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Reverse engineering of a toothed gear

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Abstract. *With the rapid development of modern industry, the need for spare parts has increased. Most mechanical systems have transmission components which are composed of toothed gears. In most cases, the manufacturer of the spare part does not exist on the market and the need to reproduce the failed part needs to be met. Usually, toothed gears are obtained using special cutting machines, like Gleason, Lees-Bradner, and Pfauter. To be able to reproduce the part by using a common manufacturing process, the current paper presents a RE method for obtaining the 3D geometry of a toothed gear in the scope of machining the part using a CNC 3-axis mill. CAD software and 3D scanning technology is used to recreate the gear's 3D model and ensure accurate dimensions for the gear teeth, including tooth spacing, depth, and angle.*

Keywords: *reverse engineering, computer aided design, toothed gear insert, 3D scanning, point clouds*

1. Introduction

The current paper aims to showcase the generation of the 3D model of a toothed gear, by applying Reverse Engineering methods, like 3D scanning technology. Reverse engineering is the process of analyzing a physical object to identify and understand the relationship between its functioning principles and components, in order to reproduce the object in another form or of superior quality. It can also be described as the process of duplicating an existing component by capturing the physical dimensions of its parts. The main purpose of this method is to create models as precise as possible of an object that reflect its basic geometry through scanning. [1]

Other research has concluded that through reverse engineering, it is possible to reconstruct the tooth profile using point clouds obtained through a non-contact methodology. The basic settings of the reconstructed gear machines were estimated based on derived data from the original gear and were compared with those of a specific model. The results indicate that most of the basic settings of the gear machine are well estimated, although precise estimation of the root cone angle is necessary for an accurate determination of the base pitch and machine root angle settings. [2]

In other research such as [3], an attempt was made to create a gearbox with a parallel shaft and two speeds. They succeeded with reverse engineering to reach the conclusion that they could scan and generate a model of this already used unit. After finding out the necessary data for operation, they calculated the ideal model for a new unit and rebuilt the assembly. And the paper [4] also describes the scanning of a gear wheel with the help of Artec space spider & Geomagic Design X software.

As a brief historical overview, gears are one of the ancient tools, having first appeared as early as the 27th century BCE in China. Aristotle provided the earliest description of gears in the 4th century BCE, noting that the direction of rotation is reversed when one toothed wheel drives another toothed wheel.

Straight gears, as in this work, have teeth parallel to the axis of rotation; they are used to transmit rotation between parallel shafts. Compared to other types, straight gears are the simplest. [5]

