REVERSE ENGINEERING METHOD USED FOR INSPECTION OF STIRRER´S GEARBOX CABINET PROTOTYPE

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Reverse engineering is a technology that enables acceleration of data acquisition for CAD, CAM, CAE systems and thus greatly reduces the time of development, design and production of components. In general, reverse engineering technology can be considered as the conversion of analog data to digital data, which is further processed. Individual industries are still increasing their demands for accuracy, size, quality, and so, therefore the use of digitization is found in many manufacturing areas such as the automotive, aerospace, shipping, medicine, industrial design, design, and so on. The paper deals with the analysis of the prototype component of the agitator gearbox in the form of a rough and chip-machined casting. The inspection of the shape of the gearbox consisted in reading the reference CAD model, establishing the digitized shape with respect to this reference model, checking the dimensions and creating a color map of the variations at selected points.

KEYWORDS

gearbox, part inspection, 3D scanner, reverse engineering, digitization

1 INTRODUCTION

Reverse engineering technology is one of the promising emerging areas of contemporary engineering. Reverse engineering is characterized by the opposite sequence of activities towards the classical production process. In the classical process, the designer builds on the basis of proposals a design of virtual CAD model of some component, which becomes a model for the production of a physical part. In reverse engineering, initially, a physical object is converted to model data by the digitization, with which the designer can work further with the available CAx data processing applications [Navratil 2000] [Piska 2009].

Reverse engineering technology allows you to measure data or check the component in a relatively short time compared to conventional measurement techniques. The time required to measure a complex component is shortened from weeks to hours, up to a maximum of days. With the increasing complexity of the product, the application of this technology is more advantageous [Navratil 2000] [Piska 2009].

2 ATOS SYSTEMS

ATOS systems are widely used for the most demanding digitization applications. Specific design based on two CCD cameras and light projection principle allows you to calculate digitized data using a stereo method. Combined with the reference point method used to automatically link individual views, the stereo method creates very high quality data. With this technology, ATOS takes the lead in quality control applications and demanding industrial digitization. The ATOS scanner can easily be adapted to different measurement sizes, with easy calibration and easy calibration of the system based on supplied calibration elements [Navratil 2000] [Piska 2009].

The resulting data set of measurements is very high quality STL file, the 3D coordinates of points, cross-sections, contour lines or output quality protocols. ATOS software allows you to evaluate and compare measured data files with default CAD geometry or a scanned reference piece and perform extensive analyzes of measured data [Navratil 2000] [Piska 2009].

2.1 Digitization

Digitization is a digital image acquisition process where the continuous image function f (x, y) is replaced by the corresponding discrete function I (x, y). Digitization takes place in two steps [Navratil 2000] [Piska 2009] [Sedlak 2008a]:

- quantization,
- sampling.

Each conversion of a continuous function to a discrete one is necessarily associated with the occurrence of an error, which is caused by the loss of part of the information of the original continuous function. By appropriately setting the digitization parameters, e.g. sampling frequency or quantisation interval, these errors should be minimized so as not to negate the information contained in the digital image. Digitization is done using digitizers (scanners). These devices can work on different principles that predict the way digitization is done. The choice of the digitization method or the reverse engineering method is affected by the following factors [Sedlak 2008b] [Zouhar 2007]:

- preparing the prototype of the upper / lower gearbox of the stirrer,
- the acquisition of individual scans,
- the connection and polygonization of each scan,
- adjustment of the protrusion of the upper / lower gearbox of the agitator.

An ATOS Compact Scan 2M Optical Scanner from GOM GmbH was used to digitize the stirrer gearbox and obtain nodal points. The device is located at the complex graphic workplace of the Faculty of Mechanical Engineering, BUT. ATOS Compact Scan 2M is an ATOS-based, blue-light projection technology with two digital cameras each with a resolution of 2 million pixels. Very simply, the scanner projects light stripes on the surface of the model, which are captured by two 1623 x 1236 pixel CCD cameras. Subsequently, using the mathematical methods, it is automatically calculated the location of the points in the space. Based on the identification of individual points by both cameras and using the principle of optical triangulation, the spatial coordinates of the given points are calculated. For scanning, self-adhesive reference points with a diameter of 3 mm are used. New projection technology with an integrated light control unit - The blue LED used by ATOS is resistant to changing ambient lighting. The accuracy of the scanner is determined by using VDI standards according to VDI 2634 for optical systems [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Sedlak 2008b] [Zouhar 2007].

