Dimensional Error Analysis and Computer Aided Modelling of Gear Box Cover Plate by using CMM

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***Abstract*—** As the Manufacturing companies are increasingly embracing computer integrated manufacturing (CIM), the need for Computer-Aided-Measurement increased as well. The evolution of the Co-ordinate Measuring Machine (CMM) was a big breakthrough in dimensional metrology as the need for more accurate measuring devices increased. CMM usage in various industries within last decades became very popular for quality inspections. Measuring machines can be use in direct determination of correction values of dimensions and the metrological aspects.

In this work the dimensional error analysis of gear box side cover plate used in Rotavetor in Jadhao Icon industry, situated to nearby MIDC in Amravati. This work explains the procedure of correct dimensions taken from the failure parts which has many issues such as tolerance, limits, fits, allowances and deviations. Also this project work states the methods of correct dimensioning of parts over the conventional method. In this work the coordinate machine is utilized for measuring the gear box plate also the scanning takes place for the generation of correct profile and other dimensions to prepare a CAD model using CATIA software. The error analysis is conducted using the conventional methods, CMM method and CMM scanning readings. Also the new method is introduced for the above in the area of quality inspection program was developed. This dimensioning method proves and solves the issues related to the quality inspection. These error analyses helps to the Industry and solve the number of problem associated with the dimensioning of gear box plate and the other part that directly and indirectly connected to the gear box mechanism. The numbers of observation have been taken for the dimensional error analysis which will also introduce in the new parts. This work proves the necessity of dimensional analysis in the area of quality inspections.

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I. Introduction

The first CMM was developed by the Ferranti Company of Scotland in the 1950s as the result of a direct need to measure precision components in their military products, although this machine only had 2 axes. The first 3-axis models began appearing in the 1960s (DEA of Italy) and computer control debuted in the early 1970s (Sheffield of the USA). Leitz Germany subsequently produced a fixed machine structure with moving table.

In modern machines, the gantry type superstructure has two legs and is often called a bridge. This moves freely along the granite table with one leg (often referred to as the inside leg) following a guide rail attached to one side of the granite table. The opposite leg (often outside leg) simply rests on the granite table following the vertical surface contour. Air bearings are the chosen method for ensuring friction free travel. In these, compressed air is forced through a series of very small holes in a flat bearing surface to provide a smooth but controlled air cushion on which the CMM can move in a frictionless manner. The movement of the bridge or gantry along the granite table forms one axis of the XY plane. The bridge of the gantry contains a carriage which traverses between the inside and outside legs and forms the other X or Y horizontal axis. The third axis of movement (Z axis) is provided by the addition of a vertical quill or spindle which moves up and down through the center of the carriage. The touch probe forms the sensing device on the end of the quill. The movement of the X, Y and Z axes fully describes the measuring envelope. Optional rotary tables can be used to enhance the approachability of the measuring probe to complicated work pieces. The rotary table as a fourth drive axis does not enhance the measuring dimensions, which remain 3D, but it does provide a degree of flexibility. Some touch probes are themselves powered rotary devices with the probe tip able to swivel vertically through 90 degrees and through a full 360 degree rotation.

As well as the traditional three axis machines CMMs are now also available in a variety of other forms. These include CMM arms that use angular measurements taken at the joints of the arm to calculate the position of the stylus tip. Such arm CMMs are often used where their portability is an advantage over traditional fixed bed CMMs.

CMM

A coordinate measuring machine is a 3D device for measuring the physical geometrical characteristics of an object. This machine may be manually controlled by an operator or it may be computer controlled. Measurements are defined by a probe attached to the third moving axis of this machine. Probes may be mechanical, optical, laser, or white light, amongst others. A machine which takes readings in six degrees of freedom and displays these readings in mathematical form is known as a CMM. The typical 3 "bridge" CMM is composed of three axes, an X, Y and Z. These axes are orthogonal to each other

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in a typical three dimensional coordinate system. Each axis has a scale system that indicates the location of that axis. The machine will read the input from the touch probe, as directed by the operator or programmer. The machine then uses the X, Y,Z coordinates of each of these points to determine size and position with micrometer precision typically.

