REVERSE ENGINEERING OF TRAM TRANSMISSION GEAR

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Abstract: *Components and sub-assemblies of machinery and equipment will wear out over time and leads to their destruction and hence production downtime. The easiest and fastest way to overcome this problem is to replace these elements with a new one. However, the problem arises when the desired element is not available on the market, the technical documentation is not available or the costs of obtaining a new item are too high. A good example of this situation is the industrial problem related to the halt in the spare parts caused by the closure due to the global spread of the Corona virus. To overcome these problems, reverse engineering can be used. The best solution is to replicate the desired part digitally. The purpose of this paper is to solve an industrial problem related to lack of spare parts such as tram transmission gear. The CAD model of this component is not available, but the finished part (physical part) is available for reverse engineering. The 3D scanning of the gear was carried out using a FARO LASER ARM (Non-contact scan) and the obtained point cloud was processed using CAM2 MEASURE 10, CATIA V5.R20 and MATLAB software for surface approximation and geometrical modeling of scanned part. The CAD model built and the digital version obtained could be used to continue the reconstruction process and also allows improvements to be made to the part without generating any additional cost.*

Keywords: *Reverse engineering; transmission gear; FARO Scan Arm; point cloud, surface approximation.*

1 INTRODUCTION

In recent years, the world has witnessed rapid technological development in various fields of life, especially in the industrial field, where the development and production period of new products has become very short, which forced the engineers to keep pace with this development.

One of the methods used by companies and engineers is the reverse engineering technique. Reverse engineering is the process of analyzing a product or system to understand how it was designed and how it works. This is often done by taking apart the product or system and examining its components, or by using software tools to analyze its code or behavior. The goal of reverse engineering is to gain insights into the product or system that can be used to improve it, replicate it, or create a new version of it. Reverse engineering is used in many fields, including engineering, software development, and manufacturing, and it can be applied to a wide range of products and systems, from mechanic and electronic devices to complex software applications [1].

In reverse engineering, CAD models are often unavailable or unusable for parts that need to be duplicated or modified. This is a particular problem for long-life cycle systems where spare parts stocks have run out and where the original supplier is unable or unwilling to supply custom build runs of parts spare parts at affordable prices and in a timely manner.

In previous works, Reverse engineering has been used to produce many mechanical parts, such as gaskets, O-rings, bolts and nuts, gaskets, and engine parts, and is widely used in many industries [2].

A comprehensive review of various issues related to reverse engineering technology, from data acquisition methods to procedures for converting discrete data into a continuous model, can be found in [3-6].

According to Germain [7], Reverse engineering, defined as the creation of models from exemplary objects, is increasingly prevalent in many industries, including manufacturing, automotive design and computer animation.

Xian et al [8] reported that reverse engineering is a systematic analysis method that involves analyzing three-dimensional objects, analyzing the spatial profile, and improving the performance and competitiveness of existing products. Broadly speaking, reverse engineering is a series of four independent steps, each step building on the findings of the previous step preceded by a screening process. The whole process progresses linearly with time [9]. Since the reverse engineering process can be time consuming and expensive, reverse engineers generally considers whether the financial risk of such an endeavor is preferable to purchasing or licensing the information from the original manufacturer, if possible [10].

Popa et al. [11] proposed two algorithms - one for the polyhedral expression of a helical surface determined by reverse engineering methods, and another for determining the specific enveloping condition when this surface comes in contact with a discrete surface. The authors then presented an example of the application of these algorithms to a compressor rotor that was measured using a 3D measuring machine.

For example, when a new machine comes to market, competing manufacturers may buy one machine and disassemble it to learn how it was built and how it works [12]. The objective of reverse engineering is to be able to carry out a future modification or expansion of a system as inexpensively as possible by obtaining design and definition documents. Reverse engineering is therefore half the chain of an overall measure that is called reengineering. This process is not limited to looking at data structures [13].

A reverse engineering technique was used to extract the 40% cross-section thickness of the long-eared owl's airfoil and apply its arc to the blade design [14]. Reverse engineering of solid shape concerns the problem of taking point data scanned from the surface of a geometric object, for example a mechanical component and producing a CAD model representing that object [15].

