technology. 3D scanners can generate the accurate files which can be used to restore historic buildings. 3D scan data is also used to simulate or visualize the historic places.[19]

#### **4.3.4 Survey**

Construction and civil engineering fields are heavily depending on surveying, but it took lot of time and the workers have to wait for long and also exposed to the environment when surveying. 3D scan technology is used in various types of projects by removing uncertainty, finishing the projects quickly and reducing the costs. [18]

## 5 Reading and editing data in GEOMAGIC DESIGN X

For further possibilities of creating a machining cycle, it is necessary to convert the point cloud to an acceptable size. In this case the transfer pointcloud on the surfaces are then transfer to solid body for the completion of the model. The procedure follows the scanning of the workpiece surfaces, in that way we can convert the model into STL format. STL format is a network of connected triangles, which follows the shape of the object. The subsequent procedure shows how much it advances in the treatment area STL format and what production it involves in simple components. There is no perfect describing the dialogs, but the function in the program is and how it affects the production and quality of the product surface. Therefore, the focus should be on dialog boxes for the items associated with that model. Data processing and working with point clouds used programming GEOMAGIC Design X software.

### 5.1 Retrieve data in GEOMAGIC Design X

Import the data in desired format (\*.STL). Then the GEOMAGIC will open the module for the working with point cloud. For transferring the scanned data into a solid model, it requires the following steps:

#### 5.1.1 Region group

Region group classifies the area of a mesh based on the geometry features. The region group mode that transfers the data automatically or manually will classify and edit region on a mesh with the following characters. [19]

- Generating and editing mesh region history will not register in the feature tree.
- The region group mode icon will have dimmed more than one mesh that exists until one of them is selected.
- The region group mode can be exist by clicking the Region group icon or apply button at the bottom right corner.
- By clicking the cancel button at the bottom right

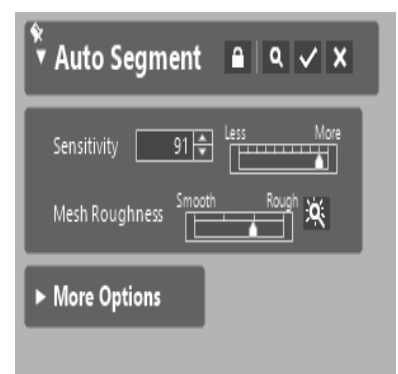


Figure 10. Auto segment

corner removes all changes in the region group mode.

- Mesh roughness should be in rough surface mode option should have the clear surface view.
- Sensitivity of the CAD model should be '91'.

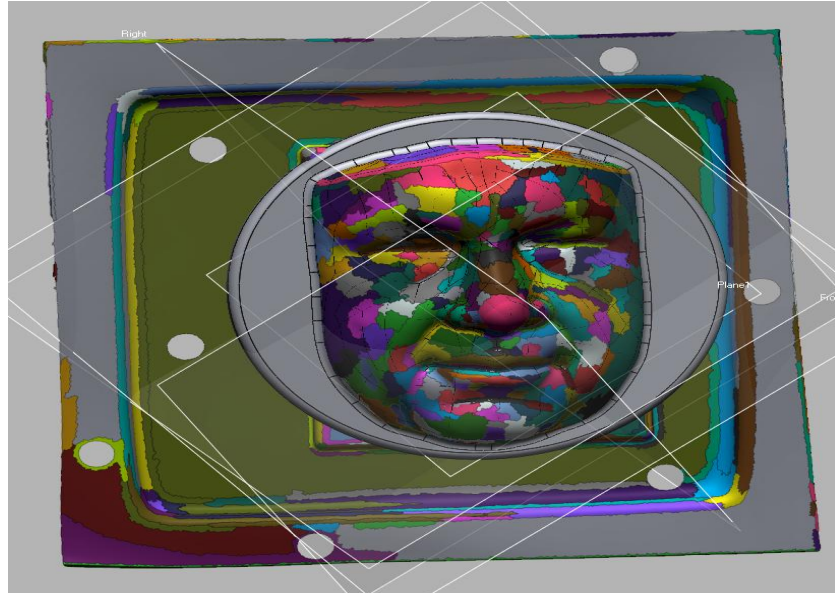


Figure 11.Auto segment

### 5.1.2 3D sketch

- The 3D sketch mode creates the 3D geometric such as splines, section and boundaries on a mesh. Created curves can be edited by using trim, offset and project commands.[19]
- While entering the 3D sketch mode will display the tool palette that globally applies all functions to all entities in the model.
- The difference between 3D Mesh sketch and 3D sketch modes is that the curves generated in the 3D Mesh sketch mode is always lay on the mesh but the curves in 3D sketch will exits freely in space.

### 5.1.3 Extract contour curves

Extract contour curves enables the real-time preview and edit the region separately by selecting or deselecting the regions with the paint brush selection mode. While you are editing the regions, you can resize the selection area by holding down the ALT key on your keyboard and dragging.[19]

The other parameters mode such as line, rectangle and circle can also be used while editing the separators.

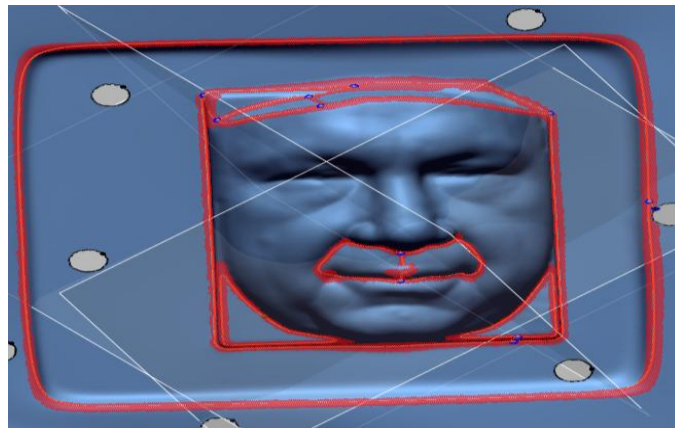


Figure 12.Extract contour curves

### 5.1.4 Construct patch network

In these you can edit the 3D patch network which has been constructed in the previous step. The shuffle patch group command is necessary to shuffle and reorient the patch panel's in the 3D patch network for a better continuity between them.[19]

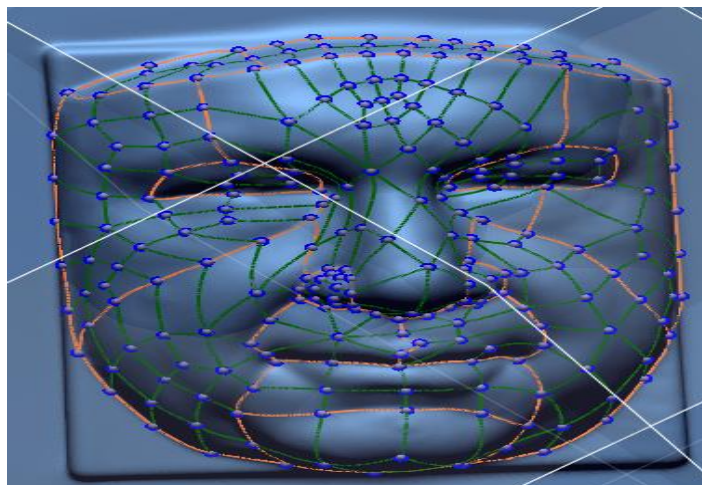


Figure 13.Construct patch network

### 5.1.5 Shuffle patch groups

In this surfacing you can directly access to 3D mesh sketch mode and shuffle patch groups command by clicking patch networks and shuffle patch group.

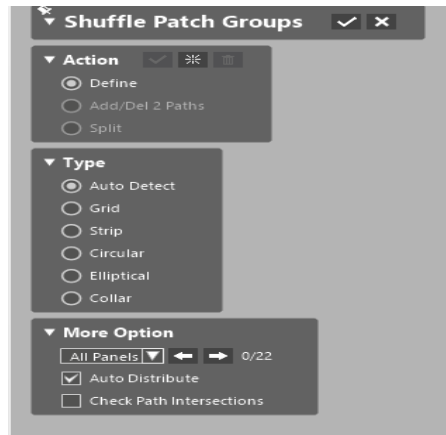


Figure 14. Shuffle patch group

To decrease the number of patch path in patch panel click auto detect in the dialog. While define option is selected so that the patch panels are placed properly. If the shuffle patch group is not redefining, then the vertex of this position in each corner of the patch panel.

