

# Reverse Engineering of Pump Casing and Impeller

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**Abstract** - Reverse Engineering (RE) is usually undertaken in order to produce a virtual 3D CAD model of a component or to redesign the system for better maintainability with the assumption that there is no access to original design data or the original design data has been lost or never existed. Recent advancements in the field of contact and non-contact type 3D measurement systems has led to advancement in Reverse Engineering. This paper presents a method of Reverse Engineering applied to a case of Pump Casing and its Impeller in order to recover the original design. The paper gives detailed insight on manual surface reconstruction with the help of wireframe model, wireframe model being created from intersecting curves forming a three or four sided surface patch. The surface model is then analyzed for surface continuity between different surface patches and finally a 3D deviation report is plotted in order to get a complete deviation idea between scan data and extracted design.

**Keywords:** Reverse Engineering, 3D Scanner, Point Cloud, Surface Reconstruction, 3D Deviation.

## 1. INTRODUCTION

Reverse Engineering in general is the process of extracting knowledge or design information. This may often involve disassembling something (a mechanical assembly or device, electronic component, etc.) and analyze its components and working in detail. But when it comes to Reverse Engineering in Mechanical CAD, it means creating a virtual 3D CAD model of a component with the assumption that there is no access to original design data or the original design data has been lost or never existed [1]. In Forward or General Engineering we begin with an idea and end up with a finished product, but in reverse engineering we begin with a physical component and end up with a 3D CAD model.

Reverse Engineering process starts with converting real world images into virtual 3D data which is done using 3D measurement equipment, procedure being called scanning. Various factors are considered while scanning of the component, such as reflect ability of the component, its surface quality, the manufacturing process the component has undergone. Expectation for quality scan is matt, bright surface [2]. The output of scanning process being point cloud is used for fitting surface patches in order to create the skin of the 3D component.

Depending on the end requirement, the quality of surface constructed may differ. For instance, sometimes the requirement is only for a rapid prototyping in order to

have a good idea of shape contours of the component. In such case it would be too time consuming to generate a high quality surface despite of requirement. However in other cases like automotive body panels or aircraft surface components, for aerodynamic, aesthetic and visual appealing reasons, smooth lines and contours are needed as the basic requirement.

Surface creation is the most challenging, time consuming and crucial process in Reverse Engineering. A number of software packages are available in the market, which specialize in dealing with surfacing. Among the different procedures involved for surfacing in Reverse Engineering, one is creation of surface from meshing of the point cloud, other is Rapid Surfacing wherein surface patch is created from intersecting curves forming a three or four sided patch [3], for which a wireframe or skeleton model consisting a number of intersecting curves needs to be extracted from the point cloud in order to create a suitable CAD model.

This paper describes the digitizing process of the component right from scanning, STL file extraction, surfacing and 3D deviation check of the extracted CAD model. The approach used for surface creation is combination of manual and semiautomatic method. Although manual method involves more time and attention but yields in a far better quality of surface [3].

## 2. Reverse Engineering Procedure

### 2.1 Hardware and Digitization from component.

Impeller and Pump Casing as shown Figure 1 (a) & (b) has used as component for scanning. Both the components were manufactured by casting process. The component may require some kind of workpiece preparation such as proper cleaning and application of temporary white spray paint on the surface in case the reflect ability of component is not good [2,7]. Many a time surface preparation is required but in this case no surface preparation was required for both Pump Casing and Impeller. There are a number of data acquisition systems available in the market. They are majorly classified into contact and non-contact type 3D measurement equipment [4]. The equipment we have used is non hybrid laser scanner integrated with touch probe. The hardware used is seven axis Romer Absolute Arm (7330SI 3.0m) with integrated Laser Scanner as shown in Figure 1 (c), which generates a laser projected line of 65mm width with maximum data acquisition rate of 50,000 points/s and

accuracy of 30µm is used to scan the surface of pump casing and impeller [5]. The software used is POLYWORKS V12 for scanning and extracting the STL file [6]. The complete scanning of the pump casing and impeller took 2.5 hours, multiple set or groups of scans were taken in order to capture all the geometric features. The operator must ensure that in order to align two or more different set or group of scans, they must have some common shape features. Later this group of scans are aligned using manual shape based alignment to bring all scans in one coordinate system under IMAlign module. In order to scan all geometric features, firstly complete geometry was scanned, later the Pump Casing and Impeller were cut down into two parts to access the inner design features, later all the three different scans were combined using shape based manual alignment method.

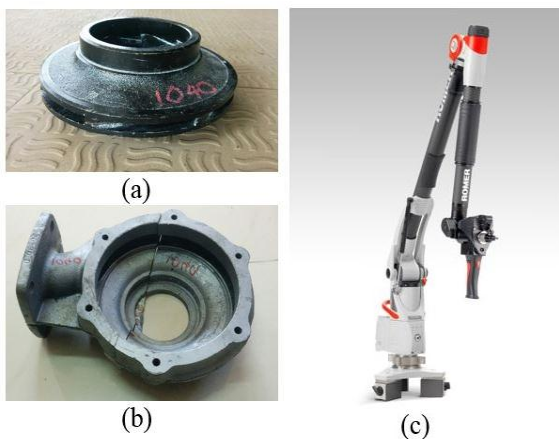


Figure 1. (a) Photograph of Impeller  
(b) Photograph of Pump Casing  
(c) Romer Absolute Arm with Scanner

### 2.2 Preprocessing of the Point Clouds.

Once all the geometric features of component are scanned and brought under one coordinate system, alignment procedure begins. A group of scan is first locked and other group of scans is aligned using common shape features manually as shown in Figure 2 (a) under IMAlign module in Polyworks. This initial alignment is further improved by deploying a least square iterative algorithm using a Best Fit alignment command to reduce the surface overlap distance between different group of scans until good shape and optimal scan is obtained as shown in Figure 2 (b). When a good and optimized scan is achieved the last step involved is to optimize the number of scan data points.

The scan geometry is then checked and treated for any noise, i.e. unwanted scan points which may have induced due to improper handling or manual error or obstruction in scanning, etc. using IMEdit module in Polyworks [1,2,3,10]. As the scanning is done manually patch by patch over the entire surface of the component. This may lead to overlap of the scan data in the point cloud

as the operator has to look on the computer screen and operate the machine. This leads to number of scan points way much over the bare minimum required to define the geometric features or entities of the component. Further this heavy point cloud may lead to delay in system response. Hence to ensure the number of points to be just enough to define all the dimensions, point overlay reduction is carried out which deploys a least square systematic iterative algorithm so as to have a strict control over the density and distribution of the points until a desired convergence is obtained. A total of 292915 number of data points were observed after point overlay reduction.