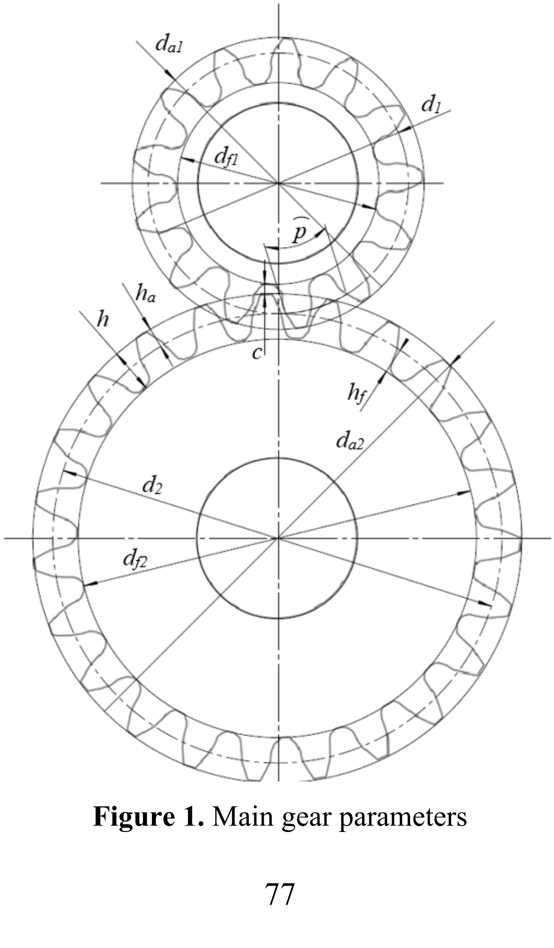

Figure 1. Main gear parameters

2. Materials and methods

The gear we aim to reverse engineer using 3D scanning technology is part of a classical mill's gearbox, a component vital for the machinery's operation. Over time, due to wear and tear or other factors, some of its teeth have become damaged or broken, impairing its functionality, as seen in Figure 2.

Figure 2. The damaged part

By employing 3D scanning technology, we intend to capture the precise geometry of the intact portions of the gear, as well as the damaged areas. Through this method, we can accurately map out the contours and dimensions of the gear, including the intact teeth and the areas where damage has occurred.

Once the 3D scan is completed, we can utilize reverse engineering techniques to analyze the scanned data and reconstruct the original design of the gear. This involves identifying the parameters and specifications of the gear, such as tooth profile, pitch diameter, and helix angle. With this information, we can create a virtual model of the gear, incorporating the necessary adjustments to compensate for the damaged or missing teeth.

The goal of this reverse engineering process is to produce a functional replacement gear that seamlessly integrates with the existing gearbox.

First, we have defined the main parameters of the gear, through measurement. The essential component elements of gears are module (1), pitch (2), number of teeth (3), clearance (4), pitch diameter (5), addendum (6), dedendum (7), total depth (8) as follows:

