Study Paper on Analysis & Application of Gear using Reverse Engineering

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Abstract- *Rapid prototyping has become an increasing part of product development process chains resulting in reduced time to market and reduced development costs. As manufacturers strive to further reduce development cycles to maintain market competitiveness, the use of reverse engineering technologies have started to play key roles in the product development cycles. Integration of these technologies into existing development cycles provides tools to maintain design integrity during development stages as well as between successive product lines. One aspect of reverse engineering is the interspacing of data obtained from these technologies to manufacturing processes such as rapid prototyping.*

The engineering design supported by CAD/CAE techniques allows optimizing the product concept before manufacturing with assistance of CAM, in management for rapid product development and rapid set-up production in advance. For some product development processes reverse engineering (RE) allows to generate surface models by three-dimensional (3D)-scanning technique, and consequently this methodology permits to manufacture different parts (for cars, for household appliances) and tools (moulds, dies, press tools) in a short development period.

I. INTRODUCTION

Why rapid product development is necessary? , asked many workers special in countries of middle and east Europe. Owners and directors of factories answer is, that the involved money in process must give maximal benefit in other case they not make investment in such production. Very important production is cars manufacturing, where every of car content thousand and more pieces, which must be made as quicker and cheaper is possible, by achieving of prescribed quality.

For example: By small or bigger changing of car model there are changes in many of pieces too. The time of changing became shorter and shorter and requirements set in motion all in the production chain in great hurry with time. In such case Reverse Engineering (RE) proves to be very useful and successful than other methods. It makes use of tools, which are different scanning systems, which help in the short time exact dimensional explanation in digital concept, which is useful for direct control on machine tool in advance.

The RE is now an accepted part of modern product design and manufacturing process. The RE process can be loosely defined as process that result in the creation of a mathematical model from a physical one. There are some reasons why this is necessary:

- Some parts exist for which no design/manufacturing documentation exists.
- In some cases it is necessary only to extract 2D profile data from the model as the complete part may be efficiently modeled using these profiles and a surface CAD/CAM system.
- Potential application area can be found in the injection moldings industry (rapid tooling, recovering broken moulds or duplicating a mould); other fields such as medical, eyewear or the toy industry.

II. REVERSE ENGINEERING

There are two types of engineering,

1) Forward engineering
2) Reverse engineering.

1) Forward Engineering: It is the traditional process of moving from high-level abstractions and logical designs to the physical completion of a system. In some situations, there may be a physical part/product without any technical details, such as drawings, bills-of-material, or without engineering data.

2) Reverse Engineering: The process of duplicating an existing part, subassembly, or product, without drawings, documentation, or a computer model is known as reverse engineering (RE). Reverse Engineering is also defined as the process of obtaining a geometric CAD model from 3-D points acquired by scanning/ digitizing existing parts/products. Reverse Engineering is the process of designing, manufacturing, assembling, and maintaining products and systems.

RE not only helps in duplicating parts but also in understanding the working of the component which to be reverse engineered.

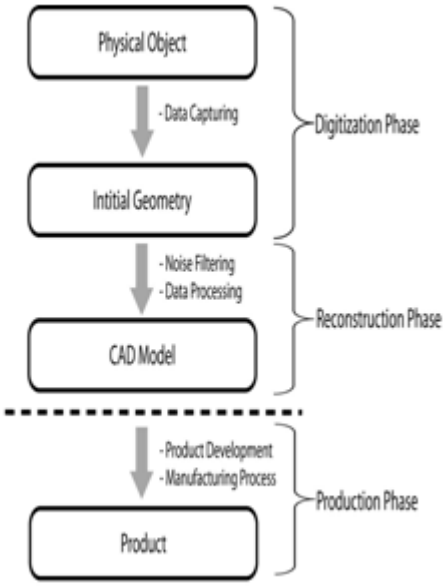

Fig. 1. Reverse Engineering Process

III. REASONS FOR USE OF REVERSE ENGINEERING

Following are some of the reasons for using reverse engineering:

1. The original manufacturer no longer exists, but a customer needs the product, e.g., aircraft spares required typically after an aircraft has been in service for several years.
2. The original manufacturer of a product no longer produces the product, e.g., the original product has become obsolete.
3. The original product design documentation has been lost or never existed.
4. Creating data to restore or manufacture a part for which there are no CAD data, or for which the data have become obsolete or lost.
5. Inspection and/or Quality Control–Comparing a fabricated part to its CAD description or to a standard item.
6. Some bad features of a product need to be eliminated e.g., excessive wear might indicate where a product should be improved.
7. Analyzing the good and bad features of competitors' products.
8. Creating 3-D data from a model or sculpture for animation in games and movies.
9. Creating 3-D data from an individual, model or sculpture to create, scale, or reproduce art work.

