

USE OF REVERSE ENGINEERING TECHNIQUES FOR INSPECTING SCREWS SURFACES OF A HELICAL HYDRAULIC PUMP

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Abstract: Recently, 3D measurement systems have developed more and more in various fields. With the help of 3D measuring systems, the measurement time in design, manufacture, assembly and production is substantially reduced. In this paper, it is proposed to redesign two pieces of a helical pump (driver and driven screws) based on numerical models obtained by scanning. These models are obtained based on the processing of point clouds resulting from the 3D scanning of the respective pieces. After completing the actual scanning process, the numerical models were measured using specific software to determine the dimensional characteristics and their modeling was performed in a computer-aided design program. Subsequently, the inspection was performed by overlapping the scanned model and the CAD model of each piece, in order to be able to compare the analytical models with the real pieces. This comparison allows to appreciate the degree to which the analytical model obtained by redesign corresponds to the real piece. In this way, the ability of future pieces obtained based on the analytical model to be able to accomplish the desired functional role can be appreciated.

Key words: reverse engineering, helical hydraulic pump, 3D measurement, CAD model.

1. INTRODUCTION

Nowadays, 3D measuring systems have developed more and more in different fields due to their efficiency when analyzing a piece that could not be verified by means of coordinate measuring machines or if the measurement process can be very complicated, with the help of 3D measuring systems the measurement time in design, manufacture, assembly and production being substantially reduced. These systems are based on a 3D optical scanner without physical contact. The purpose of this scanner is usually to create a pattern, initially consisting of a “point cloud” obtained from the surface of the scanned object. This point cloud is then used to make the numerical model of the scanned piece. The operation of transforming the point cloud into a numerical

model, composed of elementary areas of triangular shape, is called polygonalization.

A detailed image, consisting of thousands or tens of thousands of measurement points, can be recorded in seconds and is processed by dedicated software. The numerical model obtained can then be compared with the theoretical model. The dimensional accuracy of 3D measuring systems is at a micron level, providing fast scanning and high quality graphics.

Reverse engineering is the process of analyzing a real-world object or environment in order to collect data on its shape, structure and appearance, so that it can be used later to construct digital 3D models (Akerdad et al., 2021).

The worm-type pieces existing in the structure of helical pumps and compressors, are working bodies whose profiles include different shapes, such as circle arcs, straight segments, helical curves, involutes-cycloids, cycloidal curves or various non-analytical curves (Baroiu, Popa et al., 2017, Teodor et al., 2018, Yan et al., 2017, Baroiu, Berbinschi et al., 2017). Studying the energy efficiency problems of these pumps and compressors involves establishing mathematical models of their profiles, comparing various geometric parameters or using graphical methods that can sometimes be considered difficult or time consuming methods (Dong et al., 2019, Joshi et al., 2020, Malov, 2020).

The problem that often exists in the processes of reconditioning the screws of the helical pumps and compressors consists in making the tools that generate the helical channels of the worms, starting from the existing physical characteristics, for which, often, there is no specific technical documentation (Baroiu, Popa et al. 2017).

In such situations, obtaining the constructive shape of the screws can be done by effectively measuring them, making 3D models of the screws and, starting from them, profiling the generating tools (disc tools or cylindrical-front tools), with which the helical

channels of the pieces will be processed (Baroiu, Popa et al., 2017).

In this paper, it is proposed to redesign two pieces of a helical pump (driver and driven screws) based on numerical models obtained by scanning. These models are obtained based on the processing of point clouds resulting from the 3D scanning of the respective pieces.

After completing the actual scanning process, the numerical models were measured using a specific software to determine the dimensional characteristics and their modeling was performed in a computer-aided design program.

Subsequently, the inspection was performed by overlapping the scanned model and the CAD model of each piece, in order to be able to compare the analytical models with the real pieces. This comparison allows to appreciate the degree to which the analytical model obtained by redesign corresponds to the real piece.

In this way, the ability of future pieces, obtained on the basis of the analytical model, to be able to fulfill the desired functional role can be appreciated. The inspection can provide information about the deviations of the pieces from the theoretical models. These deviations can be analyzed for the entire piece or for its functional surfaces.

2. SCANNING PROCESS

The two pieces with helical surfaces are scanned with Atos Core device, figure 1, an equipment produced by the German company GOM (Spectromas, 2022), which uses a modern and innovative technology for the fully automated inspection and measurement of pieces, existing in the Department of Manufacturing Engineering, within the Faculty of Engineering, “Dunărea de Jos” University of Galați.

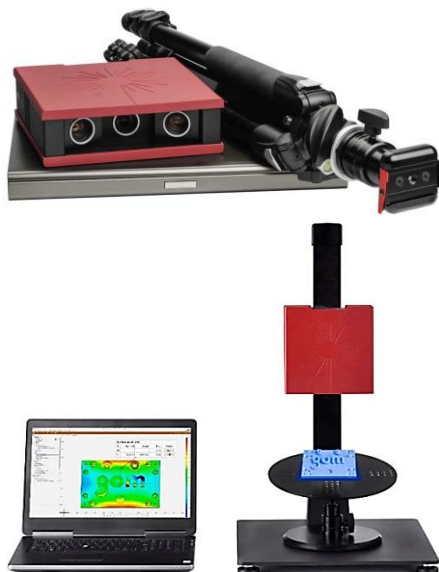


Fig. 1. Atos Core scanner (ATOS, 2022).