Based on a large-scale survey of literature, Geng & Bidanda [16], concluded that RE needs can be categorized as follows: Design of new product, modification of existing products, loss of product design data and verify the product.

Wang et al. [17] proposed a method for the reconstruction of 3D models. The method makes it possible to reconstruct a geometric model from the mesh of the object. It consists of four main steps:

- First, the input mesh must be processed to eliminate noise.
- Second, the mesh is segmented in order to obtain individual geometric entities.
- Then, two methods are integrated: method based on solid entities and method based on surface entities, in order to reconstruct the primitive entities from the geometric entities segmented in the previous step.
- Finally, modeling operations such as surface cutting operations are performed to assemble the primitive entities in order to obtain the final model.

In fact, reverse engineering needs a methodology in order to manage manufacturing knowledge during the RE process and to guide the user. The interest of such a methodology would be to allow the development of a manufacturing-oriented CAD including the different stages of a Pre-Project Manufacturing Study. In our view, the DFM (Design For Manufacturing) concepts will serve as a reference base for the realization of the knowledge acquisition stage of the REFM methodology.

Design for Manufacturing is the practice of designing products with manufacturing in mind. The DFM activity makes it possible to optimize the manufacture, quality, reliability, cost and production time of a product [18, 19]. Implementing the DFM approach requires the collaboration of design and manufacturing within an industry. In other words, DFM concerns a designer who is in charge of refining, from a manufacturing point of view, the definition of a mechanical part [20].

Recently, reverse engineering has various fields of application but to create an old artifact, it might be the only technique available. It can also be used to replicate the gear or create a modified version of it. This is often done when replacement parts are needed for an older or discontinued transmission system, or when a custom gear is required for a specific application.

Overall, reverse engineering of transmission gears is an important process for improving the performance, reliability, and longevity of transmission systems in a wide range of industries. The objective of this work is therefore to solve an industrial problem related to lack of spare parts such as tram transmission gear by designing and producing this part based on an original or physical model (physical part) without the use of an engineering drawing. The CAD model of this component is not available, but the finished part (physical part) is available for reverse engineering.

2 MATERIALS AND METHOD

In order to transform a physical object into a digital model, reverse engineering is widely applied. Engineers often use this method to piece together all of the technical documentation, build a replica, rebuild a damaged item, or recompile a production process. The tools mainly used in reverse engineering could be three-dimensional scanners or traditional measurement methods using a caliper, altimeter, measuring machine, etc.

Reverse engineering of a transmission gear involves analyzing the gear's design and construction to understand its function and how it interacts with other gears in the transmission system. This can be done by taking precise measurements of the gear's dimensions, tooth profile, and surface finish, and using this information to create a 3D model of the gear.

The 3D model can then be used to simulate the gear's performance under different operating conditions, such as varying speeds and loads.

In this section, a tram transmission gear is considered for reverse engineering. During motion and power transfer, this gear has worn out over time due to friction. This leads to a short life cycle, and requires periodic changing of the part. The CAD model of this component was not available, but the finished part was available for reverse engineering (Fig.1).

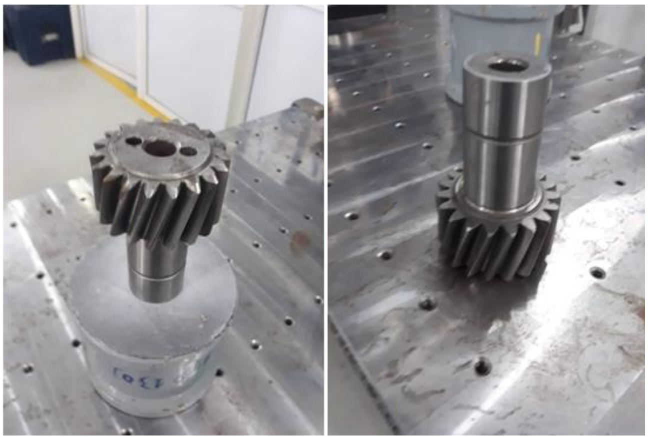


Fig 1. Tram transmission gear

The FARO Laser Scanner (Fig. 2) is a portable, non-contact measurement system that accurately captures 3D data. The system rotates 360° and measures everything in its line of sight at an acquisition speed of up to 976,000 points/s.

