3-Dimensional Inspection of Injected Plastic Parts

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The paper argues the necessity of 3-dimensional inspection of injected plastic parts, presenting the special demands and particular condition related to the specificity of part material nature. A measuring strategy on the coordinate measuring machine is presented for verifying the position, dimensional accuracy and shape of the circular holes, slots and the line form for plastic parts used in the automotive industry due to the dimensional changes caused by shrinkage and warpage. The reverse-engineering technique applied in the try-out phase to the production launch is also presented.

Keywords: injection, shrinkage, warpage,3-D measurement, reverse engineering

The key to implement the control of the injection moulding process is to utilize a strategy through which we understand the moulding process from the plastics point of view. It is important to understand how the various variables of the process acting on the plastic material determine the characteristics of the finished plastic part. To achieve the maximum degree of process control and have positive effects on the finished plastic product being molded, it is important to measure and control the plastics variables.

In a typical injection moulding process there are around twenty parameters, divided in two groups: product and process parameters, that should be monitored to control the process and ensure consistency [1-9]. The product parameters are: product dimensions, weight and appearance. The product dimension is one of the most important parameters. Obviously, product dimensions have to be monitored to make sure that the product is within dimensional specifications [10,11].

The main conditions affecting the injection process and all the details that can contribute to the variability from measurement point of view are listed in the variation analysis diagram (fig. 1).

Measurement of the product dimensions is often the most critical measurement in the injection moulding process. The choice of the measurement method will depend on several factors, such as the shape and dimensions of the product, the tolerance, the cost of the measurement equipment, and so on.

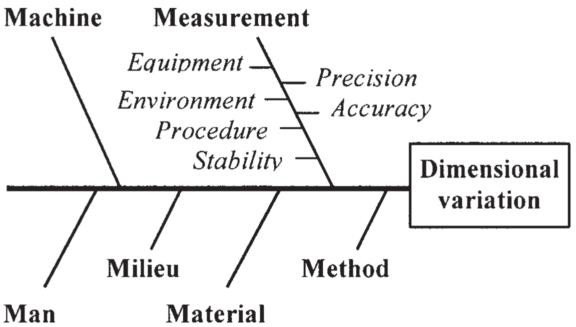

Fig. 1. Variation analysis diagram for dimensional variation

<u>*Present status in 3D measurement*</u>

The evolution of parts, from cylindrical or prismatic shape to free-form shape, implies an evolution of measuring equipment. Today, the measuring systems have to correspond more and more to the requirements of an "agile production" [12]. The solutions for 3D measurement can be divided into groups depending on various characteristics, such as, technology, system construction or measurement type [13].

The coordinate measuring machines (CMMs) are considered the most modern control equipment. Process control and quality assurance in modern manufacturing operations depend increasingly on the performance of the CMMs.

CMMs have largely replaced manual measurement methods, which are typically based on the use of hand-held tools, and have reduced the time and manpower required in quality control operations. Today, 80% of work pieces control is effectuated with CMMs [14]. CMMs are useable for various measuring tasks and parts, with low measuring uncertainty compared to other means. CMMs recommend themselves to measure small precision parts, big parts (car-bodies, plastic parts), as well for the calibration of master parts and measuring gages. CMMs not only provide the capability to inspect standard geometrical dimension, but also parts with special features [15, 16].

The devices used to explore the part in order to generate information on the measurand are the sensors, which are grouped in two families: contact and non-contact sensors [17-19]. Due to their high measuring accuracy, the contact (tactile) sensors are the most used measuring systems, and are suitable for a wide range of measurement applications. To get the measuring points, they suppose a contact between the stylus ruby ball and a part surface. Some probe systems offers modules with a range of trigger forces that allow the probe performance to be best matched to the measurement task. For example, the low force module can be used for low trigger forces applications - e.g. rubber seals, plastic parts, etc. However, the point-to-point measurement offers low measurement throughput because they involve mechanical movement from one measurement point to the next. As a result, they collect only sparse data, leaving many critical areas unverified. But, in continuous measurement the sensor remains in contact with the part, following its profile and measuring points according to pre-determined laws in a single measuring path. Generally, very accurate and relatively larger than point to point, the continuous sensors, thanks to their capacity of following a profile and determining the relevant spatial co-ordinates, in an almost continuous mode, can supply very complete information on the form of the measured feature.