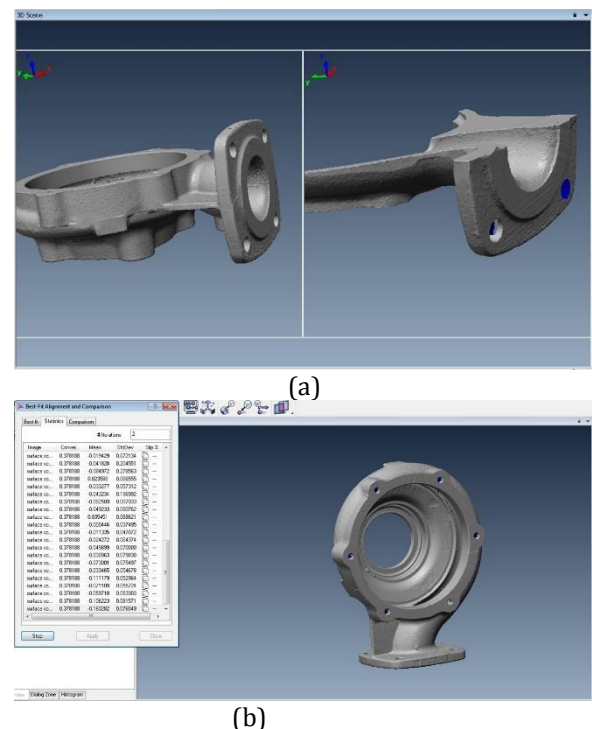


Figure 2 (a) Manual shape alignment in IMAlign module  
(b) Best Fit alignment in progress

### 2.3 Extraction of STL file.

Before extraction of the STL file, the imperfections such as missing data points, gaps, holes, etc. in the scan data are to be eliminated and refurbished and further optimized [1,2,3,10]. The output of the point cloud or the POLYWORKS software is .pwk file which is not readable on many platforms. In order to be readable for the file on various platforms, a stereolithography (STL) file needs to be extracted. The extraction of file may take time as the process is itself time consuming. It took 20-30 minutes for STL file to extract. Depending upon the complexity and the dimensions of the geometry sometimes the extraction may take several hours.

### 3 Surfacing and solid model.

#### 3.1 Surfacing of Impeller.

The Impeller point cloud or STL file is called upon into the Geomagic Studio software which specializes in dealing with surfacing for point cloud. Geomagic Studio builds a new ground in freeform modeling technology, providing a unique and comprehensive approach to 3D modeling and inspection for every stage of product design. We can play with point cloud in a number of ways in this software.

The first and foremost important thing is to allot coordinate system to the point cloud. For this to do a series of steps are to be followed. Once allotment of coordinate system is done, it becomes very easy to extract the design of the impeller. In this case the coordinate system was in alignment with z axis and placed on the plane surface as seen from top view. As the impeller is axis symmetric around the Z axis of its centerline of rotation. Hence a majority geometry or design of impeller can be extracted using a single cross section along the radial direction. Taking a section along the x axis of the impeller will highlight a set of points as shown in Figure 3. Using basic commands such as 2 point line, 3 point arc, 3 point circle, etc. an approximate but good sketch along the impeller section of point cloud is constructed. The fillets, chamfers and other such end operations shall be done after a solid model is obtained.

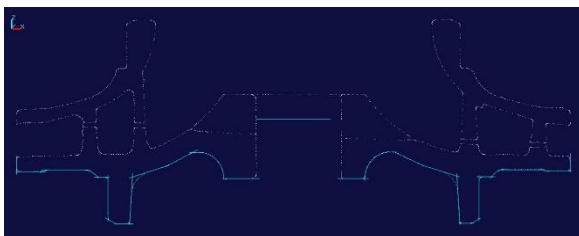
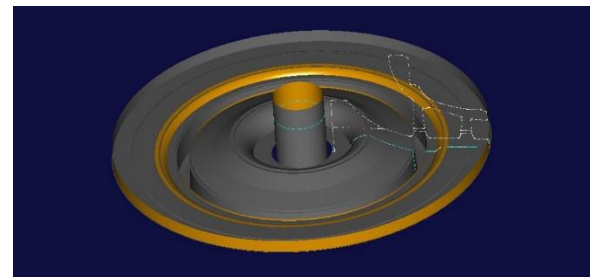


Figure 3. Different radial sections of Impeller

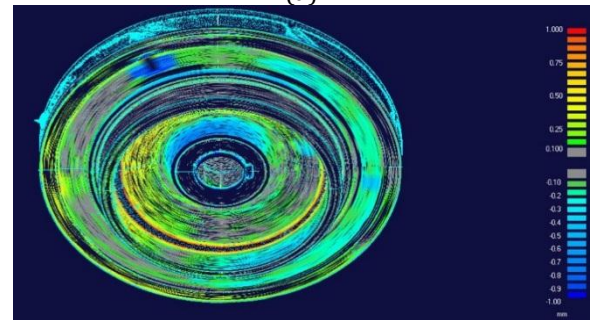
Once the sketch is drawn, it is simply revolved as surface around the z axis of the coordinate system which results in the bottom surface of the impeller as shown in Figure 4 (a). Now one should note that the surface drawn is merely from a section of point cloud, when checked for deviation it may or may not satisfy the desired or complete point cloud. Hence different radial sections in different radial directions are taken and the best suited, least deviation plot surface is selected. The drawn surface may or may not comply with the complete scan data. Hence a quick deviation check is performed between point cloud and the surface drawn. The max and min deviation to be checked is for +/- 1mm with an increment of +/- 0.1mm on either sides with a color plot resolution of 0.001. The deviation is as shown in Figure 4 (b). It gives us a good idea about the point deviation between point cloud and surface. For a surface to be good the majority of the point

cloud should lie in grey scale. Similar process and deviation check is performed for the rest of the impeller.

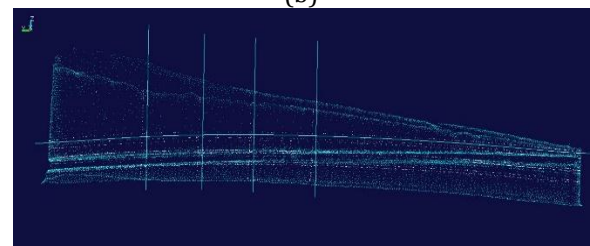
Unlike others the critical vane geometry design cannot be extracted using basic set of surface primitive commands. A non-primitive approach is used to extract the vane design and quick deviation check is performed. The vane face geometry was extracted using a number of different commands.