### 5.1.6 Fit surface patches

To create NURBS surface model within the 3D patch network, fit surface command is used. You will create a 3D NURBS model from the created 3D patch network.

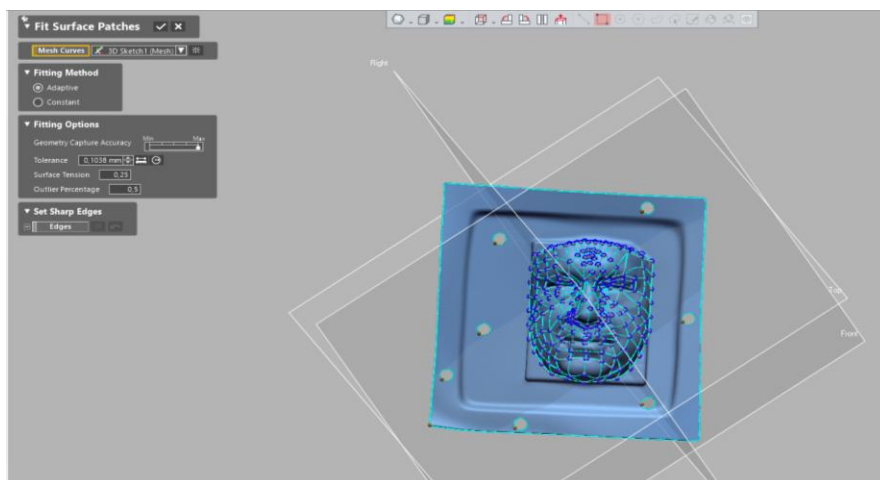


Figure 15. Fit surface patches



3D sketch is used as Mesh Curves. Select the Adaptive option which is used for fitting option. Adjust the slider of the Geometry Capture Accuracy option toward to Maximum to improve the accuracy of fitting surface patches then click ok to finish the command.

### 5.1.7 Trim surfaces

Trim command is used to cut the surface body by removing material using a surface, solid body or curve.

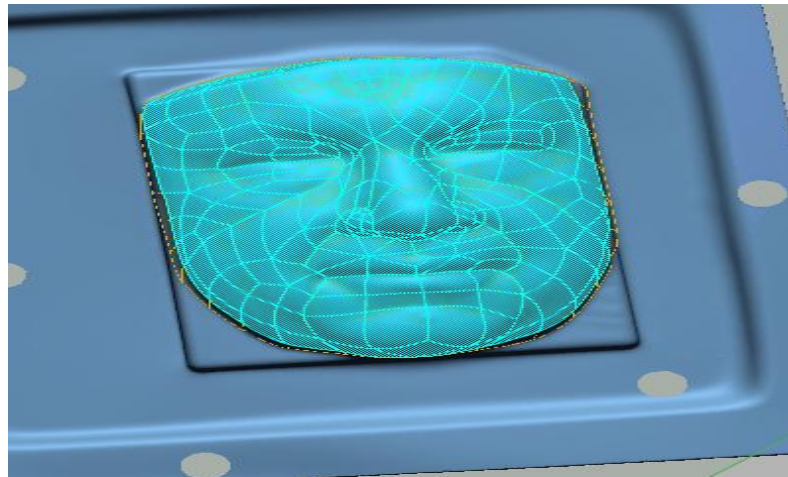


Figure 16. Trimmed surface

The trim command is useful for:

- Creating the feature by surface modelling method
- Creating metal sheet part
- Trimming a surface by using a curve
- Removing surface material with intersecting surfaces.

### 5.1.8 Boolean operation

The Boolean command combines two or more solids bodies to generate a single body or multiple bodies by using three other merges like merge cut and intersect. [18]

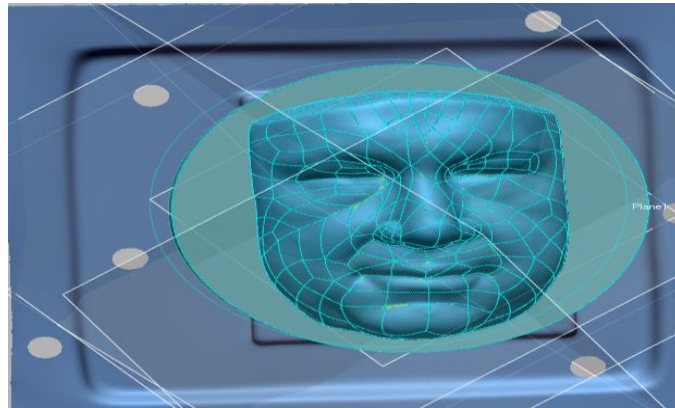


Figure 17. Boolean part

Boolean command is useful for:

- Combining solid bodies
- Splitting solid bodies
- Obtained shared area between overlapped solid bodies[18]

### 5.1.9 Extrude

Extrude command is used for stretches an object section in a straight-line direction and then generates closed body. The object section is expressed by single or multiple profiles on sketch view. A profile must be drawn in sketch view such as circle or spline or the combination of lines etc. [19]

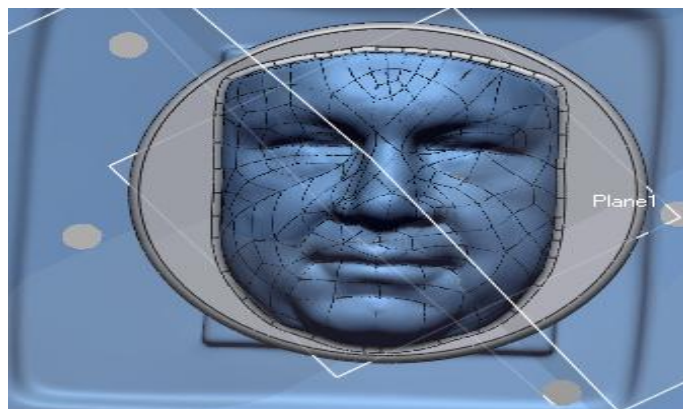


Figure 18.Extruded part

To extrude, first we need to create a plane on the surface where we need to extrude.

### 5.1.10 Fillet

- Fillet command is used for generating rounded features on a solid body that can be applied on edges or faces.
- Fillet command is use for rounded edge part.
- Constant fillet – creates constant radius fillet by selecting edges or faces and specifying the fillet radius.
- Use the estimate radius from mesh to automatically extract the approximate fillet radius from a mesh. [19]

### 5.2 Final 3D model

- After finishing with all the commands, we can obtain the final object in 3D model. Now the model is ready for further operations associated with machining.
- For machining this model in five-axis turning milling machine it is necessary to save in STEP format.

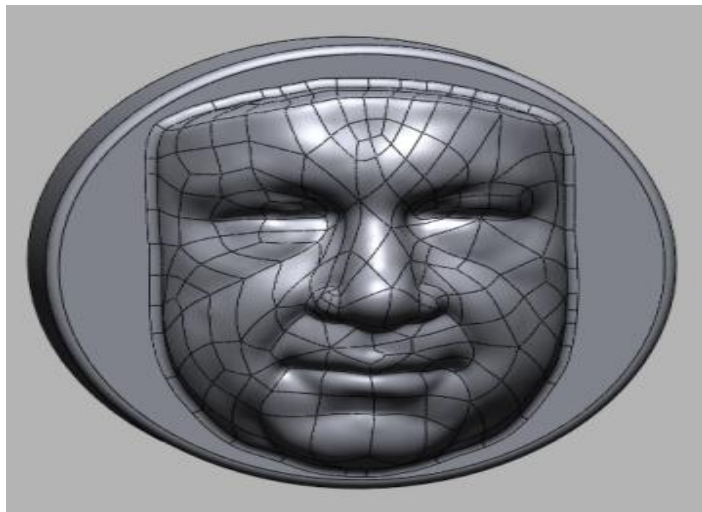


Figure 19. Final 3D model

## 6 Edgcam

Edgcam is a computer aided manufacturing (CAM) system that allows you to generate machining strategies and CNC code from CAD models.[20]