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The non-contact systems have been made available in relatively recent times with respect to the rather consolidated tactile technology. Traditional non-contact optic methods include structured light using moiré patterns, laser scanners and trackers, and photogrammetry-based techniques [20, 21]. The optical sensors are generally used to measure tools, edges of sheet metal or plastic parts, very small parts impossible to be measured with contact sensors, and parts made with very soft materials (e.g. some plastic parts or rubber seal) where even the negligible pressure applied by tactile sensor may damage the part surface and make the measurement impossible. These methods generally achieve higher throughput than contact methods. However, they normally achieve lower accuracy rates, and each method has specific disadvantages that limit its use. The non-contacting sensors increase the productivity of the CMM thanks to the very high data acquisition speed, but they still have some limitations if compared with conventional tactile sensors. Table 1 shows the general characteristics of contact and non-contact sensors.

Table 1

GENERAL CHARACTERISTICS OF SENSORS

Characteristic	Tactile	Non-contact
Metrological performance	High	Medium
Sensitivity to the surface conditions of the part (finishing, roughness, colour, etc.)	Scarce	High
Sensitivity to the hardness and flexibility of the part	High	None
Sensitivity to the ambient illumination conditions	None	High
Data acquisition speed	Medium	Very high
Deep reach capability	High	Very low

<u>Contributions to the injected plastic parts measurement</u>

The 3-dimensional inspection of the injected plastic parts are done, most of the cases, on the CMMs with contact sensors, except the small injected plastic parts difficult to access to measure if some internal features, or the injected plastic parts made with very soft materials. Even if the tolerance zone of the injected plastic parts is generally larger than the tolerance zone of the machined parts made of steel, the inspection can be more difficult due to the warpage of the part, caused by shrinkage. The warpage is more pronounced to the big and complex parts with thin walls.

The measuring procedure for the injected plastic parts with important warpage supposes for start to locate the position of the feature that will be measured and after that to measure the feature. Problems can appear when it has to measure small holes. In this case the diameter of the stylus ruby ball is closed to the dimension of the hole, and due to the warpage of the part there is a big deviation from the nominal position of the center of the hole. In this case there is a collision risk between the stylus ruby ball and the edge of the hole. To reduce the damage risk of the probe caused by collision, it is recommended to move the probe inside the hole with slow speed.

a. Geometrical elements localization procedure on a warpaged injected plastic part by using contact sensor

In the following, is presented a procedure to locate a small circular hole, a small slot and an edge for an injected plastic part used in the automotive industry (fig. 2). The part has the dimensions range 800x100x500mm, thin walls (e.g. 2mm) and complex shape.

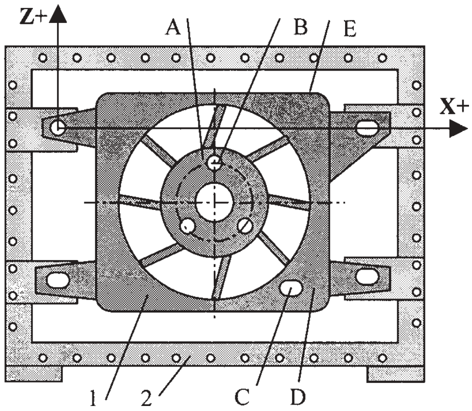
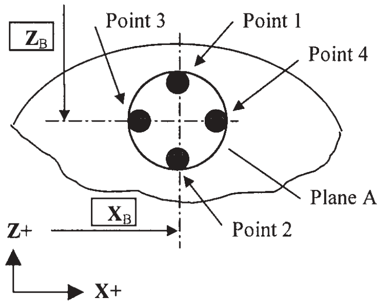


Fig. 2 Example of injected plastic part on the fixture

a.1. Strategy used to get the center of a circle

Before to get the circle B (e.g. ϕ5mm) it must make a pre-orientation of the center of the hole. Then it has to measure the circle a second time (e.g. 8 points) in a depth of "wall thickness/2" according to the plane A.

To get the circle B first it has to touch a plane around the hole (plane A – fig. 2 and 3a) and make a space orientation. Set this plane in Y to Zero. Go inside the circle (slow speed) at the nominal position of the center of the circle (X_B, Z_B) in depth of "wall thickness/2" to plane A. Measure the symmetry in Z (Point 1 and Point 2 – fig. 3a) in the circle. Get Zero in Z with this symmetry point. According to this Zero in Z touch the symmetry in X (Point 3 and Point 4). The symmetry point is Zero in X. According to this symmetry point in X touch the symmetry in Z – this is the final center for circle.



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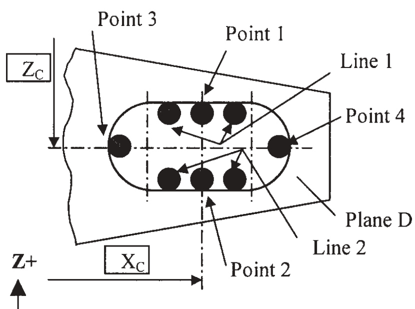

-b-

Fig.3 The circular hole and slot measurement

a.2. Strategy used to get the center of a slot

To get the slot C, first it has to touch a plane around the hole (plane D – fig. 2 and 3b) and make a space orientation. Set this plane in Y to Zero. Go inside the slot (slow speed) at the nominal position of the center of the slot (X_C, Z_C) in depth of "wall thickness/2" to plane D. Measure the symmetry in Z (Point 1 and Point 2) in the slot. Get Zero in Z with this symmetry point. According to this Zero in Z touch the symmetry in X (Point 3 and Point 4). The symmetry point is Zero in X. According to this symmetry point in X touch the symmetry in Z – this is the final center for Z.