The Atos series of contactless 3D scanners provide precision scans with detailed resolution at high speeds. Atos is designed with advanced hardware and intelligent software for accurate, repeatable measurements, with flexibility and process reliability. The scanner is specialized in three-dimensional measurement of pieces up to 500 mm in size (Spectromas, 2022).

Atos Core uses a set of stereo cameras that operate on the principle of triangulation. The two cameras and the projector capture three images of the pieces during each scan, thus involving fewer measurements and providing high quality data even for pieces with complex geometry (GOM, 2022).

Therefore, the Atos Core scanner is an ideal and accessible solution for 3D measurement of small and medium-sized pieces, where monitoring of high quality data and processes is important. Image processing after scanning is done using the GOM Scan software. This is an easy-to-use and intuitive scanning software, a solution dedicated to the fields of reverse engineering and rapid prototyping.

The graphical interface of the software allows to go through all the work stages: from calibration, to automatic setting of scan parameters (resolution, exposure times) and polygonalization.

The two pieces that were scanned, the driver and the driven screws, are shown in figure 2.

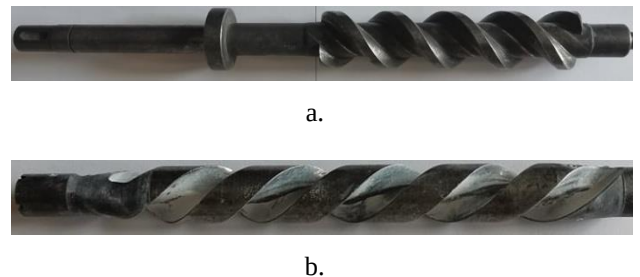


Fig. 2. The pieces used in the scanning process:
a - driver screw; b - driven screw.

To start the scanning process, it is necessary to apply the reference markers on the pieces so that they can be recognized by the scanning equipment and software. To ensure high scanning accuracy, it is necessary to apply an anti-reflective spray to the pieces so that the glossy surfaces of the pieces to become matte surfaces, because glossy surfaces generally lead to poor scanning quality.

After applying the reference markers and the anti-reflective spray, the actual scanning process of the driver and driven screws begins.

After scanning each piece, the polygonalization process begins, which consists of correlating all the scans of the pieces and obtaining the complete numerical models.

Figure 3 shows the final models of the two pieces scanned using the Atos Core equipment.

The files will be saved in *.stl format, allowing them to be opened in various software design programs, such as Autodesk Inventor, CATIA, SolidWorks, AutoCAD etc.

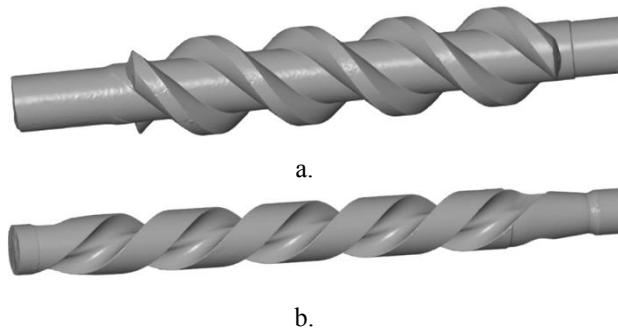


Fig. 3. Scanned parts: a - driver screw; b - driven screw.

3. THE INSPECTION PROCESS OF THE SCREWS SURFACES OF A HELICAL HYDRAULIC PUMP AND THE GRAPHICAL MODELING

The inspection of the surfaces of the pieces is done through the GOM Inspect program, to establish their dimensional characteristics, as well as their modeling in a dedicated software program.

GOM Inspect software allows the evaluation of data obtained by measurement using optical scanners, lasers or other measurement systems. The program offers various possibilities, such as: creating geometric elements; checking the correspondence between the measured and programmed elements; creating reports after completing the inspection of the piece, with tables, images of the inspected piece, diagrams, etc. GOM Inspect program is used in product development processes, quality control and production.

3.1. The inspection of the driver screw

Initially, a reference system of the piece will be construct to determine the dimensions of the driver screw.

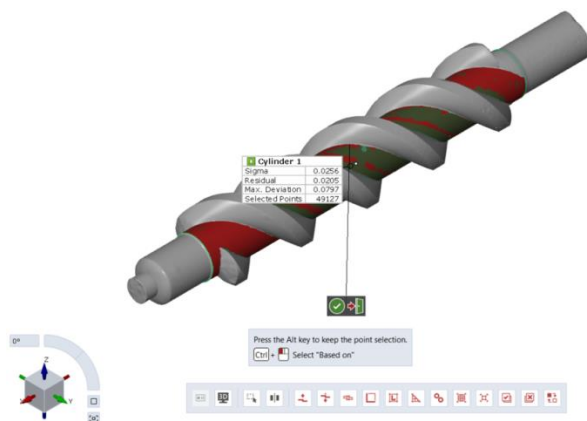


Fig. 4. The construction of the cylinder on the driver screw.

To do this, a cylinder is built that approximates the

area at the base of the screw using the *Fitting Cylinder* command from the *Construct -> Cylinder* module, figure 4.