$$m = \frac{(d_2 - 2)}{z} = \frac{(86 - 2)}{42} = 2 \tag{1}$$

$$p = \pi \cdot m = \pi \cdot 2 = 6.28\,\text{mm} \tag{2}$$

$$N = \frac{d_0 - 2 \cdot m}{m} = \frac{88 - 2 \cdot 2}{2} = 42 \tag{3}$$

$$c = 0.1 \cdot m = 0.1 \cdot 2 = 0.2\,\text{mm} \tag{4}$$

$$d = m \cdot N = 2 \cdot 42 = 84\,\text{mm} \tag{5}$$

$$h_a = m = 2\,\text{mm} \tag{6}$$

$$h_d = m + c = 2 + 0.2 = 2.2\,\text{mm} \tag{7}$$

$$h = 2 \cdot m + c = 2 \cdot 2 + 0.2 = 4.2\,\text{mm} \tag{8}$$

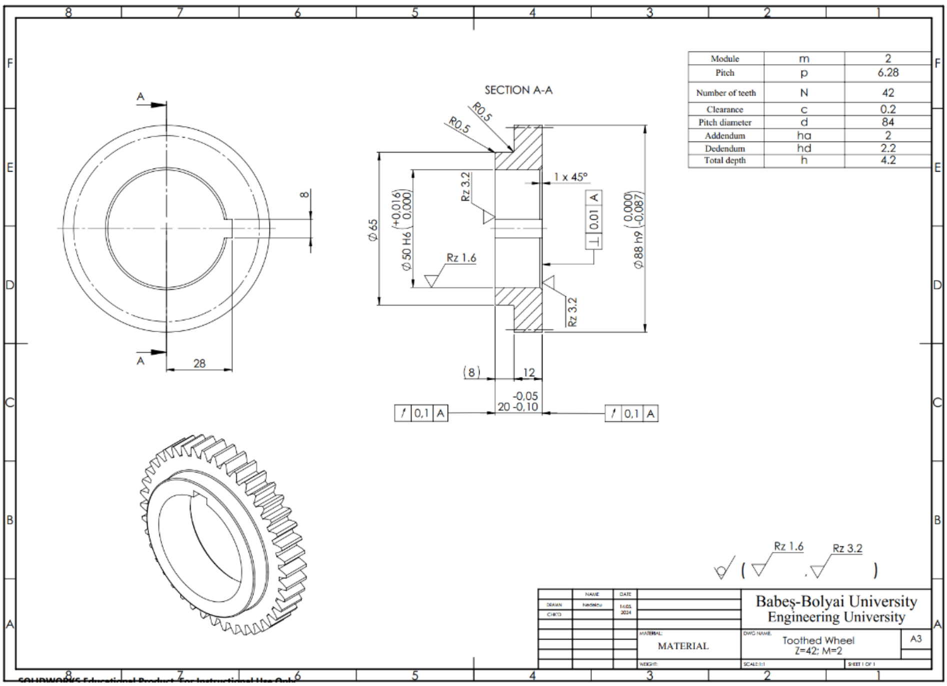

Figure 3. Execution drawing

2.1. The 3D scanning of the toothed gear

The equipment utilized comprises a POP 3D Scanner, a rotary table, and the necessary computer. The POP handheld 3D scanner integrates a proprietary 3D camera module and embedded chip to deliver precise and rapid 3D scans, designed to be compact and portable with multi-mode scanning capabilities suitable for product development, prototyping, 3D printing, and artistic creation. Utilizing Binocular Structured Light technology, the Revopoint POP 3D Scanner ensures high-accuracy 3D point cloud data acquisition with a single-frame precision of up to 0.15mm. Equipped with depth cameras including two IR sensors and a projector, it swiftly captures object shapes, while an RGB camera captures texture details. This device supports high-precision and texture scanning modes, facilitating the direct generation of vivid 3D models.

Figure 4. 3D scanner

The first stage consisted in positioning the component on a rotary table, it was tried to be as centered as possible and in a horizontal position. The 3D scanner was turned on and the rotary table too. The table rotated at 2.5 RPM during the entire operation. The scanner was fixed at a distance of about 40 centimeters. During the data were entered on a computer. For scanning, the color scanning module and the normal one were used.

3. Obtaining the 3D model from the scanned data

In the Geomagic design X software, I introduced the 3D scans that are initially brought as a cloud of points, the Mesh Buildup Wizard is used, from here there are several stages that consist of the selection of elements that are not aligned correctly and adjustments. After corrections, a model is made only as a surface. And the last stage is making a solid model according to the surface generated after processing.

Scanning can be done in different profiles, directions, angles and depths, and what is very important, in the end, a combination of scans can be performed in a unitary whole, of great resolution and finesse, being the most recommended application in the field reverse engineering.

The procedure for obtaining a 3D model from 3D scan data, as can be seen in Figure 4, consists of the actual object scan, division of the scanned model into regions, virtual extrusion of regions, superposition of surfaces on the network of scanned points, volume processing of surfaces and filling design with scanned parameters.

First the point cloud data of the gear is obtained by 3D color scanning or RGB-D scanning, which is a technique used to capture three-dimensional objects along with their color information.