The main stages in Edgcam are;

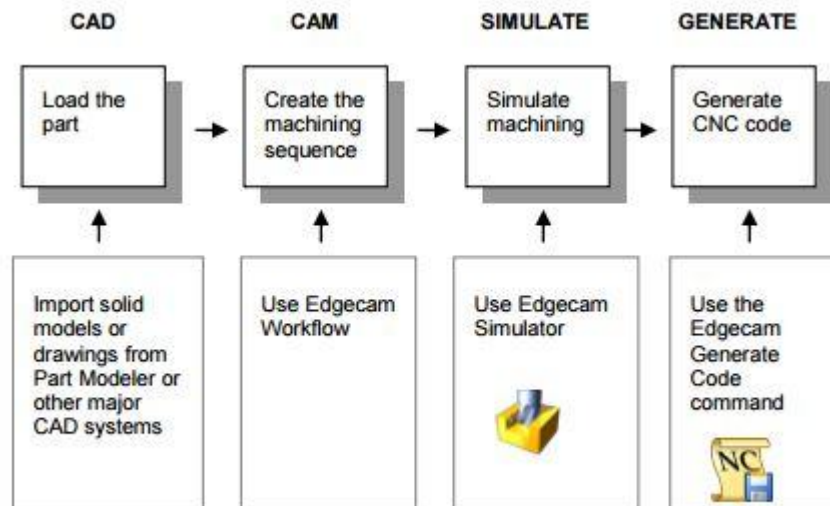


Figure 20.Main features of Edgcam

### 6.1 Workflow of Edgcam

The workflow is designed for the manufacturer to reduce costs, improve quality and a shorter lead time. Operators can able to apply toolpath to prismatic parts in minutes.[21]

There are five stage processes in workflow as follows; [21]

- Loading and positioning of the component
- In CAM systems the user has to set the manual environment mode to use traditional command to create the datum.
- Manufacturing method and suitable machine tools

The user is presented with a list of suitable machine tools based on the components geometry, ensuring machine limits.

- Adding user-defined stock from a database
- Based upon the components dimensions a selection of defined stock materials is listed that allows a suitable stock can be applied easily.

- Importing fixtures
- These can be used for defining the fixtures, including vices, and clamps can be applied using the fixture manager.
- Managing strategies to aid manufacture

It is derived in a way for suggesting method for manufacture to machine the part on a feature-by feature basis, with the logical cutters path.

## **6.2 Edgecam applications**

### **6.2.1 Edgecam Mill Turn**

The usage of tail stocks, spindles turrets along C-axis are regular features on today's Multi-tasking machine tools. Edge turning and milling combination provides a safe machining environment.[22] [21] with the addition of five axis milling, the simulation of the machine tools is made even easier.

- Single machining environment is used.
- It provides full machining tool and toolpath simulation.
- With the help of turn/mill operation component cycle will reduces.
- It can reduce the machine tool that proves out by graphically simulating the tool path.
- It support twin spindle, twin turret, pickoff spindle on C, Y and B-axis machining.

### **6.2.2 Edgecam Milling**

Edgecam provides functions to generate efficient toolpath from wireframe and solid geometry on a variety of machine too configurations that ranges from 3 to 5 axis machines.

- It is easy to operate tool interface.
- It can control the total toolpath.
- Easy to use graphical interface.
- Wide range of options provides the complete control of the tool.
- 5-axis module includes full machine simulation to aid

### **6.2.3 Edgecam turning**

Edgecam turning provides a wide range of machine tool turning centres and mill/turn machines. Edgecam produces advanced rough and finishing turning cycles together with the support facing. Tool path calculation is considered into account for inserting the tool in order to machine the material to avoid gouging and eliminate air cutting.[23] [21]

- Turning operation reduces programming time.
- It will reduce the component cycle time.
- It will increase the tool life utilization.
- Eliminating the programming errors and reduces the potential scrap time.

### **6.2.4 Edgecam feature based manufacturing**

In this features are based on the manufacturing and are enabled by Edgecam solid machinist for native loading of solid CAD files and features recognition. [21] Edgecam workflow understands the components topology. Workflow has a significant impact on the shortening programming time. It is simple to operate.

## 7 Practical part

### 7.1 NC programming for machining parts

For the creation of the NC program, Edge cam software is used. This program can be used in terms of balance ratio (price/performance), relatively very powerful and affordable. Controlling of the software is very interactively accessible and relatively easy. Environmental program consists of two parts. One is called Design and the graphics are used to working with the model. Second name is called technology is used for the creation of machined cycle and generating NC code. Model axis machining is created, with the assistance of rough turning process cycle, followed by a cylindrical milling cutting diameter 16mm. Finishing operation will be made by profiling ball cutter having a diameter of 6mm.

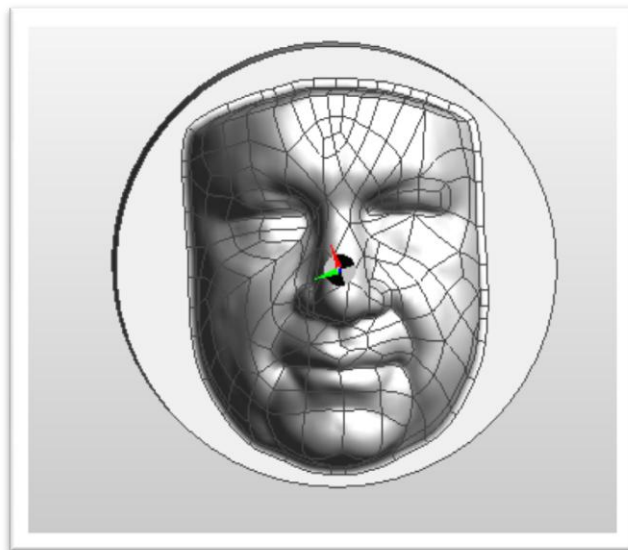


Figure 21: Model form in Edge cam

### 7.2 Preparation procedure for the formation of a machining cycle

In this design the portion of the program is loaded in step file (\*.stp). The settings menu is selected in ZX – turning, this prioritized axis is between the machine and the workpiece. The choice of the zero point before the workpiece is carried out by the functions.

Rotation of the model in coordinate system was done by the selecting the Edit Transformation → → Rotation.

### 7.3 Selection of the machined part and protected area

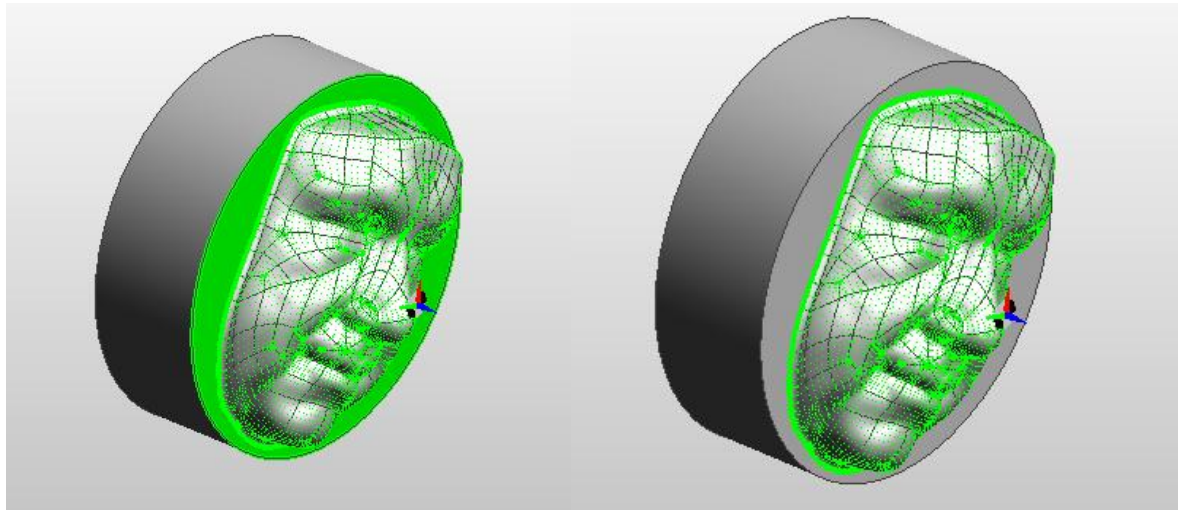


Figure 22: Green surface represent the selected surface layers left plate1, right plate2

In the tree structure of the program will create a new layer called plate1 and plate 2. These areas used to select either machined part or protected surfaces. The protected area is the one that prevents the start-up tools to locate on the model, which they do. On this model selected areas, which represent the individual layers. Plate2 will contain only the top portion of the rugged surface of the model.