Subsequently, a point is constructed using the *Point from Line* command from the *Construct -> Point* module, having as direction the axis of the cylinder. Using the *Point-Normal Plane* command, a plane is construct, perpendicular to the cylinder axis, the reference point being the previously constructed point 1 and the normal direction being the cylinder axis, figure 5.

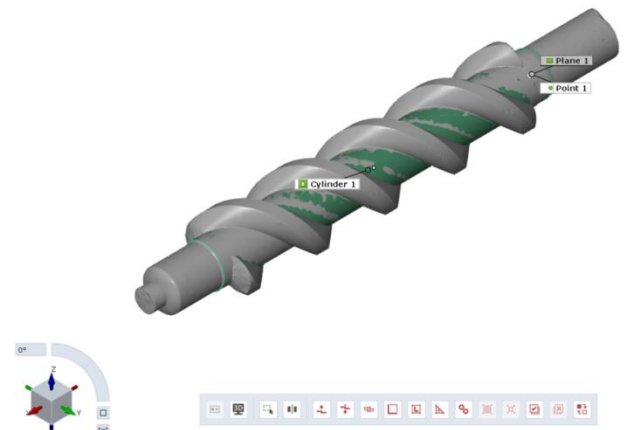


Fig. 5. The construction of the plane on the driver screw.

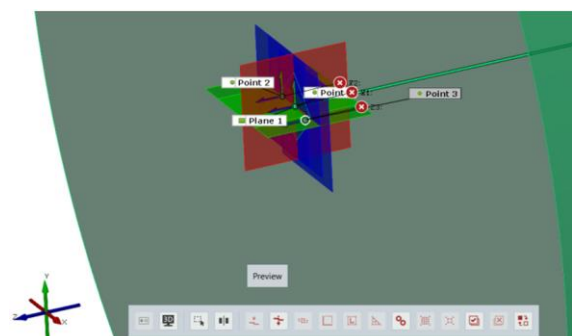
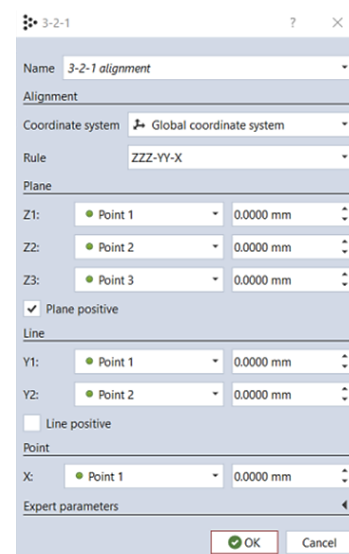


Fig. 6. 3-2-1 Alignment command

Finally, for the construction of the reference system it

is necessary to make an alignment, using the 3-2-1 *Alignment*  command. This command is usually used as an initial alignment. With the 3-2-1 function, the position of the nominal coordinate system can be defined. Thus, in addition to the starting point (*Point 1*), two points are constructed on the plane perpendicular to the axis of the cylinder (*Plane 1*) to describe the plane, using the *Point*  command and,

having all the elements constructed, the alignment defining the coordinate system can be made, figure 6. To determine the dimensions of the driver screw, the contour of the piece will be constructed using the *Single Section*  command from *Construct -> Section* module, figure 7, having as reference plane a plane parallel to the axis of the cylinder (in this case, the *X* plane).