2.1.1 Triangulation

Triangulation is a frequent method of digitizing objects. Fig. 1 shows the principle of triangulation. The source sends a laser beam to the object to be measured. The camera captures the reflection of the ray from the object surface. The source and the camera make an angle α and are separated by a value b.

The source, the camera lens, and the point of the incident ray together form a triangle. The distance from the object is calculated according to the relationship (1) [Raja 2008] [Sedlak 2007] [Sedlak 2003] [Stylianou 2010] [Weber 2010].

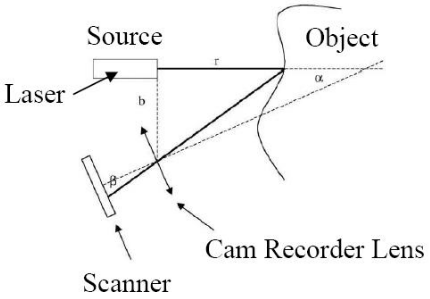

Figure 1. Principle of triangulation [Pieraccini 2001]

Distance from the object [Pieraccini 2001]:

$$r = b \cdot \tan^{-1} \cdot (\alpha + \beta) \quad \text{[mm]} \qquad (1)$$

Where:

α - the angle between the source and the camera [°],

β - the angle between the camera and the sensor [°],

r - distance from object [mm],

b - source and camera distance [mm].

2.1.2 Methods based on stereovision

Methods based on stereovision use the principle of stereoscopy, which is to capture the image by two cameras, see Fig. 2. Individual cameras create a 2D image of a given scene from a different point of view. The resulting geometry is obtained from the mutual orientation of the cameras and the different positions of the points recorded by the right and left camera (disparit). The main problem of stereo vision is the poor correspondence of the matching points in pictures with a slight texture or edges. The correspondence problem causes inaccurate measurements, and therefore stereovision is often used in combination with various active methods. Stereovision has many applications, especially in the areas of advanced technologies [Zatocilova 2013] [3D Measurement MAPV 2009].

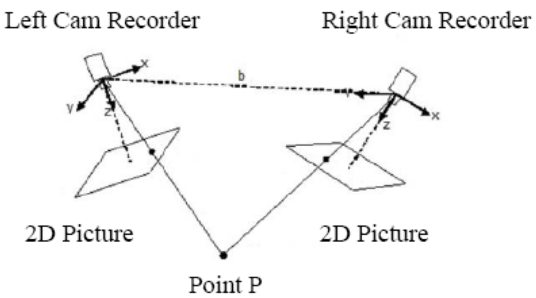

Figure 2. Typical stereovision system [3D Imaging with NI LabVIEW 2012]

2.1.3 Fringe Projection Method

As shown in Fig. 3, light stripes are projected onto the scanning surface. Upon impact on a surface that is not flat, the strips are deformed. The resulting image is scanned by one or two cameras and using the algorithm the system calculates the coordinates of the individual points in the space. Advantage of the method is a large number of measured points from one frame [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Zatocilova 2013].

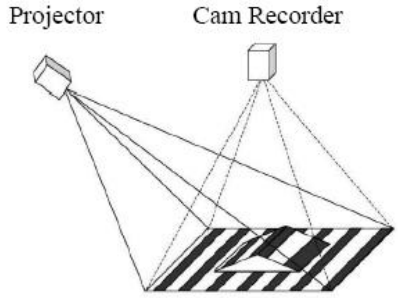

Figure 3. Principle of the Fringe Projection Method [Pieraccini 2001]

3 DIGITALIZATION OF THE MIXER GEARBOX PROTOTYPE

The digitization of the mixer gearbox prototype took place in several steps. The first step was the preparation of the prototype, which included the placement of the reference points and the surface treatment. To connect the individual scans taken from different angles of view, it was necessary to use appropriately positioned reference points. These points were automatically recognized and their location in the space was recorded for each scan. The exact spatial position of the individual scans is evaluated using these points. In each new scan, it was necessary to capture at least three points from the previous scan [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Sedlak 2008b] [Zouhar 2007].

When making individual scanning it was possible to move both the model and the scanner. After focusing the scanner on the desired area, the object is illuminated, thus initiating the digitization process to be reached [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Sedlak 2008b] [Zouhar 2007]:

- capturing reference points,
- projection of light stripes.