### 7.4 Preliminary instructions for machining parts

To machine the contour surface on the upper side of the cylinder, it is necessary to create a guide curve along which the tool will copy the path. With the profile of the circuit units, selected circuit curve. The curve is stored in the tree structure layer in the same manner with the previous areas.

Additionally, the point distance of 50 mm is placed at the centre of the model. This point is important for the machine operation in the raid tools. The distance from the centre of the tool is dependent on the diameter of the workpiece and the tool diameter.



### 7.4.1 Creating the blank

The selected shape of this cylinder diameter is 140mm. In the dialog box for entering the coordinate values with the length. Around the model, it appears red contour shaped blank which can be varied in a transparent or network. Now, after a preparatory step in a design part is to go into the technological part of the program. Including technological part opens a dialog for how the clamping of the workpiece in the spindle and to select the most efficient part.

In this technology, the model appears in the universal chuck mounted inside the machine. For better quality, we can have made individual display and storage elements vary according to the needs of the visualization. For better handling, the part is shown separately.

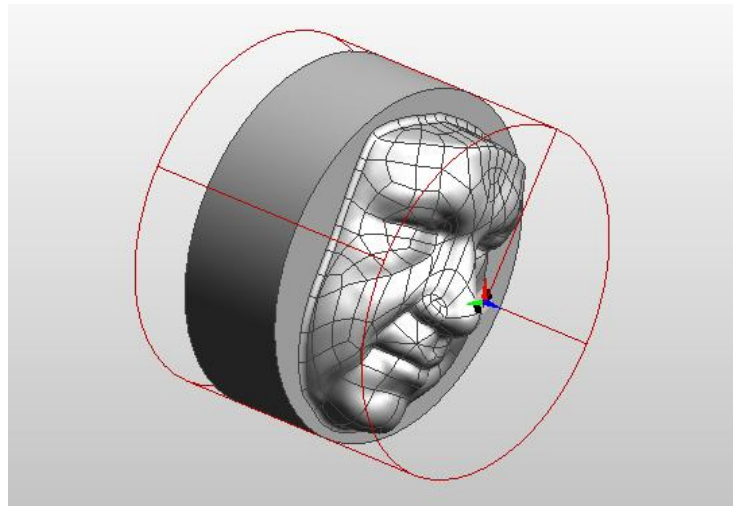


Figure 23: Model with blank cylinder

### 7.4.2 Selection of the tools:

The first tool will be machined around the cylindrical cutter. In the dialog box, the setting tool parameters must be set according to diameter and the type of tools, the length of tool is driven, it would be impossible to give the instructions to the machining.

## 7.5 Turning operation

After selecting turning operation, a dialog box will appear on the window, under which there is select the parameter for the required operation, according to requirements of the workpiece.

The image shows a 'Turning Tool' dialog box with the following fields and values:

- General Tab:**
  - ToolStore: i nuz pravy HP
  - Mount Description: (empty)
  - Position: 14
  - Group Code: 2
  - Comment: (empty)
  - Offset: (empty)
  - Code ID: (empty)
  - Centerline Side: None
- Insert Definition:**
  - Symbol: <None>
  - Edge Length: 16
  - End Angle: 140
  - Nose Radius: 0.6
  - Included Angle: 35
  - Inscribed Circle: (empty)
  - Side Angle: (empty)
  - Units: Millimetres
- Sandvik Coromant Wiper:**
  - % Feed non Wiper: (empty)
  - Wiper Style: None
- Tool Definition:**
  - Orientation: Axial (selected), Radial, Reverse Axial, Angle
  - Hand of Tool: Right
  - Feed Type: Per Rev
  - Reverse: (unchecked)
  - Angle: (empty)

Figure 24. Turning operation

### 7.5.1 Orientation: Axial

If you select another option in orientation tab, the turning operation will work in random direction and the tool cutting will change into another orientation. Positioning of the tool axis will be crucial for relative to the machine tool coordinate system as shown in the below figure.

**Book marks:**

**Edge length:** 16mm

**Edge angle:**  $140^{\circ}$

**Nose radius:** 0.6mm

**Feed type:** per revolution

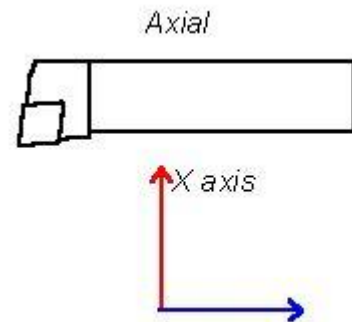


Figure 25. Orientation of the tool[1]

### 7.5.2 Toolstore

Selection of toolstore is important for cutting the object in given dimension and finishing of the surface will be accurate. Following steps are required for toolstore selection.[1]

- When loading the tool, the insert thickness value will specify on the geometry tab and the toolstore will automatically be passed through the tool changing dialog. The tool graphics in the Edgcam simulation will reflect the specified insert thickness.
- Holder graphics are used to represent the holder for this tool.
- For specifying the offset distance from the shank CPL to Holder CPL. The usage of the Y value will allow the holder graphics to be staggered in that direction of the shank.
- Coolants are not required for this machining because the object what I choose for manufacturing is carbide.
- Maximum RPM will specify the maximum revolution per minute for CSS.

### 7.6 Roughing and profiling: A mill with a diameter of 16mm

After selecting roughing, a dialog window containing tabs will appear, under which there is select the parameter for the required operation, according to the requirements of the workpiece.

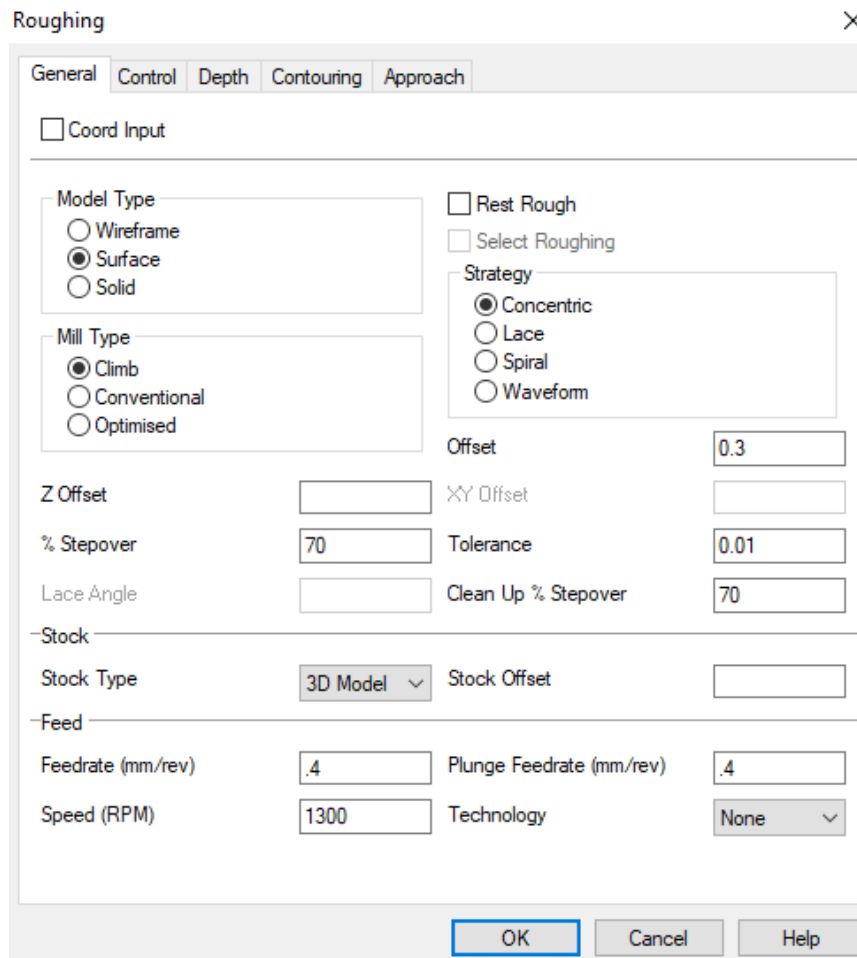


Figure 26. Dialog box instruction for roughing

**Stock type:** 3D-Model

If you select another stock type, the roughing operation cannot select the object to be cut, along with that an error message will appear that it is not possible to generate the pathways.