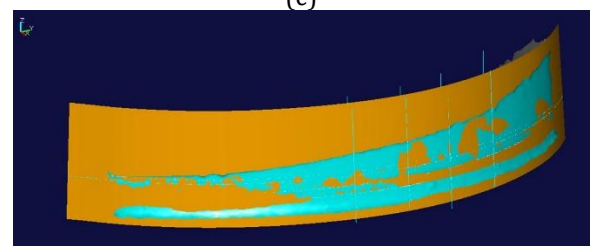
(a)



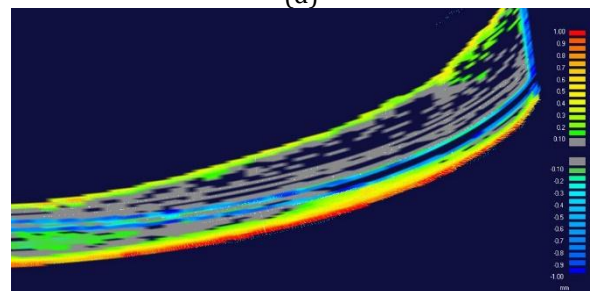
(b)



(c)



(d)



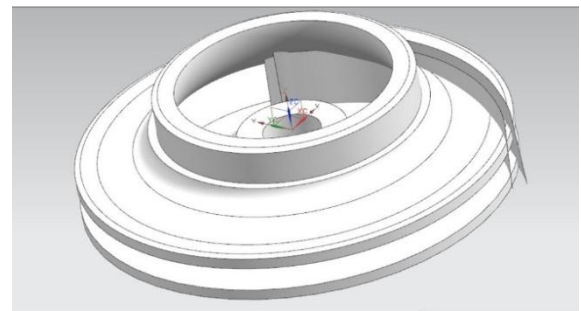
(e)

Figure 4 (a). Surface constructed from revolve feature  
 (b). Deviation check for surface constructed  
 (c). Vane Geometry being extracted  
 (d). Vane surface constructed  
 (e). Vane surface deviation check

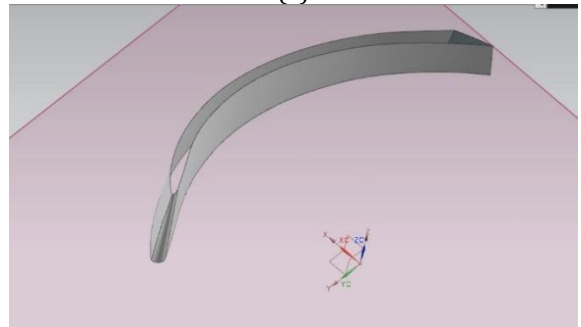
There may be number of ways or methods to construct vane varying from user to user, but the important thing is the conclusion from the deviation check. In this case as seen in Figure 4 (e), majority of the point clouds are within +/- 0.1mm distance from the surface, the rest of the points are observed in yellow and red color because there is a fillet in between vane and its adjacent surface, which as told earlier will be covered once we obtain a solid geometry.

### 3.2 Solid Model of Impeller.

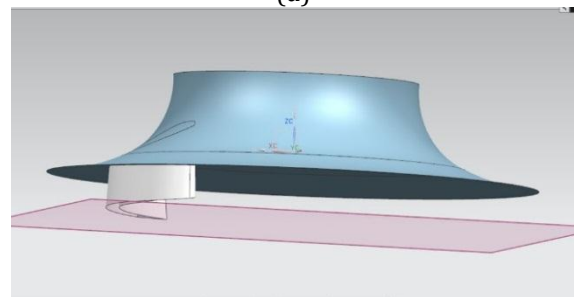
Finally when all the design features are successfully extracted the model is saved into IGES format and later imported in NX. Trimming operations are performed in NX, later sew command is used to convert the surfaces to solid model. After successful completion of solid model, end operations are performed on it such fillet, chamfer, etc. Finished model is then compared to original scan data in Geomagic Qualify software which gives a detailed 3D Deviation Report including various annotations and user defined views as well as various snapshots as shown in Figure 5. While obtaining a sold model, one may face many problems if there is any gap left between the surfaces or not properly trimmed.



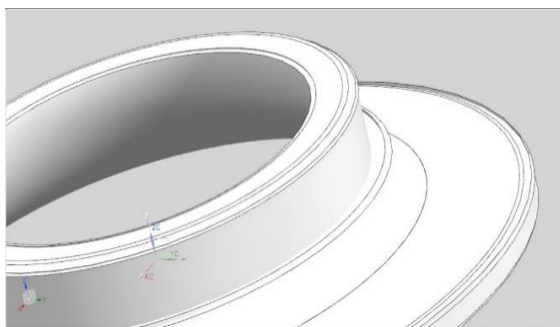
(c)



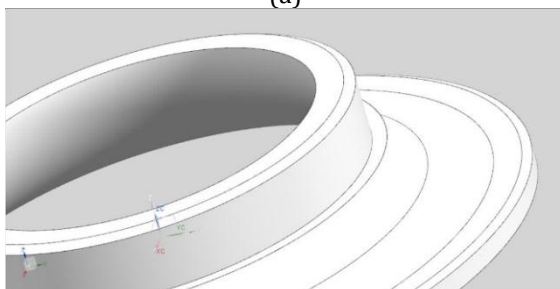
(d)



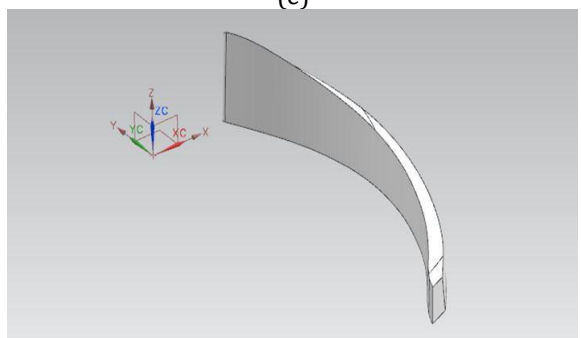
(e)



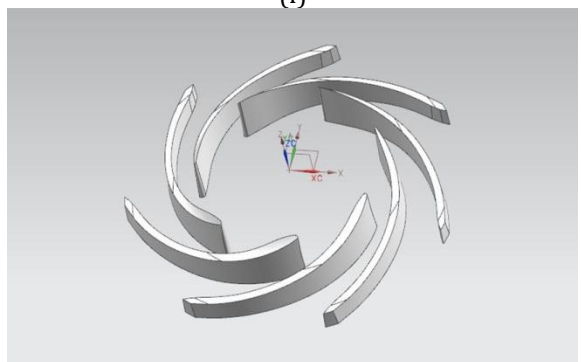
(a)