Fig 2. FARO Laser Scanner

The FARO gage is a high-precision 3D measuring machine (Fig.2) with a working volume of 1.20 m and measurement repeatability of 0.018 mm. Different fixing options allow rapid implementation directly on a workstation or in the production workshop. The gage is equipped with Bluetooth® wireless technology. Users can inspect and transmit data up to 10 m away, even through walls, and without cables.

The FARO Design ScanArm is a portable 3D scanning solution specifically designed for 3D modeling, reverse engineering and CAD-based design applications for the entire product lifecycle management process.

The Design ScanArm was the perfect solution to scan our part and for any similar tasks. A FARO CAM2 Measure 10 software is used in connection with the ScanArm (Fig. 4). The software is ideal for CAD and non-CAD inspection and geometric dimensioning and tolerance.

Fig 4. CAM2 MEASURE 10 software

Fig 5 presents an explanatory diagram of the steps followed during the process of reverse engineering of our part.

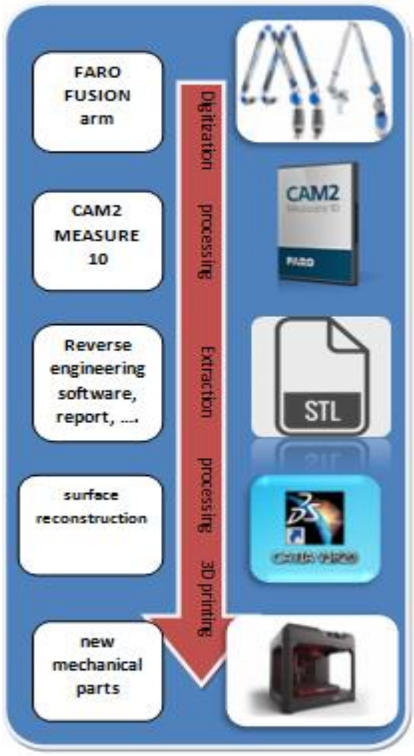


Fig 5. Steps followed during the reverse engineering process of our part

The first step is to obtain the point cloud of a tramway transmission gear. The physical part is available (Fig 6). This phase is therefore dedicated to preparing the part to be digitized and carrying out the actual digitization to capture the information describing all the geometric characteristics of the part such as steps, slots, pockets and holes.

In order to reconstruct the CAD model of our part, the part is sprayed with an aid color to identify the surface for the 3D inspection process (Fig. 6).

Fig 6. Part coloring

Then, the measurement process is started and the point cloud is created directly on the computer during the 3D scanning (data acquisition) (Fig. 7).

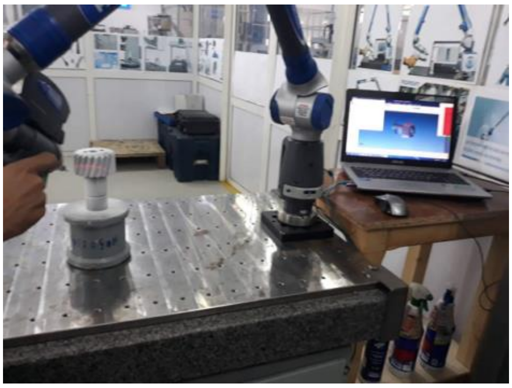


Fig 7. Data acquisition and point cloud creation

3 RESULT AND DISCUSSION

After the data acquisition process, the next steps to take are to import the point cloud, reduce the noise in the collected data and reduce the number of points. A wide range of commercial software is available for point processing. The result of the point processing phase is a clean, merged point cloud dataset in the most convenient format.

The next step therefore is the visualization and processing of data in CAM2 MEASURE 10 software (Fig. 8).

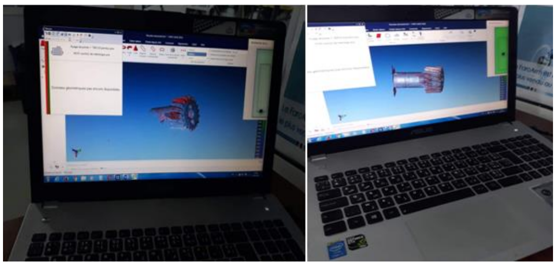


Fig 8.Data processing in CAM2 software

Export the point cloud in STL format from CAM2 MEASURE 10 software and import it into CATIA V5 software (Fig. 9).

