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# Investigation on Reverse Engineering for Design and Development of Mechanical Parts

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**ABSTRACT:** The reverse engineering has already found an extensive application in industry and other different fields. Reverse engineering (RE) is a process of taking the existing physical model and reproducing its surface geometry in three-dimensional (3D) data file on a computer-aided design (CAD) system. This paper will analyze the real situation in one industrial plant and provide comparative analysis of the application of current measuring methods and possibility of incorporating digital measurement. The reverse engineering (RE) is based on a method of reducing the time of dimensioning and modeling of mechanical parts which can be complex by geometry or dimensionally very accurate. In this paper we can give some practical examples of parts that are really produced in one manufacturing factory. Recommendation for digitalization will be of crucial importance for every company in its measurement and quality control activities.
**Key words:** reverse engineering (RE); manufacturing; CAD; measurement; digitalization

## I. INTRODUCTION

Global competition in the world industry today is very high. So the companies are trying continu- ally to be competitive on global market by looking for new ways to reduce production times and de- velop new products to meet all the consummers re- quirements. Mostly, the investments of the manu- facturing companies are concentrated on Reverse Engineering (RE), CAD / CAM, Rapid Prototyping (RP) and a large number of new technologies thatoffer greater production, business benefits and greater profit.

Reverse engineering (RE) is now considered as one of the new technologies that provides bigger business benefits using shortening the product de- velopment cycle.

Reverse engineering has been associated with the copying of an original product design for com- petitive purposes. In the manufacturing world to- day, however, the concept of reverse engineering is being legally applied for producing new products or variations of old products. The term reverse comes from the concept of bi-directional data exchange be- tween the digital and physical world [12].

Its application is already proven in many areas of engineering and every day life. There are many reasons why it should be used.

Some of the reasons for using reverse engi- neering are given below:

- The original manufacturer no longer exists, but a customer needs the product.
- The original product design documentation has been lost or never existed.
- Creating data for renewing or manufacturing a part for which there is no CAD data, or for which the data have become unusable or lost.
- Inspection quality control – comparing a fab- ricated part to its CAD description or to a standard item.
- Some bad features of a product need to be eliminated.
- Strengthening the good features of a product based on long-term usage.
- Exploring new ways to improve product per- formance and features.
- Architectural and construction documenta- tion and measurement.
- Fitting clothing or footwear to individuals and determining the anthropometry of a population.
- Generating data to create dental or surgical prosthetics, artificial engineered body parts, or for surgical planning.
- Creating 3D data from a model or sculpture for animation in games and movies.
- Creating 3D data from an individual, model or sculpture to create, scale, or reproduce art work.

The above list is not exhaustive and there are many more reasons for using reverse engineering, than documented above [1].

Classic machining process begins from CAD model and ends by component production. Reverse Engineering process is opposite. At the beginning is real component and it ends with digital model (Fig- ure 1) [2].

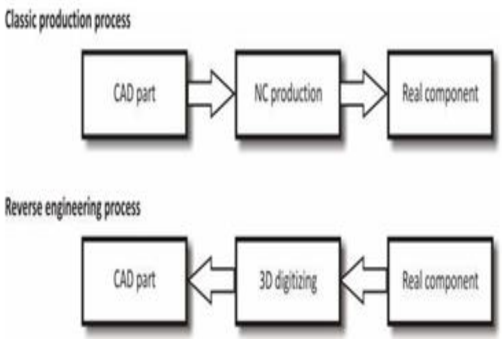


**Fig.1.** Comparison of reverse engineering and classic production processes [2]

## II. DEVELOPMENT AND APPLICATION OF REVERSE ENGINEERING

Reverse engineering covers a variety of ap- proaches to reproduce a physical object with the aid of drawings, documentation, or computer model data. In the broadest sense, reverse engineering is manual work or use of computer and some kind of software to reproduce something.

Reverse engineering is one of the methods used by companies in order to accelerate their prod- uct design process and this method is desire for ac- cess to the new technologies with minimum cost, risk and time [11]. This method in the developing countries that are not so advanced in terms of prod- uct and technology design knowledge, compared to the developed countries, is a logical response to in- crease designing capability and accelerate the de- sign and manufacturing process.