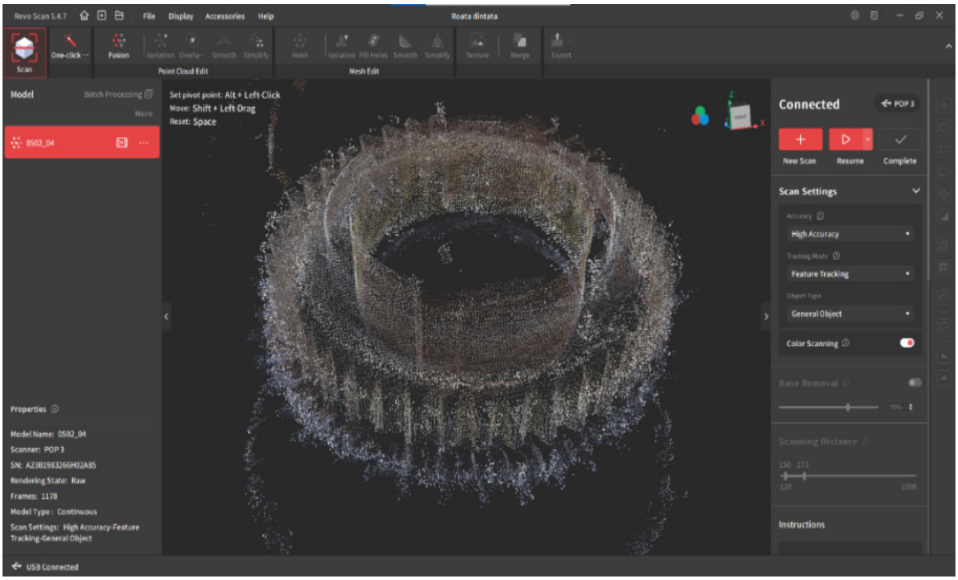

Figure 5. Point cloud data of the toothed gear using color scanning

A second set of point cloud data of the gear is obtained by normal 3D scanning, which is the process of collecting XYZ points in space to represent an existing physical object. It results in a cloud of points, a collection of data stored as a matrix of discrete coordinates, which define the shape and dimensions of the object. At this stage, a preliminary graphic description of the object on the computer is possible.

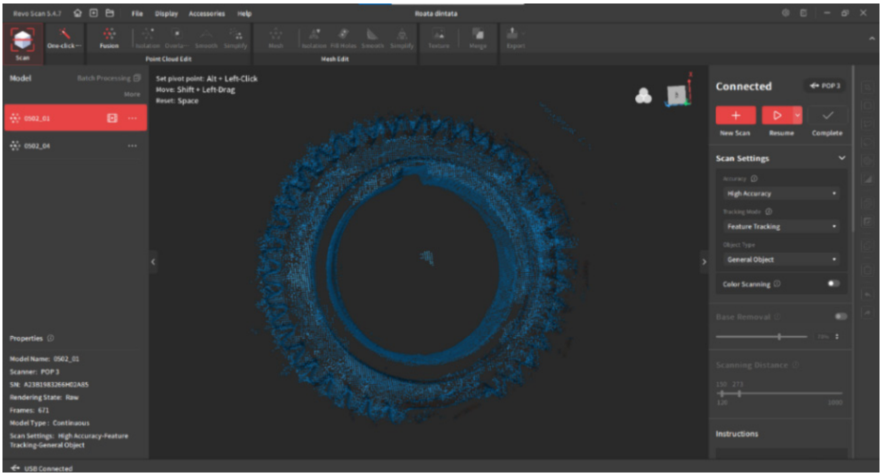

Figure 6. Point cloud data of the toothed gear without color scanning

The mesh buildup wizard in Geomagic Design X is employed for processing the scanned data. First, the two scans are opened, and the type of scanner is selected and afterwards the point cloud data is cleaned by deleting unnecessary data.

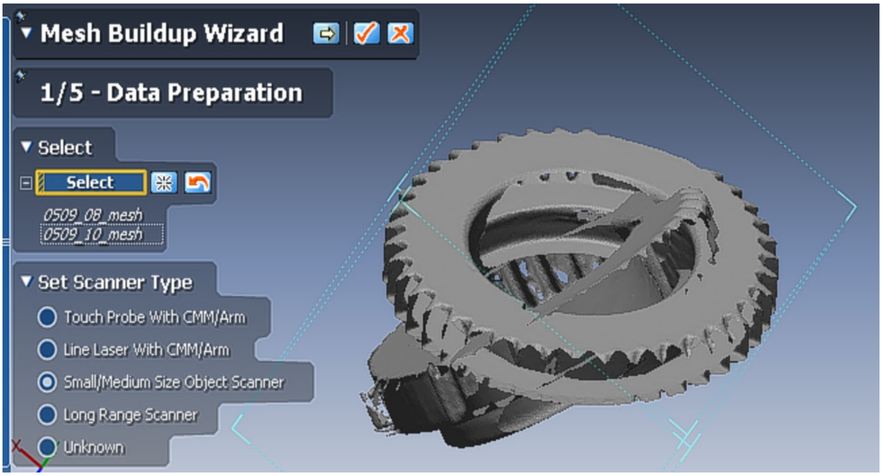

Figure 7. 3D scan data preparation

The scans are aligned by using the Best-Fit-Aligning method and data merging is applied.

