

MMaMS 2012

## Application of reverse engineering techniques in mechanics system services

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### Abstract

In today's industry and production systems it's important to do mechanics or measurements systems services regularly. In case of damages it is required to eliminate these in shortest time period, to avoid time losses and obviously also financial losses. In case of destructive failure of devices, or their parts it is required to change them for new one. However, nowadays we know various types of techniques which are available for substitution of damaged parts in very short time period. One section of these techniques is reverse engineering. Especially techniques like 3D scanning and rapid prototyping. Submitted article analyse reverse engineering techniques utilizable for mechanics or measurements system services.

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*Keywords:* Reverse engineering, 3D scanning, rapid prototyping, innovative tools, product design

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### 1. Introduction

Reverse engineering (RE) methods are representing important part of prototypes creation [3]. Big companies are investing in RE for decreasing of competitiveness, decreasing of time needed for prototypes creation and also for decreasing of time needed for real product production. There are many reasons for using RE. Base criterion for choosing RE as creation method is absence of digital 3D CAD model. Application possibilities of RE increasing parallel with developing of hardware and software which is used for products creation and design. Examples of these techniques application are for example real products digitizing, CAD model with produced product comparison or machine settings via CAM systems after digital measurement.

Reverse engineering application in automotive industry is integral part of car creation processes. 3D scanners are most used by design part of car. It would be time-consuming and difficult to transfer real designer's car model into 3D CAD model without 3D scanning. This process decrease to minimum with help of 3D scanner technologies and the designer can transfer his design in few minutes to CAD software.

Classic machine process begins from CAD model and ends by component production. RE process is opposite. At the beginning is real component and it ends with digital model (fig.1).

One from many options to use RE is using it for service operations in production. Classic service process by device malfunction is trying to repair it in shortest time, or changing of damaged part. Though, part changing can take some time

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when there aren't any spare parts available. That's unacceptable in production process. So here is option to use RE and rapid prototyping for decreasing the repair time to minimum.

#### Classic production process



#### Reverse engineering process



Fig. 1 Reverse engineering and classic production processes comparison

## 2. Innovative techniques and tools for working out

Main techniques used by reverse engineering are *digitizing* and *rapid prototyping*.

### 2.1. Digitizing

Digitizing processes allow us to transfer real part surfaces to digital form. Depending on used technique, principle of digitizing is to scan points in space and they output in CAD software. Main type of digitizing processes is the 3D scanning [4].

3D scanning is a method which allows us transferring scanned points from space to CAD software and to utilize them. There are more types of digitizing devices that allow this transfer. Main types are:

- optical
- laser
- contact
- destructive

Fastest and in machine industry most used are laser and optical 3D scan devices. These devices allow us to scan shapes of the real parts with machine industry precision demands.

There is measurement device FARO with laser scan probe FARO Laser ScanArm (fig. 1) used on automotive production department of Technical university of Kosice. This device used a group of sensorial parts in its arms for exact determination of probe position in space. Additional scan probe ScanArm is using a laser ray beamed from device and projected on scanned part surface. Projected laser ray is afterwards scanned with high sensitive CCD cam. Laser ray projection (fig. 2) distance in space is automatically re-counted in dependence on angle and distance of device probe. This kind of progress can determinate a position of several thousand of points in seconds. This is rapidly increasing the 3D scanning process in comparison to contact 3D scanning methods.



Fig. 1 FARO Platinum Arm with Laser ScanArm in Automotive production section Lab



Fig. 2 Laser beam projection line

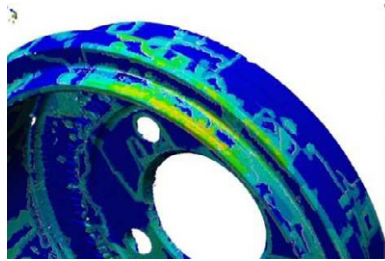


Fig. 3 Point's cloud reduction

3D scanning output is the point's cloud. For further utilization it's required to customize the point's cloud via CAD software into solid part or planes. This point's cloud is mostly too large, so for best output data it's necessary to do some editing. We are talking for example about points overlay reduction (fig. 3). Hole CAD model creation process is a complex process described in many publications so we'll devote our paper only to some parts of this process.