Reverse engineering is no longer used just only for bringing again the old technology back to life. It is also for using existing or old technology as a launch pad directly into the future [3].

Reverse engineering techniques are being used in a wide range of applications and it is not restricted only to the industry. The type of reverse engineering that will be discussed in this paper is a technique where the physical dimensions of a part are being captured in order to be produced a detailed drawing of the part. In the Computer Aided Manufacturing (CAM) world, this is referred as part to CAD con- version, where the geometry of the physical objects is captured as digital 3D CAD data [4].

The generic process of reverse engineering is a three-phase process shown in Figure 2. The three phases are: scanning, point processing, and devel- opment for the particular application specific geo- metric model [1].**Scanning phase:** This phase is connected with the scanning strategy. Its include: selecting the cor- rect scanning technique, preparing the part to be scanned, and performing the actual scanning to cap- ture information that describes all geometric fea- tures of the part such as steps, slots, pockets, and holes.

**Point processing phase:** This phase involves importing the point cloud data, reducing the noise in the data collected, and reducing the number of points. A wide range of commercial software are available for point processing. The output of the point processing phase is a clean, merged, point cloud data set in the most convenient format.

**Application – Geometric model develop- ment phase:** The generation of CAD models from point data is probably the most complex activity within reverse engineering. Sophisticated surface fitting algorithms are required in order to be gener- ated surfaces that accurately represent the three-di- mensional information described within the point cloud data sets.

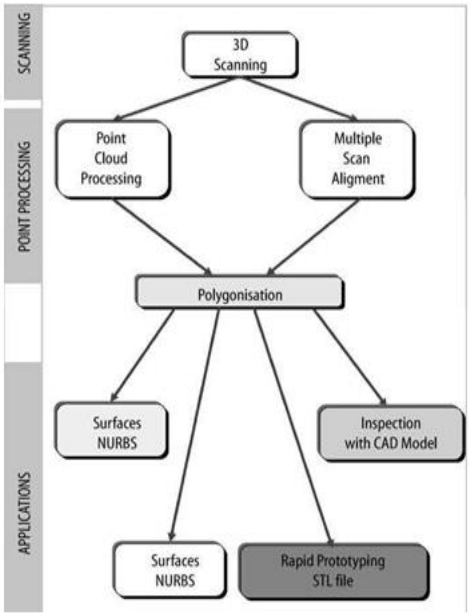


**Fig. 2.** Reverse Engineering – the generic process [1]

Reverse engineering strategy must consider the following:

- Reason for reverse engineering of a part.
- Number of parts to be scanned – single or multiple.
- Part size – large or small.
- Part complexity – simple or complex.
- Part material – hard or soft.
- Part finish – shiny or blurry.
- Part geometry – cylindrical or prismatic and internal or external.
- Accuracy required – linear or volumetric.

Computer-Aided Reverse Engineering (CARE) relies on the use of computer - aided tools for ob- taining the part geometry, identifying its material, improving the design, tooling fabrication, manufac- turing planning and physical realization. The structure is shown in Figure 3.

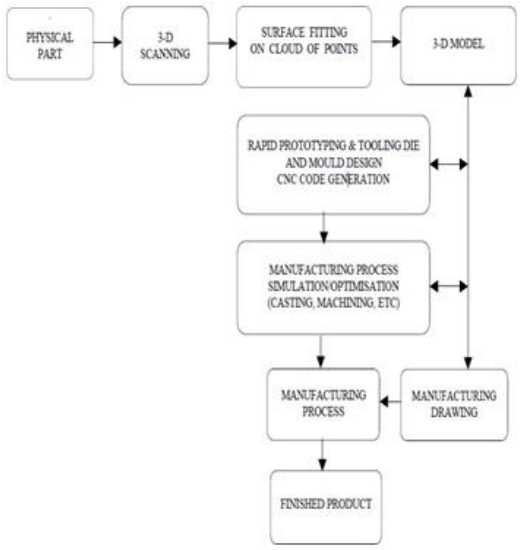


**Fig. 3,** Computer-aided reverse engineering framework [5]

A solid model of the part is the backbone for computer-aided reverse engineering. The model data can be exported from or imported into CAD/CAE/CAM system using standard formats such as IGES, STL, VDA and STEP. The three most important sets of data in reverse engineering activities are related to the CAD model generation, material identification, and manufacturing [5].

