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Computed tomography as a quality control technique in the 3D modelling of injection-moulded car system components

Tomografia komputerowa jako technika kontroli jakości w procesie modelowania 3D elementów samochodowych formowanych wtryskowo

Abstract

This paper presents the sophisticated capabilities of industrial computed tomography (CT) in the development and 3D modelling process of new car system components. Usually, the process of the development of new car components takes three to five years. At each development process stage, quality control is crucial to catch all internal and external defects. This is particularly important with regard to components made using an injection-moulding process. Computed tomography as a non-destructive testing method is an excellent tool for controlling and improving both the manufacturing process and the 3D modelling of tested components. All analyses performed with use of CT are essential for meeting customer requirements. This paper shows how industrial computed tomography can control the quality of the car components development process.

Keywords: industrial CT, CAD 3D model, STL, quality control, product development process

Streszczenie

Praca przedstawia zaawansowane możliwości przemysłowej tomografii komputerowej (TK) w rozwoju i procesie modelowania 3D nowych elementów samochodowych. Zazwyczaj proces powstawania części nowego samochodu trwa od trzech do pięciu lat. Na każdym etapie rozwoju produktu kontrola jakości jest kluczowa w wychwyceniu zarówno wewnętrznych jak i zewnętrznych wad. Jest to niezwykle ważne zwłaszcza dla elementów wywarzanych w procesie wtrysku. Tomografia komputerowa jako nieniszcząca metoda badawcza jest wspaniałym narzędziem do kontroli oraz ulepszania procesu wytwarzania i jednocześnie ulepszania modelu 3D badanego elementu. Wszystkie analizy wykonane przy pomocy TK są niezbędne, aby sprostać wymaganiom klienta. Artykuł pokazuje zastosowanie przemysłowej tomografii komputerowej jako narzędzia do kontroli jakości w procesie rozwoju elementów samochodowych.

Słowa kluczowe: przemysłowa TK, model 3D CAD, STL, kontrola jakości, proces rozwoju produktu

1. Introduction

The main aim of engineers in technological research and development centres is to design components that can be produced in accordance with the relevant quality requirements whilst meeting the applicable standards and tests. Computed tomography is a very useful machine for the testing and assessment of dimensional accuracy and structural failures. The industrial application of CT is also used in reverse engineering to scan finished products in order to rebuild a 3D model in CAD software and make improvements. We can also use this model for 3D printing. Finally, after all simulations, calculations and modifications of the CAD model, tests on real prototype part, and corrections on its technical drawing specification, a product that meets all the requirements is produced.

Fig. 1. Industrial CT Nikon XT H 225 [1]

2. The design process of plastic components

2.1. The principles of injection moulding

It has to be mentioned that there are several processes for moulding plastic to transform it into useable shapes. Plastic car elements are manufactured using various injection technologies. Within the automotive industry, both interior and exterior injection-moulded plastic elements are produced, for example: engine covers, handles, shields, fans, shrouds, tanks, dashboard, seats, doors, brackets, clips.

While the injection moulding is one of the most widely used processes, other processes include:

- reaction injection moulding,
- rotational moulding,

- blow moulding,
- compression moulding,
- extrusion moulding,
- rotocasting,
- transfer moulding,
- thermoforming,
- vacuum-forming,
- blown film extrusion.

A good design is of great value for any manufactured product, but for plastics it is absolutely essential. They creep and shrink as time passes; their properties change over the temperature range of everyday life; they may be affected by common household and industrial materials.

A well-designed object combines concept with embodiment (Fig. 2). Unless the two are considered together, the result is an article that either cannot be made economically or fails in use. This is particularly important consideration for plastics. It is crucial to choose the right material for the task. When this is achieved, it is equally important to adapt the details of the design to suit the characteristics of the material and the limitations of the production process [4].