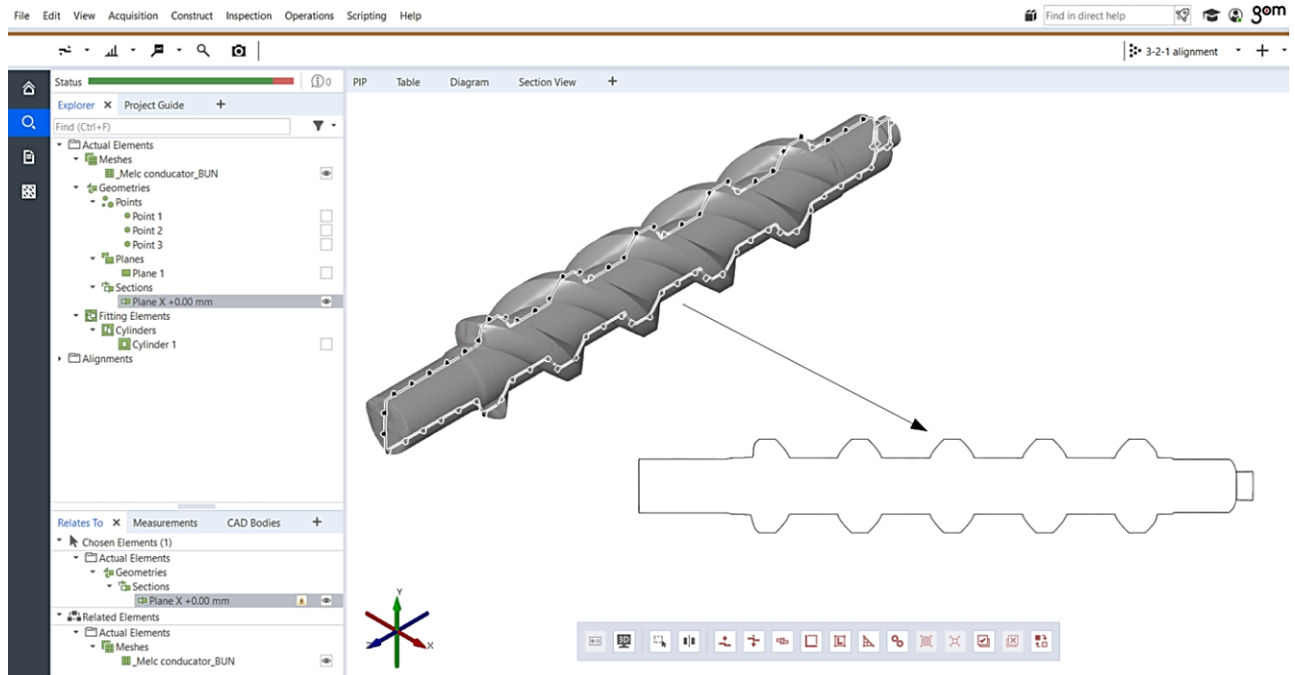


Fig. 7. Construction of the contour of the driver crew.

For the construction of the involute, the *Single Section*  command is used, having as reference plane the plane *Z*, at a distance of -55 mm from the original reference plane.

The final result is shown in figure 8. Thus, by means of these two contours, the dimensional characteristics of the driver screw necessary for its modeling in a specific software program can be determined.

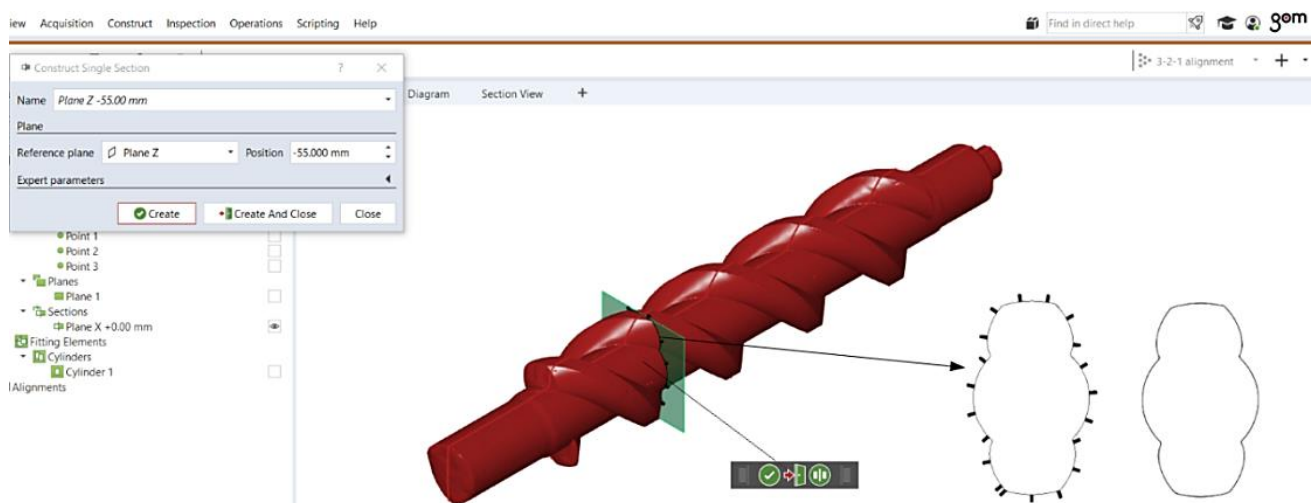


Fig. 8. The contour of the involute of the driver screw.

For example:

a. to determine the maximum length, two points positioned at the ends of the driver screw using the *Point* command are chosen, and by the 2-Point

Distance  command, from the *Construct* -> *Distance*  module, the maximum length of the piece can be measured, figure 9.

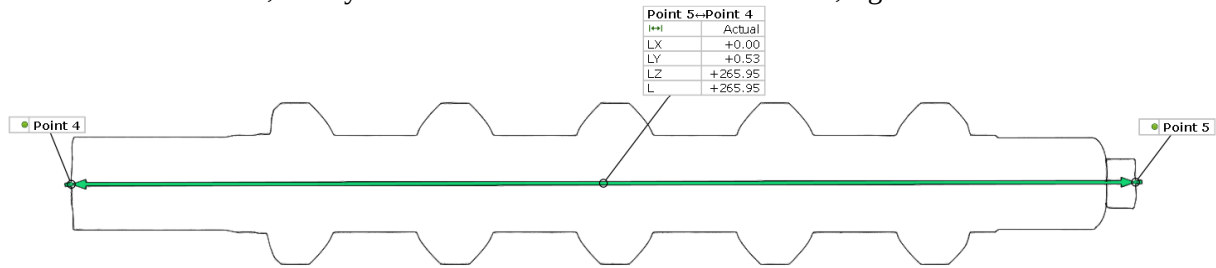


Fig. 9. Measuring the maximum length of the driver screw.

b. to determine the inside diameter of the driver screw, a circle on the involute is construct, using the *Fitting Circle*  command, figure 10, and in order to

determine the dimensions of the involute, equidistant points are generated on its contour, using the *Point* command, figure 11.

