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RAPID MOULD MANUFACTURING FOR SCULPTURED SHAPED PART BY REVERSE ENGINEERING AND CAD/CAM

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Abstract: *Meeting the dead lines to retain the customer in this competitive market, complex 3D moulds are a challenge before Die and Mould manufacturers, that too when it is to produce the part without the aid of drawings or design data in a very short time. As manufacturers strive to further optimize the development cycles to maintain market competitiveness, the use of reverse engineering technologies have started to play the pivotal role in the product development cycles. Reverse Engineering has become an increasing part of product development process chains resulting in reduced time to market and reduced development costs. Integration of this technology 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 interfacing of data obtained from this technology to various manufacturing processes. This paper discusses about the work carried out at Central Institute of Tool Design to develop the part by integrating Reverse Engineering process loop and CAD\CAM application to optimize the time and cost in real time tool and mould production.*

Key words: *Reverse Engineering, mould design, coordinate measuring machine, point cloud data.*

1. INTRODUCTION

In a constant endeavour to optimize the product development cycles and costs, tool design engineer must always think of how to shorten a specific procedure even further. In this case we are emphasizing about tool and mould making. This paper is therefore specific to choosing the right approach in tool and mould manufacturing, focusing on 3D model development and mould design to generating NC codes for consequent CNC machining.

Reverse engineering technologies are beginning to play a large role in helping to achieve this goal. This stems from the capabilities of technologies to provide support to a broad range of applications such as continual maintenance of CAD data, on-line inspection techniques, and virtual reality [3]. As reverse engineering is already a well known and established technology [6], the million dollar question is how to optimize it further and use effectively? There is no specific answer or conclusion to this. Each task has its own methodology to be followed and has to be performed separately.

In the field of tool and mould production there are several applications where a product already exists and a mould for its production has to be made. If such product consists of complex geometry which maybe includes even some artistic relief surfaces, it is very hard or almost impossible to reproduce it by any classical method. One possibility is to use copy-milling. But due to copy milling machines mostly being quite old this is a very time consuming procedure. Here 3D digitizing and reverse engineering come into place [6].

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The Reverse Engineering technique is one of the working tools in the Integrated Engineering that permits the optimization of the products' design and performance, so that the aim for a flexible production with minimum costs, high quality and offered to its beneficiaries as soon as possible, become more and more a tangible reality. This technique of recent date in terms of modern production systems, still has a relatively limited application, it being accessible particularly to specialists from important universities and industrial units, who possess already structured knowledge and procedures and what is more important, who can afford modern, but still expensive, equipments and facilities. To many specialists, mainly those from small and medium enterprises or universities, the Reverse Engineering technique still seems an exotic alternative, although the advantages of its use are evident. In the absence of some sufficiently cogent information in the industrial field, existing data shows that in institutes of research and universities, although approached with interest, this technique stands at the beginning. One of the limitations of the development of this study is also the concern that many of the fully developed Reverse Engineering techniques require expensive equipments (three-dimensional measuring and scanning machines, rapid prototyping machines, computers with considerable hardware and software resources.) [5].

Reverse Engineering has been defined as a process for obtaining the technical data of a critical spare component. Computer-aided reverse engineering relies on the use of computer-aided tools for obtaining the part geometry, identifying its material, improving the design, tooling fabrication, manufacturing planning and physical realization.

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 systems using standard formats such as IGES, STL, VDA and STEP [1].

Reverse engineering can greatly reduce the time taken to create the solid model of a part, if a physical replica already exists. The part geometry is digitized using a contact or non contact system. The resulting point cloud is stitched together using specialized software to create the part model The resulting point cloud is stitched together using specialized software to create the part model [4]. Each method has its own advantages and disadvantages which are discussed below:

Advantages of contact type digitizing process includes (i) high accuracy,(ii)ability to digitize/measure deep holes/slots and features, (iii) insensitive to reflecting/transparent surfaces, (iv) less cost. The disadvantages are slower process and distortion of softer objects by the probe.

Similarly the advantages of non-contact type digitizing process are faster process, no physical contact, insensitive to softer materials, good accuracy, and ability to scan intricate areas where touch probes diameter may be too large to accomplish the task. The disadvantages being sensitive to reflective/transparent surfaces, low accuracy, uncontrollable point data, high cost of equipment.

Solid modelling is a technique for representing solid objects suitable for computer processing. Other modelling methods include surface models and wire frame models. [2] Primary uses of solid modelling are for CAD, engineering analysis, computer graphics and animation, rapid prototyping, medical testing, product visualization and visualization of scientific research.