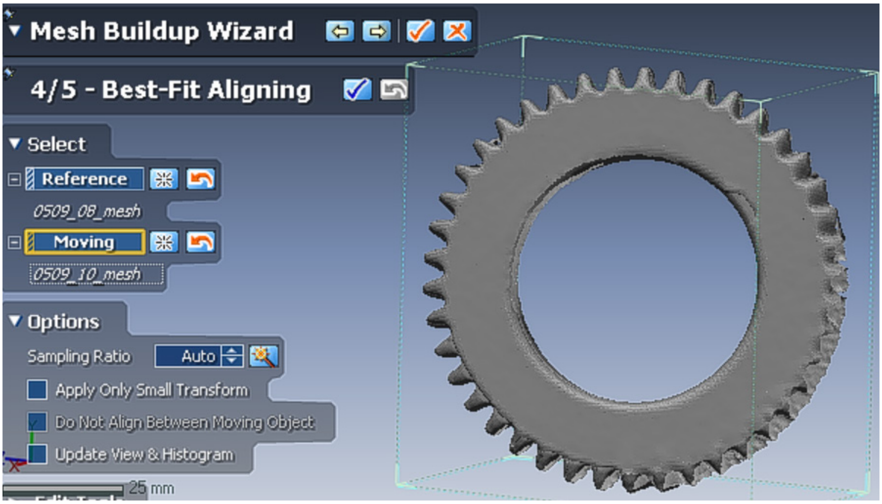

Figure 8. Aligned scans

After the volume processing is finished, Geomagic Design X Healing Wizard is used for reverse engineering and converting the 3D scan data into usable CAD models. The Healing Wizard is a tool designed to automate and simplify the process of fixing imperfections and errors in scanned data.