Parts of CMM:

Co-ordinate measuring machines include three main components:

- The main structure which include three axes of motion
- Probing system
- Data collection and reduction system - typically includes a machine controller,

Mechanical probe:

In the early days of coordinate measurement mechanical probes were fitted into a special holder on the end of the quill. A very common probe was made by soldering a hard ball to the end of a shaft. This was ideal for measuring a whole range of flat, cylindrical or spherical surfaces. Other probes were ground to specific shapes, for example a quadrant, to enable measurement of special features. These probes were physically held against the work piece with the position in space being read from a 3-Axis digital readout (DRO) or, in more advanced systems, being logged into a computer by means of a footswitch or similar device. Measurements taken by this contact method were often unreliable as machines were moved by hand and each machine operator applied different amounts of pressure on the probe or adopted differing techniques for the measurement.

Figure: Mechanical Probe

A further development was the addition of motors for driving each axis. Operators no longer had to physically touch the machine but could drive each axis using a hand box with joysticks in much the same way as with modern remote controlled cars. Measurement accuracy and precision improved dramatically with the invention of the electronic touch trigger probe. Although still a contact device, the probe had a spring-loaded steel ball (later ruby ball) stylus. As the probe touched the surface of the component the stylus deflected and simultaneously sent the X.Y,Z coordinate information to the computer. Measurement errors caused by individual operators became fewer and the stage was set for the introduction of CNC operations and the coming of age of CMMs.

Mechanical probes are lens-CCD-systems, which are moved like the mechanical ones, and are aimed at the point of interest, instead of touching the material. The captured image of the surface will be enclosed in the borders of a measuring window, until the residue is adequate to contrast between black and white zones. The dividing curve can be calculated to a point, which is the wanted measuring point in space. The horizontal information on the CCD is 2D (XY) and the vertical position is the position of the complete probing system on the stand Z-drive (or other device component). This allows entire 3D-probing.

Types of CMM:

1. Articulated arm
   a) portable or tripod mounted
   b) probe can be placed in many different directions
2. Bridge
   a) horizontally suspended
   b) x-axis carries the bridge
3. Cantilever
   a) supports probe from movable vertical support
4. Gantry
   a) frame structure raised on side supports

Reverse Engineering:

Engineering is a growing field that continues to evolve to suit the rapid changes of the 21st century. Engineering fields are constantly improving upon current designs and methods to make life simple and easier. When referring to technology, simple and easy can be directly related to fast and accurate. Simple meaning that, you do not use up valuable time in assembly or doing a specific task. Easy meaning how many times you will have to do the process or task. When we think of engineering we think of the general meaning of designing a product from a blue print or plan. Engineering is described as "the application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems". This type of engineering is more commonly known as Forward Engineering. An emerging engineering concept is utilizing forward en .Reverse engineering is the opposite of forward engineering. It takes an existing product ,and creates a CAD model, for modification or reproduction to the design aspect of the product. It can also be defined as the process or duplicating an existing component by capturing the components physical dimensions. Reverse engineering is usually undertaken in order to redesign the system for better maintainability or to produce a copy of a system without access to the design from which it was originally produced With this knowledge, computer vision applications have been tailor to compete in the area of reverse engineering. Computer vision is a computer process concerned with artificial intelligence and image processing of real world images. Typically, computer vision requires a combination of low-level image processing to enhance the image quality(e.g. remove noise, increase contrast) and higher level pattern recognition and image understanding to recognize features present in the image. Three-dimensional (3D)computer vision uses two-dimensional (2D), images to generate a 3D model of a scene or object. There has been a mandatory need for 3D reconstruction of scenes and objects by the manufacturing industry, medical industry, military branches and research facilities .Manufacturing industry utilizes reverse engineering for its fast rapid prototyping abilities and accuracy associated with the production of new parts.