**Strategy:** Concentric

It is a way of making tracks on the surface of the work piece.

**7.6.1 Check allowance**

When choosing the value of the item. In addition to the model, with this we can ‘undercut’ the workpiece. There is some effect due to the addition change of the mode

to gouge the workpiece. In order to prevent the undercutting, it was necessary to change the milling type to climb and increase the stepover percentage to '70'.

### **7.6.2 Pitch toolpath**

The maximum distance (line cycle) is given in percentage of the diameter of the selected tool. For example, typing the numbers 100 (line spacing) equals to the tool diameter, the higher number would uncut the materials between the lines.

**Pitch path by the wall%** you set your own pitch-offset tool for outer-lane round the circumference of the machining area. It is useful where it is on the periphery of a thin wall and force loading tool with greater offset, if it is used to deform. If the left empty or incorrectly determined the spacing greater than the normal pitch, apply for external normal track pitch toolpath. When using the scanning strategy is the pitch of the external toolpath is limited to 20% of the tool diameter, so as to avoid uncut material residues. [1]

### **7.6.3 Depth of cut**

Depth of cut specifies the machine is cut. This is always interpreted as a negative number, whether you enter it as negative or not. In 3D roughing the depth will adjust by the Z- Offset. In this case, the depth of cut for machining the object is '-30'.

### **7.6.4 Cut increment**

It specifies the depth for each successive cut. The value must be a positive number. The cut increment value set the vertical distance between successive planes.

### **7.6.5 Tool control**

The path should be selected at the centre of the tool in order to keep within the containment boundary.

## High speed cornering

All toolpath corners has an angle from the profile, however it is sharp. A radius is introduced to sharp toolpath corners.

The parameters for generation of the track: Many curves for the projection on the surfaces: forming boundary contour. Marking a new starting point for the profile:

Orientation of the profile, which side the face will be machined, whether it is external or internal surfaces. Confirmation is required to general tool path.

Finishing machining contour is accomplished by the command profile function. Writing the instruction is facilitated by using a copy for the previous instruction. The generated tool path is required for machining the contour edge surfaces.

For all the related operations that are not used for the same tool, you need to finish off by using instruction command **< to exchange >**

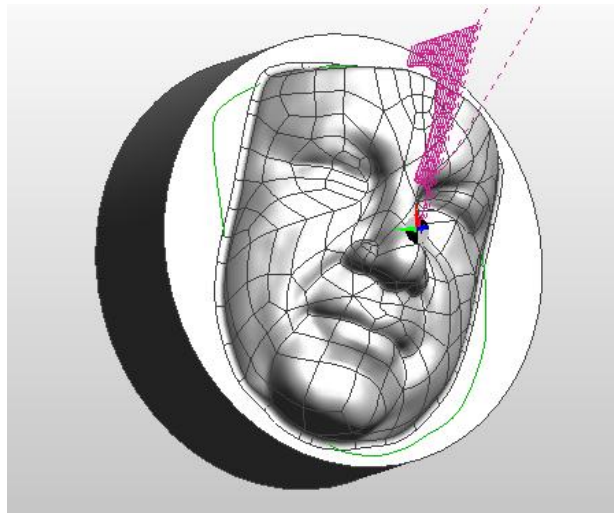


Figure 27.Machining contour

## 8 Five-axis machining cycle

Most of the places on workpiece were machined with three-axis operations because they occur in a place where the tool receives, e.g. cavities and negative shapes. This is because of the size and shape of the tool. The machining of such inaccessible places is machined by the use of 5-axis cycle.

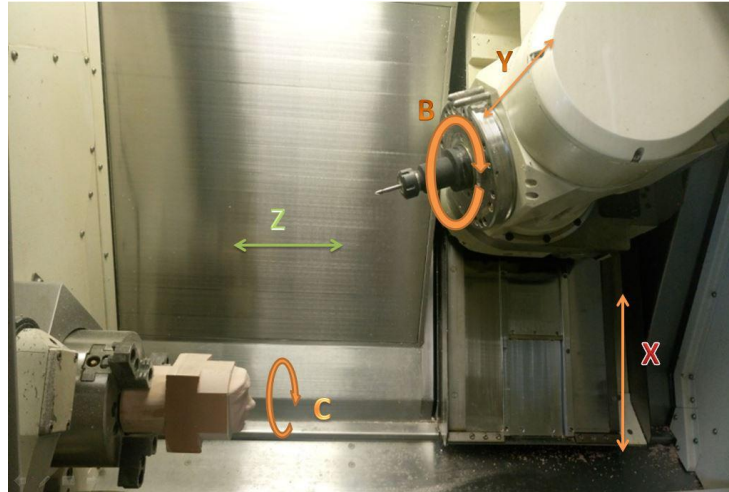


Figure 28. 5-axis coordinate system Mazak Integrex 100- IV

5-axis machining cycle is a machine when the tool is held in the direction of movement X, Y, Z, and the rotation around the axis along the Y-axis = B = C around the Z-axis.

This software has been machined entire area at least once by using the 5-axis cycle and not to block the C-axis. Comparing the surface finish on the machine with Edgcam program area is seen, so that the area of the program has Mastercam visible the places where the unmachined places are compared with the unprocessed points on the 5-axis toolpath Edgcam program. It is therefore necessary, in 5-axis machining cycle of negative spaces are accessed to the surfaces individually. On conventional CNC milling machine, however, such a problem did not occur, so that it can adapt to a greater work range of the motion in each axis.

## 8.1 Procedure for five-axis machining

Preparation of the model and the assignment of the blank is the same as in the preceding machining cycle; a difference arises in the selection of the areas to be machined. You must select surface that cover their uncut portion size and will not interfere with the already machined parts. [1]

### 8.1.1 Machining left cavities

The first surfacing in the 5-axis machining cycle turns on the left side of the model as well as the left cavity of the model. Switching from a rotating planar mode is activated, some features that were previously inactive as shown in the figure. 35

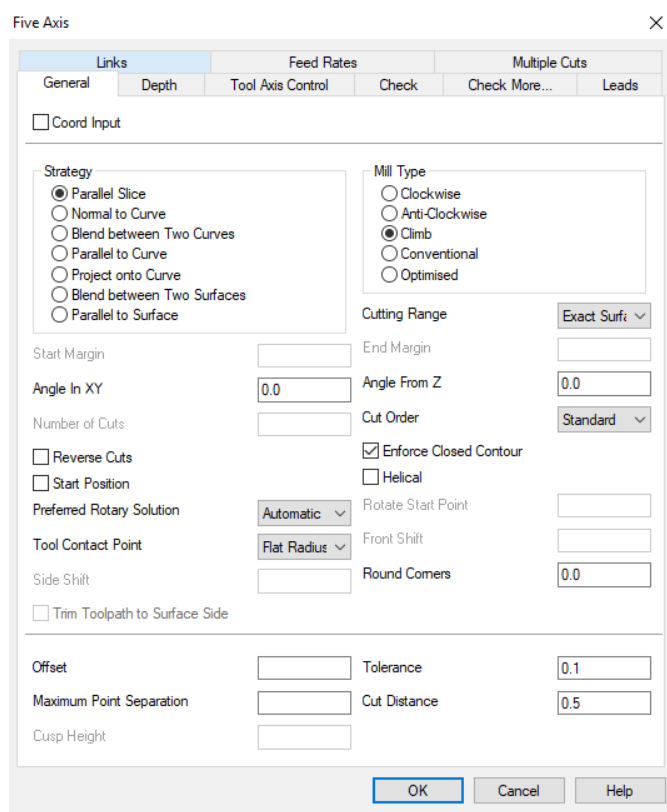


Figure 29.5-axis machining dialog



### 8.1.2 Items for defining five-axis cycle

Bookmark basic the above figure

**Strategy formation pathways:** cutting toolpath intersections go after a series of parallel planes with the machined surface. The cut distance set the distance between the planes. The direction parallel to the intersecting planes is determined by the angle in the XY plane and its vertical inclination angles to the Z-axis. The distance between the planes indicates the pitch parameter pathways.[1]