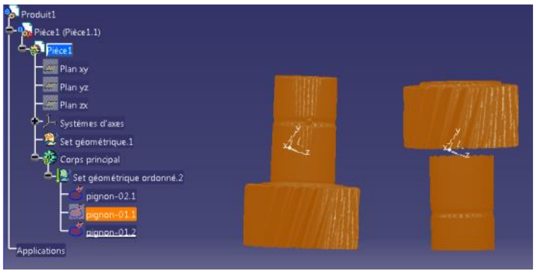


Fig 9. Importing STL files into CATIA V5 Software

After automatically adjusting the two point clouds, they should be merged into a single point cloud (Figs. 10 and 11).

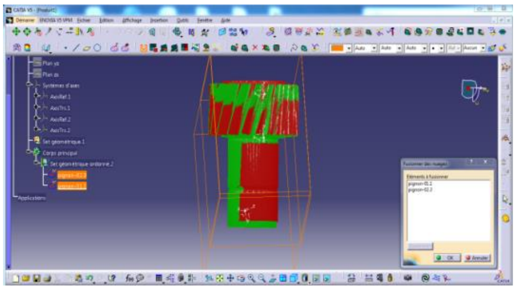


Fig 10. Merging of the two point clouds

To find the transformation matrix that was used to merge the two point clouds we used the ICP algorithm with the help of MATLAB software.

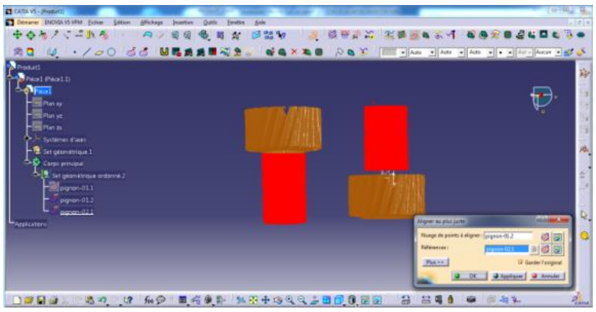


Fig 11. Representation of two cylinders

Our part is a cylindrical shank helical gear. Before running the registration program on the scanned part, the ICP algorithm was first tested on a cylinder on Matlab (Figure 12).

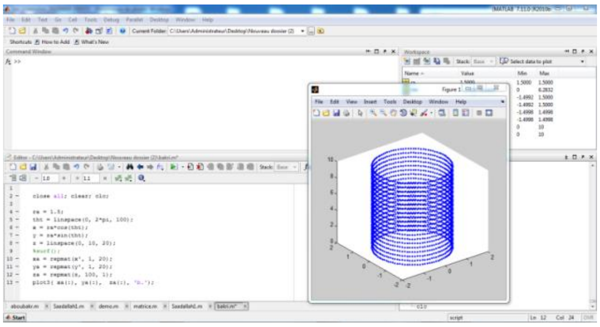


Fig 12. Representation of the reference cylinder on Matlab

The developed cylinder then underwent a rotation and a translation (Fig. 13). The ICP algorithm takes the two point clouds as input and returns the rigid transformation (rotation matrix R and translation vector T), which best aligns the point clouds. The default method is to use minimization by least squares, but other criteria can also be used (Figs. 12 to 14).

