Reverse Engineering – Speeds up manufacture of thermoforming tools

P M Hackney, M Sarwar, and J Van Bedaf

School of Informatics, Engineering & Technology, Northumbria University, Ellison Building, Newcastle Upon Tyne NE 1 8ST, United Kingdom
Tel: 0191 227 4589, Fax: 0191 227 3854, Email: Phil.Hackney@unn.ac.uk

ABSTRACT

Reverse Engineering has traditionally been utilised in the digitising of complex, ergonomic, aesthetic components, this paper examines the application of 3D digitising for the manufacture of thermoforming mould tools.

Thermoform moulding is seen as a flexible, rapid and low cost tooling route for low to medium volume production of polymer parts especially in the packaging sector.

Initial tools are traditionally resin cast or of simple wooden construction, after trials and customer acceptance of the designs, then more robust tooling is required. As product development progresses then tooling in metals such as Aluminium or metallic resins is often required.

The rational for metallic tools is increase cooling rates thereby increasing production rates and reducing part piece costs coupled with reduced wear.

This case study from the Centre for Rapid Product Development analyses the application of touch probe reverse engineering and surfacing techniques for the production of the "A" surface, air extraction vent system and the conformal cooling system required for high performance thermoforming production tooling.

The Centre for Rapid Product Development is a national and regional resource for innovative applied design and manufacturing technology and applications for the North East of England

Key words: *Reverse Engineering, Thermoforming, Vacuum Forming tooling,*

1. INTRODUCTION

The thermoforming of polymers has several advantages over other polymer manufacturing processes. The preserved perspective of thermoforming also known as vacuum forming is its low accuracy and its low volume process utilizing simple low cost tooling[1]. This has restricted the application of the process to simple trays, packaging etc. predominately imported from low wage economies.

In the modern product development environment where time and costs are critical for a product's success, processes that can provide components quickly and with minimal tooling costs will rise to prominence[2]. Thermoforming is one such process currently being increasingly adapted for production outside its traditional tray and packaging environment, into products ranging from drinks dispensers to train interiors.

An Engineering Company "ABC" (anonymous for commercial reasons) are a specialist thermoforming product design and tool manufacture company, based in the North East of England. "ABC" takes customers' specifications and turn them into products. After approval of the concept, they then design the tooling, manufacture the tooling and trial the product. The process is initially 3D CAD based, to complete the design and 3D CAM is used to CNC mill the soft tools.

However at this stage the tooling is modified by hand to add new features – strengthening ribs, grooves, drafts, fasteners, live hinges etc. Modifications occur by material removal or resin build up with prototypes taken at each stage until the customer is satisfied [3].

The problem now, is how to manufacture the production multi-cavity tooling, not to create single batches as per the prototype tool but to automatically form, crop and stack 100's per minute of the example part, Figure 1.

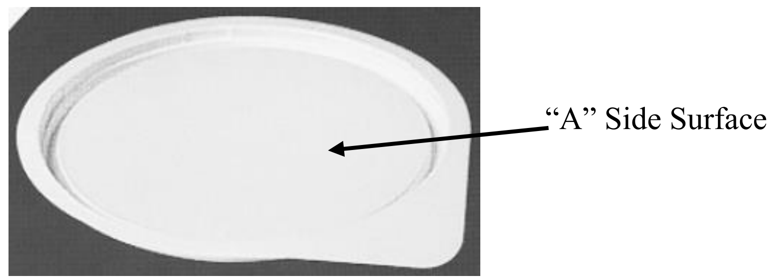

Figure 1: Typical simple thermoformed part

The traditional solution for the manufacture of production tooling was slow for three main reasons:-

1. Manufacture of 'A' surface (top surface) is slow using copy milling, as stock material removal techniques are very poor by definition of the mechanical process.

2. Air vent holes to pull the polymer sheets to the mould surface need to be small < 1 mm – the drills for these holes are delicate and short in length. Therefore larger holes need to be drilled into this 'B' surface (Rear Surface).

3. Mould cooling is required to achieve the production rates required. In the past tooling valued at many thousands of pounds has been rejected because of poor production due to hot and cold spots on the "A" surface affecting the thermoforming process.