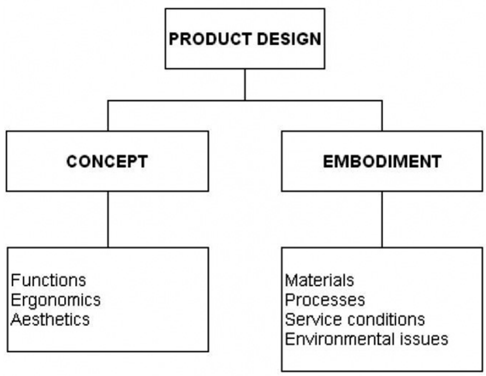

Fig. 2. Design considerations [4]

The complexity of plastic car elements is increasing, while simultaneously, there is a need to minimise development times. In order to meet these requirements, a high degree of quality assurance is needed [5, 6]. The product development process is laborious and long-lasting and must always be improved in conjunction with the development process for moulds. The engineering tasks involved in injection moulding are: the design of the geometry of parts and moulds; the machining and polishing of cavity/core surfaces and cooling lines; the assembly of plates, pins and mould bases; the performing of prototype tests with appropriate choices of material and processing parameters [7]. Therefore, there are strict rules and recommendations for product and mould design. Parts to be injection moulded must be very carefully designed to facilitate the moulding process. It is crucial to adhere to these rules to maintain a high quality of the final products.

There are a few very important points that must be taken into account during the design of both the part and the mould. This narrow range of design rules facilitates the versatility of injection use with regard to:

- the material used for the part,
- the desired shape and features of the part,
- the material of the mould,
- the properties of the moulding machine.

Industrial CAD designers or engineers design the products and the moulds, but the moulds are produced by a mould maker or a toolmaker. Moulds are made usually from metal, either steel or aluminium, and are precision-machined to form the features of the desired part. Figure 3 shows an injection moulding machine [8].

Keeping in mind the material shrinkage, all designing rules need to be applied in order to obtain a plastic part with the specified tolerances. Meeting all the requirements of the entire development and manufacturing process are difficult tasks for the engineers. To read more about mould design and injection moulding, refer to [9–13].

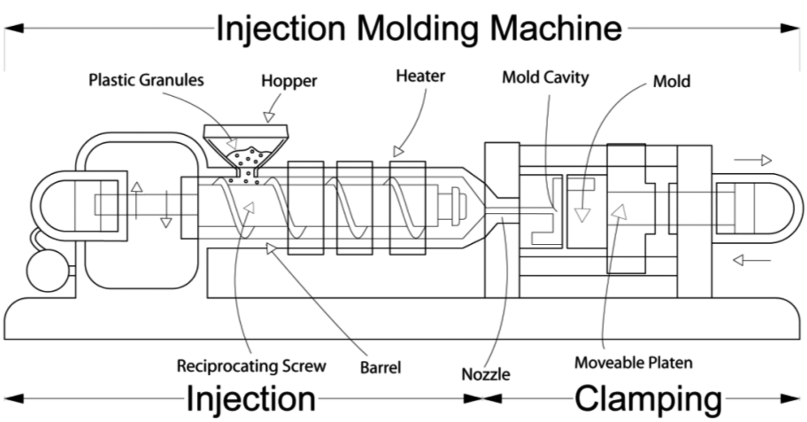

Fig. 3. Injection moulding machine [8]

2.2. Development process

Basically, there are three main stages of the development and manufacturing process: mock-up, prototype, series. In projects, there are more stages according to, inter alia, purchasing, management. However, we are concerned only with the basics of the development process in this paper. Firstly, research and development engineers have to check car packaging (car environment) and calculate stack up tolerances. The designing process then starts for each part and the whole assembly with the desired specified tolerances. The first attempts at trying new ideas are usually based on older versions of the products and developed according to requirements and updated car packaging. In the designing process, there are a few steps which are repeated until the final part is obtained. These steps are: designing the part according to the packaging and designing rules; CAE simulations with test specification in accordance with customer requirements; testing of the part; calculations and changes to the design and tolerances. Tests on an actual part can also be performed on a 3D printed part if the kind of test allows that, for example, an acoustic test of a fan system, some vibration tests. These processes can be repeated many times if needed. At each step, the engineer has to calculate stack up tolerances and prepare technical drawings with specified tolerances taking into account all the design rules of the plastic part and moulds.

To ensure high quality products, very precise measurement techniques are needed to control the quality of the product at each development and production stage. Then with help comes computed tomography. Computed tomography is used to perform fast and precise measurements of the product and compare it with the CAD model. It is vital to check all specified tolerances on the technical drawing. As previously mentioned, plastics have an unpredictable nature and moulds need to be perfectly designed to achieve the final part after shrinkage as required by the drawing. CT software provides the option to compare a CT scan of the product with the CAD model in order to map shape deviation, check for structural defects (internal and external) and prepare a dimensional report GD&T. That metrology CT process refers to Fig. 4.