## 2.2. Rapid prototyping

Rapid prototyping means fast production of prototypes from alternative materials. We know several types of rapid prototyping processes. Most used are [1]:

- *Stereolithography SLA* – an additive manufacturing process which employs a vat of liquid ultraviolet curable photopolymer "resin" and an ultraviolet laser to build parts' layers one at a time.
- *Selective laser sintering SLS* – an additive manufacturing technique that uses a high power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal (direct metal laser sintering), ceramic, or glass powders into a mass that has a desired 3-dimensional shape.
- *Fused deposition modelling FDM* – an additive manufacturing technology commonly used for modelling, prototyping, and production applications.
- *3D printing* – InkJet, Z Corporation
- *Laminated object manufacturing LOM* – layers of adhesive-coated paper, plastic, or metal laminates are successively glued together and cut to shape with a knife or laser cutter.

Thanks these prototypes production methods it's possible to produce functional prototypes which can be consequently tested or to be directly used to those purposes in short time. For progress of those activities about rapid prototyping look at fig. 4.

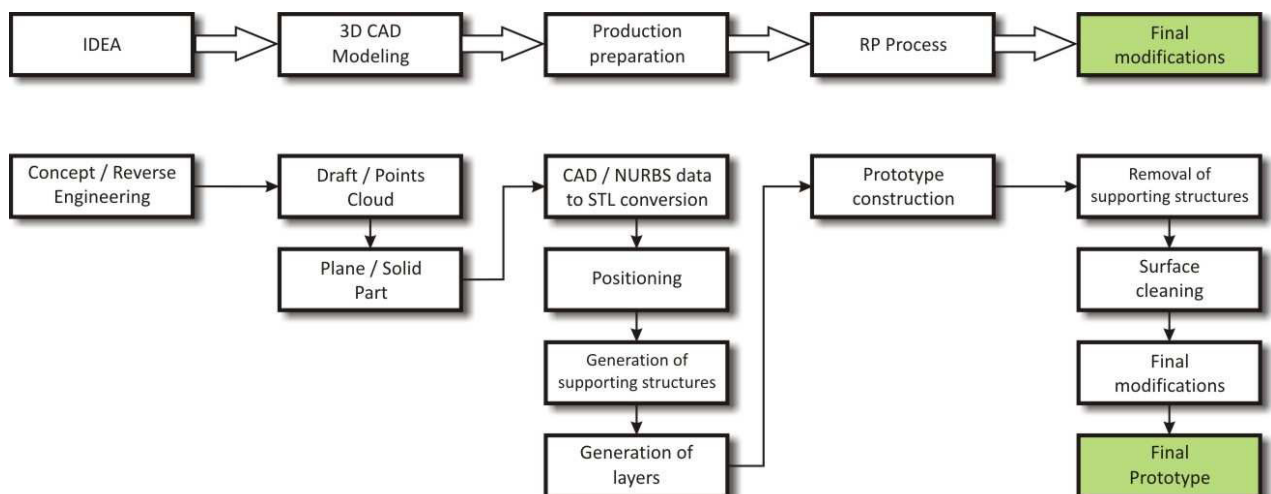


Fig. 4 Rapid prototyping methods progress [1]

Thanks they properties, the rapid prototyping methods propose large number of options also in service operations area, or for spare parts production. In connection with rapid tooling methods is nowadays this engineering area an irreplaceable part of hi-tech production industry.

### 3. Solutions for damaged parts – 3D scanning

Damage of machine parts is a serious problem. It affects production fluency and causes financial losses due machine malfunction. Most threatened are components like transmission parts, tools or electronics. Our example shows case of a damaged transmission gear wheel.

Under mechanical stress of these parts can cause a progressive abrasion or damage. In case if the gear wheel is made from brittle material, there is much higher risk of damage. Our example of modern RE techniques application shows transmission gear wheel made from plastic material. This was irretrievably damaged under machine running (fig.5). As it came to snap of part of wheel it doesn't allow another machine running (fig.6). Damaged gear wheel like this should be changed for a new one.