2. COMPANY/INDUSTRY BACKGROUND

"ABC" is a mould design and manufacturing company and has invested heavily in computer aided design/computer aided manufacturing software and hardware.

"ABC" is a thermoforming-tooling specialist and has a very high level of experience and expertise in the tooling industry and also manufactures thermoforming tools to fit a range of flat bed blister packing machines[4], Figure 2. Hence, to get accuracy in the outcome of the production, "ABC" uses the latest technology systems which help them to gain the advantage in a highly competitive industry.

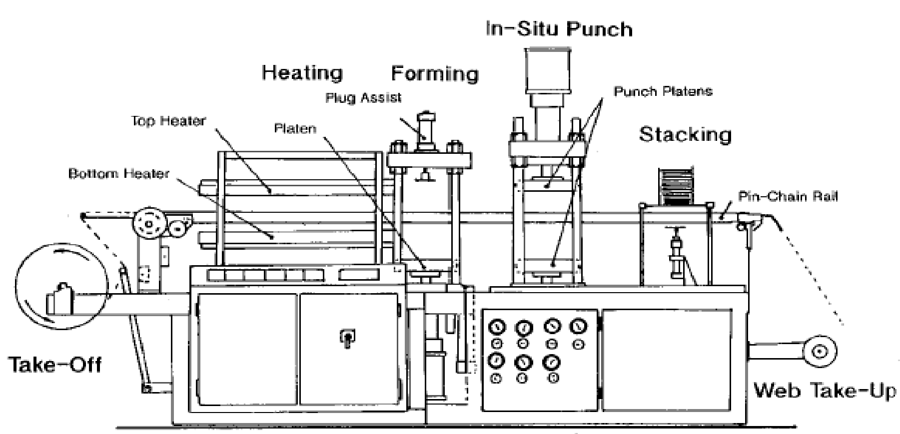

Figure 2: Thermo Forming Machine

“ABC” has a well equipped tool room with the latest CNC machines, where the thermoforming tools are traditionally manufactured after being designed in a CAD package.

The thermoforming tools consist of various parts and stages:

- Mould build up
- Cutter build up
- Anvil
- Plug build up
- Pusher
- Pressure box
- Tool frame

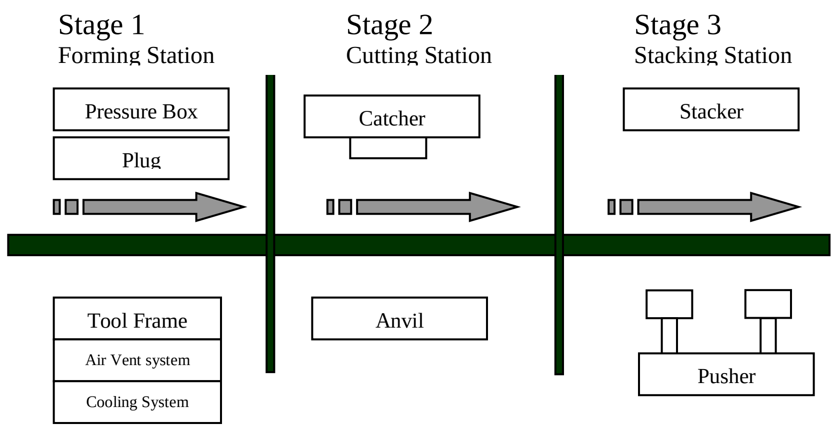

Figure 3: Steps in the thermoforming process

3. STATEMENT OF PROBLEM

Following discussions with Thermodynamix the following issues were identified;

- “ABC” were losing their market position
- Competition quoted shorter lead times with more competitive tenders
- “ABC” remained innovative in their design solutions but couldn’t deliver tooling to customers within the short delivery timescales demanded.
- Thermoforming is a complex process for intricate complex multi-functional components.
    - Design takes time
    - Product testing takes time
    - Product refinement is accomplished best by skilled production/tooling engineers, by modification to tooling
    - Designs are often a refinement of a previous version
    - Tooling modified by hand to ensure product meets customers requirements

Typical time breakdown of a two month project were:

- 25% of product development time is design and prototype production
- 25% trialling and modification
- 35% hard tool production
- 15% quote/delivery/final trials etc

"ABC" have already invested heavily in the front and exit of the process with a high end CAD packages such as PowerShape from Delcam for the design and 3D CAM PowerMill for the manufacture, capable of producing code for several DNC milling and turning machines. Where "ABC" needed a step change was in the middle of the process – during the trial and modification stage

Figure 4: Multi – Cavity Mould Tool

4. IMPLEMENTATION PROCESS

The process implemented within "ABC" was a two-phase solution, with the emphasis on proof of process before investing time and capital in a long term solution. The first phase has been completed with the second phase dependant upon order books and customer requirements.