Subsequently, the positioning and display of scanned points are calculated. After capturing the entire surface, the next step was to align each scan. Alignments were smoothed or scanned with large deviations. The sequential step was polygonization, where the scanned points were approximated by a triangular network. The size and density of the resulting network can be controlled by user-adjustable parameters. The polygon network requires further adjustments, such as adherence of holes to reference points, smoothing and optimization (triangle reduction). The final step was to export the model to the STL format (most common format) [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Sedlak 2008b] [Zouhar 2007].

3.1 Quality of digitized data and CAD compatibility

The quality of the resulting polygonal network is very important for further processing in reverse engineering, rapid prototype production, and for inspection analysis. Outputs from the ATOS scanner have long been recognized in the 3D digitization market due to the quality of the data the scanner generates. The powerful tools for calculating the polygon data network are further optimized as well as the polygon network editing functions [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Sedlak 2008b] [Zouhar 2007].

4 INSPECTION OF MIXER GEARBOX CASTING

The casting inspection was performed using the ATOS Compact Scan 2M Non-contact Optical Scanner. The analyzed prototype component was the agitator gear box in the form of a rough (not machined) and chip-machined casting. The inspection of the shape of the gearbox consisted of loading a reference CAD model, establishing a digitized shape with respect to this reference CAD model, checking the dimensions and creating a color map of the variations at selected points. The default data for shape inspection was the polygon mesh of the agitator gearbox shown in Fig. 4 [FRVS 2013] [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Shape Inspection of Component].

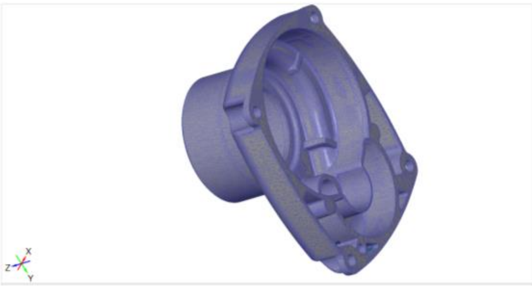

Figure 4. General view of the formed polygon network [GOM GmgH]

4.1 *Inspection of component shape - comparison of the digitized and reference CAD model*

The tools for measuring and comparing variations of the digitized part of the component and the reference CAD model were available in the GOM Inspect program. The contextual icon menu, see Fig. 5, offers the alignment of the scan and the reference model, the comparison of the surface shape, the point inspection, the inspection with cuts and the I-inspect function, such as measuring distances, deviations and geometric tolerances etc. It was necessary to import CAD data and set them on a polygon network [FRVS 2013] [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Shape Inspection of Component].

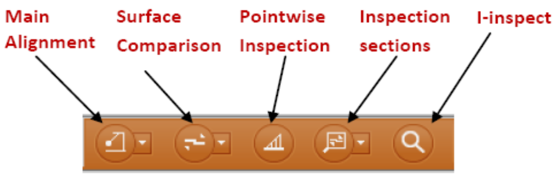

Figure 5. Tools of the Inspection Icon Menu [GOM GmgH]

4.2 *Import of the reference CAD model*

The import of the reference CAD model was done using the "File -> Import" menu. For common purposes, it is not necessary to change the import parameters. In the element tree, there is a "Nominal elements" section with a reference CAD model. The digitized and reference CAD models are still using their coordinate systems and are not aligned with each other, see Fig. 6 [FRVS 2013] [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Shape Inspection of Component].

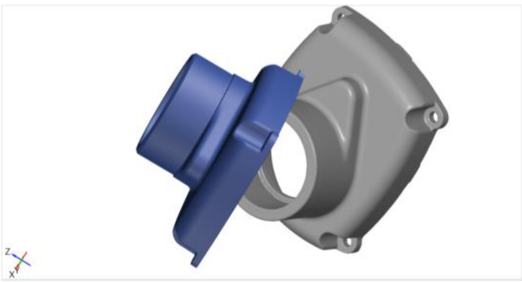

Figure 6. Digitized model and reference CAD model - unassigned [GOM GmgH]

4.3 *Pre-set of the reference CAD and digitized model of the mixer cabinet - Initial Alignment*

To set a reference CAD model to polygon data, use the tools found in the main menu. The first step should always be a pre-set up. The easiest way is automatic preloading using the "Prealignment: Operations -> Alignment -> Initial Alignment -> Prealignment" tool, see Fig. 7. If both models do not resist after confirmation, you need to increase "Search time" [FRVS 2013] [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Shape Inspection of Component].