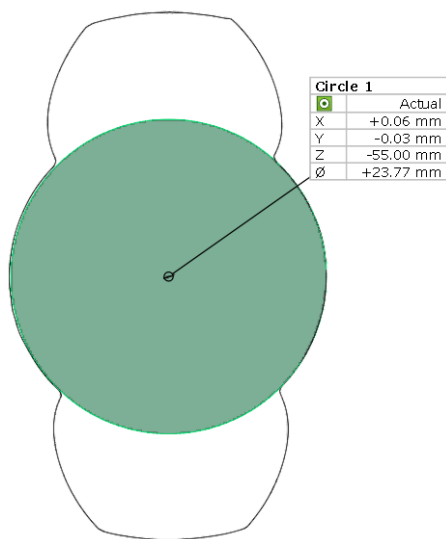


Fig. 10. Determination of the inner diameter of the driver screw.

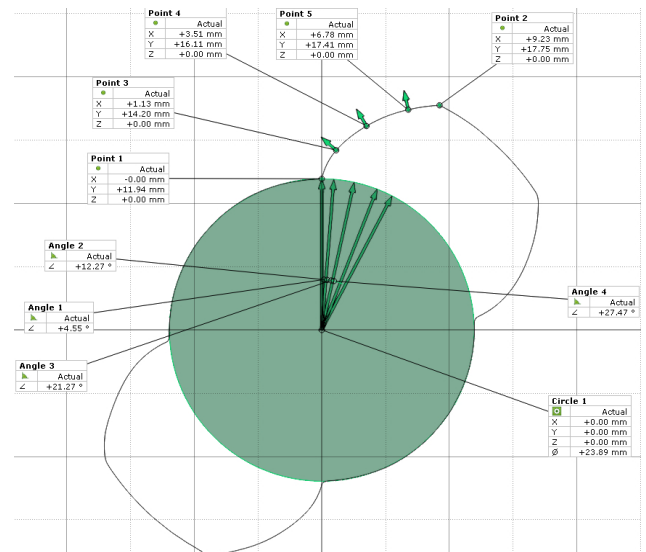


Fig. 11. Construction of points in order to determine the dimensions of the involute of the driver screw.

Therefore, using the construction commands, the dimensional characteristics of the driver screw required to make the 3D model can be determined.

3.2. The inspection of the driven screw

The steps for determining the dimensions of the driven screw are the same as for the driver screw. Thus, the cylinder, the point, as well as the plane perpendicular to the axis of the cylinder will be built, in order to construct the reference system, figure 12.

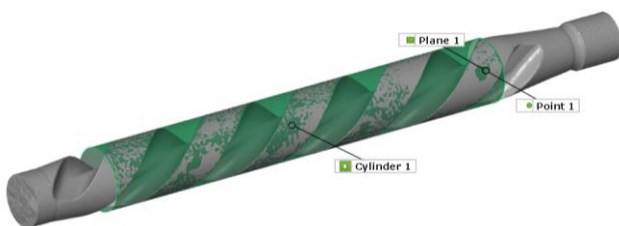


Fig. 12. The construction of the cylinder, the point and the plane perpendicular on the driven screw

After constructing the two points on the plane perpendicular to the cylinder axis and after the realization of the alignment that defines the coordinate system, the contour of the piece can be made using the *Section* command, figure 13, having as reference plane a plane parallel to the cylinder axis (in this case, the X plane).

Using the same command, the involute of the driven screw will be constructed, having as reference plane the Z plane, at a distance of 33 mm from the initial reference plane, figure 14.

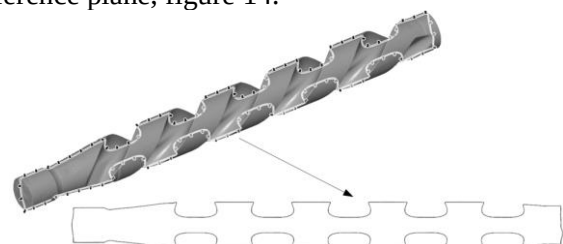


Fig. 13. Construction of the contour of the driven screw.

Therefore, by means of these two contours, the dimensional characteristics of the driven screw necessary for its modeling in a software program can be determined.

For example:

a. to determine the maximum length of the driven screw, two points positioned at the ends of the rotor are chosen, and, by means of the *2-Point Distance* command, the length of the piece can be measured, figure 15.