Need for Reverse Engineering

- The original manufacturer of a product no longer produces a product .
- There is inadequate documentation of the original design
- The original manufacturer no longer exists, but a customer needs the product.
- The original design documentation has been lost or never existed.
- Some bad features of a product need to be designed out. For example, excessive wear
- Might indicate where a product should be improved.
- To strengthen the good features of a product based on long-term usage of the product.
- To analyze the good and bad features of competitors' product.
- To explore new avenues to improve product performance and features.
- To gain competitive benchmarking methods to understand competitor's Products and develop better products.
- The original CAD model is not sufficient to support modifications or currentManufacturing methods.
- The original supplier is unable or unwilling to provide additional parts.
- The original equipment manufacturers are either unwilling or unable to supply
- Replacement parts or demand inflated costs for sole-source parts.
- To update obsolete materials or antiquated manufacturing processes with more Current, less-expensive technologies.

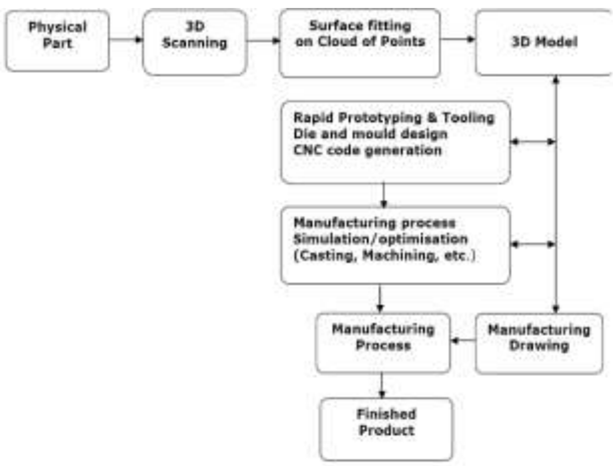

Figure no: Reverse Engineering

Reverse Engineering Applying Contact Techniques

Reverse engineering is a growing industrial market for manufacturing and development. Various individuals and groups have developed new techniques, which have been improvements to the current existing techniques available.

Their research describes a prototype of a reverse engineering system which uses manufacturing features as geometric primitives for mechanical parts. Their method is geared toward reverse engineering of mechanical parts. They have identified a feature based approach that they state produces highly accurate models, even when the original 3D sensor data has substantial errors. In the feature based approach, the registration of two different point clouds is performed by matching three points to three points, three spheres to three spheres, or three planes to three planes. Their main innovation was to use the features to fit scanned data, rather than using triangulated meshes or parametric surfaces patches. This research claims to have advantages over the current practice of ordinary CMMs. It states the resulting models can be directly imported into featured-based CAD systems without loss of the semantics and topological information inherent in featured-based representations. It assumes that the models are already generated into CAD model formation.

Non-Contact Data Acquisition Techniques

Non-contact methods use light, sound or magnetic fields to acquire shape from objects. In the case of contact and non-contact, an appropriate analysis must be performed to determine the positions of the points on the objects surface. Each method has strengths and weaknesses that require the data acquisition system to be carefully selected for the shape capture functionality desired.

Optical methods of shape capture are probably the broadest and growing in popularity over contact methods. This is because they have relatively fast acquisition rates. Laser triangulation is one of the important method. This section will discuss the various principles of each method.

Laser Triangulation is a method, which uses location and angles between light sources and photo sensing devices to deduce position. A high-energy light source is focused and projected at a pre-specified angle at the surface of interest. A photosensitive device, usually a video camera, senses the reflection of the surface and then by using geometric triangulation from the known angle and distances, the position of a surface point relative to a reference plane can be calculated. The light source and the camera can be mounted on a traveling platform which then produces multiple scans of the surface. These scans are therefore relative measurements of the surface of interest. Various different high energy light sources are used, but lasers are the most common. Triangulation can acquire data at very fast rates. The accuracy is determined by the resolution of the photosensitive device and the distance between the surface and the scanner.