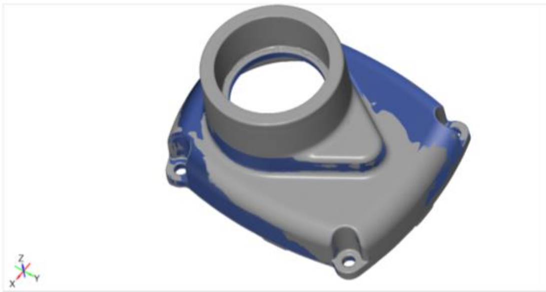

Figure 7. Pre-set of the reference CAD and digitized model [GOM GmgH]

4.4 *Inspection of the diameter of the mounted cylindrical part of the mixer housing casting*

To control the casting diameter of the mixer casting, a cylindrical surface was formed on the digitized network. On the digitized network when the reference CAD model was off, a cylindrical surface was selected. To select the surface of the diameter, the "Edit -> Selection in 3D -> Geometry Based Selections -> Select Cylinder Based" menu option was used, as shown in Fig. 8. A cylindrical surface was created using the "Construct -> Cylinder - > Auto Cylinder (Nominal)", see Fig. 9 [FRVS 2013] [Shape Inspection of Component]. As a result of the cylindrical surface, it was deduced that its radius was 28.498 mm. In the same way, the radius on the mounted cylindrical part, which is 28.500 mm, can be subtracted from the referenced CAD model (when the digitized model is turned off), resulting in a deviation of the actual diameter on the mounted cylindrical parts of the mixer (28.498 – 28.500) x 2 = -0.004 mm [FRVS 2013] [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Shape Inspection of Component].

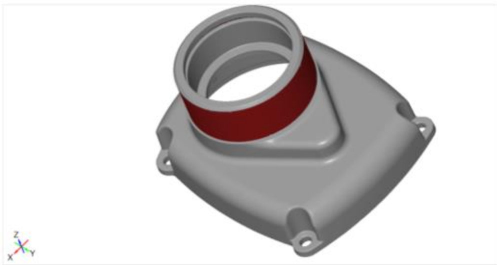

Figure 8. Selection of surface mounted diameter of the mixer casting - digitized net [GOM GmgH]

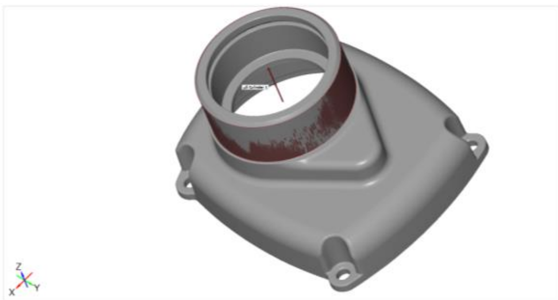

Figure 9. Creating a cylindrical surface on the surface of the mixer casting diameter [GOM GmgH]

4.5 *Final set-up of the reference CAD and digitized mixer housing model – Alignment*

The "Local Best-Fit" method, which searches for the best match between CAD and the digitized model on selected (local) mutually matching surfaces, was applied for the final set-up. In this case, the machined surfaces of the resulting components had to be used, since the casting surface without machining could be expected to have a significantly greater variation. The "Edit -> Selection in 3D -> Geometry Based Selections" menu could be used to select the machined surfaces. In this way, the face plane of the surface of the cast plunger diameter (Select Plane-Based) and the outer surface of the cast die diameter (Select Cylinder-Based) has been selected, see Fig. 10. The final setting was done using Local Best-Fit, see Fig. 11 [FRVS 2013] [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Shape Inspection of Component].

Figure 10. Selecting surfaces for mutual alignment [GOM GmgH]

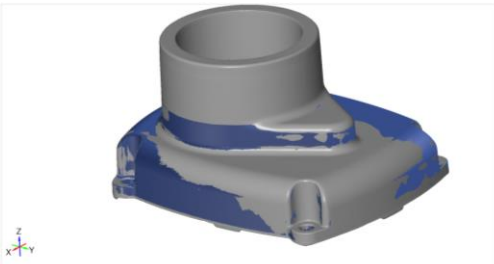

Figure 11. Mutual setting using the "Local Best-Fit" function [GOM GmgH]

4.6 Display of true shape deviations

Viewing deviations of the digitized shape was performed by the Inspection -> CAD Comparison -> Surface Comparison on CAD. The range of the color legend can be selected as required but always with respect to the desired part [FRVS 2013] [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Shape Inspection of Component].