While computer-aided manufacturing (CAM) is the use of computer-based software tools that assist engineers and machinists in manufacturing or prototyping

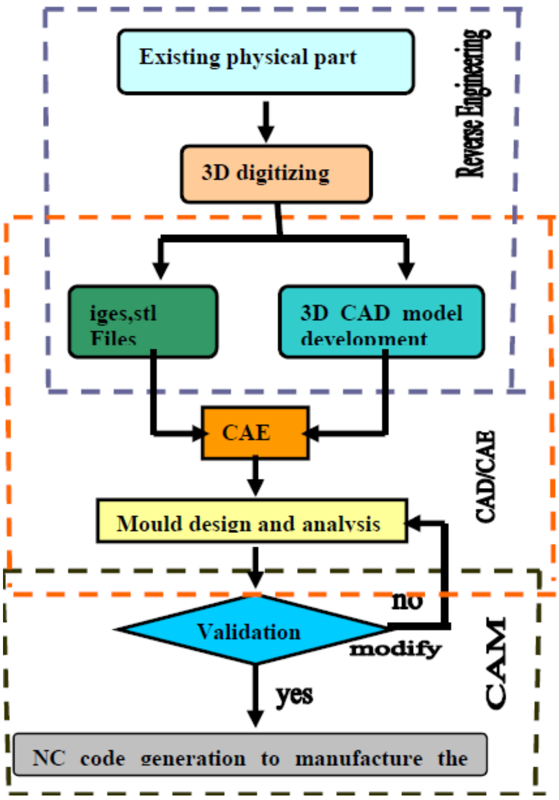


Fig. 1. Proposed methodology integrated with CAD\CAM.

product components. Its primary purpose is to create a faster production process and components with more precise dimensions and material consistency, which in some cases, uses only the required amount of raw material (thus minimizing waste), while simultaneously reducing energy consumption.

Integration of CAD and CAM environment requires an effective CAD data exchange. Usually it had been necessary to force the CAD operator to export the data in one of the common data formats, such as IGES or STL, that are supported by a wide variety of software. The output from the CAM software is usually a simple text file of G-code, sometimes lengthy commands are transferred to a machine tool using a direct numerical control (DNC) program [7].

This paper describes how the 3D CAD model developed from reverse engineering data was used to design moulds and subsequent NC code generation to machine on a CNC machine.

The above technologies are briefly described in this paper, highlighting our efforts toward indigenous development and application, focusing on bottleneck and least-explored areas with the largest potential for lead time reduction. The methodology proposed in this paper is presented in Fig. 1.

2. METHODOLOGY

2.1. Data Capturing/Digitizing process

The RE process can be divided into three steps: (i) digitizing; (ii) data segmentation; (iii) data fitting.

The first objective of RE methodology is to generate a conceptual model (example: surface triangulated) from a physical model: a sample (part or tool) or prototype. In this sense the 3D-scanning (digitizing) techniques aided by specialized software's for model reconstruction are necessary. During the scanning process, an analogue-canning probe is commanded to move back and forth (contact or non-contact) across the unknown surface and the system records information about the surface in the form of numerical data—generates a point's cloud matrix (3D-coordinates). This data may then be used to create a CNC-program to machine a replica or geometric variant of the shape. Alternatively, the data can be exported in various formats to a CAD/CAM system for further processing. When digitizing a part at least the following factors must be taken into consideration:

- What is the physical part made of?
- What is the physical condition of the part?
- Need for fixtures.
- Alignment requirements.
- Digitizer errors.
- Available digitizers.
- What is the required use of the resultant geometric model?

In this work, the methodology of digitization and collection of coordinates of every point of contact of the probe with the part surface has been adopted to have better control over the points while CAD model development. Though this process is very slow to collect enormous points for cloud of points, it has high accuracy compared to all other mechanical methods.3D coordinate machine used for this purpose is shown in Fig. 2.

Fig. 2. ZEISS-Prismo5 3D Co ordinate Measuring Machine.

Parameters selected for CMM for effective collection of data points are given below:

- The digitizing pitch in X-direction was taken as 3.0mm and in Y-direction 5.0mm.
- Ǿ4mm probe is used for entire component digitizing.
- Ǿ 1mmm probe is used to digitize intricate areas.

The digitizing process was performed manually.

All the probes were initially calibrated with a round master. Holos digitizing software was used for digitizing and surface patches creation.

Before scanning, certain parameters have to be set so as to achieve the required accuracy in captured data, the important ones being chordal tolerance, pitch, step over , scanning direction, scanning speed, area to be scanned etc. It is also necessary to do the Z-plane setting, axis alignment and X-Y-Z references. Once the references and planes are determined, the following steps were followed:

(i). Define area patches by marking boundary edges as shown in Fig. 3.