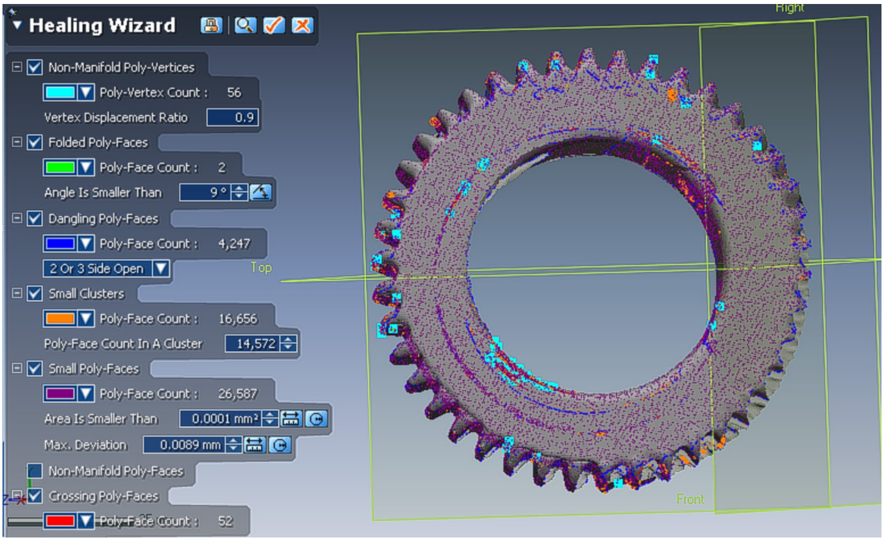

Figure 9. Healing wizard

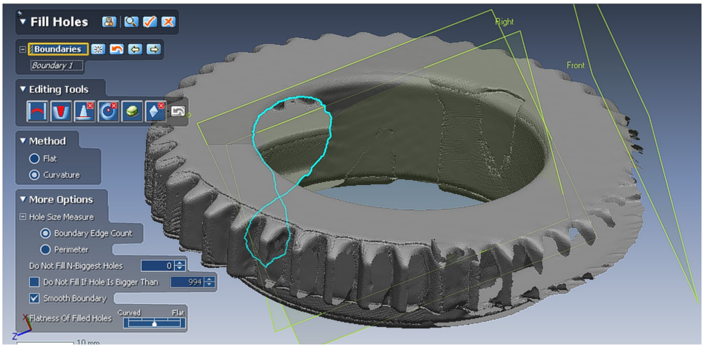

Figure 10. Creating the mesh file and filling the holes

The geometry of the part is reconstructed based on the obtained mesh file.

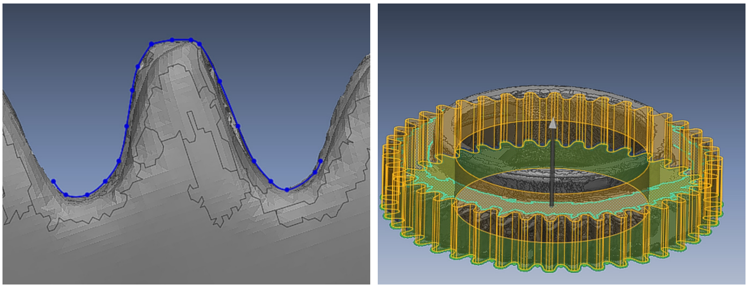

Figure 11. Reconstruction of the geometry

4. Determining the precision of the scanned model of the toothed gear

After the 3D model is generated from scanning and converted into a solid representation using the software Geomagic Design X, it undergoes a process of comparison with an ideal 3D component. This comparison involves assessing the accuracy and fidelity of the scanned model relative to a reference or ideal model.

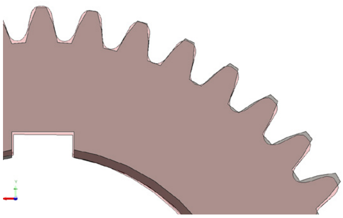

Figure 12. Comparison of the tooth profile

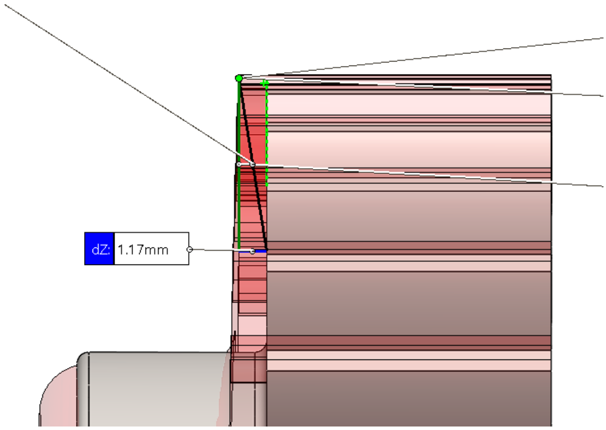

Figure 13. Maximum deviation

5. Conclusion

Despite the short processing time of just 20 minutes, our analysis reveals that the accuracy achieved in comparing the scanned model to the ideal component is exceptionally high. This underscores the efficiency and effectiveness of the scanning and processing methodologies employed. The rapid turnaround time, coupled with the attainment of precise results, not only demonstrates the advancements in technology but also highlights the feasibility of integrating 3D scanning into various applications where speed and accuracy are paramount. This success opens up avenues for expedited workflows and enhanced productivity across industries, promising substantial benefits in design, manufacturing, and quality control processes.

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