4.6.1 Color map of deviations

For the software comparison of the shapes of the two model parts, the reference CAD model and the part model, or the element on the model with the ideal geometric element, the so-called color maps are used, see Fig. 12. The individual compared components were first precisely set in the same coordinate system and then overlapped. Instead of setting in the coordinate system, the so-called "Best-Fit" function was used, which based on the mathematical calculation establishes the components on top of each other so that the distance between the corresponding points on the surface of the individual components is minimal. In addition, according to the specified parameters, a texture has been generated on the surface of the overlapped parts, which has the following property - after the set steps, a certain color or shade is assigned to a certain distance between the measured points on the surface. For example, if the red color means the distance between the surfaces larger than the holiday, it is possible to see the red color on the surface of the overlaid parts wherever this distance is exceeded. In order for the result to have sufficient information, one of the measured elements should be determined as a reference, which is one that the system will consider ideal and the distance to measure [FRVS 2013] [GOM GmgH] [MCAE SYSTEMS, s.r.o.] [Shape Inspection of Component].

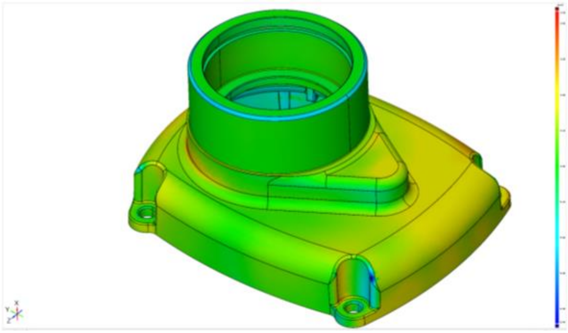

Figure 12. Colored map of deviations [GOM GmgH]

5 DISCUSSION OF THE ACHIEVED RESULTS

Component Inspection: "**Reference CAD Model**" vs. "**Chip machined selected cast surfaces - upper / lower half of digitized mixer gearbox**":

- Displaying the resulting deviations at the selected points, see Fig. 13 and Fig. 14.

The reference model for the upper / lower half of the mixer gearbox is the parametric model supplied by the company ("**Reference CAD model**") against which the digitized upper / lower half of the mixer gearbox ("**Machined selected casting surfaces - upper / lower half of the digitized mixer gearbox**"), see Fig. 13 and Fig. 14 [Sedlak 2016].

Results obtained by inspection of the upper / lower chip machined half of the mixer gearbox [Sedlak 2016]**:**

- The ATOS Compact Scan 2M optical scanner only captured the surface of the prototype upper / lower of the mixer gearbox.
- No proportional asymmetry (scattering of values) was detected at the prototype upper / lower of the mixer gearbox during the inspection, which would affect the manufacturing inaccuracy of the casting or chip machining of the required functional surfaces.
- A chalk powder with a thickness of about 0.05 mm was sputtered on the surface of the toothed wheel prototype. The chalk powder has been applied uniformly to the surface, but it is not excluded that an unsymmetrical deposit could occur which would affect the magnitude of the dimensional variations at the selected points.
- For the digitization of the prototype upper / lower of the mixer gearbox using the ATOS Compact Scan 2M optical scanner, a measuring range of 250 x 190 x 190 mm^3 was used, which, due to the size of the prototypes of castings (capture of all details).
- None anomalies were detected on the digitized prototype of the upper / lower of the mixer gearbox, which would affect their production process.

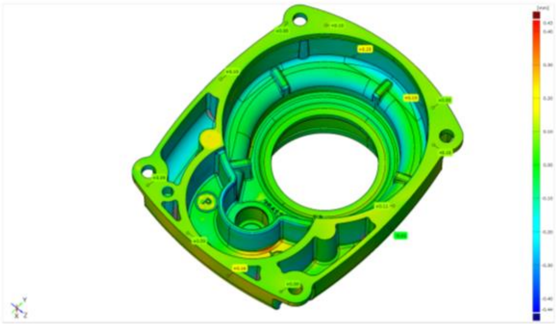

Figure 13. Mutual alignment of the reference CAD prototype and the digitized STL model of the upper half of the mixer gearbox (chip machined selected casting surfaces) [GOM GmgH]