Fig.5 Damaged component - gear-wheel



Fig.6 Missing part of gear-wheel

In this case it's also possible to apply reverse engineering to eliminate machine failure due part damage. The damaged part will be 3D scanned and aroused point's cloud will we get into CAD part. Adding a missing part of gear wheel will in CAD be needed, and finally a new one gear wheel due rapid prototyping will be created.

#### 3.1. 3D scanning

First step of replacing the damaged gear wheel is to get his CAD model. Our example study assumes absence of original part CAD model. There are many factors that are affecting 3D scanning processes. One from them is reflective ability of components surface. Expectation for quality 3D scan is matt, bright surface. Problem of optical scanning systems are for example high shine of surfaces like chrome-plated surfaces or also black surfaces that doesn't reflect laser ray.

Surface colour of our example part is theoretically proper for 3D scanning; however there was a problem with point's cloud by scanning of unadjusted surface. Those inaccuracies riced mainly about tooth system (fig. 7). It came there to uncontrolled laser ray scattering. That caused incorrect scanning. This problem looks like points in space, which doesn't exist in real (fig. 8). Number of points scanned like this is big and it causes really serious problem by CAD modification for rapid prototyping processes.

One option to eliminate this unwanted effect is to eliminate it by the points overlay reduction, which allows us under specific options to automatically eliminate the unwanted or incorrect points. As the quantity of these points is big it's possible to use this software function only in stint volume and the result wouldn't be acceptable.



Fig. 7 Issuable area of gear-wheel

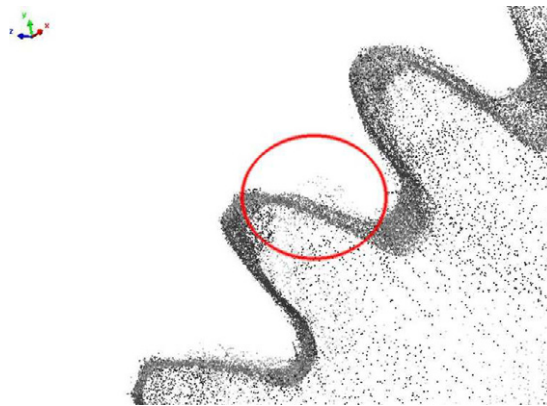


Fig. 8 Inaccuracy of 3D scanning

We used for this effect eliminating “control penetration coating” for surface colour modification. With help of this coat we changed surface colour of tested part to white, what allow us to scan the surface more precisely (fig.9).

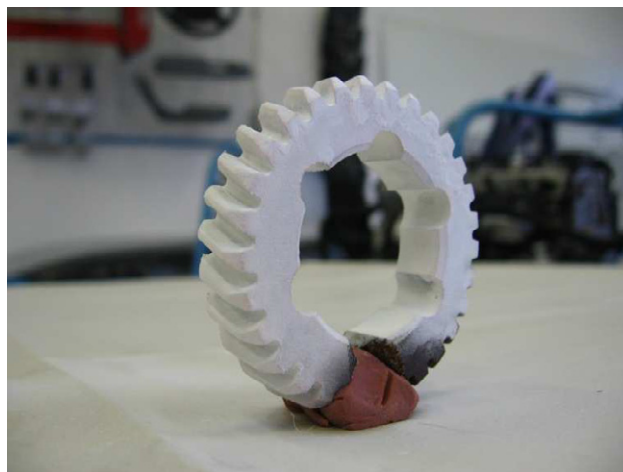


Fig. 9 Gear-wheel after surface modification



After these modifications we get a satisfying point's cloud, which was ready for another processing. After the surface scanning, we needed an axis for CAD design of the missing part of component. For this purpose we used measurement device FARO with 3 mm probe for inner cylinder of gear wheel to scan (fig. 10). Those gave us missing axis for tooth system patterning and also the smaller cylinder surfaces served us for gearing pattern angle definition.