Aim and Objectives:

- To study the conventional methods of Measurements
- To study the CMM measurements techniques such as direct measurements and scanning.
- To prepare the Inspection program using CMM
- To developed a CAD model using CATIA software
- To Measure the conventional, scanning, inspection program dimensions
- To conduct a dimensional error analysis for the measured dimensions from the various methods
- To prepare the correct dimensions chart for the given part.

Reasons for reverse engineering:

Interfacing. RE can be used when a system is required to interface to another system and how both systems would negotiate is to be established. Such requirements typically exist for interoperability.

Military or commercial espionage. Learning about an enemy's or competitor's latest research by stealing or capturing a prototype and dismantling it. It may result in development of similar product.

Improve documentation shortcomings. Reverse engineering can be done when documentation of a system for its design, production, operation or maintenance have shortcomings and original designers are not available to improve it. RE of software can provide the most current documentation necessary for understanding the most current state of a software system

Obsolescence. Integrated circuits often seem to have been designed on obsolete, proprietary systems, which means that the only way to incorporate the functionality into new technology is to reverse-engineer the existing chip and then re-design it.

Software Modernization. RE is generally needed in order to understand the 'as is' state of existing or legacy software in order to properly estimate the effort required to migrate system knowledge into a 'to be' state. Much of this may be driven by changing functional, compliance or security requirements.

Product Security Analysis. To examine how a product works, what are specifications of its components, estimate costs and identify potential patent infringement. Acquiring sensitive data by disassembling and analyzing the design of a system component. Another intent may be to remove copy protection, circumvention of access restrictions.

Bug fixing. To fix (or sometimes to enhance) legacy software which is no longer supported by its creators.

Creation of unlicensed/unapproved duplicates.

Academic/learning purposes.RE for learning purposes may be understand the key issues of an unsuccessful design and subsequently improve the design.

Competitive technical intelligence. Understand what your competitor is actually doing, versus what they say they are doing.

Literature review

Quality and process control activities in a mechanical product's life cycle require that components be measured, or dimensionally inspected. Computer-controlled dimensional inspection is typically performed with Coordinate Measuring Machines (CMMs), which are very precise Cartesian robots that use touch probes to measure the coordinates of points on a work piece's surfaces. Automatic planning and programming of inspection tasks with a CMM involve spatial reasoning, to determine how to orient the part on the CMM, which probes to use, how to orient the probes, an so on. This paper introduces the notions of accessibility and approachability, which are important for inspection planning, and describes two sets of implemented algorithms for computing accessibility information. One of these sets of algorithms performs exact computations on polyhedral objects and is relatively slow, whereas the other uses discrete approximations and achieves high speed by exploiting standard computer graphics hardware. The discredited algorithm has been tested on real-world parts, and is sufficiently fast for industrial applications.

Dimensional Error Analysis:

In physics and all science, dimensional analysis is the practice of checking relations among physical quantities by identifying their dimensions. The dimension of any physical quantity is the combination of the basic physical dimensions that compose it. Some fundamental physical dimensions are length, mass, time, and electric charge. All other physical quantities are made up of these fundamental physical dimensions. For example, speed has the dimension length (or distance) per unit of time, and may be measured in meters per second, miles per hour, or other units. Similarly electrical current is electrical charge per unit time (flow rate of charge) and is measured in coulombs (a unit of electrical charge) per second, or equivalently, amperes. Dimensional analysis is based on the fact that a physical law must be independent of the units used to measure the physical variables. A straightforward practical consequence is that any meaningful equation (and any inequality and in equation) must have the same dimensions on the left and right sides. Checking this is the basic way of performing dimensional analysis.