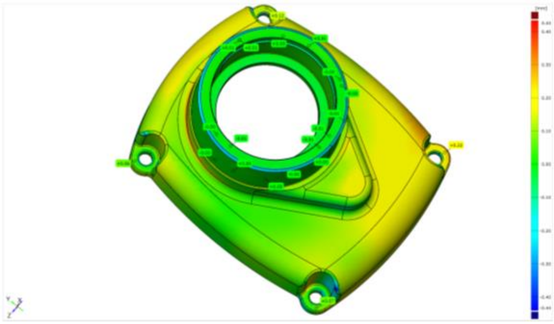

Figure 14. Mutual alignment of the reference CAD prototype and the digitized STL model of the lower half of the mixer gearbox (chip-machined selected casting surfaces) [GOM GmgH]

Analogous results were also obtained for [Sedlak 2016]:

- Gross cast - "**Reference CAD model**" vs. "**Upper half of the digitized mixer gearbox**", see Fig. 15.
- Gross cast - "**Reference CAD model**" vs. "**Lower half of the digitized mixer gearbox**", see Fig. 16.

The difference to the machined surface of the required functional areas was only in the machining accessories. No deformations were found on both agitator gearbox castings, which would affect the production process (machining, assembly, noise, sprocket life, total manufacturing inaccuracy).

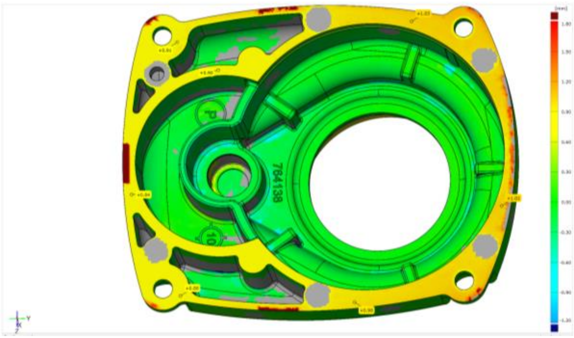

Figure 15. Mutual alignment of the reference CAD prototype and the digitized STL model of the upper half of the mixer gearbox (rough casting) [GOM GmgH]

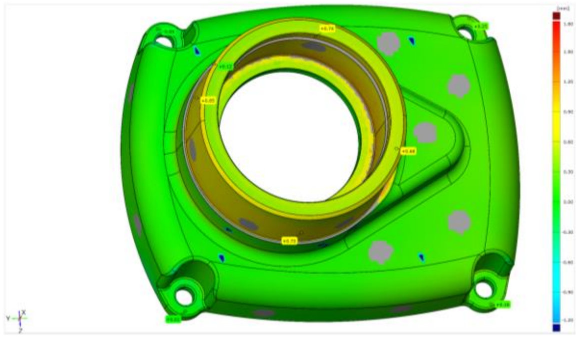

Figure 16. Mutual alignment of the reference CAD prototype and the digitized STL model of the lower half of the mixer gearbox (rough casting) [GOM GmgH]

6 CONCLUSIONS

The use of reverse engineering methods is a useful tool for retrofitting and creating missing 3D documentation. With enough information, it is appropriate to combine the data obtained by digitizing with the "ideal" 3D model created on the basis of 2D documentation.

Based on actual object scanning, a number of measurements can also be performed using appropriate programs. In practice, these measurements would be either very difficult to implement or would not be feasible at all.

The aim of the paper was to analyze the prototype upper / lower case of mixer gearbox in the form of rough and chip-machined castings (selected functional surfaces). The inspections found that the measured deviations of the dimensions at the selected points (see the legend of the color display of the map of deviations) relative to the upper / lower half of the mixer gearbox reference CAD correspond to the tolerance on the drawing documentation, the accuracy of the equipment used, the part preparation before digitization Chalk powder) and human factor.

ATOS scanners are highly accurate devices with high measurement reliability. The scanner continuously monitors the situation before, during and after measurement. The monitoring monitors the relative movement of the scanner - the measured object, the change of ambient light, and the calibration of the scanner is checked at each measurement. The new Blue Light projection technology used by the scanner is resistant to changing ambient lighting. The accuracy of the scanner is determined using VDI standards according to VDI 2634 for optical systems.

3D scanners are suitable for components of more complex shapes with general surfaces. From the digitized data, you can obtain information about the component dimensions, the geometric deviations of the whole component and the variations in the individual points.

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