4.1. PHASE I – LOW COST-IMMEDIATE SOLUTION

This solution utilised equipment currently available within the local area and comprised of a contact scanning using a Renishaw Cyclone dedicated digitising machine and limited surfacing of the modified tooling data using CopyCad.

4.1.1. The Solution

The solution compressed several key stages as described below;

4.1.2. Pre-scanning

- Pre-inspection - the tools are cleaned first to ensure no dust, dirt, granules etc have been left on the mould after modifications.
- The moulds were then coated with a light spray lubricant to assist and increase the scanning speed.

4.1.3. Setup

- The parts were located upon the scanning machine bed, roughly flat and aligned in the x or y planes.
- The parts were accurately aligned in the Z-plane and the 'X' or 'Y' plane using planes and line constructed from 3 or 2 points defined by contact with the tool shown in Figure 4.
- The datum point for manufacture was then selected and used for the scanning datum, often a central highest point was chosen inline with "ABC" manufacturing standard practices.
- As most of the tools were rectangular in outer profile, 2D scanning of edges was not normally required. However for one tool the second silhouette profile was captured to enable "ABC" to manufacture the cropping tool to remove the part from the waste material.

4.1.4. 3D Scanning

- With the datum set the scan volume needs to be defined. After many trials and experiments the most efficient method found was to scan in both X and Y directions with a stepover of 0.2 to 1.5 mm depending upon the surface geometry of the part. Typical grid setups and scanning can be seen in Figure 5.
- Scanning can last from 4 to 48 hours, depending on part geometry and size – 48 hours for a part 500 x 300 x 100 deep, with a scan stepover of 0.2 mm in 'X' and 'Y'.
- The 3D point cloud data was saved as a tracecut model file for late processing.
- The long scanning time is balanced by the start setup time < 30 mins, with the remaining time in operation unmanned and usually overnight.

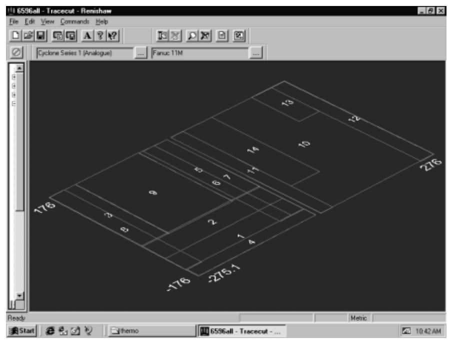

Figure 5: Grid setup with 14 "x" and "y" grid set

4.1.5Data Processing

"ABC" needed surface data to machine along to reproduce modified tooling and from 3D CAM's roughing and finishing strategies which are not applicable for traditional "copy milling".

The following process was utilised:-

- Import the Tracecut point models into copy CAD.
- Generate a triangle model using all the points in the point cloud.
- Tolerance the model to the chordial tolerance required – typically 0.05 mm – this reduces the file size.
- Save the files as a "Delcam machine triangles" (.DMT) which "ABC"'s CAM software and CAD package powershape can import and utilise.