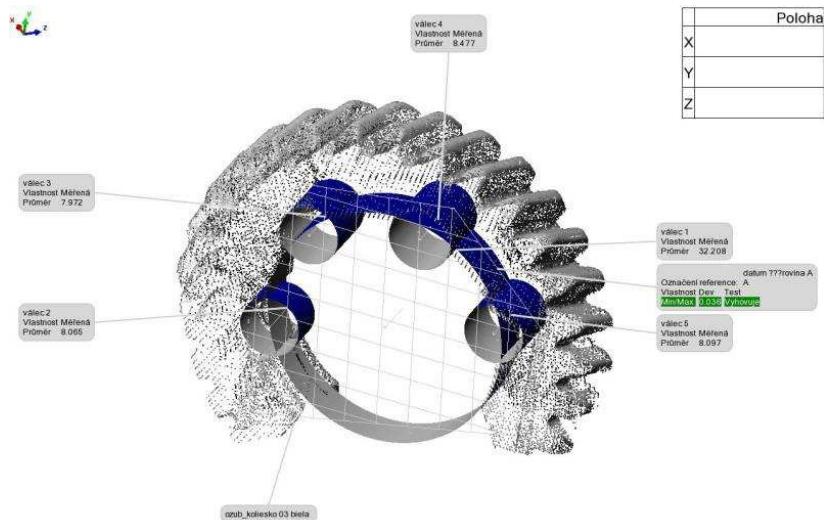


Fig. 10 Objects integration for gearing pattern

#### 4. Preparations for prototyping

The starting point for further modifications of scanned surface and for the creation of 3D CAD model was a transformation of point's cloud from PolyWorks into 3D software CATIA V5. This was realized by universal file format for data transfer between various 3D software solutions - „IGES“. Advantage of this file format is an option of big size data transfer. In our case we talk about a number of points positions.

In this phase of our project it was important to transfer the point's cloud into usable form, because the point's cloud doesn't interpret the final surfaces, it only interpret the surface points (fig.11). To create the final surface by overlaying the point's cloud with a mesh, it is necessary to make number of operations. We used Catia's Digitized Shape Editor.

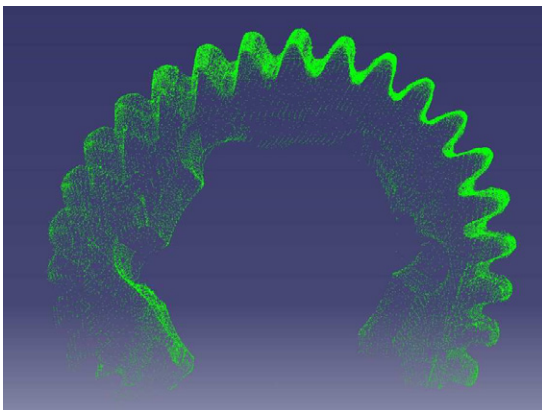


Fig.11 Point's cloud in CATIA V5

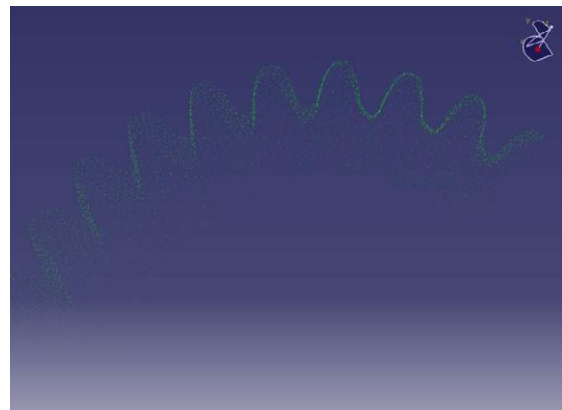


Fig.12 Reduced points

Final surface quality depends on number of scanned points. Via laser scanning of gear wheel surface it was 603 612 points scanned. This number of points creates our start point for solution. After using the points reduction method and via

points overlay processes we were able to reduce the points number to 58 581, what finally represented a solvable set of points (fig.12).

The decreasing of point's number against the first set of points was about 90%. In numerical expression represent such a decreasing enormous amount. Though from function view point it doesn't really matters. We can get the final surface also with less set of points. Crucial demand is the correct placement of single surface guiding points. It's important to meet the rule about denser points positioning in places where the way vectors are suddenly changing. This allows the tightest overlay of surface witch is changing a curving. As in our case it negotiates about complicated shaped part, we had to observe this and also other important aspects.