Reverse engineering (RE) is generally defined as a process of analyzing an object or existing sys- tem using hardware and software, to identify its components, their interrelationships and to investi- gate how it works in order to redesign it or produce a copy without access to the design from which it was originally produced.

Reverse engineering hardware is used for re- verse engineering data acquisition, which for 3-D modeling, is the collection of geometric data that represent a physical object. There are three main technologies for reverse engineering data acquisition: contact, noncontact and destructive. Outputs of the reverse engineering data acquisition process are 2D cross-sectional images and point clouds that define the geometry of an object (Figure 4).

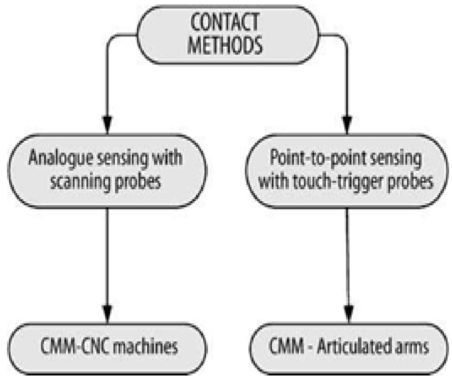


**Fig. 4.** Reverse engineering hardware classification [1]

Reverse Engineering software is used to trans- form the reverse engineering data produced by re- verse engineering hardware into 3D geometric mod- els. The final outputs of the reverse engineering data processing chain can be one of two types of 3D data:
(i) polygons or (ii) NURBS (no uniform rational B-splines). Polygon models, which are normally in the STL, VRML, or DXF format, are commonly used for rapid prototyping, laser milling, 3D graphics, simulation, and animations. NURBS surfaces or solids are frequently used in computer-aided design, manufacturing, and engineering (CAD-CAM-CAE) applications [1].

Except the advantages obtained by the use of reverse engineering, during the implementation, we encountered some barriers that are necessary to be overcome for its wider acceptance. As can be seen from Figure 5, this study proposes a three-phased factor analysis approach in order to determine the critical factors that effects the adoption of reverse engineering technologies.

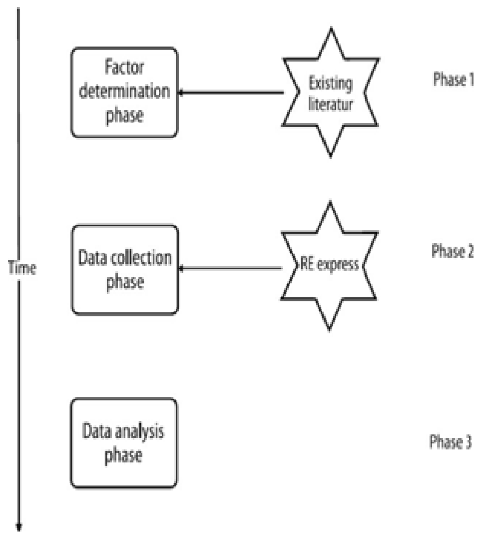


**Fig. 5.** Factor analysis approach [1]

**Factor determination** phase is a hypothetical research model and it uses a multidimensional model to represent the organizational, environmen- tal, and project dimensional factors. Using of a such dimensional model allows clustering the factors, and also facilitates a logical data collection and analysis study.

**Data collection phase** offers a qualitative ap- proach using interviews with experts in the field of reverse engineering. The data collection was carried out by reverse engineering expert and a qualified co- ordinate measuring machine (CMM) operator. Both of them analyzed the collected data. Face-to-face in- terviews, approximately 50 minutes longm were conducted. The number of interviewees was deter- mined during data collection. The interviewing was stopped in the moment, when no new information was obtained from interviewees and saturation was reached.

**Data analysis phase** is closely aligned with the empirical phase. After data are collected, the data are prepared for analysis. The quantitative data are typically entered into a statistical program and qualitative data are often transcribed in order to fa- cilitate data analysis.

