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The Reverse Engineering technique performed on a Francis Runner Geometry through Photogrammetry

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Abstract. The Reverse Engineering is a reliable technique to convert a real geometry of a part into 3D computer file. One reason for scanning a part may be the lack of the drawings to manufacture a new one that will replace the old part. The paper illustrates the Reverse Engineering of a Francis runner geometry with a diameter of 1160 mm and 19 blades, which, after 50 years of operation, has pronounced wear marks, high porosity surfaces and cracked areas. The geometry will be scanned through Photogrammetry technique and processed with the following software packages: Agisoft Photoscan and Geomagic Design X (formerly Rapidform XOR); finally, the solid geometry and the drawing of the runner were generating using the SolidWorks software.

1. Introduction

Reverse engineering relies on the reconstruction of a part geometry using 3D scanning process, the usual areas of application being: architecture [1], [2], cultural heritage [3], medicine [4-6], soil erosion assessment [7], [8], paleontology [9]. The Photogrammetry technique is applied in the mechanical field: for deformation measurement [10-12], for quality control and inspection [13-15], for components reconstruction geometry [16-18]. There are some of reasons to use the reverse engineering process [19]: "*to compare products, in preparation for imitating a product, to get technical data that do not exist or the original supplier is no longer willing or able to provide, to shorten market entry times, to enhance existing data, to perform product verification, to aid in product design*". Common scanning technologies are Laser scanning and Photogrammetry technique, many of published papers including as a subject the comparison between them [20], [21]. Photogrammetry is the technique used to extract geometric information from two-dimensional images/videos, by taking multiple overlapping photos and obtaining measurements from them in order to create 3D models of objects or scenes.

One reason for scanning a part may be the lack of the drawings to manufacture a new one that will replace the old part. This is the case of the Francis runner, the subject of the present paper, which, after 50 years of operation, has pronounced wear marks, high porosity surfaces and cracked areas as shown in Figure1.

Figure 1. The existing runner with wear marks, high porosity surfaces and cracked areas

Using the reverse engineering technology, the geometry of a Francis runner with an 1160 mm diameter and 19 blades will be reconstructed by following the next steps:

- 3D scanning of the runner using Photogrammetry and the Agisoft Photoscan software;
- the runner reconstruction using the Geomagic Design X and SolidWorks software packages.

For 3D scanning of the runner geometry, the conditions to be ensured by the beneficiary are as follows:

- placing the rotor on a horizontal support;
- providing a working space with light around the rotor over a radius of at least 4 m;
- the possibility of manipulating the rotor with the crane.

2. The 3D scanning of the runner

The 3D scanning of the runner requires the following stages [22]:

- *Acquire photos* - with a high quality camera; the input data was captured from the platform where the runner was placed; a number of 113 photos were taken with a CANON EOS 600D camera from a ≈ 4 m mean distance; the mean ISO-value for each photo is 800 by shutter 1/50 ÷ 1/60 and focal length 28; some images of the runner are presented in Figure 2;
- *Import Photos* - loads all the raw images into the Agisoft Photoscan interface;
- *Photo's inspection* – the quality of the images must be a minimum of 0.5, but 0.7 is recommended; the *Quality* factor is calculated by the Agisoft Photoscan software;
- *Align Photos and build sparse cloud* - this processing step compares the pixels in the photos to find matches and build a 3D geometry from them; a sparse point cloud of 5,326 points is generated (Figure 3); the software tries to identify common points between pairs of images and estimate camera locations;
- *Build Dense Cloud* - once satisfied with the alignment, the sparse point cloud is processed into a dense cloud, with 12,891,212 points, where each matchable pixel will get its own X, Y, Z location in 3D space (Figure 4);
- *Build Mesh* - this step connects each set of three adjacent points into a triangular face, which combine seamlessly to produce a continuous mesh over the surface of the model; this step is optional, because the mesh was generated using Geomagic Design X software;
- *Build Texture* - in this step, the original images are combined into a texture map and wrapped around the mesh, resulting in a photorealistic model of the original object; this step is optional;
- *Scale the geometry* – the geometry was scaled based on 3 distances between three markers and verified for other multiple points (Figure 5);
- *Export the geometry* – export the dense point cloud to Geomagic Design X software.