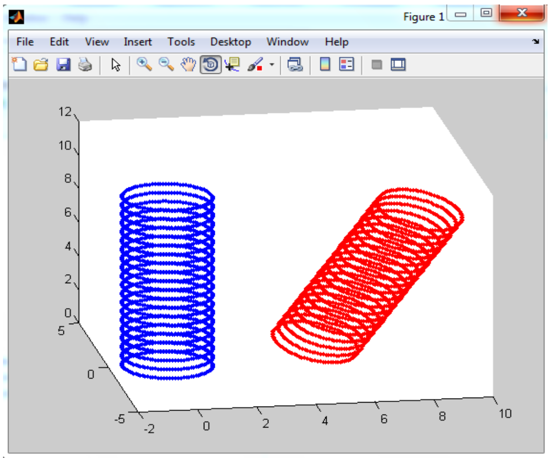


Fig 13. Reference cylinder versus transformed cylinder

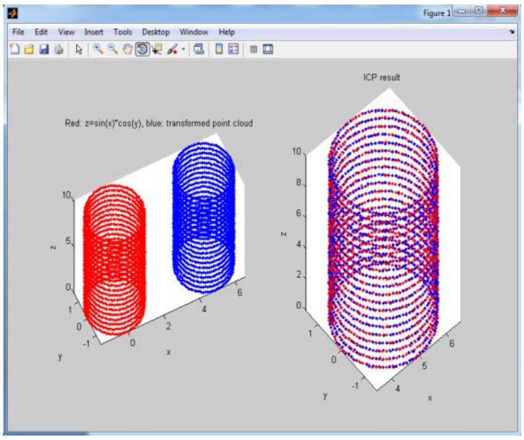


Fig 14. Results of the ICP algorithm.

The last phase is the geometric model development phase. Generating CAD models from point data is probably the most complex activity within RE, as powerful surface fitting algorithms are required to generate surfaces that accurately represent the three-dimensional information described in the sets of point cloud data.

CATIA program and the download STL were than used to develop the CAD model.

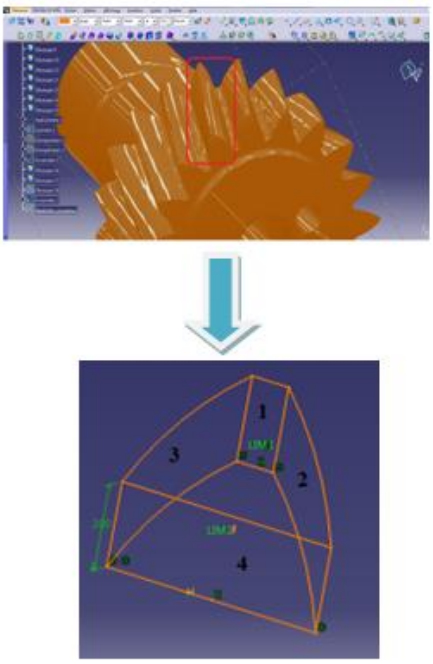


Fig 15. gear tooth faces

The construction of the gear tooth requires reconstruction the surfaces that make up it, as shown in figure (Fig. 15).

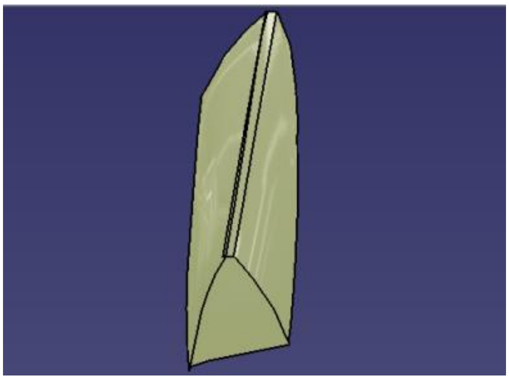


Fig 16. The gear tooth shadow after reconstruction

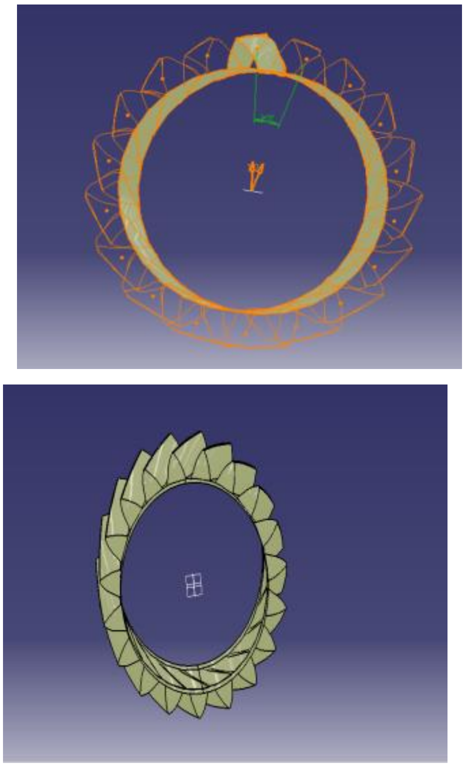


Fig 17. Gear teeth after circular repeat

Figure 18 shows that the point cloud matches perfectly the shadow drawn.