(b)



(f)



(g)

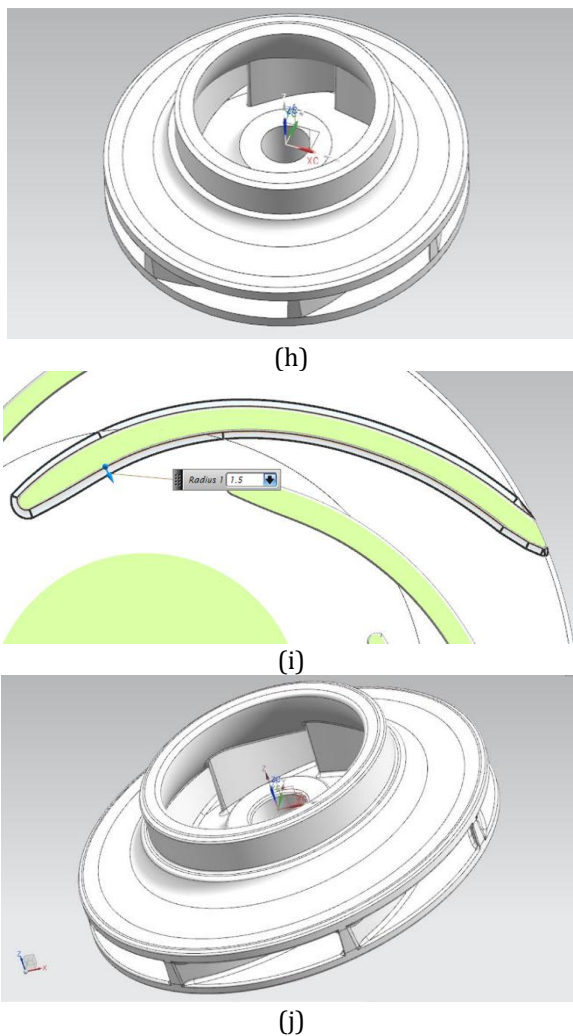


Figure 5 (a). Before trimming  
 (b). After trimming  
 (c). Vane surface imported  
 (d). Vane geometry  
 (e). Vane geometry top & bottom faces construction  
 (f). Solid body of Vane  
 (g). Associative circular copy of Vane–Total 7 Vanes  
 (h). Complete Solid Body generation after use of Sew command  
 (i). End operations in progress - Fillet, chamfer, etc.  
 (j). Complete Impeller Geometry

**3.3 3D Deviation Report of impeller.**

After successful extraction of geometric parameters, the complete solid model of impeller must be checked for deviation to get a correct and precise idea about the deviation of each and every surface point on the constructed solid model using Geomagic Qualify. Geomagic delivers the highest accuracy, speed and comprehensive, automated reporting on the quality of as-built parts for first-article inspection, production inspection using CMM and laser scanning tools.

Scan data STL file and IGES file of impeller is imported into the software. IGES model of impeller is set as reference and scan data of it as test specimen. A total of 292915 number of data points were tested for 3D deviation check. The parameters for the test are as in the table given below.

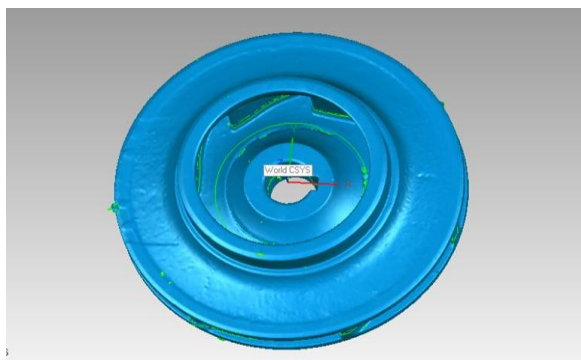
Tolerance Type	3D Deviation
Units	mm
Max. Critical	1.000
Max. Nominal	0.100
Min. Nominal	-0.100
Min. Critical	-1.000

Table 1. Parameters for Deviation check

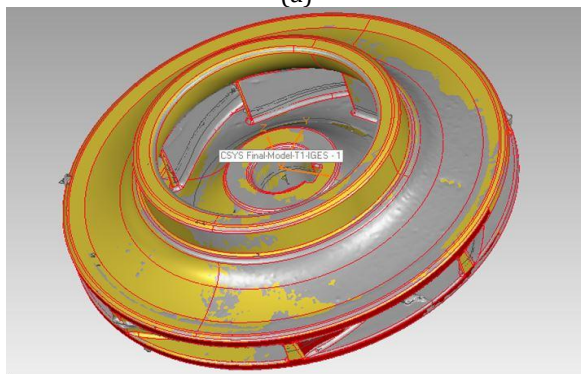
A detailed report was made and different annotations were plotted to get deviation at the desired point. The software is very helpful in customizing the way one desires its report. As the impeller was manufactured by casting process, hence the process induces surface roughness and surface variation. As around 74% of the points lie in the range of +/- 0.4 mm, the design extracted is a good design. The following table gives detailed deviation distribution of the data points.

>=Min	<Max	# Points	%
-1.000	-0.700	4709	1.608
-0.700	-0.400	22194	7.577
-0.400	-0.100	53241	18.176
-0.100	0.100	94409	32.231
0.100	0.400	68738	23.467
0.400	0.700	15467	5.280
0.700	1.000	5750	1.963

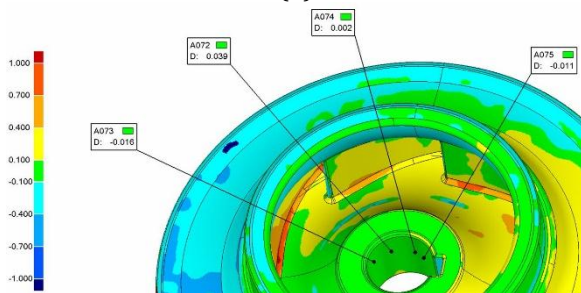
Table 2. Deviation Distribution of data points



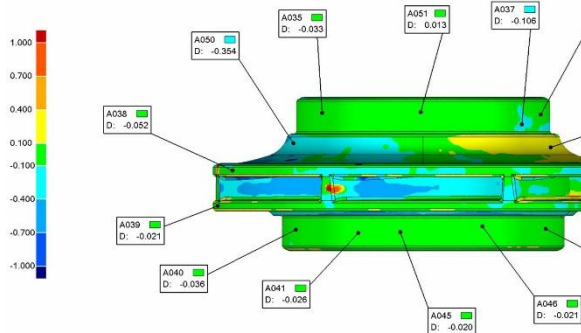
(a)