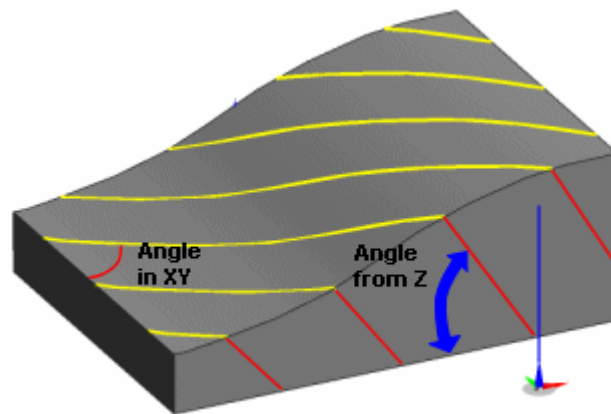


Figure 30.Strategy formation pathways[1]

Important is the angular rotation of the paths in the XY and Z (**Fig.**) which affects the quality and size of the resulting toolpath.

**Bookmarks:** Tool axis control: Method of machining: 5-axis

### 8.2 Relative to the cut direction

The tool is rotated from its surface normal orientation in two planes, by specified angles. One plane is parallel to the cut direction and normal to the surface at the contact of the point. The tilt in the plane is the 'Lag Angle'. The other plane is set by side tilt definition type. For example 'Follow Surface' when the side tilt plane is a vertical plane that includes the surface normal.[1]

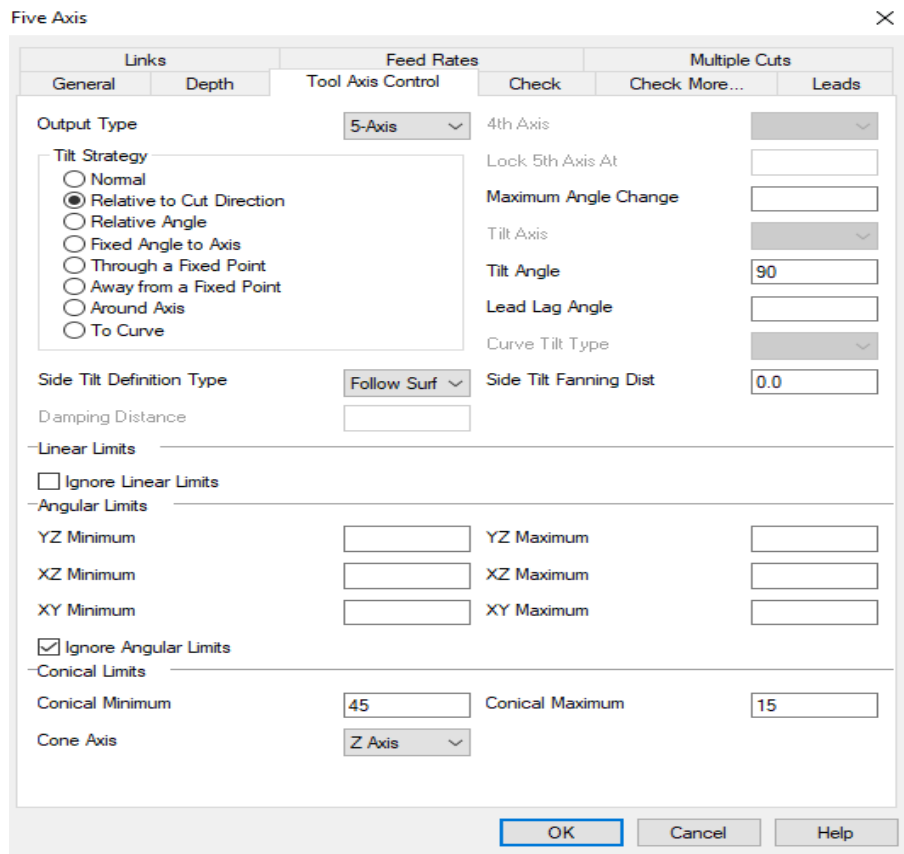


Figure 31. Dialog 5-axis machining-bookmark tool axis control

**Tilt Angle:**  $90^0$

**Conical limits:** It must be set due to restriction of the tilt and the tool to the surrounding areas of the model with which it could collide. Restriction tilt tool carried out by means of an angle. In any case after many attempts, set the values for the conical limits. In this case, we need to ignore the angular limits. (Fig.36)

### Collision avoidance

**Bookmark:** Collision monitoring

This is the relation between the objects for which the collisions occur.

**Control 1:** Tool: In some controlled surface area, there are collision avoidance methods;[1]

Removal paths => path that would cause a collision is to be removed (fig.36).

**Control 2:** Utility model against collision avoidance

**Method:** Removal path

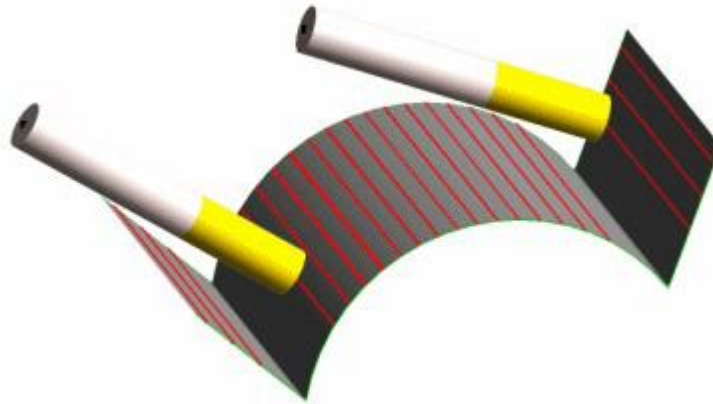


Figure 32. Removal path = collision avoidance[1]

### 8.3 Simulation and tool path verification

Switching the simulation mode in Edgecam program, it is necessary to start the machining simulation. The simulation is completed by a series of control that leads to work easy on the model. For example, speed control simulation or information about the surface quality. In this simulation tab we can see red, blue, green and yellow colours on the surface of the model. If the model is in dark blue and blue colour on the surface is fine. The range of colours from dark blue to green shows the addition of the descending size toward the final model. Red and yellow colour indicates the undercut of the object due to irreversible damage to the part and the greater loss of the material.

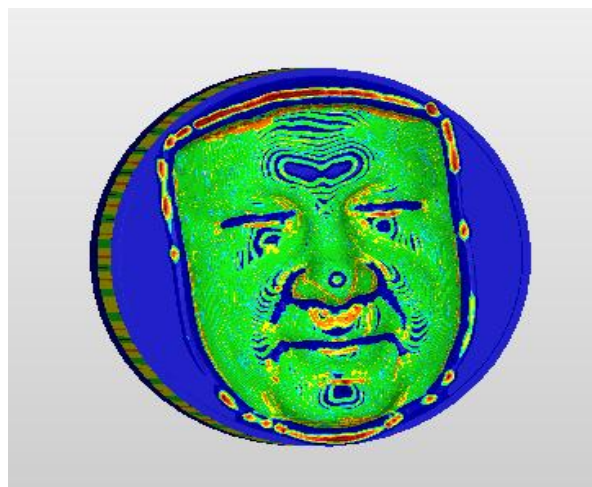


Figure 33. Final simulation

## 8.4 Generating NC code

To create a real model, it is necessary to convert the graphic appearance of the generated paths in math, in the form of command lines with coordinates and the instructions for movements. This lodge feature in Edgcam named Generate Code NC.[1]

### 8.4.1 Production of the CNC machine

#### Preparation of the blank:

The model will be the part of ‘artificial wood’. It is a material which has similar properties and the mass of the wood (**Fig.37**). With the difference that it is a homogeneous, not chipped and has better heat dissipation than the conventional timber which is under the same machining conditions burning. When machining, therefore it is not necessary for the coolant, even though we are using large feed rate and speed it should not cause any damage to the tool. The main disadvantage is dust and adhesion of the dust particles inside the machine.