(ii). Processing cloud points. This includes merging of points cloud if the part is scanned in several settings.

(iii) Manually probe the edge boundaries.

(iv) Create reference surface.

(v) Digitize the reference surface.

(vi) Reduce the gaps on edge boundaries and merging the patches.

2.2. Data processing\3D model development

The sequential steps after obtaining CMM data are to first convert the points into Lines, Arcs, Curves (Fig. 4),

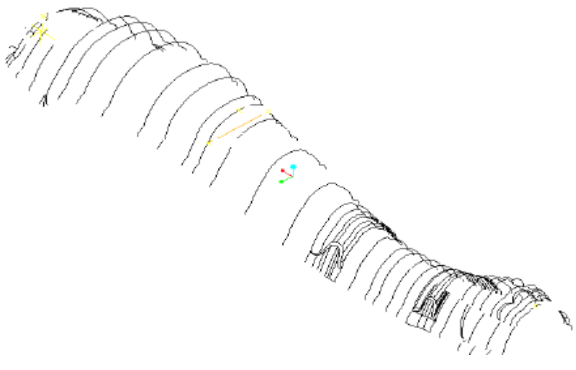


Fig. 3. Boundary edges and curves at various sections after digitizing.

and surfaces. It can be performed by processing the so captured data with the aid of a high end CAD software(Pro/E was used in this case) or even with the same scanning software if it supports data manipulation feature. The free form surface is created through the boundaries of these datum curves as shown in (Fig. *5*). and final surface model developed is shown in (Fig. 6).

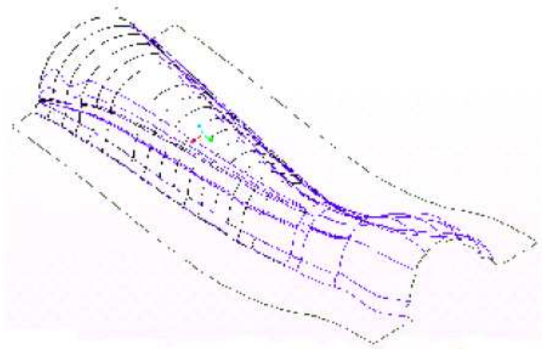


Fig. 4. Smooth curves creation by tweaking operation.

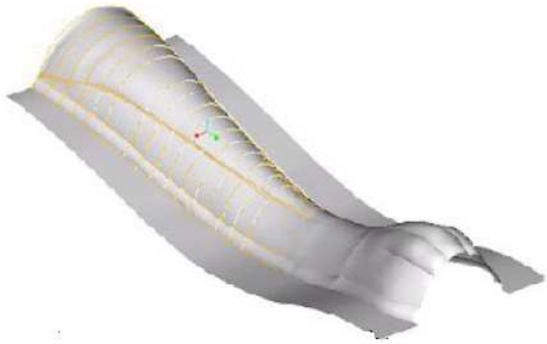


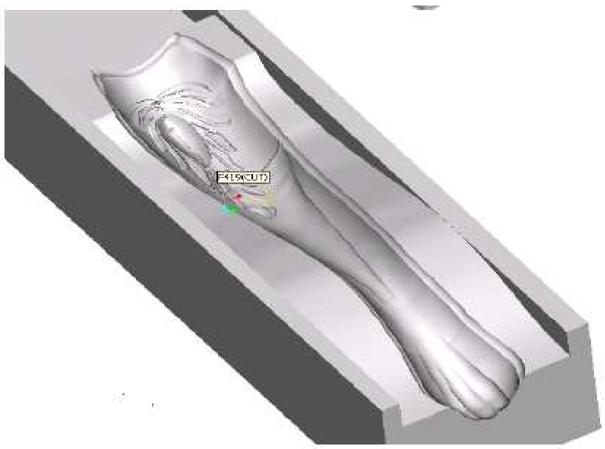
Fig. 5. Free form surface creation through the boundaries and curves (yellow color) using advanced blend option.

a

b

Fig. 6. (a)(b) Final surface model development using advanced surfacing features in Pro/Engineer.

a



b

Fig. 7. (a) Extracted core ; 7(b) Extracted cavity model.

The data thus generated can be used to manipulate for different requirements like.

(i) Surface offset to the thickness of component.
(ii) Giving shrinkage allowance;
(iii) Mirror;
(iv) Rotation;
(v) Combinations of models;
(vi) Parting surface creation;
(vii) Mould Block design;
(viii) Core And Cavity extraction.