(b)



(c)



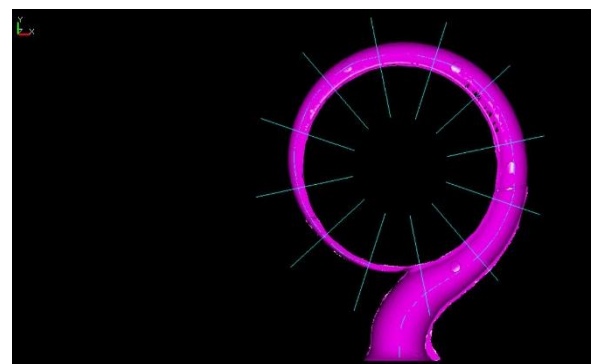
(d)

### 3.4 Surfacing of Pump Casing.

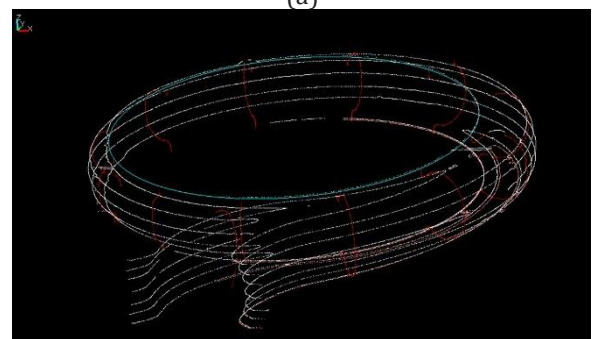
The first and foremost important thing is to assign the scan data a coordinate system, in this case the top surface of the casing where the outer covering will be bolted is selected as the plane for the coordinate system and the center of the volute casing as the final position because it will be easier for the geometric entities to extract same as impeller.

Unlike the impeller, Pump casing is a bit different to capture the geometric entities, it consists of volute casing for design reasons. The shape of volute casing cannot be captured using traditional approach, hence to extract the wireframe model to replicate the complete surface by constructing small patches all the over the volute section of the casing.

The term wire frame comes from designers using metal wire to represent the three-dimensional shape of solid objects. 3D wire frame allows to construct and manipulate solids and solid surfaces. Using a wire-frame model allows visualization of the underlying design structure of a 3D model. The wireframe technique will be used for inner and outer volute profile of the pump casing, rest of the parameters will be captured by traditional or logical approach. The inner profile of the point cloud is separated from the casing and sections are taken as described below.

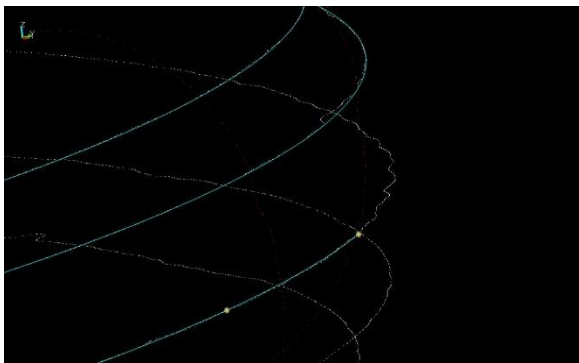


(a)

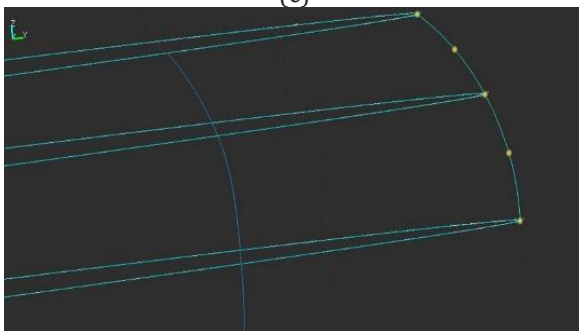


(b)

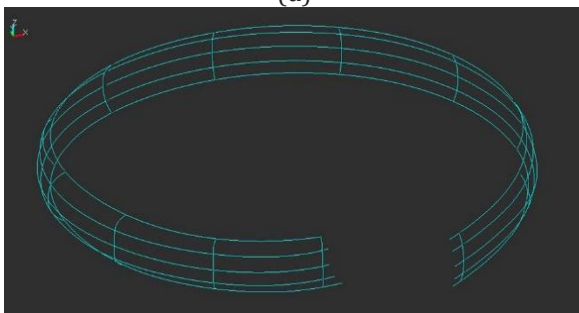
Figure 6 (a). Scan data being set as test specimen  
 (b). IGES model being set as reference  
 (c). Annotation view 1 of model  
 (d). Annotation view 2 of model



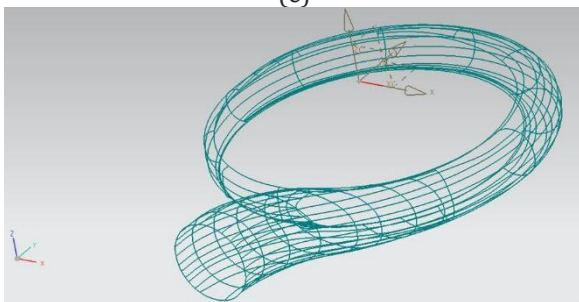
(c)



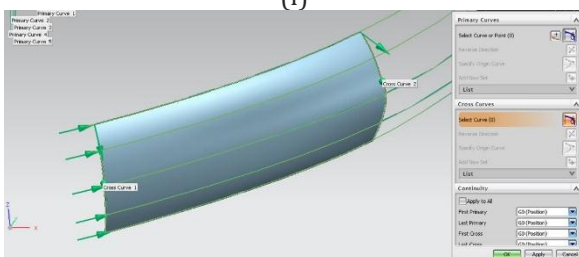
(d)



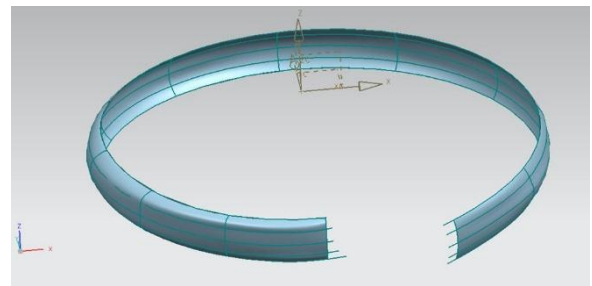
(e)