As we know with reverse engineering, for an existing mechanical part we make the technical drawings in order to make a production of it. Be- cause the original part already physically exists, some people believe that reverse engineering and duplicating are the same.

But this is not true, because duplicating pro- cess is based on expected short time benefits in or- der to make profit through manufacturing of prod- ucts which will provide less of the properties and functional specifications compared with the original products. Duplicating differs from reverse engineer- ing in sense that products made with duplicating will result in products on low level technology. In case of complicated products, duplicating will not result in adoption of technology of manufacturing. Instead of that, the reverse engineering will result in preparing production technology, similar or better, than previous used for manufacturing the original part. Manufacturing of products with reverse engi- neering approach is based on a long term benefits and innovations. Application of updated standards, manufacturing of optimized products and working on products development and improvement is the best scheme in adopting reverse engineering meth- ods [3].

## III. TECHNIQUES AND TOOLS FOR CASE STUDY

Main techniques used by reverse engineering for our case study are calipers used for measure- ment, Autodesk Inventor software used for CAD modeling and CNC milling machine that it used for realizing the physical part. The current situation in the factory offers the above mentioned possibilities. The production is mainly individual with different quality requirements. So the application of the re- verse engineering is not continuous, but it depends on every specific case.

A) Calipers

Using the calipers as device of measurement is considering as (reverse engineering) manual pro- cess for taking the dimensions from different me- chanical parts. Then, from these measurements, we could manually define a 3D computer model using CAD primitives. There are different constructions of calipers, but in principle there are not very big differences between them. All of them have a pur- pose of reducing the measuring error and increasing the accuracy of the reading. The Figure 6 shows standard vernier caliper.

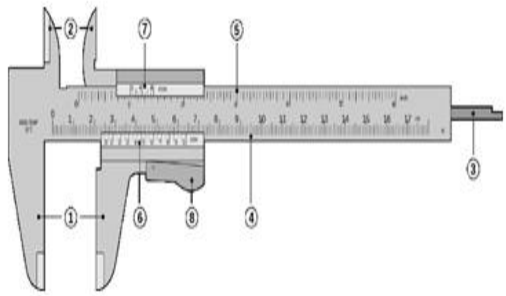

**Fig. 6.** Vernier caliper [6]

The parts of the caliper include:

1. **Outside large jaws**: used to measure ex- ternal diameter or width of an object.
2. **Inside small jaws**: used to measure inter- nal diameter of an object.
3. **Depth probe/rod**: used to measure depths of an object or a hole.
4. **Main scale**: scale marked every mm.
5. **Main scale**: scale marked in inches and fractions.
6. **Vernier scale** gives interpolated measure- ments to 0.1 mm or better.
7. **Vernier scale** gives interpolated measure- ments in fractions of an inch.
8. **Retainer**: used to block movable part to allow the easy transferring of a measurement.

B) CNC milling machine

CNC is the abbreviation of computer numeri- cal control. The working principle of these highly flexible machines is based on converting the CAD (Computer Aided Design) of the part with

CAM (Computer Aided Manufacturing) software in cut- ting tool trajectory (in coordinates). These Com- puter Numerical Control (CNC) machines made revolution in manufacturing, enabling production of different complex parts, with different accuracy and different materials.

CNC milling machines are the most widely used type of CNC machines. Typically, they are grouped by the number of axes simultaneously op- erating. Axes are labelled with various letters [7].

The machine shown in Figure 7 was taken from the factory where the mechanical parts pre- sented in this paper, as case study, were produced.


**Fig. 7.** CNC milling machine [8]

## IV. PRACTICAL ANALYSIS

Damage of machine parts is a serious problem in production. It affects production efficiency and causes financial losses due to machine(s) malfunc- tion. Most threatened are components like transmis- sion parts, tools or electronics. Our examples show cases of a damaged: tool part (precision) and me- chanical part (complex geometry).

A) Tool part (precision)

Figure 8 shows tool part which has some dam- age or cracks along the channels and holes.

For this part, which has to be produced again, first must be estimated the costs and required time for manufacturing. The precision and the type of tool material are the two main components neces- sary for the measurement and reconstruction proce- dure.