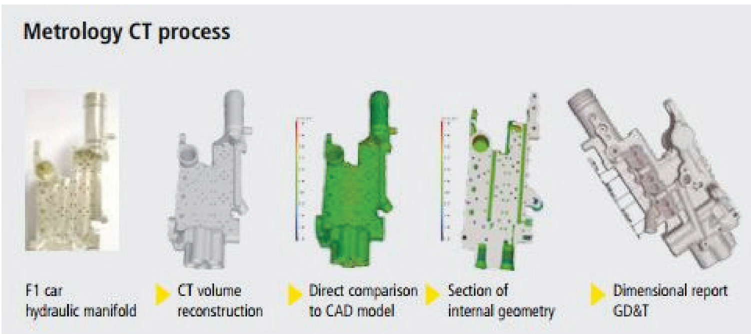

Fig. 4. Metrology CT process of product inspection [1]

3. Industrial Computed Tomography

In the 1980s, computed tomography found its application in industry as a non-destructive testing (NDT) technique. Today, it has become a crucial metrology tool for the assessment and comparison of geometric tolerances and dimensions. Industrial CT as an NDT technique allows products to be scanned without disassembling them into their component parts. This technique also provides highly accurate results of external shapes and internal structures without applying any external forces, pressure or stress. It allows parts to be measured in both 2D and 3D. When used as a research and development tool, as is the case in this paper, it is very important that CT is applied for quality control, the investigation of failures and for preproduction inspection. These strategies can help to reduce manufacturing costs, can reduce both the costs and time of production, and can provide help to designers and engineers with regard to calculations and improvements to the design of both the part and the mould. Images are easy to interpret and there is also the option to map shape deviations and measurements of structural defects; this is very useful in preparing metrological reports of scanned parts [14, 15, 16, 17, 18, 19].

There are two variants of projection systems commonly used in industrial CT scanning. One is a system with a cone beam (see Fig. 5a) and the other is with a flat beam (see Fig. 5b).

a) b)

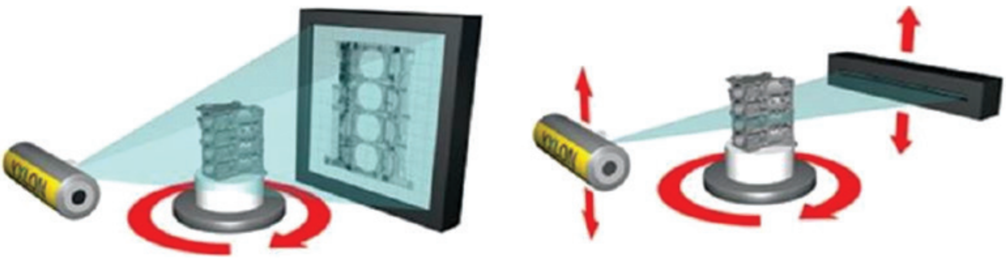

Fig. 5. Scheme of CT with a) cone beam and b) flat beam [20]

3.1. Benefits of using CT scanning in automotive applications

The application of industrial computed tomography at each product development stage in the automotive industry:

- design and styling of car system components
- small and large inspection potential with regard to:
  - fault detection and failure analysis
  - dimensional measurement of internal and external structures
  - advanced material research, for example, plastic parts, small castings
- internal inspection of components: dimensional measurement
- assembly inspection of complex mechanisms
- part-to-CAD comparison
- digital archiving of models
- reverse engineering
- 3d printing
- improvements of CAD model and production (moulding and casting)

4. Case study: plastic parts – fan system shroud and fan

Many plastic components are found in car cooling systems. This section of the paper focusses on the fan system, which includes one of the most complicated plastic parts in its assembly. The system includes a shroud which takes the main stresses and loads from the motor and fan, and the fan itself with each blade having a complex shape. Critical areas of the assembly are the mounting points; it is at these points where the worst simulation results occur. Both the simulation and tests on actual parts are made in accordance with the recommended specification denoted on the customer requirements document. During the vibration test on the actual parts (prototype assembly of cooling module), signs of wear appear. Vibration tests typically show the same main signs of wear as the simulations, but there are exceptions to this. Usually, the vibration test also shows that such wear is caused by material defects or due to the parts not being within geometrical tolerances. Computed tomography can be a useful tool in such circumstances. Prototypes are scanned in order to find the cause of defects and determine their type. CT scanning is fast and very effective for the assessment of all kinds of internal and external defect. Thanks to CT optimal scanning volume there is no need to cut parts into smaller pieces to make a scan. The entire part can be placed on the CT table to scan and analyse everything which is not visible to the naked eye. Computed tomography has dedicated software with options to create, after measurements, map of shape deviations and visualisation report.