Reverse engineering enables the duplication of an existing part by capturing the component's physical dimensions, features, and material properties. Before attempting reverse engineering, a well-planned life-cycle analysis and cost/benefit analysis should be conducted to justify the reverse engineering projects. Reverse engineering is typically cost effective only if the items to be reverse engineered reflect a high investment or will be reproduced in large quantities.

IV. PRODUCT DEVELOPMENT APPROACHES

Nowadays the management of engineering product design could be realized based on the two methodologies presented through two information flows called "conventional Approach or Classical production process" and "Non-conventional approach or Reverse engineering process".

1. Conventional Approach :

The conventional approach to develop products with CAD/CAE/CAM techniques normally starts with the geometric modelling utilising a CAD system. The geometric model could be represented as a wire frame or as surfaces or as a solid structure. Via conceptual modeling, the generated CAD information could be exported subsequently in standard format (IGES points/STL binary, ASCII data, DXF polyline, VDA points or IGES/STL surfaces) and imported in the same data format to CAE systems (allowing numerical model simulation) and/or to CAM systems (allowing to generate tooling trajectories—NC-code).

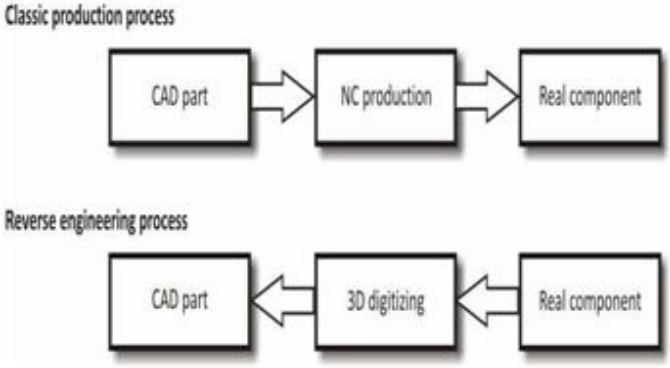

Fig. 2. Classical and Nonconventional approach of production

2. Non-conventional approach :

The product development by conventional approach is not applicable when the goal is to reengineer or to simulate and to optimize parts/moulds/tools already existents without information in CAD data format. Consequently, will be necessary to apply techniques that allow capturing the geometry of parts/moulds/tools and to generate a conceptual numerical model that will be used in CAE and CAM systems . This process is regularly called reverse engineering.

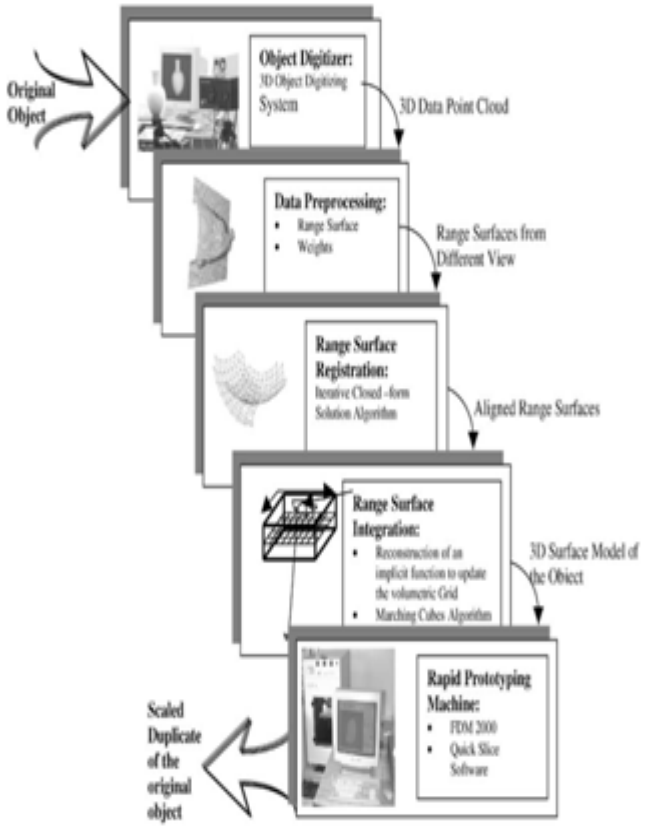

Fig. 3. Schematic diagram of the reverse/conventional engineering system

V. DIFFERENCE BETWEEN REVERSE ENGINEERING AND OTHER TYPES

The most traditional method of the development of a technology is referred to as "forward engineering." In the construction of a technology, manufacturers develop a product by implementing engineering concepts and logics. On other hand, reverse engineering begins with final product, and works backward to recreate the engineering concepts by analyzing the design of the system and the interrelationships of its components.