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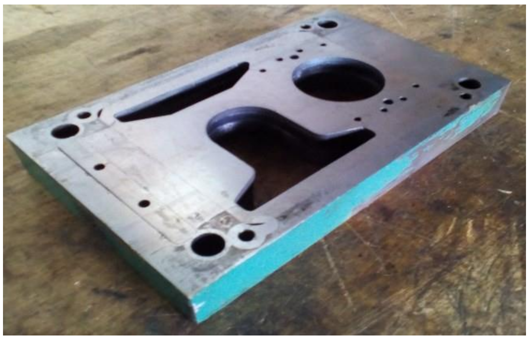

**Fig. 8.** Tool (original version) [8]

Based on the damages that exist on the tool, we have recommended that it should be produced a completely new part. In this case it is possible to ap- ply reverse engineering to eliminate possible ma- chine damage due to the tool damage. The tool part was measured with calipers and we made a CAD model of the part (tool) with autodesk inventor (Fig- ure 9).

After we have made the measurements of the existing work piece and created a 3D model through the software (Figure 10), the next step was the ma- chining the part on the respective machine (Figure 11).

The tool part was drawn in 1:1 ratio, so its con- version in required different forms was very easy.

The software used in this case (Autodesk IN- VENTOR 2017) is very professional and provides many opportunities for designing and correction of parts.

**Fig. 9.** Measurement of tool part [8]

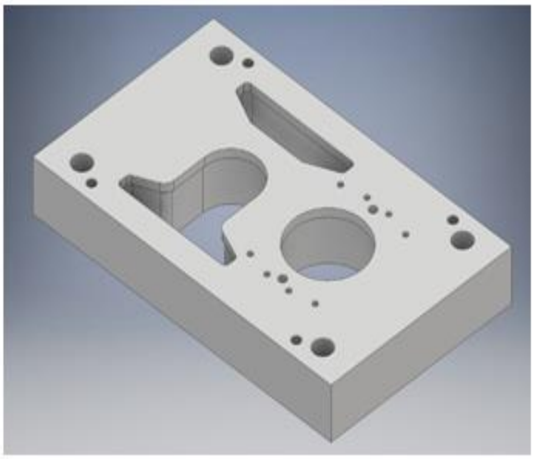

**Fig. 10.** CAD model of tool part

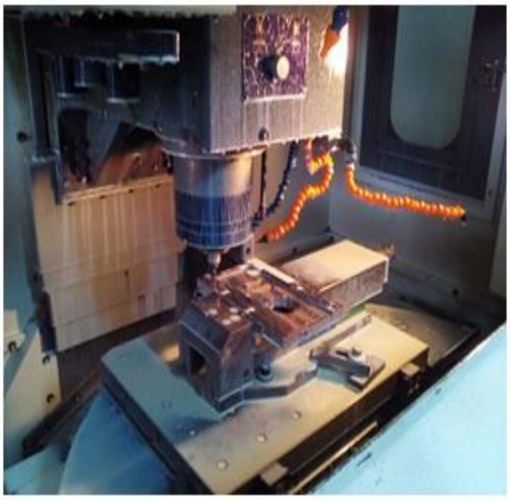

**Fig. 11.** Production of tool part with CNC Milling machine [8]

B) Mechanical part (complex geometry)

The mechanical part shown in Figure 12 is used like housing for holding shafts with bearings and it makes an assembly with bolts with an others part. This broken mechanical part should have been manufactured again with previous estimation of costs and necessary time for production. The complex geometry of this mechanical part was very difficult to be measured and to be created a 3D geometrical model.

The requirement was to compare the original part produced with casting, with the part made of construction steel manufactured by milling. We made some optimization in geometric shape of the mechanical part in order to obtain easier manufac- turing, but the functionality remained still un- changed, the same like in the original part.

Based on the damages that are presented in the Figure 12, we recommended that mechanical part should be produced as a new one. In this case it is also possible to apply reverse engineering in order to eliminate the part damage. The part was meas- ured with calipers and we made a CAD model of the mechnaical part with Autodesk Inventor.