4.1. Shroud – internal and external defects

Fan system – shroud specifications:

- *development stage:* prototype,
- *material:* PP-GF40,
- *simulation test – cooling module:* performed after each CAD model design modification, the highest stresses shows on the brushless motor mounting areas but are not critical
- *test on the real parts – cooling module:* vibration,
- *problem:* cracks on the shroud crown on the brushless motor mounting points area after vibration test – Fig. 6.

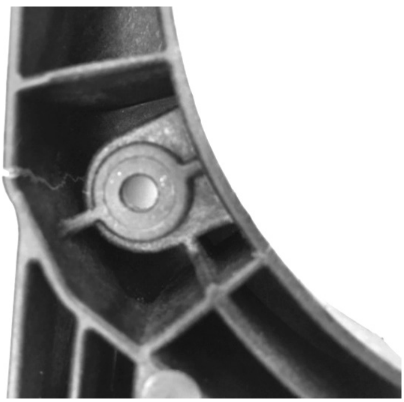

Fig. 6. Mounting area on the shroud crown after vibration test – visible crack

A vibration test was carried out on one of the prototype versions of the cooling module. The test caused cracking of the shroud crown on the brushless motor mounting area. The shroud was scanned by an Industrial CT Nikon XT H 225; it shows that there were a lot of internal material defects (Figs. 7 and 8). After analysing all the defects formed during the vibration test, the shroud was remodelled. Figure 9 shows the two models overlapped – one before changing the design (the part subjected to the vibration test) and the other after remodelling. Changes to the shroud design were accepted and manufactured as a new prototype version. The new part was tested successfully on a cooling module vibration test. To eliminate internal defects, not only was the shroud design changed, the mould and injection moulding process was also improved. Internal defects visible on the CT scan as material discontinuities cause weakening and cracking of that area. Changes to the design of both the part and the mould were crucial in improving the effectiveness of the injection moulding process.

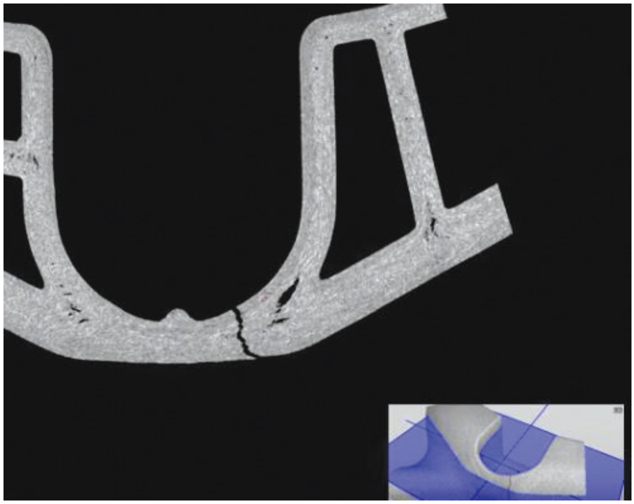

Fig. 7. Mounting area on the shroud crown after vibration test – visible crack on the CT scan and material discontinuities

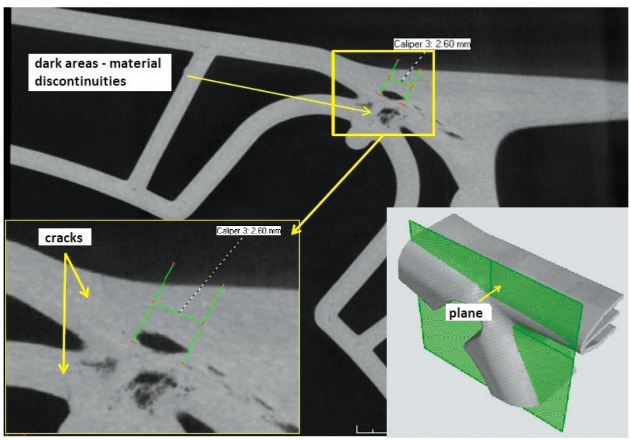

Fig. 8. Mounting area on the shroud crown after vibration test – material defects visible on the CT scan