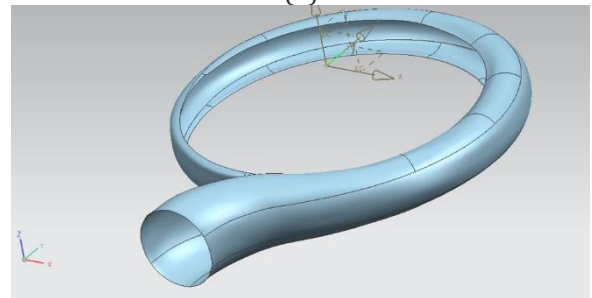
(f)



(g)



(h)



(i)

Figure 7 (a). 12 radial cross sections on the inner profile of point cloud

7 (b). Point cloud after radial and horizontal sections

7 (c). Circumferential B-spline in progress

7 (d). Cross B-Spline in progress

7 (e). Wireframe model in Geomagic Studio

7 (f). Complete wireframe model in NX

7 (g) & (h). Surface patches in progress

7 (i). Complete inner profile surface in NX

In the industry, the casing is designed using various formulas and a number of radial cross sections parameters are obtained. These cross sections are later utilized to construct a CAD model in software. The industry practice is to take 12 to 13 radial cross sections starting from the tongue of the casing and progressing along the circumferential direction [8]. The same approach is used to capture the design of the casing, 12 radial cross sections were taken in Geomagic Studio software as shown in Figure 7 (a) starting from the tongue of the casing, and also horizontal sections were taken for circumferential B-splines. Thus we get a skeleton model of point cloud sections as shown in Figure 7 (b).

Once we have skeleton point cloud model, we draw the circumferential B-splines or NURBS passing through the point clouds as shown in Figure 7 (c) using B-spline command in Geomagic Studio software, later cross B-splines are drawn as shown in Figure 7 (d). Care must be taken while drawing the cross B-splines, the cross B-splines must intersect the earlier constructed circumferential B-splines & as well as pass through radial point cloud. After constructing various B-splines we get a wireframe model as shown in Figure 7 (e). Note that all the B-spline lines are not constructed in one go, hence while drawing the next B-spline, G0 and G1 continuity must be maintained in order to ensure that the surface generated must be smooth and continuous [3,9]. Figure 7

(f) shows complete wireframe model of the inner profile of the casing. This wireframe model is saved and exported in IGES format to Siemens NX. Surface patches are constructed using 'Through Curve Mesh' command in Siemens NX software as shown in Figure 7 (g) & (h). Figure 7 (i) shows the complete surface model of the inner profile of the casing.

Of the five main B-splines drawn which are covering the major area of the inner profile and almost identical, one is chosen and comb analysis is shown in Figure 8. The comb analysis indicates the smooth variation of curve along the circumferential direction, the negative comb indicates change in slope of curve with smooth variation indicating no abrupt changes in curve.

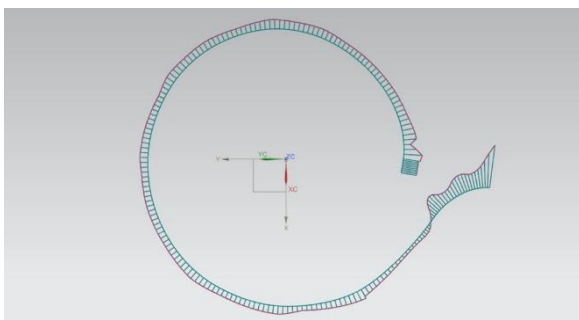


Figure 8. Comb analysis of B-Spline.

STL file can be only read but not operated in Siemens NX, Figure 9 shows scan data overlapped with surface model of inner profile of casing. This gives a brief idea about the surfaces constructed.

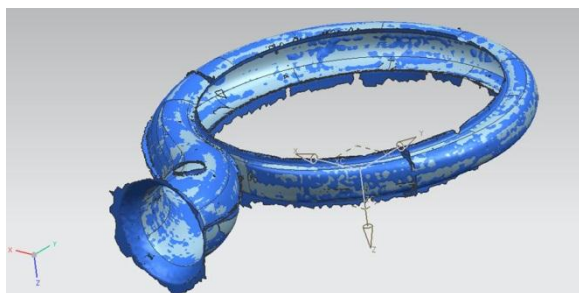


Figure 9. Inner profile Scan data (blue color) overlapped with surface data of inner profile of casing.

The constructed surface was again called back in Geomagic Studio and a quick deviation check was performed as shown in Figure 10.

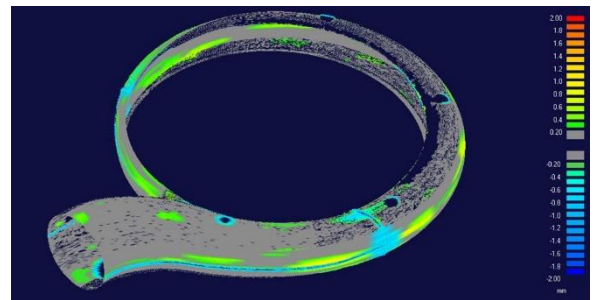


Figure 10. Deviation check for inner profile constructed.

The deviation check parameters were +/- 2 mm with an increment of +/- 0.1 mm as the casing was a casted one. The results shows that the constructed surface of inner profile is a good, smooth and continuous, and a satisfactory number of points lie on the surface constructed.

The zebra analysis is a tool for diagnostic shading to visualize curvature and continuity of surfaces. The zebra analysis is done for inner profile of the casing to check for smoothness and continuity between different surface patches [3]. Figure 11 shows zebra analysis for inner profile. The analysis below indicates smooth continuity between different surface patches.