Value engineering refers to the creation of an improved system or product to the one originally analyzed. While there is often overlap between the methods of value engineering and reverse engineering, the goal of reverse engineering itself is the improved records of how the original product works by uncovering the principal design. The working product that results from a reverse engineering effort is more like a duplicate of the original system, without necessarily adding modifications or improvements to the original design.

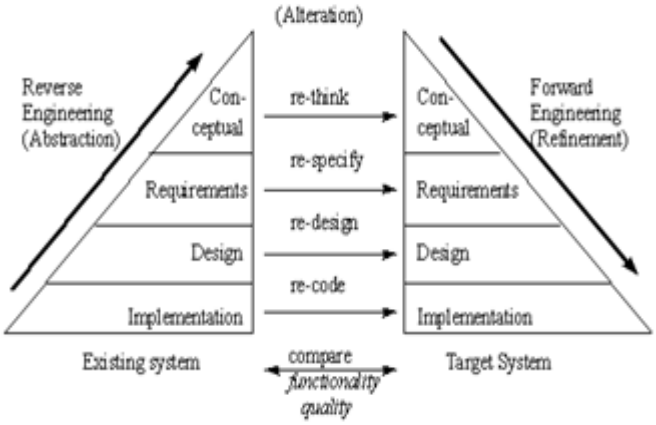

Fig. 4. Difference between Reverse engineering and other types

VI. STAGES INVOLVED IN REVERSE ENGINEERING PROCESSS

In order to reverse engineer a product or component of a system, engineers and researchers generally follow the following four-stage process:

1. Identifying the product or component which will be reverse engineered.
2. Observing or disassembling the information documenting how the original product works.
3. Implementing the technical data generated by reverse engineering in a replica or modified version of the original.
4. Creating a new product (and, perhaps, introducing it into the market).

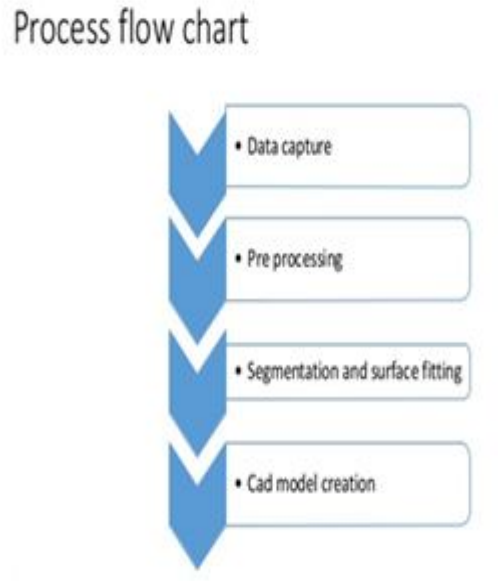

Fig. 5. Stages involved in the Reverse engineering process

1. In the first stage in the process, sometimes called "prescreening," reverse engineers determine the candidate product for their project. Potential candidates for such a project include singular items, parts, components, units, subassemblies, some of which may contain many smaller parts sold as a single entity.
2. The second stage, disassembly or recompilation of the original product, is the most time-consuming aspect of the project. In this stage, reverse engineers attempt to construct a characterization of the system by accumulating all of the technical data and instructions of how the product works.
3. In the third stage of reverse engineering, reverse engineers try to verify that the data generated by disassembly or recompilation is an accurate reconstruction the original system. Engineers verify the accuracy and validity of their designs by testing the system, creating prototypes, and experimenting with the results.
4. The final stage of the reverse engineering process is the introduction of a new product into the marketplace. These new products are often innovations of the original product with competitive designs, features, or capabilities. These products may also be adaptations of the original product for use with other integrated systems, such as different platforms of computer operating systems.