Dimensional analysis is routinely used to check the plausibility of derived equations and computations. It is also used to form reasonable hypotheses about complex physical situations that can be tested by experiment or by more developed theories of the phenomena, and to categorize types of physical quantities and units based on their relations to or dependence on other units, or their dimensions if any. The basic principle of dimensional analysis was known to Isaac Newton (1686) who referred to it as the "Great Principle of Similitude "James Clerk Maxwell played a major role in establishing modern use of dimensional analysis by distinguishing mass, length, and time as fundamental units, while referring to other units as derived. The 19th-century French mathematician Joseph Fourier made important contributions based on the idea that physical laws like F = ma should be independent of the units employed to measure the physical variables. This led to the conclusion that meaningful laws must be homogeneous equations in their various units of measurement, a result which was eventually formalized in the Buckingham π theorem.

Manufacturing Process Manufacturing Gear Box Cover Plate

There are mainly 2 processes used for manufacturing of gear box cover plate,

1. Casting of cast steel grit(G25)
2. Machining operations such as drilling, threading

Casting:

Casting is a manufacturing process where a solid is melted, heated to proper temperature (sometimes treated to modify its chemical composition), and is then poured into a cavity or mold, which contains it in the proper shape during solidification. Thus, in a single step, simple or complex shapes can be made from any metal that can be melted. The resulting product can have virtually any configuration the designer desires.

In addition, the resistance to working stresses can be optimized, directional properties can be controlled, and a pleasing appearance can be produced.

Cast parts range in size from a fraction of an inch and a fraction of an ounce (such as the individual teeth on a zipper), to over 30 feet and many tons (such as the huge propellers and stern frames of ocean liners). Casting has marked advantages in the production of complex shapes, parts having hollow sections or internal cavities, parts that contain irregular curved surfaces (except those made from thin sheet metal), very large parts and parts made from metals that are difficult to machine. Because of these obvious advantages, casting is one of the most important of the manufacturing processes.

Today, it is nearly impossible to design anything that cannot be cast by one or more of the available casting processes. However, as in all manufacturing techniques, the best results and economy are achieved if the designer understands the various options and tailors the design to use the most appropriate process in the most efficient manner. The various processes differ primarily in the mold material (whether sand, metal, or other material) and the pouring method (gravity, vacuum, low pressure, or high pressure). All of the processes share the requirement that the materials solidify in a manner that would maximize the properties, while simultaneously preventing potential defects, such as shrinkage voids, gas porosity, and trapped inclusions.

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Drilling:

Drilling is a cutting process that uses a drill bit to cut or enlarge a hole of circular cross-section in solid materials. The drill bit is a rotary cutting tool, often multipoint. The bit is pressed against the work piece and rotated at rates from hundreds to thousands of revolutions per minute. This forces the cutting edge against the work piece, cutting off chips from what will become the hole being drilled.

Exceptionally, specially-shaped bits can cut holes of non-circular cross-section; a square cross-section is possible Drilled holes are characterized by their sharp edge on the entrance side and the presence of burrs on the exit side (unless they have been removed). Also, the inside of the hole usually has helical feed marks.

Drilling may affect the mechanical properties of the work piece by creating low residual stresses around the hole opening and a very thin layer of highly stressed and disturbed material on the newly formed surface. This causes the work piece to become more susceptible to corrosion at the stressed surface. A finish operation may be done to avoid the corrosion. Zinc plating or any other standard finish operation of 14 to 20 microns can be done which helps to avoid any sort of corrosion.

For fluted drill bits, any chips are removed via the flutes. Chips may be long spirals or small flakes, depending on the material, and process parameters. The type of chips formed can be an indicator of the machinability of the material, with long gummy chips reducing machinability.