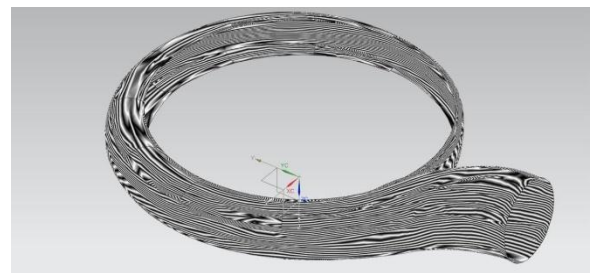
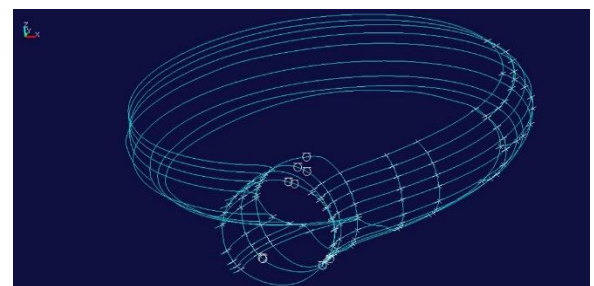


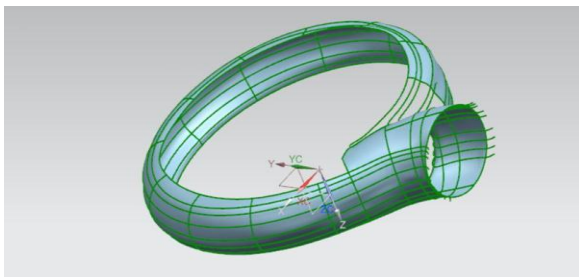
Figure 11. Zebra analysis for inner profile

Similar procedure is repeated for the outer volute profile of the casing. Wireframe model is first obtained in Geomagic Studio and surfacing is done in Siemens NX.



(a)

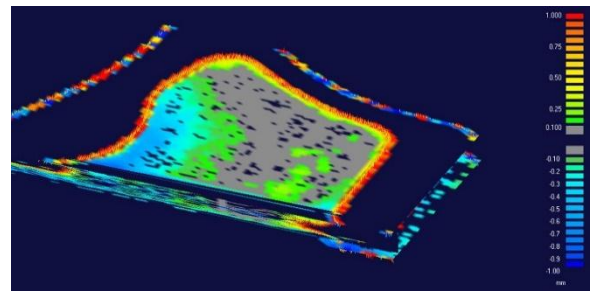




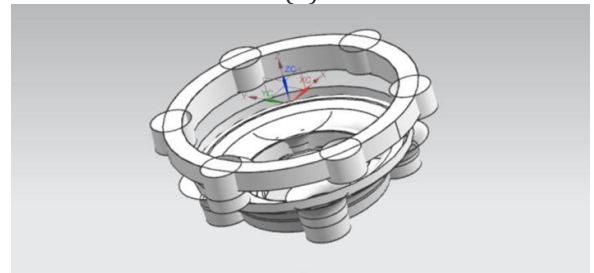
(b)

Figure 12. (a) Wireframe model of outer volute profile  
(b). Surface construction from wireframe.

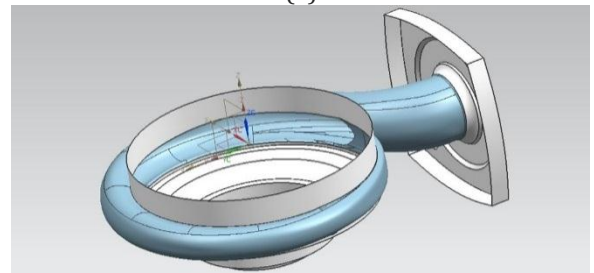
The rest of the surface are extracted using traditional or logical approach. The bottom inner surface is extracted same by applying the same procedure as that of impeller i.e. taking multiple sections along X & Y planes and cross section is constructed using basic set of commands, then revolve the section around Z axis which will generate a surface, among the multiple sections one with best fit and least deviation is selected after surfacing.



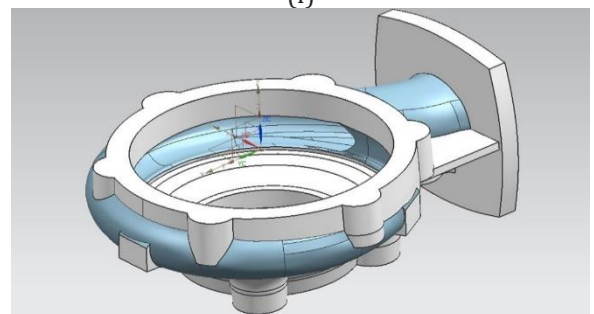
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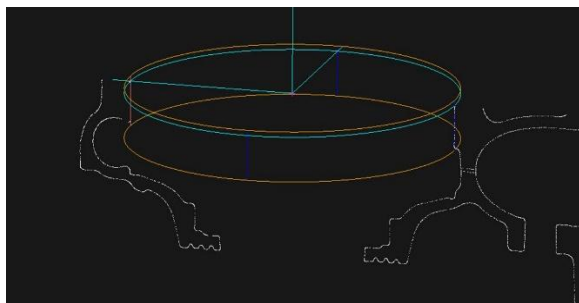
(e)



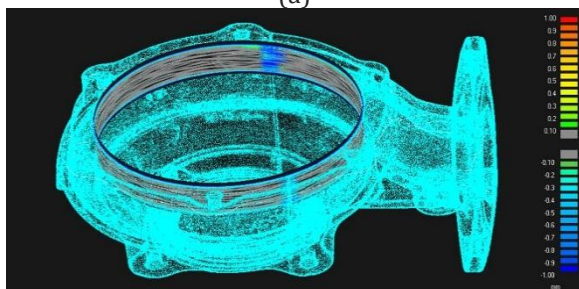
(f)



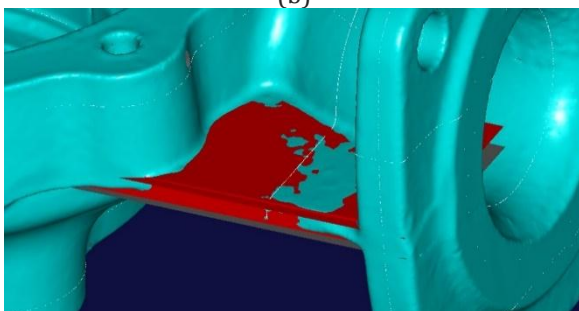
(g)



(a)



(b)



(c)

Figure 13 (a). Construction of surface of casing  
(b). Deviation check for surface  
(c). Outer rib surface of casing  
(d). Deviation check for surface  
(e). Surface construction using traditional approach  
(f). Complete inner profile of casing after trimming  
(g). Complete surface profile of casing after trimming without holes, fillets, etc.

### 3.5 Solid model of Pump Casing.

After complete extraction of surfaces in Geomagic Studio, surface deviation check is performed and files are saved in IGES format. IGES files are imported in Siemens NX, trimming operation are performed. After trimming, sew command is operated to attach all the surfaces

together and to leave no surface gaps. After sew operation we get a complete solid model of casing as shown in Figure 14.