Fig. 6. 3-D Scanners and CMM

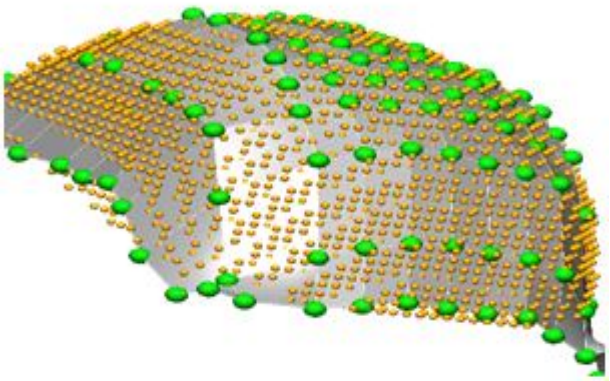

Fig . 7. Segmentation and Surface fitting

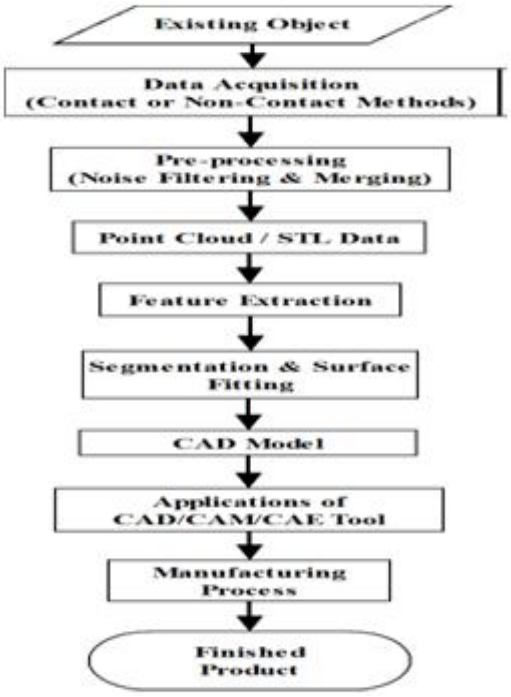

Fig. 8. Basic flow of Reverse Engineering

VII. APPLICATIONS

Reverse engineering (RE) is the process of creating a CAD model from a physical part or prototype .In the conventional product development cycle, the initial conceptual or aesthetic design of sculptured surfaces is often described by stylists who formalize their ideas by making clay or wooden models. Recently, RE is increasingly employed in medical applications.

For example, physical models are molded from a part of the body, such as the stump of an amputated limb, and an appropriate model is then captured and developed from the mold and used to custom-fit an artificial limb. Necessary CAD models can be generated using RE technology based on the corresponding geometric database, which is usually created by capturing the shape information from the original physical model by mechanical contact or optical noncontact measuring techniques. In the area of mechanical engineering alone, Reverse Engineering techniques can be used for:

1. Inspection of parts and comparison of the actual geometry with computer aided design (CAD) models.
2. Capturing the shape of an existing part, possibly one that is outdated, so that a replacement part can be manufactured through a rapid prototyping approach, numerically controlled (NC) machining of surfaces interpolated through the captured points.
3. Capturing the deformed shape of an object, after some sort of impact test, to compare the actual deformed shape with that predicted by finite element analysis.

4. Wear measurement of tooling.

But if the list of mechanical engineering applications alone seems endless, there are applications in medicine, such as prosthetic design and manufacture, aerospace industry, animation, civil engineering, and many other fields.

VIII. ADVANTAGES

- Restoration of outdated damaged components of machines.
- Data storage and quick access.
- Research work for advancements.
- Time saving for rapid prototyping.
- More reliable process with high precision.
- Easy analysis of components before assembling.

IX. DISADVANTAGES

- Skilled workers are required.
- Costly equipments are required.
- Time consuming for individual analysis of component.
- Every work cannot be approved due to patenting of products.
- Makes use of some of the most reliable technologies but their use is limited to specialized laboratories and for small objects.

X. CASE STUDY: ANALYSIS AND SOLUTION FOR DAMAGED PARTS (EXAMPLE: GEAR)

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. As it came to snap of part of wheel it doesn't allow another machine running. Damaged gear wheel like this should be changed for a new one.

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.

Fig. 9. Damaged Gear wheel

Step1) 3D scanning:

First step of replacing the damaged gear wheel is to get its 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. 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 were mainly about tooth system. It aroused due to uncontrolled laser ray scattering. That caused incorrect scanning. This problem looks like points in space, which doesn't exist in real. We used for this effect elimination "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.