The manufacture of the block size is 150 mm \* 160 mm\* 300 mm. To facilitate the clamping of the material into the machine chuck block had to be adapted to the shape of the rotary cylinder. Because it is necessary to clamp the workpiece, lock around C-axis (axis of the rotation around the Z-axis). The chuck was set to an appropriate size according to the diameter of the blank. The blank was clamped together with aluminium tape to avoid the crushing the workpiece due to pressure of the jaws. The pressure was set to the lowest value of 0.2 MPa.

Before machining, the driven surfaces have placed on a reference point. This instruction defines the distance between the reference point and relative to the tool holder. Settings must be made separately in the axes X, Y, Z, B, and C.

Subsequently the clamping tools needed to define a correction. For tool to be compensating the values has to define on the length of the ejection tool orientation and the position relative to the point of the tool holder.

### 8.4.2 Adjustment of tool length

For this purpose, it was extended to measuring eye. Drove a tool to touch and sound sensors, together with off LED indicated contact.

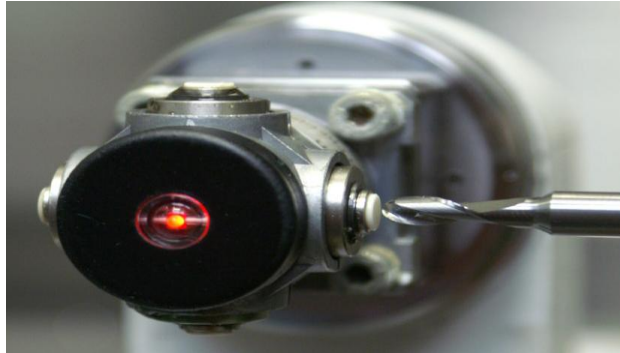


Figure 34. Tool length adjustment 6mm ball nose mill

This distance was found, which would plug into the tool compensation. For a cylindrical milling cutter of 16mm was measured for each blade separately and recorded values for longer edge.

### 8.4.3 Preparation for machining

The blank was first machined on one side by means of a turning tool, to a diameter of 100mm. Subsequently, at the machined portion is clamped, while the second part was machined, the workpiece should simultaneously have performed on the alignment force.

## **9 GOM INSPECT**

GOM inspect is a software that is used for the processing and evaluation of the data that can be measured in the optic 3D scanners, size and shape analyses, inspection.[24]

GOM inspect includes three basic parameters.

### **9.1 Parameter inspection**

With GOM'S parametric concept, each individual element can retain its own creation path within the software structure. The inspection function is used to compare the data with scanned point clouds.[25]

- All individual elements can be changed and adjusted in any-time.
- The elements links and creation of the paths are known and recorded by the software.
- Modified individual steps are easily implemented and changes are automatically inherited by dependent elements.
- Here it is possible to insert flags with deviations.

### **9.2 Editing mesh**

- 3D mesh for parts, objects and components can be calculate from 3D point cloud for visualization, simulation, and reverse engineering and CAD comparison.[25]
- The precise polygon meshes can export to several standard formats such as STL, G3D, JT Open, ASCII and PLY.
- Editing function network is suitable for editing point cloud.
- Data from 3D scanners, laser scanners, computer tomographs, CMMs and other scanners can be imported and polygonized in GOM inspect.

#### **9.2.1 Mesh processing**

Polygon meshes can also be smoothened, thinned and refined. In addition to that, holes in the mesh can be filled and curvatures are extracted by using meshing operation in the software. The mesh is processed by using curvature-based algorithm and tolerances. [25]

GOM Inspect: It contains all mesh processing functions.

### 9.3 Report

- Report function allows us to create messages that contain images, snapshots, tables, graphs and text etc.
- Creating page reports can be reused in 3D window.
- The results can be presented in user interface and also exported to a PDF format.[24]
- Customer templates are reused and each snapshot is stored in a report and can restore in the 3D window function.

### 9.4 Virtual measuring room (VMR)

The VMR is the virtual, yet it is the functional representation of the real world. VMR is fully integrated solutions that allow the complete reproduction for the automated measurement process. GOM Inspect can be used as a viewer for the Virtual Measurement Room[25]. Additional VMR software module is used for automatic measuring procedures: Import of measurement plans, offline and online programming, 3D simulation and measurements, collision check, process safety, data collection and measuring reports.[24]

### 9.5 Properties of GOM Inspect

- Dimensional analysis in 3D and 2D.
- We can also use for measuring linear dimensions, angular dimensions etc. of the diametric parameters.
- Comparing dimensional CAD model
- Import files in the format of STEP, IGES and JT Open.
- GDT
- Export point clouds to ASCII, STL and POL etc. [25]

## 9.6 Comparison between the Actual and Nominal parts using GOM Inspect software.

### GOM Inspection

In this inspection we need to make all the files what we are going to work have to convert in to the STL format here we are going to inspect mainly two items

- Actual model.
- Nominal model.

These are the models what I manufactured in the Edge cam is Actual model and the nominal model is nothing but the physical part what I got for my research.

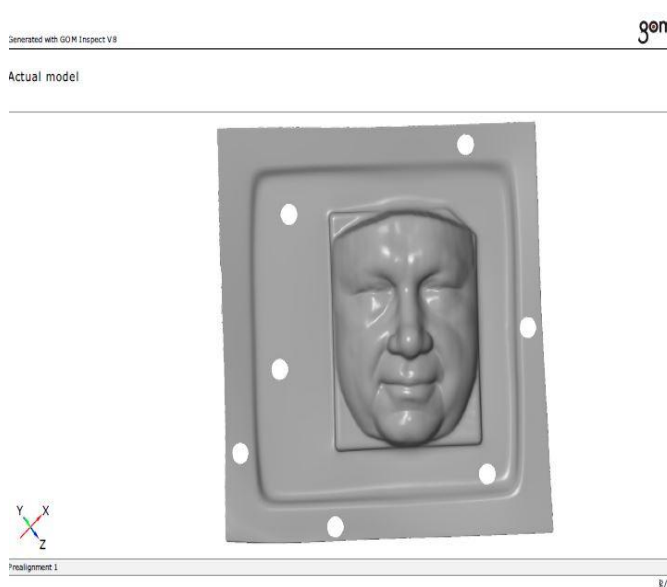


Figure 36.Nominal Data

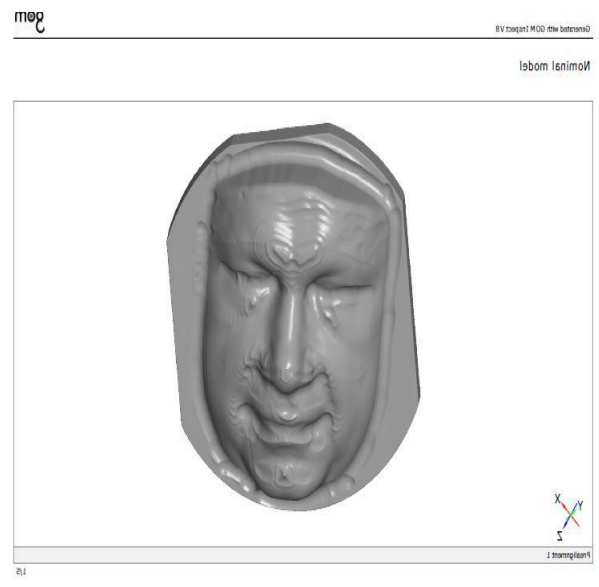


Figure 35.Actual part

### 9.6.1 Surface Comparison

In this software, first I imported nominal CAD model it instantly recognised the file type and open the CAD import dialog, the CAD file will be converted into a triangular mesh and therefore you can specify the mesh resolution. The CAD mesh density should correspond to the mesh density of the measured mesh, the structure repair mode is by default on automatic, just click okay to import the CAD file. The data appears now as the nominal CAD element, after that we need to import the actual CAD file, therefore all nominal elements appears in blue color and actual elements



appear in green color this is the important colour function in this software. The initial alignment is used to bring the data together, the prealignment aligns the actual data independently by its start position. now we can able to compare the two data measures as there are so many coordinates to compare GOM Inspect can display the deviation of the actual data to the nominal data via surface comparison. In the prealignment system the models will align according to the calibration of both models so it will align exactly on the surface of the others. After the prealignment the actual and nominal models are meant to be in different colours (in default actual will be in dark blue and the nominal in gray) and then I done the surface comparison on the nominal model with actual model by using the exclusive view command we can see the colour map down in the figure