As the entire elementary technical data of gear wheel were missing, we had to go out only from scanned points. This was the best way to test the reverse engineering methods directly on real example of functional part, which was already damaged and approximately 1/5 of it was definitely missing. In dependence on the case we chose creation process of 3D model, which mostly eliminate surface defects of gear wheel.

Creation of tooth system was realized step by step – effective using of scanned and reduced points was the requirement. Final surface was divided to several functional units that we've devoted independently (fig.13). These independent units made the whole part after we've put them together.

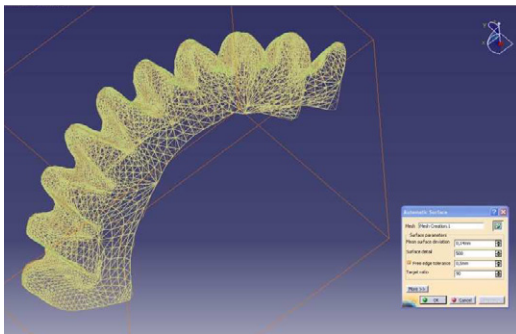


Fig.13 Mesh of a gear wheel part

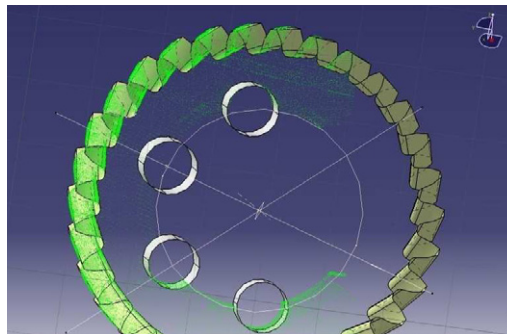


Fig. 14 Base geometry of gear wheel

Processing of construction solution (fig.14) into final shapes required to handle more techniques and using of many support applications and modules of CATIA software. Final solution is 3D plane model (fig.15), which is describing surface of gear wheel defined via scanned point's cloud. Solid part was generated from surface part which was compared against original scan (fig.16). Comparison proved accuracy of chosen progress of construct solution and as you can see on fig.16, there is clear interlacing of 3D model and the scan.

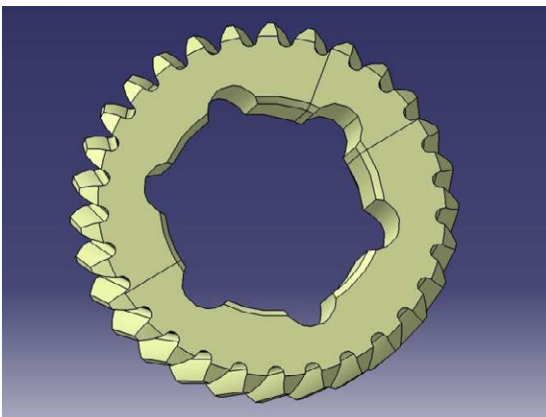


Fig.15 Plane model

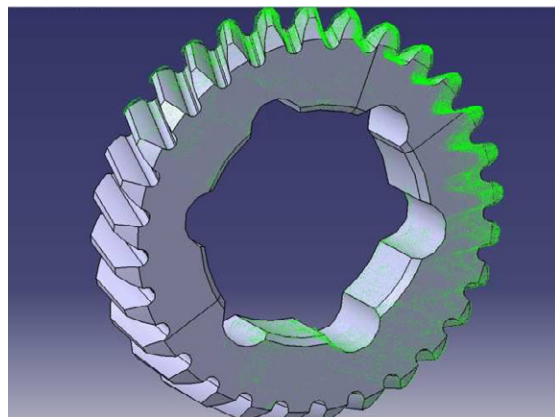


Fig.16 Solid part compared with the scan.

After a solid 3D model was generated, we've created the STL model (fig. 17) for prototype production of the new gear wheel from ABS material via rapid prototyping processes.