To get the center in X follow this strategy

Get the distance of Point 1 and Point 2. Take the half of this distance and move this result back from the Point 3. This is the center in X to measure the circle on the left side. To get the center in X of the circle on the right side take the half of the distance of Point 1 and Point 2 and move this result in front to the Point 4. Touch each circle in depth "wall thickness/2" according to plane D in an angle range of 160° with 8 points. Get the symmetry of these two measured circles. This symmetry point will be the center for X. Finally measure the slot a second time with minimum 24 points (if the software allows to do this) in a depth of "wall thickness/2" according to the plane D. If not do the following method. Measure a symmetry line out of 2 lines of the slot (Line 1 and Line 2). With this symmetry line make an axis orientation. According to this line touch the radius area on the left and right side and get a symmetry point out of these 2 points. This symmetry point is the center of the slot.

a.3.Strategy used for a line form measurement

For the line form measurement on the face site E (fig. 2) touch at first a search point on the outside of the edge (fig. 4). According to this search point touch the face site with an offset of "wall thickness/2". The reason is to avoid a failure at measuring if the part will be deformed (fig. 4). To get the line form do the following method: out of all touched points get according to the nominal the point with the maximum difference – the distance of this point to the nominal multiply with 2 is the result.

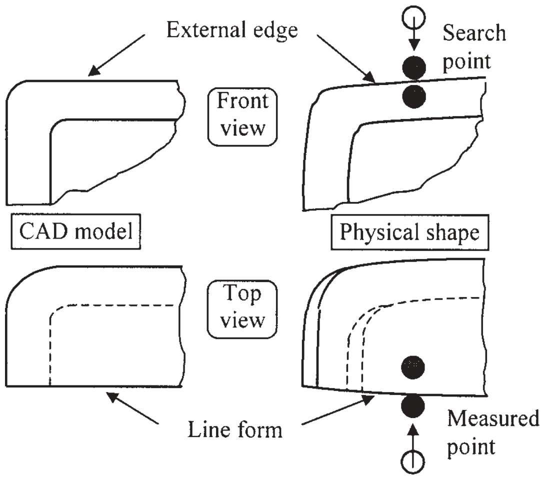

Fig.4. The line form measurement

b. First article inspection for a plastic part

The tools to produce injection-moulded parts are often built from purposely-modified, CAD data, by incorporation of uniform and non-uniform shrink factors, adding of draft angles, parting lines etc. Shrinkage behaviour of a plastic plays a critical role in determining the final dimensions of an injection-moulded part and the tool dimensions. Best practice knowledge is also incorporated to reduce thick versus thin material areas and the possible addition of features to reduce the warping and twisting of the part.

In some particular cases for simple parts, using these basic rules, tools can usually be calculated and milled to produce good quality parts, without any further modifications. For the complex injected parts with tough accuracy, even using these basic rules, the tool modifications are necessary in most of the cases. These parts need a first article inspection and periodic or continuous quality control [22, 23].

An example of the first article inspection for an injected plastic part made in PBT-GF50 and used in the automotive industry is presented. The measurements were made on the Zeiss Eclipse® CMM using the software Calypso® and Holos® [24, 25].

To measure the dimensions and the form of an injected plastic part on a CMM, the part has to be fixed on the measuring table (fig. 5), without deforming the part. The second step is to measure some features of the part necessary for the alignment of the part and to get the coordinate system of the part (fig. 6). Based on the reference system of the part, every feature of the part is measured in a number of measuring points, and for every feature will get the measurement information (fig. 7).

Because the part will be assembled with another part it is very important for the external profile of the part to fit well with the internal profile of the conjugate part. To do this, the complex profile of the part was digitized in 125 measuring points (fig. 8), in a plane situated at 2.58 mm to the front plane of the part, by using the Holos® software from Zeiss. Table 2 shows data for measuring points (only the first and the last 5 measuring points are presented), and the deviations from the nominal (CAD) points. Figure 9 shows the external profile of the part, as a graphic comparison of physical part data to a nominal CAD model, with the nominal points and the actual points of the profile.

The quality team may check whether the tolerances have been met or in which area the part is deformed. The goal is to compare the physical part with its CAD model. Based on the measurement data, the decision regarding the product quality and the "go" or "no go" of the production has to be taken.