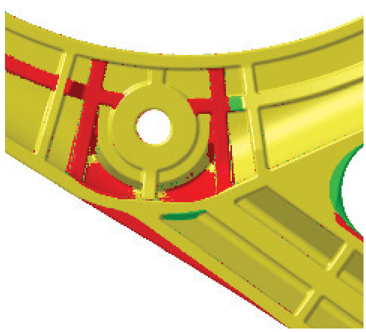

Fig. 9. Two overlapped CAD models of shroud – red indicates new added areas, green indicates old corrected areas, yellow indicates no change

4.2. Fan – shape defects

Fan system – fan specifications:

- *development stage:* prototype
- *material:* PA66-GF30
- *simulation test – cooling module:* performed after each CAD model design modification
- *test on the actual parts – cooling module:* vibration, acoustic, air flow
- *problem:*
  - test results revealed problem with balance and when balancing clip was mounted, it showed that the thickness of the blades was not within tolerance
  - during vibration test fan rub against the shroud
- *CT scanning:* after the vibration test, the fan was scanned and that STL scan model was overlapped with its CAD model. This shows that there were a lot of shape defects and shape deviations were not within tolerance. During rotation, the fan rub against the shroud causing defects and compromising efficiency. To improve the fan injection moulding process small corrections were made on the CAD fan model. The moulds and moulding process were corrected in accordance with the improved CAD model. All procedures were repeated a couple of times until the final part was within tolerance. Figure 10 presents the CAD model of the scanned fan and a map of shape deviations is presented in Fig. 11.

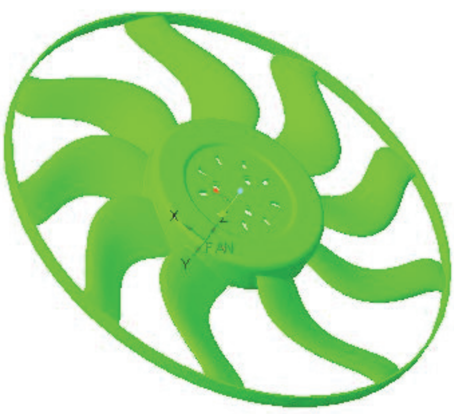

Fig. 10. CAD fan model

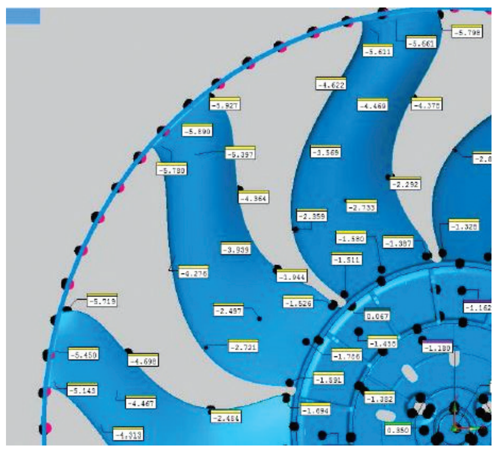

Fig. 11. Map of shape deviations – CAD model and scanned actual part overlapped

5. Conclusion

The application of industrial computed tomography to control the quality of car components at each development stage is needed. The main advantage of this method is the fact that the scan is performed without applying any external forces, pressure or stress. Thanks to the possibility it offers to investigate internal structures and shape failures in a non-destructive manner, it also functions as a tool for preproduction inspection. Moreover, we can cut costs and reduce production time by analysing CT scans of manufactured prototypes before and after testing in order to introduce improvements on time. Thanks to CT, it is much easier to check all main metrological aspects like internal material discontinuities, shape defects or dimension accuracy. Engineers can made a map of shape deviations, compare test reports with simulations and performed Part-to CAD comparison. After analyzing all these results they introduce improvements both on the product and on the mould in order to meet manufacturer and customer requirements. Software that is dedicated to CT has many excellent tool options for all kind measurements and also helps with the preparation of graphic reports including measurements and defect analysis. To summarise, industrial computed tomography is an irreplaceable device in automotive research and development centres as a quality control technique for the comparison and evaluation of geometric tolerances and dimensions in 2D and 3D.

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