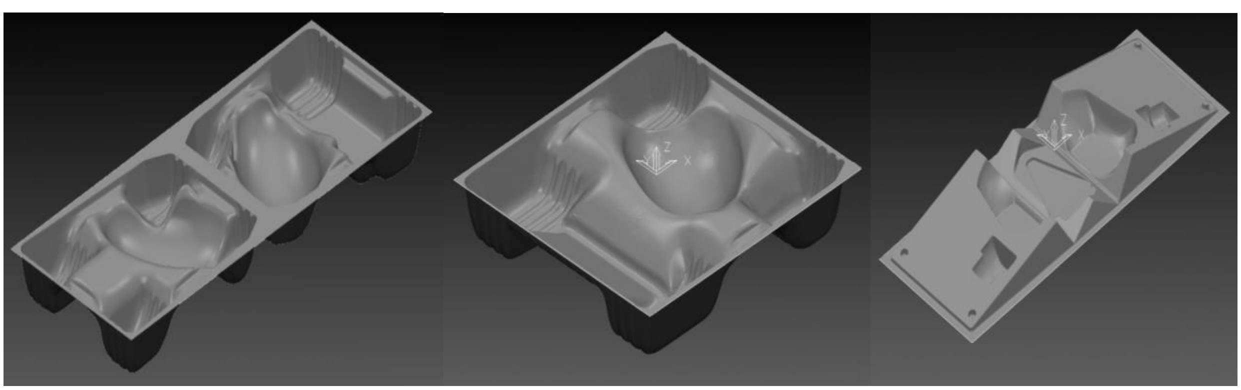

Figure 6: Three typical Triangulated scanned tools

4.1.6. Tooling Manufacture

"ABC" now had a surface representation of the modified tooling, which meant they could then:

- Generate 3D cutter paths to manufacture the hard tooling using the most efficient cutting method and speeds.
- Manufacture the 'A' side surfaces
- Offset the surface and generate cutter paths to create cooling channels to run parallel to the heated 'A' side surface.
- Using offset surface to apply the vent holes from both sides with the 'A' side, small < 1 mm holes being generated to match the 'B' side large vent channels formed on the underside of the tool.

4.2. PHASE II

4.2.1. Introduction to Phase II

This phase focussed on the search for better, more efficient methods of gathering the surface data required.

Traditional methods of reverse engineering had been used in Phase I, i.e. contact touch probes with a fine step between contact points. This method only measures less than 1% of the surface, whereas more modern reverse engineering techniques involve non-contact measurement systems using projected light[5] or waves of electro magnetic energy as in CT scanning[6]. The projected light systems fall into two categories – light triangulation and light grid systems, such as 3D Scanners Ltd Model maker system and GOM Ltd ATOS system[7].

A typical triangulation system uses a point or line of laser light to illuminate an object, the position of the point or the profile of the projected line on the object depends upon the object shape, and the 3D co-ordinates can be calculated. The light and sensor is moved around the body using rotary or 5-6-7 axis inspection arms[6].

The light grid system projects a series of binary patterns onto the object, records the pattern, increments the pattern over the object and again records the pattern. This data is then processed to generate the 3D digital model. Some systems use two light sources of different wave length to project interference patterns onto an object. The position of these light bands provides the surface data information[8].

Phase II comprised an assessment of various scanning techniques available to speed up the process.

4.2.2. Current Contact Scanning System

The current Renishaw Cyclone dedicated 3D touch contact probe system has the following characteristics:

- Relatively slow data capture 1 metre per minute. Scanning speed 4-48 hours per tool. Print data.
- High accuracy ± 0.01 mm
- Replicated the machining operation, ie good for 3 axis machining as undercuts, gouging eliminated
- High definition data
- Few stray data points
- Simple clean up procedures for point cloud data
- Direct interface into surfacing software, copy CAD
- Selective data filtering
- Best contact solution at lowest cost - £20,000.

4.2.3. Non-Contact Systems Considered

Optical triangulation laser scanning – non-contact

- Fast data acquisition, strip data
- Flexibility of movement of scanning head for undercuts etc
- Lower accuracy
- High cost of system > £50k
- Requirement to coat parts

Optical Coding - Photogrammetry

- Fast data acquisition – area data
- Expensive to purchase >£50k
- Stationery position – part can be rotated in field of view.

5. CONCLUSIONS

- A viable path has been found for the company to reduce their lead times. Lead times have been reduced from four weeks to one week for the trial to tool stage, with nominal additional external cost. Improved lead times have greatly assisted "ABC" in securing new lucrative contracts.

- The mould tools now produced, have less manufacturing faults as there are less manual measurements and manual machining operations performed.

- The vent system is more efficient, and fewer drills broken, with more accurate location.

- The mould cooling system is efficient and hot/cold spots can be avoided

- The second phase has been costed, but is currently not commercially viable unless equipment is used outside of the core business.

- The application can be applied to other manufacturing areas such as the Blow Moulding and Resin injection moulding.

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