After we have made the measurement of the existing work piece and creating the 3D model through the software, the next step was the manufacturing on the milling machine (Figure 13).
The used software (Autodesk INVENTOR 2017) provides many opportunities for design of parts complex geometry (Figure 14).

**Fig. 12.** Mechanical part (original version) [8]

**Fig. 13.** New mechanical part produced with milling and welding

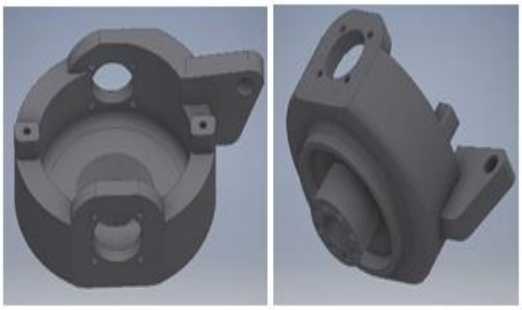

**Fig. 14.** CAD model of the mechnical part

Applying reverse engineering (RE) techniques in our case gives us great opportunities for prelimi- nary analysis before real production. On the created CAD model we could compare the dimensions with the real part and have possibility to make easy changes and improvements. .

## V. RECOMMENDATIONS FOR IMPROVEMENT

Analyzing the current situation in the factory which was given as a practical example, it could be mentioned that the measurement of the machine parts with calipers affects on continuous loss of time during the measurement process and reduces the re- liability for accurate measurements.

Error criteria set by the parts orderer for rejec- tion of mechanical parts was 0.1 mm. Parts with er- rors above 0.1 mm were considered as a scrap.

The above given examples, show us that the application of coordinate measuring machine (CMM) technology would be much better, because the accuracy will be higher and the ability to make corrections will be much faster.

Coordinate measuring machine (CMM) con- sists of a probe supported on three mutually perpen- dicular (x, y, and z) axes (Figure 15).

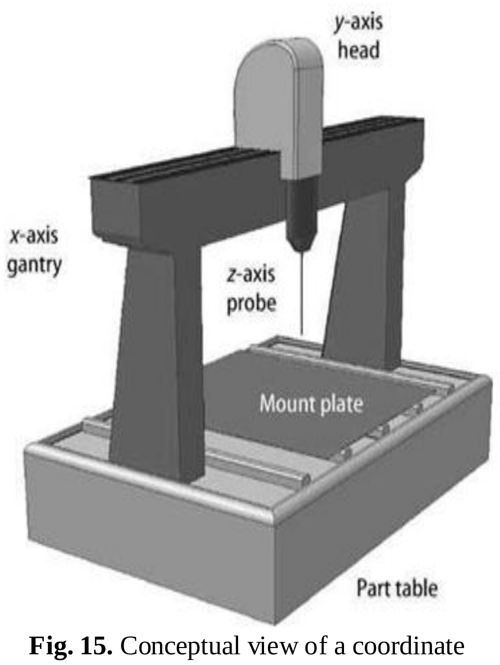


**Fig. 15.** Conceptual view of a coordinate measuring machine (CMM) [1]

Coordinate measuring machine (CMM) gener- ates 3D coordinate points, as the probe moves across the surface of the part. Operators may run co- ordinate measuring machine (CMM) in a manual mode where they move the probe around an object and collect coordinate measurements, or they may program the probe to move automatically around the part [1].

The coordinate measuring machines (CMM) can be divided into mainly two major types: with contact-type measurement system and with non- contact measurement system [9].

Reverse engineering using 3D digitizing is a potential methodology to make virtual prototype models for analysis and 3D visualization of the products [10].

Applying reverse engineering will be essential for the technical and economic development of the analyzed factory in general.

## VI. CONCLUSION

In this paper, the mechanical parts that have been selected for analysis were: tool part (precision) and mechanical part (complex geometry).

The form used for measurement the mechani- cal parts was through the calipers, which is currently the only opportunity in the factory used as an exam- ple. Drawing of the parts and creating their CAD models was on computer using Autodesk Inventor software.

Taking into the account the analysis that were made, we can conclude that digital scanning is in- dispensable and irreplaceable for application to minimize errors and reduce the time of measure- ment.

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