When possible drilled holes should be located perpendicular to the work piece surface. This minimizes the drill bit's tendency to "walk", that is, to be deflected, which causes the hole to be misplaced. The higher the length-to-diameter ratio of the drill bit, the higher the tendency to walk. The tendency to walk is also pre-empted in various other ways, which include:

Establishing a centering mark or feature before drilling, such as by: Casting, molding, or forging a mark into the work piece Center punching Spot drilling (i.e., center drilling) Spot facing, which is facing a certain area on a rough casting or forging to establish, essentially, an island of precisely known surface in a sea of imprecisely known surface Constraining the position of the drill bit using a drill jig with drill bushings Surface finish in drilling may range from 32 to 500 micro inches. Finish cuts will generate surfaces near 32 micro inches, and roughing will be near 500 micro inches

Cutting fluid is commonly used to cool the drill bit, increase tool life, increase speeds and feeds, increase the surface finish, and aid in ejecting chips. Application of these fluids is usually done by flooding the work piece or by applying a spray mist.In deciding which drill(s) to use it is important to consider the task at hand and evaluate which drill would best accomplish the task. There are a variety of drill styles that each serve a different purpose. The sub land drill is capable of drilling more than one diameter. The spade drill is used to drill larger hole sizes. The index able drill is useful in managing chips.

Threading Process:

Threading is the process of creating a screw thread. More screw threads are produced each year than any other machine element. [1] There are many methods of generating threads, including subtractive methods (many kinds of thread cutting and grinding, as detailed below); reformative or transformative methods (rolling and forming; molding and casting); additive methods (such as 3D printing); or combinations thereof. Thread cutting

Thread cutting, as compared to thread forming and rolling, is used when full thread depth is required, when the quantity is small, when the blank is not very accurate, when threading up to a shoulder is required, when threading a tapered thread, or when the material is brittle.

Single-point threading:

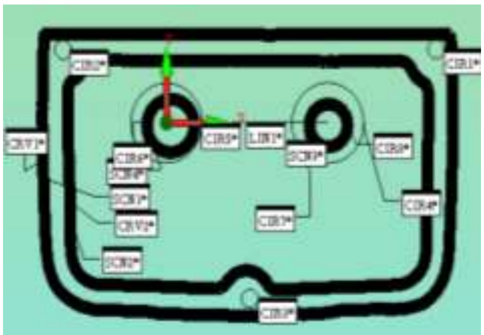
Single-point threading, also colloquially called single-pointing (or just thread cutting when the context is implicit), is an operation that uses a single-point tool to produce a thread form on a cylinder or cone. The tool moves linearly while the precise rotation of the work piece determines the lead of the thread. The process can be done to create external or internal threads (male or female). In external thread cutting, the piece can either be held in a chuck or mounted between two centers. With internal thread cutting, the piece is held in a chuck. The tool moves across the piece linearly, taking chips off the work piece with each pass. Usually 5 to 7 light cuts create the correct depth of the thread.

The coordination of various machine elements including lead screw, slide rest, and change gears was the technological advance that allowed the invention of the screw-cutting lathe, which was the origin of single-point threading as we know it today.

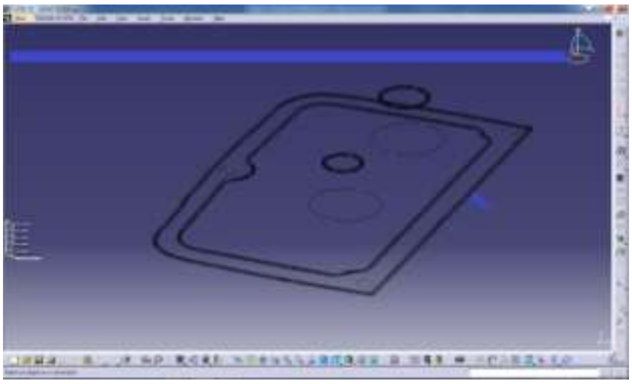
Today engine lathes and CNC lathes are the commonly used machines for single-point threading. On CNC machines, the process is quick and easy (relative to manual control) due to the machine's ability to constantly track the relationship of the tool position and spindle position (called "spindle synchronization"). CNC software includes "canned cycles", that is, preprogrammed subroutines that obviate the manual programming of a single-point threading cycle. Parameters are entered (e.g., thread size, tool offset, length of thread), and the machine does the rest.