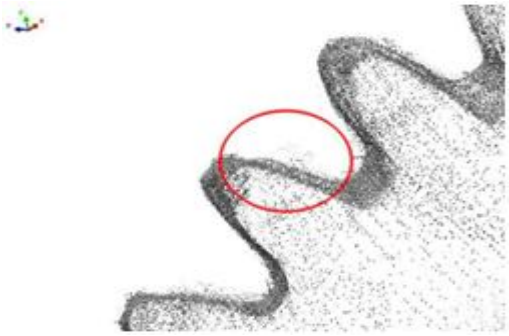

Fig. 10. Inaccuracy of 3D scanning

Fig.11.Gear-wheel after surface modification

Step2) Data Segmentation:

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. Those gave us missing axis for tooth system patterning and also the smaller cylinder surfaces served us for gearing pattern angle definition. Objects integration for gearing pattern:

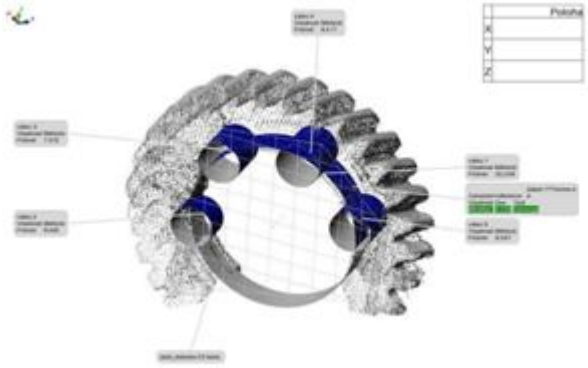

Fig. 12. Scanned Object

Step 3) 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 Poly Works 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. 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.

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. 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. Processing of construction solution 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, 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. Comparison proved accuracy of chosen progress of construct solution and , there is clear interlacing of 3D model and the scan.

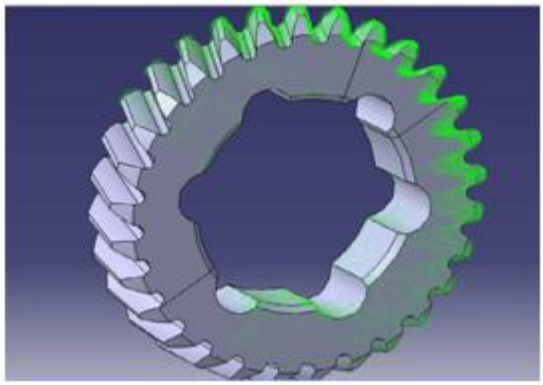

Fig. 13. Solid part compared with the scan

Step 4) Final Product :

After a solid 3D model was generated, we´ve created the STL model for prototype production of the new gear wheel from ABS material via rapid prototyping processes. 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. After that it´s possible such made wheel to test and to use it as replacement for original damaged gear wheel.

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.

ULTEM 9085 : Polyetherimide (PEI) : Amorphous, amber to transparent thermoplastic. Ultem has a high dielectric strength ,natural flame resistance .Ultem has high mechanical properties.

Fig. 14. New gear Wheel made from ULTEM 9085

XI. COCNLUSION

Reverse engineering is the process of investigating the technological principles of a device, object or system by studying its structure, function and operation within shortest possible time whether we have or don't any knowledge about that topic.

- With advancements in software's and hardware's reverse engineering automatically makes progress, to make things more understandable and accurate.
- It often involves taking something (e.g., a mechanical device, electronic component, or software Program) apart and analyzing it in detail which is to be used in understanding the structure & functioning of the object or to try to make a new device or program that does the same thing with more efficiency than the existing system.
- The purpose is to deduce design decisions from end products with little or no additional knowledge about the procedures involved in the original production.
- As computer aided Design (CAD) has become more popular, reverse engineering has become an effective method to create a 3D virtual model of an existing physical part for use in 3D CAD, CAM, CAE and other software. The reverse-engineering process involves measuring an object and then reconstructing it as a 3D model. The physical object can be measured manually using gauges, scales & meters or with the help of computers using 3D scanning technologies like CMMs, laser scanners, structured light digitizers or computed tomography.
- It is a process that can reduce the product development cycle besides cost saving. Effective use of reverse engineering application is expected to impact market in the future.

ACKNOWLEDGMENT

I would like to thank the many people who have helped me along this journey. First to my guide Mr. Sourabh Borchate sir, assistant professor at Dr. D. Y. Patil Institute of Engineering, Management and Research, Akurdi, Pune and Mr. K. Narkar sir, HOD of Mechanical Department at Dr. D. Y. Patil Institute of Engineering, Management and Research, Akurdi, Pune for their academic support as well as giving me academic freedom in research direction.

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