2.3. Mould Design/Core and Cavity extraction

Once the surfaces are manipulated to final form, the model can directly used in Mould design module of the software. With the various options available in software all the parameters like shrinkage allowance, parting surface definition, etc. that are required to extract core and cavity (Fig. 7, a and b) are applied to the model and the extracted molds parts were saved for further process.

2.4. NC code creation and Tool path simulation

There is a requirement for latest / modern systems to be compatible-i.e. they must be capable of accepting data transfer from other systems and software. There are various converters like DXF, VDA, DAT, IGES, STL etc. However, the most commonly used interface is IGES translator that is used predominantly for input of component drawings as wire frame, surface model or solid model. Tool path generation can be carried out with the aid of various CAM soft wares available in the market. The CAM software allows the user to have wide range of cutters to select from for various operations like roughing, semi finish, finish etc. In this work the cutter path needs not to follow the scanned path. The software enables to define block size, gouge checking, setting of machine coordinate system and also simulation (Fig. 8, a and b).

We can also control the step over, scallop height, step depth etc of the tool that is being used for machining.

The software also enables NC program to be compatible for almost any control systems. MasterCAM software was used to generate the NC codes.

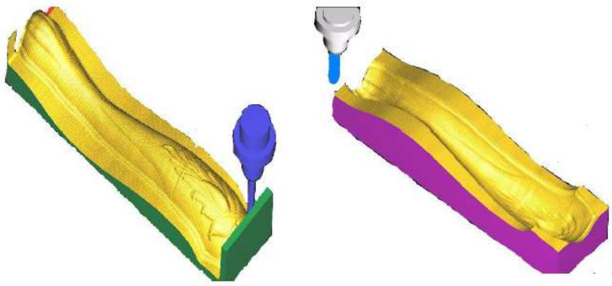


Fig. 8. Tool path simulation in MasterCAM – semi finish machining stage.

Table 1

Lead time for part digitizing and 3D model development

TIME ANALYSIS	Houes-minutes
Probe calibration	0–06
Manual digitizing	2–22
Auto cross checking the digitized points	0–55
Converting into curves	1–10
Creating patches, stitching and 3D surface model	1–40
Mould design	0–40

3. RESULTS

Digitizing was performed along and across directions on the part to improve the accuracy of surfaces. The developed CAD model was checked for surface error analysis with the original component obtaining the results presented in Table 1.

After metrological validation, the following deviations were observed

- Average error/deviation in X-direction = –0.714mm;
- Average error/deviation in Y-direction = –0.467mm;
- Average error/deviation in Z-direction = + 0.284mm;
- Cycle time for rough machining: 6 hours;
- Cycle time for finish machining: 9 hours.

4. CONCLUSIONS

Reverse engineering is a process that can reduce the product development cycle time especially when there are no drawings or outdated and no further supply from the vendor. In the future this application is going to impact and penetrate the market. For contact type method with touch probes CMM is the ideal measuring equipment. Another faster method which is termed as non contact method using laser scanning is an alternative that can save more time and cost in the long run despite high initial investment as compared to contact method.

Further the disadvantages of non contact method is huge file size, the point cloud should to trimmed and optimized to the desired boundary limits and difficult in controlling the points. Another major drawback is laser scanning cannot be used on reflecting and mirror surfaces.

The RE data available makes a faster shape metrology control of patterns, prototypes for mould manufacturing by comparing and calculating the deviation between 3D digitized\scanned data and developed 3D-CAD model, before proceeding further with manufacturing processes.

Any changes in design can be responded instantly as the changes can be easily updated in the backup 3D CAD model.

The integration of CAM\CNC enables for faster manufacturing of virtually any complicated shaped moulds, dies, press tools, patterns for foundry reducing the time as compared to conventional method of making that relies totally on the skill of tool maker.

The Reverse Engineering data enhances the metrological accuracy in product development and for mould processing technology thereby sustaining the market competitiveness. The integration of RE with CAD\CAM\CNC technologies reduces lead-time and associated costs.

- If digitizing data is converted into datum curves/curves while digitizing itself, 40-50% of manual work can be reduced.
- Digitizing along and across directions on surfaces will improve the accuracy of surfaces.
- Accuracy in surfaces will depend on complexity of the profile and the skill of the CAD engineer. The accuracy of surfaces will increase by manipulation of surfaces.

In brief from this case study, it can be concluded by employing the above discussed applications the lead time for mould manufacturing process can be reduced from nearly 8–9 weeks to 3–4 weeks as compared to the conventional method of mould design and manufacturing.

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