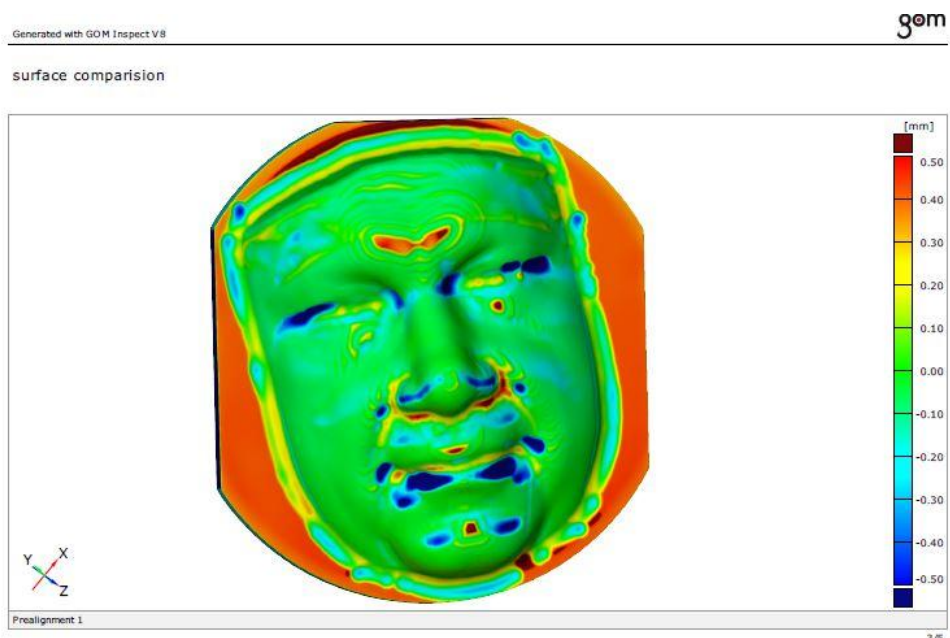


figure 37. Colour Map

### 9.6.2 Deviation Label

In the colour maps we can see the errors on the surfaces. Comparison between the actual and the nominal parts, here I made the colour labels to identify the errors in the each and every point, there we can observe errors that all the part which are in the green, red and blue colors. The red color means that the material lies above the CAD surface and blue color means that the materialized below the CAD surface you can also get more discrete values for these deviation with deviation labels, press the



## 10 Conclusion

For this work it is shown that it can be achieved for the creation of a real shape of the actual model. The accuracy of this model is influenced by several operations which the model has passed. The goal is not easy to achieve the accurate results, preceded by many experiments.

First step, the real model is digitized by using optical 3D scanner. The digitizing was done by using ATOS II scan, for this thesis work I preferred ATOS scanner because in this we can scan the model very fast and it give very accurate result. But there was some problem with model; it was a shinning and transparent object. To overcome this problem you need to apply white painting on top of the surface so that we scan the model through this scanner. After scanning the object it is necessary to capture the data in STL format for further processing. The collected data is then imported into Geomagic Design X software in STEP format for developing the surfaces on the model. In order avoid the duplicate surfaces and protrusion which are formed during scanning. This model consists of complicated curves which are not easy to develop on this software. There are some errors needed to be repaired. Model consists of faces was then converted to complete 3D solid model.

Then the 3D solid model is served as initial data for creating the machining cycles in Edgecam program. They have been performed on the 5-axis turning- milling machine. For rough mill processing of diameter 16 mm was a problem in addition to set the overall model for machining was unexplained to gouge the workpiece. Finally it is necessary to customize the planes on this model. The original plan is perform turning operation before roughing, to remove the excess material on the model. The operations left with many blank spaces, because the negative spacing in the tool. The idea is to perform the entire area on the 5-axis machining at once. However it is not possible because of the inability to impose the rotation mode in Edgecam during 5-axis machining, if the rotation of the B-axis is not possible then we can use C-axis in the NC program only for the interpolation in X, Y, Z, and B axis. In conventional CNC milling machine, however, such a problem can be rectified because it can adapt to a greater working range of motion in each axis. The problem was solved in several stages of the machining process.

The next phase of the program concerned in Edgecam was time consuming. The formation of paths for each area are needed and selected appropriately to set an area limitation or tilt angle of the tool. It took mostly through trial and error method, because there was a switch orientation of the coordinate system.

The machining operations are then transferred to NC data. NC program creation was based on the data from the 3D scanners. The data served as baseline for machining in Mazak Integrex 100-IV. Cutting machines are carried in a similar way to practice the paths. While comparing the real model to machined part, we can see some deviations in the surface. In that we can observe different colours on the object; those are red, blue and green colours. The red colour means that the material lies above the CAD surface and blue color means that the materialized below the CAD surface. It is possible to acheive higher accuracy details but very time consuming. To get accurate result it takes almost 10 -13 hours for complete process.

**List of figures:**

Figure 1. Optical scanner ATOS II [2]..... 17

Figure 2. Auxiliary laser pointer[12] ..... 20

Figure 3. Preparation for measurement ..... 21

Figure 4. Reference points ..... 22

Figure 5. Projection of strips lights ..... 22

Figure 6. Part digitizing..... 24

Figure 7. Scan to data process [19] ..... 25

Figure 8. Scan to surface process[19] ..... 26

Figure 9. Scan to mesh process[19] ..... 26

Figure 10. Auto segment ..... 28

Figure 11. Auto segment ..... 29

Figure 13. Construct patch network ..... 30

Figure 12. Extract contour curves ..... 30

Figure 14. Shuffle patch group..... 31

Figure 15. Fit surface patches ..... 31

Figure 16. Trimmed surface ..... 32

Figure 17. Boolean part..... 33

Figure 18. Extruded part ..... 33

Figure 19. Final 3D model ..... 34

Figure 20. Main features of Edgecam ..... 35

Figure 21: Model form in Edge cam ..... 38

Figure 22: Green surface represent the selected surface layers left plate1, right plate2 ... 39

Figure 23: Model with blank cylinder..... 40

Figure 24. Turning operation ..... 41

Figure 25. Orientation of the tool[1] ..... 42

Figure 26. Dialog box instruction for roughing .....	43
Figure 27.Machining contour.....	45
Figure 28. 5-axis coordinate system Mazak Integrex 100- IV .....	46
Figure 29.5-axis machining dialog.....	47
Figure 30.Strategy formation pathways[1] .....	48
Figure 31. Dialog 5-axis machining-bookmark tool axis control .....	49
Figure 32.Removal path = collision avoidance[1] .....	50
Figure 33.Final simulation .....	50
Figure 34. Tool length adjustment 6mm ball nose mill .....	52
Figure 35. Actual part .....	55
Figure 36.Nominal Data.....	55
Figure 37. Colour Map.....	56
Figure 38.Colour maps with labels .....	57
Figure 39. Sectional view with labels .....	57

## List of Tables

Table 1 Parameters of ATOS scanner[10]
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1. The electronic manuals of Edgcam. 2009.
2. *ATOS II* [Online] [cited 2016 september 30]; Available from: [http://foto.favore.pl/2011/1/29/8/276272\\_1296287668307\\_n.jpg](http://foto.favore.pl/2011/1/29/8/276272_1296287668307_n.jpg).
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