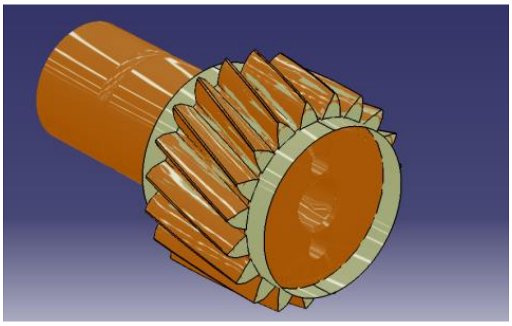
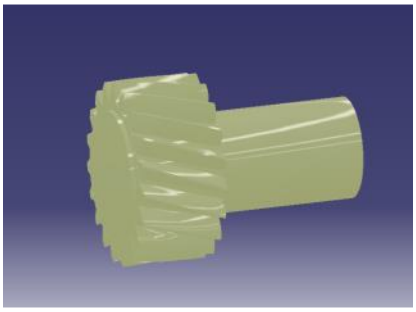
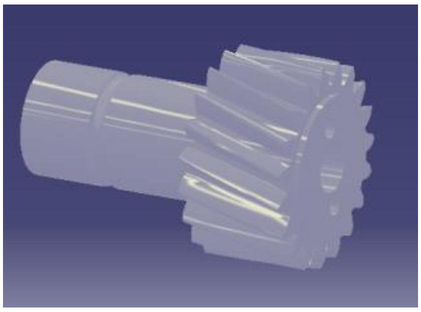


Fig 18. Point cloud vs the shadow drawn

We fill than the shadow size to become an adjustable geometric shape.



Shadow of the point cloud



3D solid

Fig 19. Transformation the shadow of the point cloud to 3D solid of the gear

Finally, the technical drawing of tram transmission gear is shown in Fig 20.

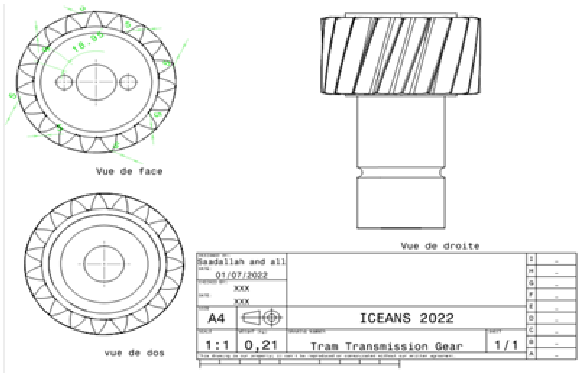


Fig 20. Technical drawing of the mechanical part

4 CONCLUSION

Reverse engineering has an important role in scientific progress and rapid development and transition in the field of industry 4.0, as it simplifies many long and complex processes in order to obtain products.

In RE, the quality of the final part is associated with the use of appropriate methods, software and materials.

The aim of this work was therefore to apply reverse engineering to the reconstruction of tramway transmission gears. In the implementation of the intended objective a laser scanner designed for automatic reconstruction of the geometry of the object was used. Data analysis and processing was carried out in the CAM2 Measure 10 program, which proved to be multifunctional, both for 2D and 3D design, automatic generation of gears and creation of technical documentation such as STL files. In a last step, the CATIA V5 software was used, which made it possible to configure the production. Using this modeling software, the data from the point cloud is converted into a CAD model. Finally, a CAD model and a digital version of the studied part are obtained.

Having a digital version of a real item also allows improvements to be made to it without incurring additional cost. These improvements can be associated with changes in the geometry of the object or the choice of a better alternative material.

Author contribution Mohamed Slamani was the supervisor of this work. He proposed the research idea, technical scheme, and all needed support conditions. He was also responsible in data analysis and writing the paper. Aboubakr Saadallah and Hadj Faid were involved in the measurement, literature study and data analysis. Jean-François Chatelain was involved in the discussion and significantly contributed to making the final draft of the article. All the authors read and approved the final manuscript.

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Declarations

Conflicts of interest/Competing interests: The authors declare that they have no conflict of interest.

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