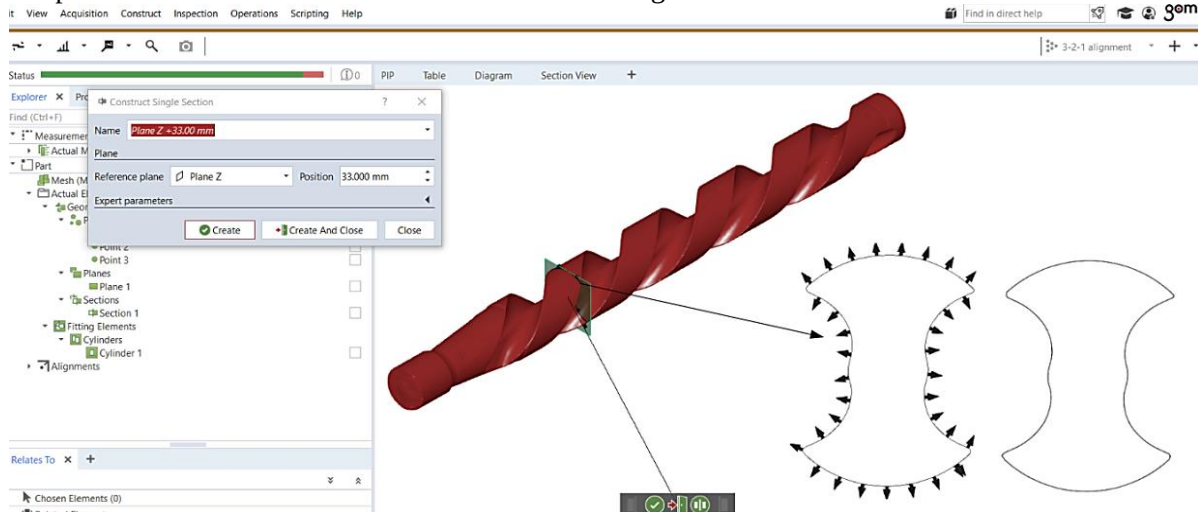


Fig. 14. The contour of the involute of the driven screw.

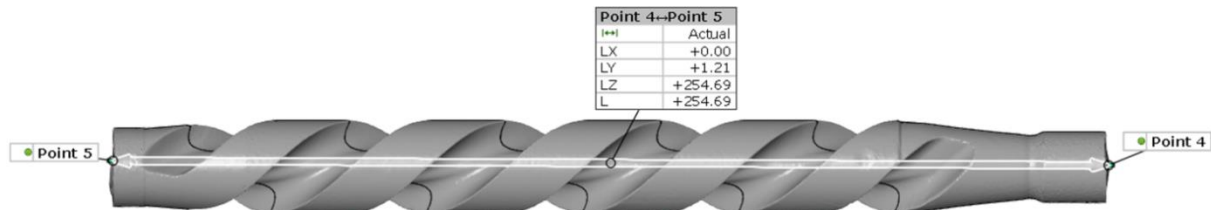


Fig. 15. Measuring the maximum length of the driven screw.

b. to determine the outer diameter of the driven screw, a circle on the involute is constructed, using the *Fitting Circle* command, figure 16, and to determine the dimensions of the involute, points on its contour are constructed, using the *Point* command, figure 17.

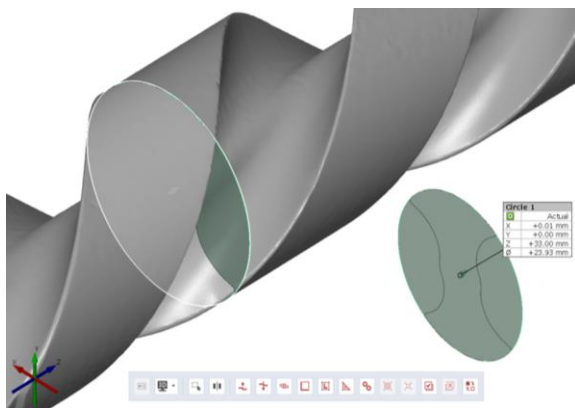


Fig. 16. Determination of the outer diameter of the driven screw.

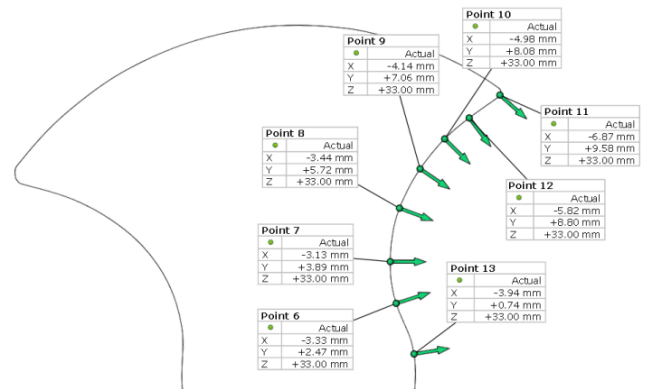


Fig. 17. Construction of points in order to determine the dimensions of the involute of the driven screw.

Thus, with the help of the construction commands, the dimensional characteristics of the driven rotor required to make the 3D model can be determined.

3.3. Graphical modeling of the driver and driven screws

In support of the realization of a fastest and most efficient design of technical products, numerous 2D and 3D graphical representation of information in a virtual environment have been developed. The advantage of these design applications is that all

components are modeled in a 3D environment, which can be optimized in terms of geometric and constructive parameters before being physically realized.

The graphical modeling of the driven and driver screws was made in the CATIA V5R21 program, a software package that makes the 3D modeling of solids as efficient and precise as possible, in the Generative Shape Design module.

The dimensional characteristics of the pieces were determined after their inspection in the GOM Inspect program, presented in the subsections 3.1 and 3.2.

Therefore, figures 18 and 19 show the virtual models of the two pieces made in the CATIA V5R21 software. The files will be saved in *.stp format, allowing them to be opened in the inspection program.

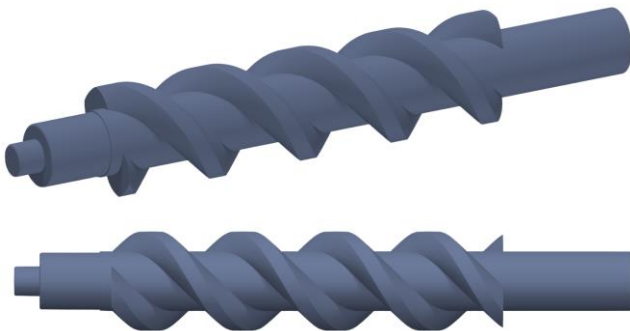


Fig. 18. Virtual model of the driver screw.