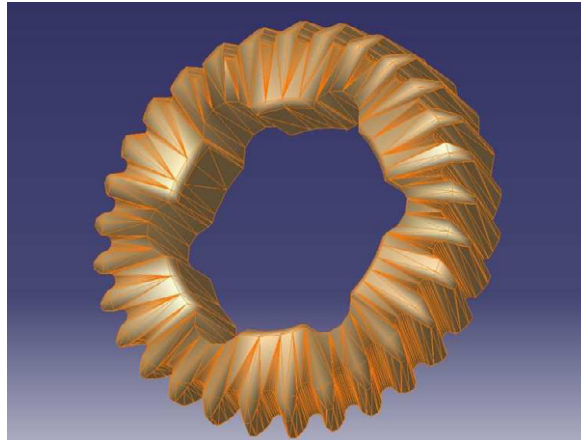


Fig. 17 STL model of gear wheel

## 5. Conclusion

According to measurement results and the digitizing process of damaged gear wheel we made 3D model. This model became a source for further measuring and it also became a source for processes of rapid prototyping via 3D printing by printer FORTUS 400mc and in finale for producing of real spare gear wheel.

Final wheel was made from ULTEM 9085. This material is the most similar material as the original gear wheel was made of. Input data for 3D printing is STL model of component. This is the continual connection between digitizing and rapid prototyping. For final new gear wheel see fig. 18.



Fig. 18 New gear Wheel made from ULTEM 9085

After that it's possible such made wheel to test and to use it as replacement for original damaged gear wheel (fig.19). For verification of the new gear wheel properties, it's possible to digitize it and thereafter to check the differences via overlay of new and original point's cloud. Thereby we can compare and identify possible differences in proportions, geometry and following the results to do corrections or via another form to affect the final shape of 3D model of gear wheel.



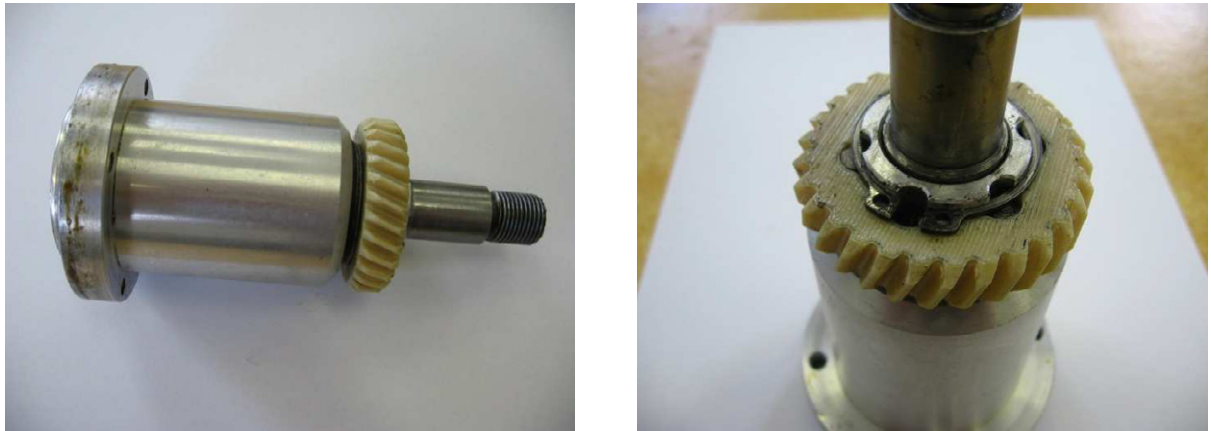


Fig. 19 Gear wheel inserted into original machine

Close connection between digitizing and rapid prototyping methods allow an effective usage of these modern methods for solving of hard technical operations. Via interconnection of these two techniques we came to the main core of reverse engineering – to create a virtual model on real component basis, which will serve for another modifications or production.

The main goal of our article was to demonstrate the simple ways needed for reverse engineering experiences. On base of reached results it's possible to talk about using of submitted RE processes in components design, and also by repair operations and services of machines and equipment. There are situations, when it's possible only via those operations to restore full functionality of machine or equipment. Supporting techniques of RE allow us without properly technical documentation to create new design, innovated or completely reconstructed solutions of chosen components, eventually whole sets.

### Acknowledgements

This contribution is the result of the project implementation: Centre for research of control of technical, environmental and human risks for permanent development of production and products in mechanical engineering (ITMS: 26220120060) supported by the Research & Development Operational Programme funded by the ERDF.

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