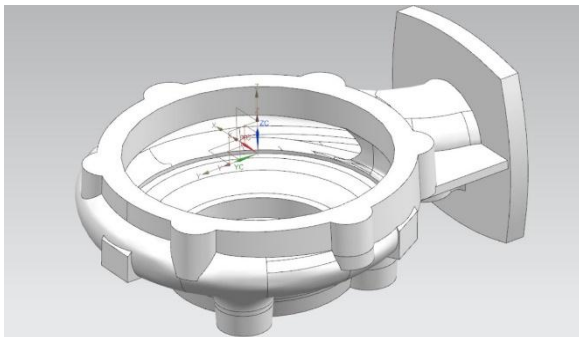
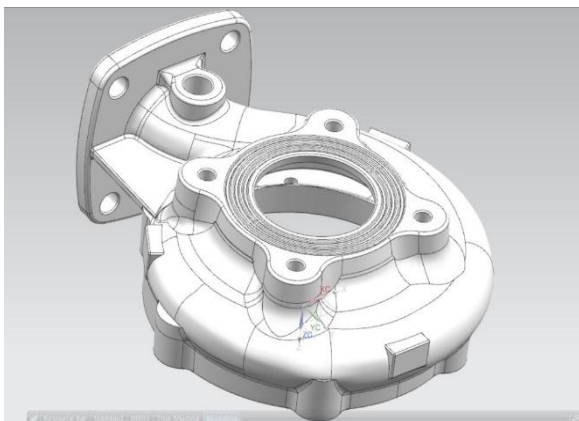
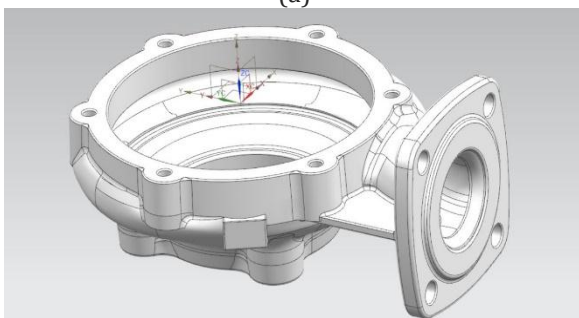


Figure 14. Complete solid model of pump casing

After successful conversion into solid model, end operations are performed as shown in Figure 15, such as fillets, chamfers, holes etc. The fillets are actually measured in Geomagic Studio and later applied in Siemens NX.



(a)



(b)

Figure 15 (a) & (b). Complete solid model of Pump Casing after end operations.

### 3.6 3D Deviation report of Pump Casing.

The solid model of casing is now tested for deviation in Geomagic Qualify. IGES file of pump casing is set as reference and scan data as test specimen, a total 497784 data points were checked for deviation. The parameters for deviation check are given in Table 3.

Tolerance Type	3D Deviation
Units	mm
Max. Critical	2.000
Max. Nominal	0.100
Min. Nominal	-0.100
Min. Critical	-2.000

Table 3. Parameters for deviation check.

A detailed report was made and different annotations were plotted to get deviation at the desired point. Following table gives detailed deviation distribution of the 497784 data points of the scan model. The deviation range used is +/- 2 mm with an increment of +/- 0.1 mm.

>=Min	<Max	# Points	%
-2.000	-1.620	1280	0.257
-1.620	-1.240	1547	0.311
-1.240	-0.860	6491	1.304
-0.860	-0.480	18853	3.787
-0.480	-0.100	90910	18.263
-0.100	0.100	218803	43.955
0.100	0.480	112407	22.581
0.480	0.860	24118	4.845
0.860	1.240	8484	1.704
1.240	1.620	2968	0.596
1.620	2.000	2072	0.416

Table 4. Deviation distribution for pump casing

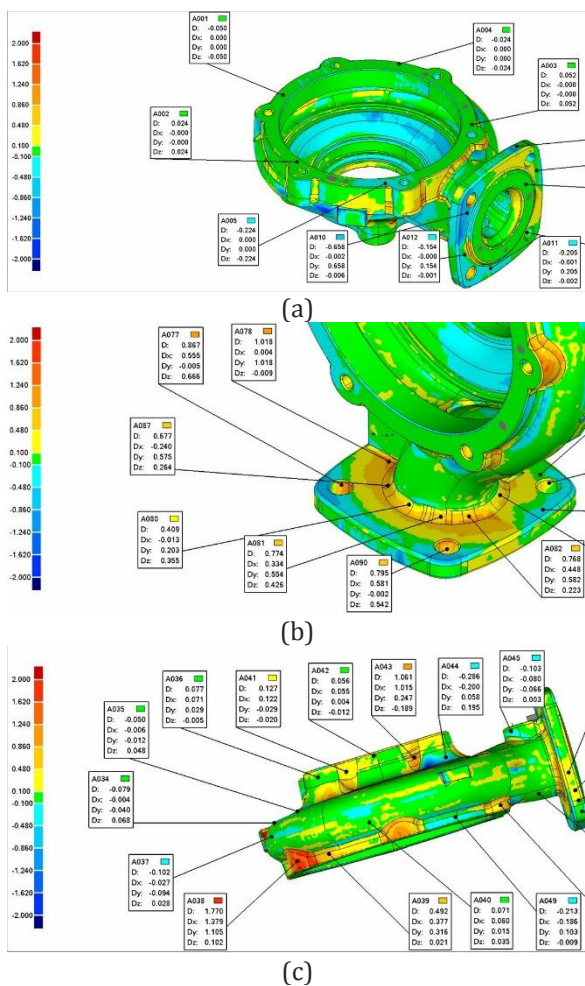


Figure 16 (a). Deviation Annotation 1  
 (b). Deviation Annotation 2  
 (c). Deviation Annotation 3

The deviation distribution says that around 93% of the point cloud lies in the range of +/- 0.86 mm. The maximum geometric features have been captured within 1 mm range, but due to some defects some points lie beyond the specified range. Hence deviation distribution range is from +/- 2 mm. The general practice for using range for casted components is +/- 2 mm.

### 4 Conclusion

Reverse Engineering is an important tool for CAD models. Recent commercial availability of Non-contact systems with high accuracy and precision and availability of commercial CAD packages has led to exploration of RE in various fields with drastic reduction in time and quality for Reverse Engineering.

The impeller geometry was successfully extracted using traditional approach, but in case of vane geometry nontraditional approach was used. Combination of wireframe and traditional approach was used for pump casing geometry extraction, later manual surface patching was used for creating quality surface patches. There may

be other methods employed for Reverse Engineering but manual surface patching for volute profile from wireframe model leads to better surface continuity and ensures smoothness between different surface patches.

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[22] Geomagic Qualify free trial for 15 days

## BIOGRAPHIES



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