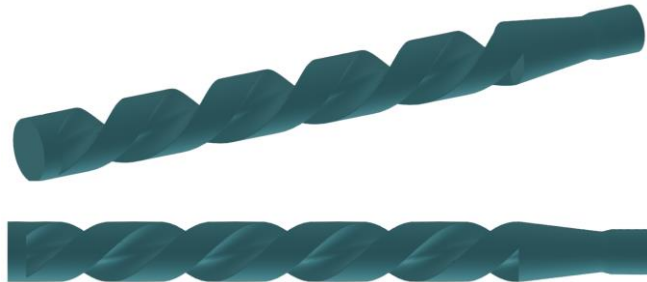


Fig. 19. Virtual model of the driven screw.

The frontal profile of the screw was determined based on the measured data, obtaining a profile consisting of two curves, see figure 20.

For the *AB* zone, the profile is involute, having the equations:

$$\begin{aligned} X &= R \cdot \sin \varphi - R \cdot \varphi \cdot \cos \varphi; \\ Y &= R \cdot \cos \varphi + R \cdot \varphi \cdot \sin \varphi, \end{aligned} \quad (1)$$

with $R=11.7 \text{ mm}$, being the radius of the base circle and φ being the parameter that defines the profile.

For the *BC* zone, the profile is an epicycloid, having the equations:

$$\begin{aligned} X &= r \cdot (k+1) \cdot \left\{ \sin \varphi - \frac{\sin[\varphi \cdot (k+1)]}{(k+1)} \right\}; \\ Y &= r \cdot (k+1) \cdot \left\{ \cos \varphi - \frac{\cos[\varphi \cdot (k+1)]}{(k+1)} \right\}, \end{aligned} \quad (2)$$

with $r=11.7 \text{ mm}$, being the roulette radius for the cycloid and

$$k = \frac{R}{r} = 1. \quad (3)$$

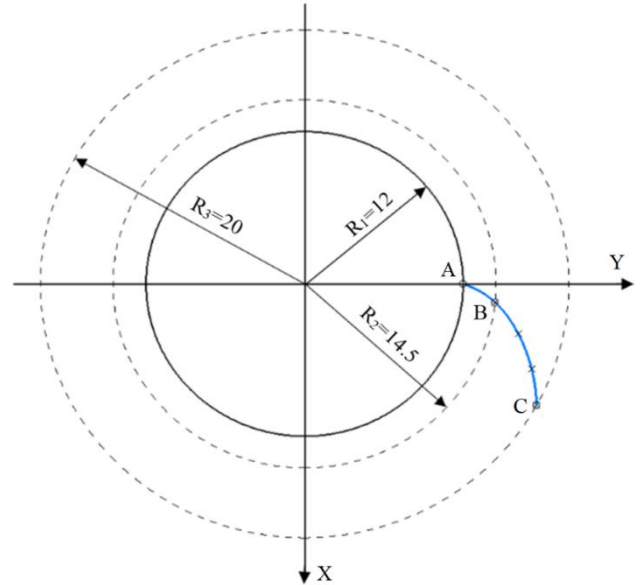


Fig. 20. The frontal profile of the screw.

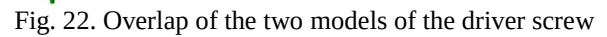
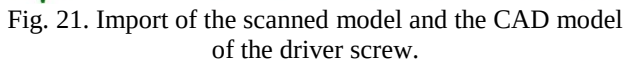
3.4. The comparison between the scanned models and the CAD models of the pieces

The comparison between the scanned models and the CAD models of the two pieces is made in the GOM Inspect program. For inspection, the actual model of the pieces, obtained by scanning, must be aligned with the nominal one, obtained by CAD modeling.

Subsequently, after the alignment, the pieces can be inspected, which means that the deviations between the two data sets can be determined.

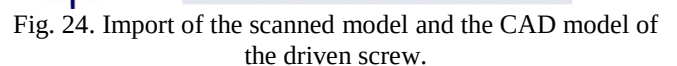
The result of the inspection is presented in the form of a deviation map in which they are symbolized by the colors: *blue* - negative deviation; *green* - zero deviation; *red* - positive deviation. Areas where the deviation has not been calculated are shown on the deviation map in *gray*.

Therefore, in the case of the driver rotor, the scanned model and the CAD model of the piece are imported. Initially, the two models are displayed with different orientations in compared to the reference system prescribed in the program, figure 21.



The *Prealignment* $\clubsuit$ command is used to overlap the two models in a single reference system and the model shown in figure 22 is obtained.

Therefore, the scanned model and the CAD model of the driven screw are imported, the two models having different orientations in relation to the reference system prescribed in the program, figure 24. The *Prealignment* command is used to overlap the two models in a single reference system and the model shown in figure 25 is obtained.



The two models are compared by accessing the *Surface Comparison on CAD* command. As in the case of the driver screw, it is chosen that the upper limit value of the deviations to be 1 mm and the lower limit value is -1 mm.

Finally, labels are created to show the numerical values of these deviations, using the *Deviation Label* command, the result being shown in figure 26.