Figure 2. Some captured images of the Francis runner

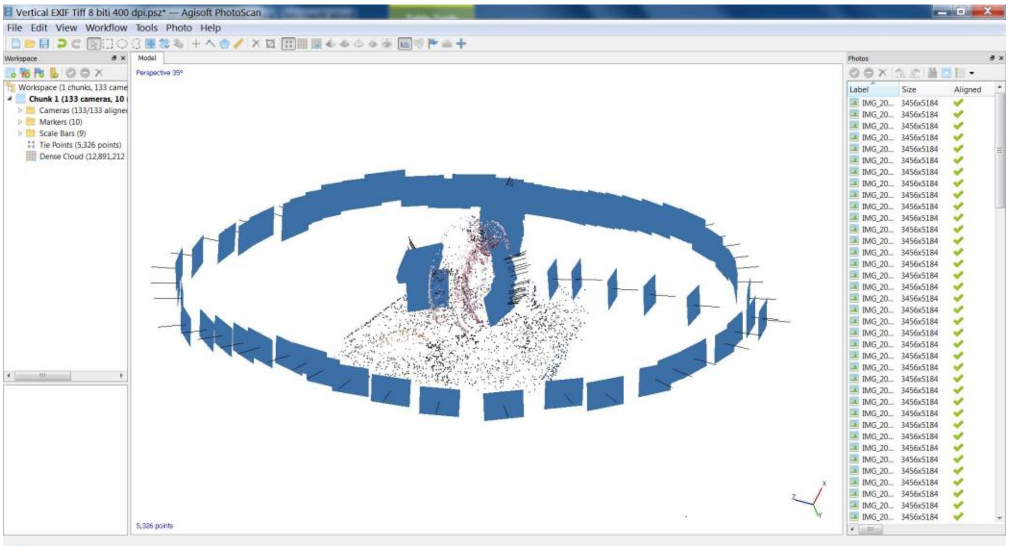

Figure 3. Images aligned and the sparse cloud with 5,326 points

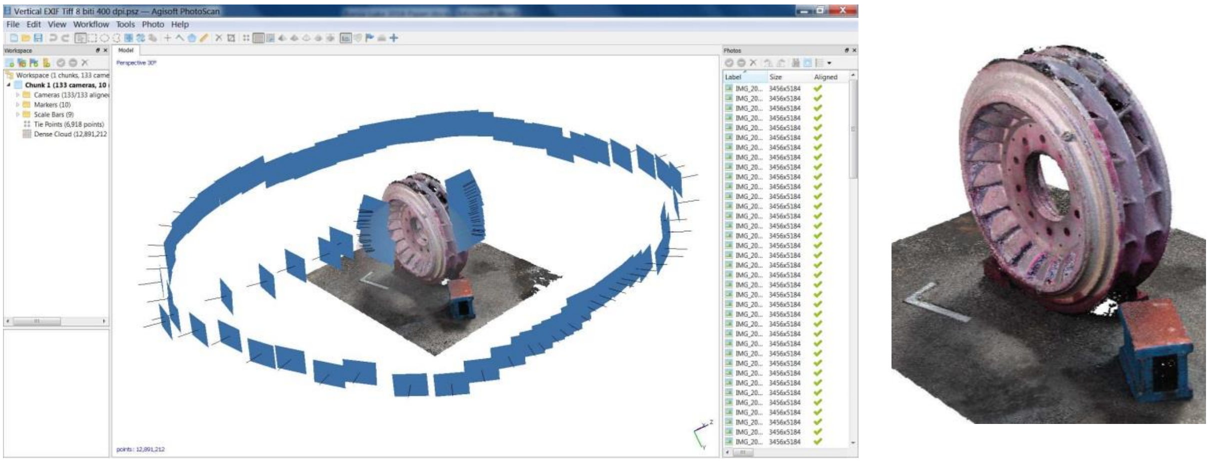

Figure 4. The dense cloud with 12,891,212 points

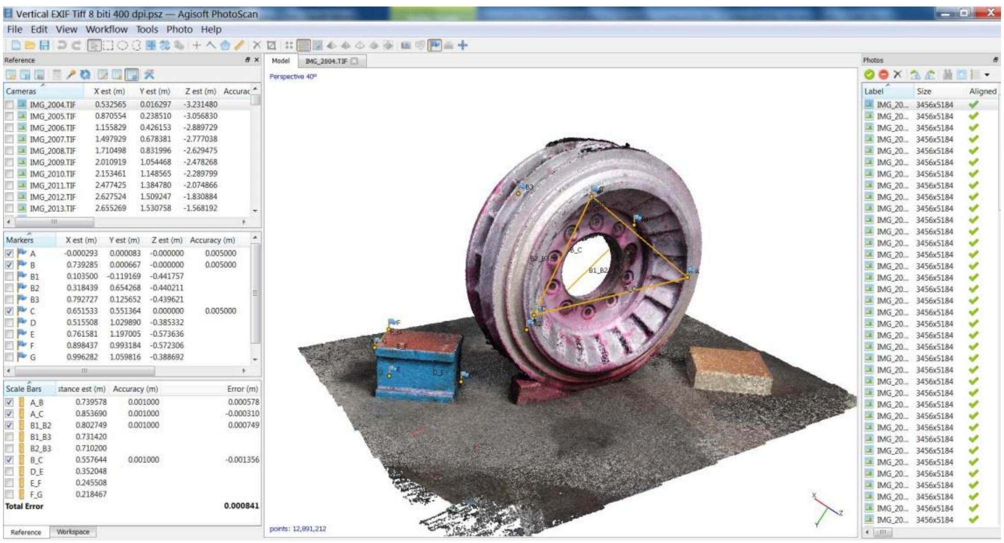

Figure 5. Scale the geometry using Agisoft Photoscan software

3. The Francis runner reconstruction

The aim of this stage was to generate the runner geometry as a solid format, by following the next steps:

- import the dense point cloud into Geomagic Design X software (Figure 6);
- generate the mesh based on a dense point cloud; the Geomagic Design X software creates a network with 6,491,472 triangles similar to the mesh from the finite element software;
- generate the median disc, the two outer disks and 1 blade using Geomagic Design X software (Figure 7);
- export the median disc, the two outer disks and 1 blade to the SolidWorks software;
- generate the geometry of the runner as a solid format in the SolidWorks software (Figure 8);
- generate the runner drawing using the SolidWorks software (Figure 9).