All threading could feasibly be done using a single-point tool, but because of the high speed and thus low unit cost of other methods (e.g., tapping, die threading, and thread rolling and forming), single-point threading is usually only used when other factors of the manufacturing process happen to favor it (e.g., if only a few threads need to be made, if an unusual or unique thread is required, or if there is a need for very high concentricity with other part features machined during the same setup .

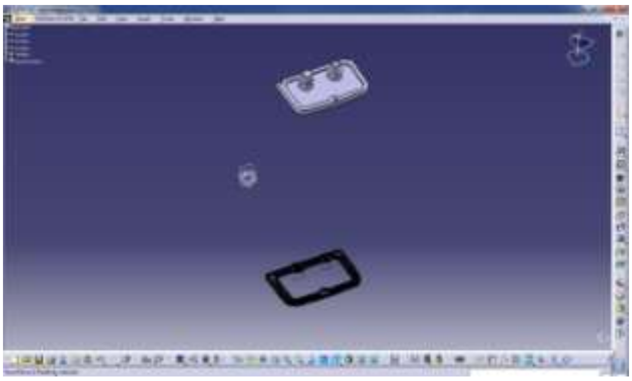
CMM Scanning and Cad Modelling Scanning Through CMM:



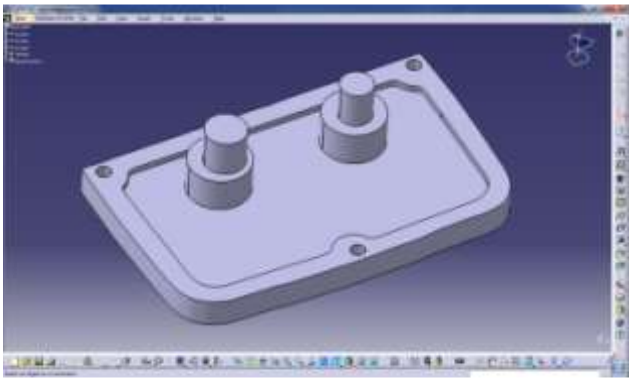
Conversion of scanning data from PC.DMIS Software into CAD data:



Conversion of solid model from scanning model of gear box cover plate:



Actual CAD model of gear box cover plate:



Scope of application:

Commonly referred to as a 3DProduct Lifecycle Management software suite, CATIA supports multiple stages of product development (CAx), from conceptualization, design (CAD), manufacturing (CAM), and engineering (CAE). CATIA facilitates collaborative engineering across disciplines, including surfacing & shape design, mechanical engineering, equipment and systems engineering.

CATIA provides a suite of surfacing, reverse engineering and visualization solutions to create, modify, and validate complex innovative shapes. From subdivision, styling, and Class A surfaces to mechanical functional surfaces.

CATIA enables the creation of 3D parts, from 3D sketches, sheet metal, composites, molded, forged or tooling parts up to the definition of mechanical assemblies. It provides tools to complete product definition, including functional tolerances, as well as kinematics definition.

CATIA facilitates the design of electronic, electrical as well as distributed systems such as fluid and HVAC systems, all the way to the production of documentation for manufacturing.

Conclusion:

Reverse engineering of geometric models and parts for CAD use is a rapidly evolving discipline in which interest is currently high. This is due in part to the recent commercial availability of active non-contact systems that can produce some level of sufficient accuracy for many applications. In this project, we have successfully made several achievements to the reconstruction efforts of modeling our selected parts using two different systems, with two different techniques. As we revisit the data acquisition systems that were chosen for this project, we will discuss some of the benefits of using both systems. We also highlight some of our achievements in generating the 3D CAD models using both systems.
Our achievements are:

• Literature survey on reverse engineering using CMM, Lasers and Structured Lighting Applications.
• Successfully generating a 3D model of the ramp using the Genex 3D Face Cam System.
• Successfully modeling the water pump using the Genex System.

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