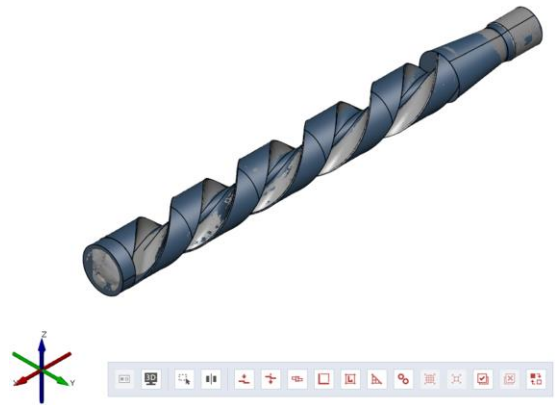


Fig. 25. Overlap of the two models of the driven screw.

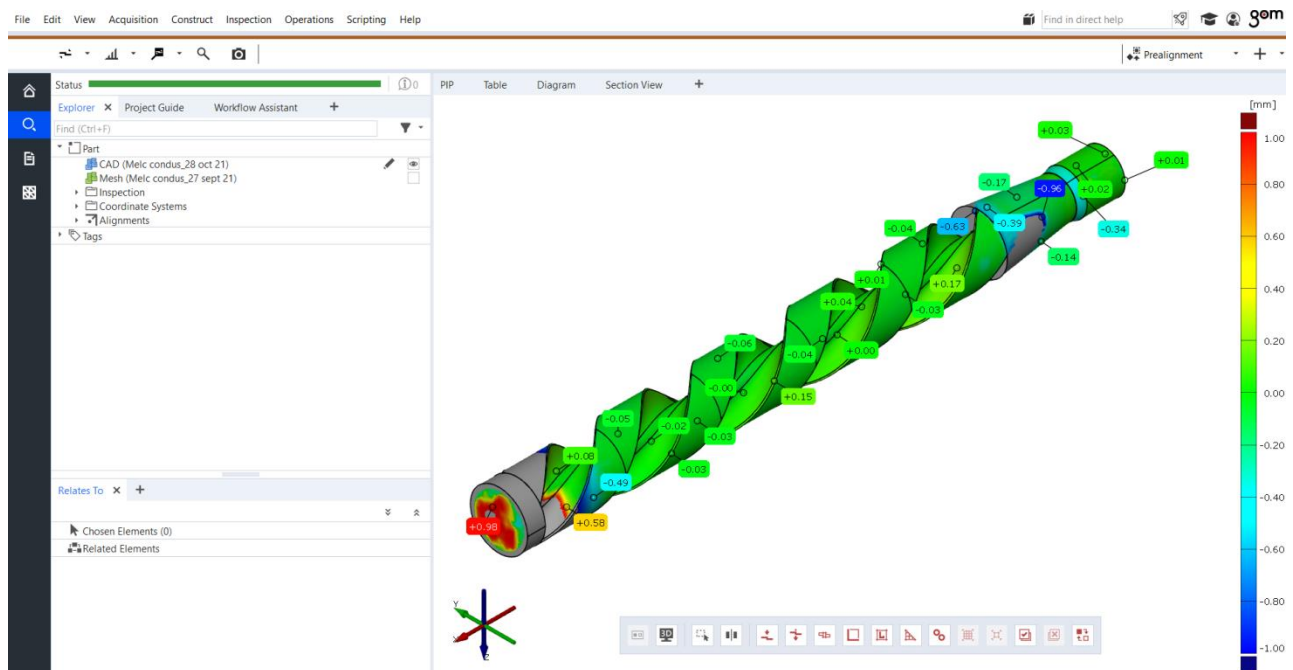


Fig. 26. Dimensional deviations in the case of the driven screw.

4. CONCLUSIONS

In some industries there is a need to redesign pieces and subassemblies due to the fact that manufacturers have to provide spare pieces in a short period of time for the created models.

In order to ensure this goal, innovative solutions are used. One of these is three-dimensional scanning. This involves, in a first stage, taking over the geometry elements of the component or subassembly, capturing compound surfaces and those characteristics that are difficult to measure using traditional techniques.

This technique is also used to fulfill the current requirements of the global production - continuously improving products and increasing their performance while reducing processing time and manufacturing costs. Thus, three-dimensional scanning has become more important in recent years in terms of the advantages it offers compared to traditional methods. The paper presented a three-dimensional scanning technique applied to pieces with a complex geometry,

highlighting multiple advantages compared to the traditional CAD design, such as: speed in work, compared to CAD design; reduced time in transposing 3D pieces or digital models; higher speed in pieces' inspection and control; precise determination of deviations compared to the initial geometric model etc. The comparison of the scanned model with the CAD model obtained based on the measured dimensions demonstrates the quality of the designed model and the fact that it can be used as a basis for the realization of the execution documentation of the respective pieces. Areas where there are significant deviations from the physical pattern are limited in extent and are exceptions. The appearance of these areas is explained by the imperfections of the pieces inspected by scanning and by the measurement difficulties caused by their complex shape and do not represent errors of the numerical models obtained by design. Another source of error is the stage of preparing the pieces for scanning, namely covering them with a

matte layer to prevent scanning defects caused by glossy surfaces. However, it can be stated that even in these cases, the errors are within acceptable limits.

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