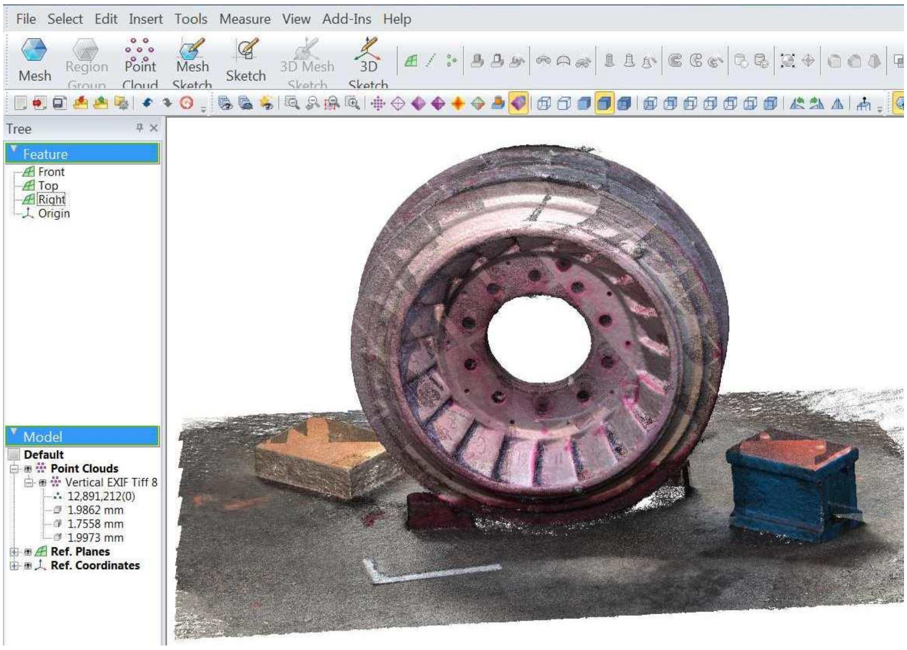

Figure 6. The dense point cloud imported into Geomagic Design X software

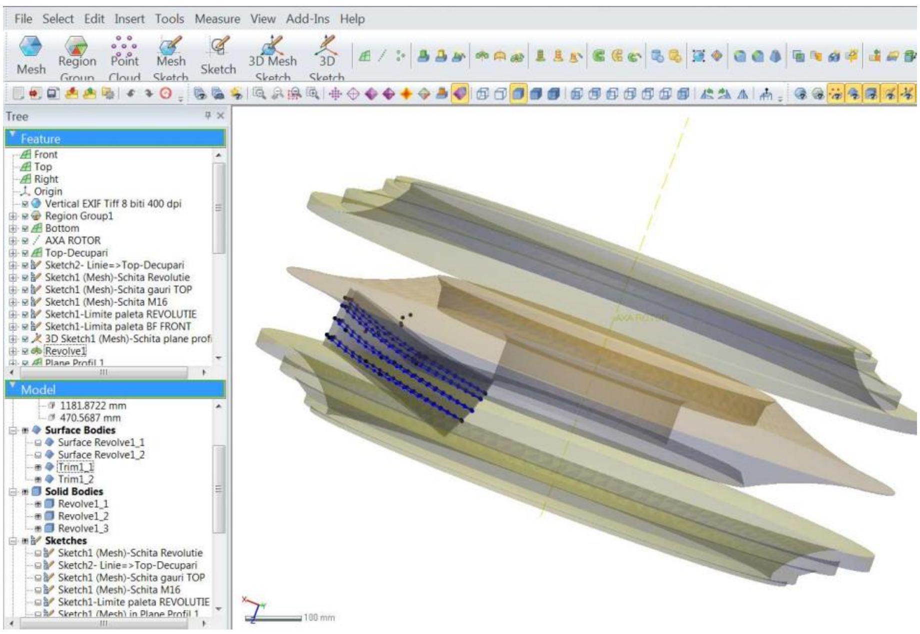

Figure 7. The median disc, the two outer disks and 1 blade in Geomagic Design X software

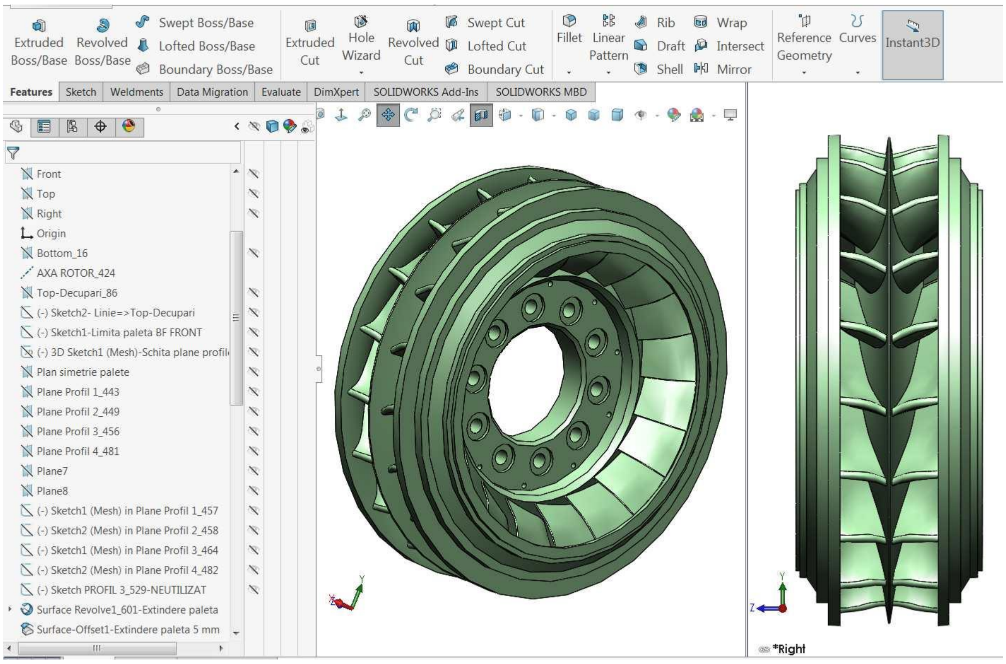

Figure 8. The solid format of the runner in SolidWorks software

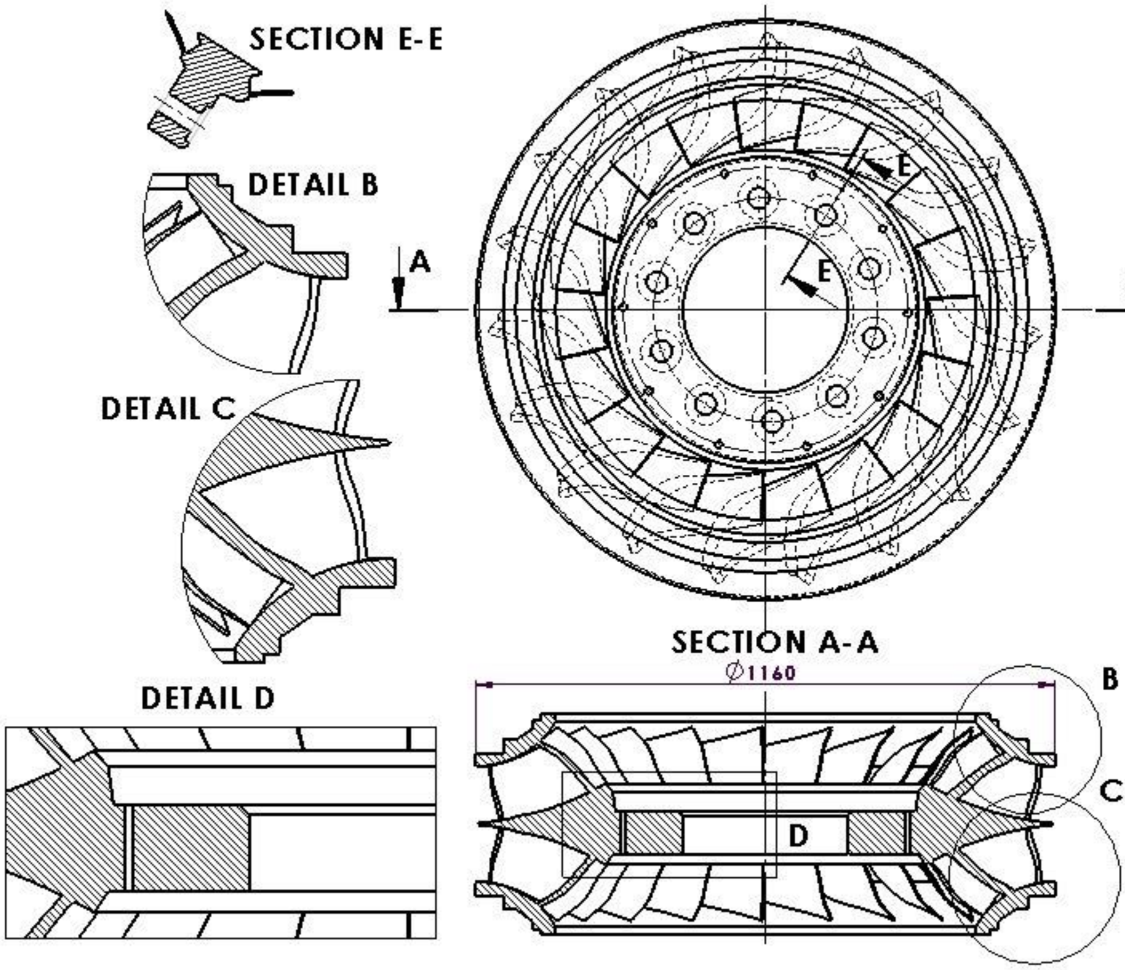

Figure 9. The runner drawing in SolidWorks software

4. Conclusions

In the case of a complex geometry like the Francis runner and in the absence of the drawings to replicate it, the reverse engineering process represents a more efficient alternative compared to contact measurement methods. The use of Photogrammetry technique enables to get the 3D geometry of the runner at a more reasonable cost than the Laser scanning technique, with comparable accuracy.

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