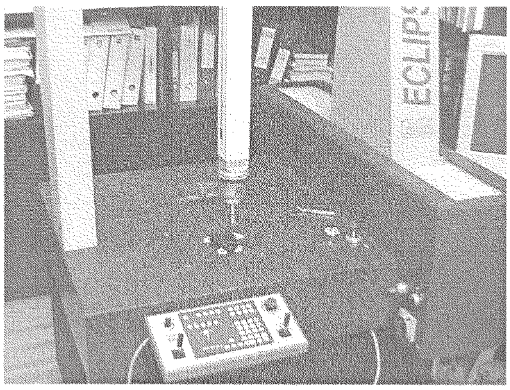

Fig.5. Part fixed on the CMM table

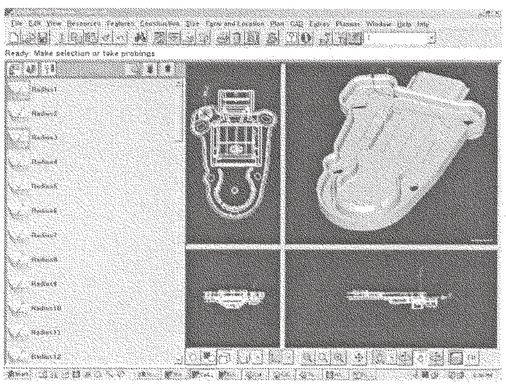

Fig.6. Reference system of the part

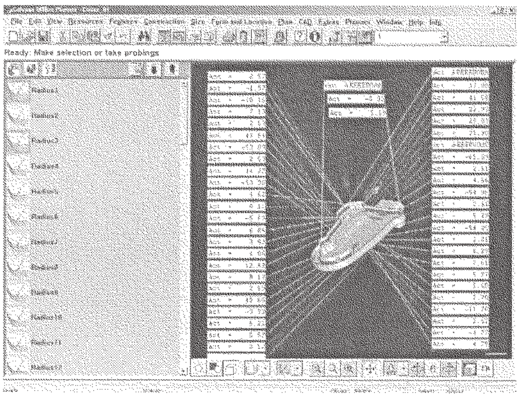

Fig.7. Measurement data of the part

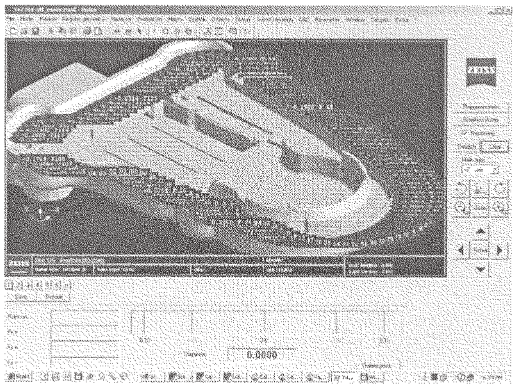

Fig.8. Measuring the profile of the part

Table 2
THE MEASUREMENT DATA [POINTS 1-5; 121-125]

Pnt.	X act X Nom	Y act Y Nom	Z act Z Nom	Ex	Ey	Ez	Distance
1	0.6657	4.4623	2.5807	-0.0957	0.2740	0.0000	-0.2902
	0.7614	4.1883	2.5807				
2	3.0754	5.2747	2.5812	-0.0910	0.2925	0.0000	-0.3063
	3.1664	4.9822	2.5812				
3	5.6691	5.5471	2.5814	0.0516	0.3088	-0.0000	-0.3131
	5.6175	5.2383	2.5814				
4	8.0522	4.3753	2.5810	0.1878	0.2115	0.0000	-0.2828
	7.8644	4.1638	2.5810				
5	9.4090	2.0823	2.5784	0.2035	0.0576	0.0000	-0.2115
	9.2055	2.0247	2.5784				
121	-9.3965	-2.3931	2.5787	-0.1914	0.0232	0.0000	-0.1928
	-9.2051	-2.4162	2.5787				
122	-8.4624	0.0145	2.5795	-0.1989	0.1575	0.0000	-0.2537
	-8.2635	-0.1430	2.5795				
123	-6.4078	1.5907	2.5878	-0.1306	0.2776	0.0000	-0.3068
	-6.2772	1.3130	2.5878				
124	-4.0812	2.6250	2.5820	-0.1169	0.2727	0.0000	-0.2967
	-3.9643	2.3523	2.5820				
125	-1.7182	3.5732	2.5800	-0.1017	0.2618	0.0000	-0.2809
	-1.6165	3.3114	2.5800				

Upper tolerance: 0.1000 mm Standard deviation= 0.2444
Lower tolerance: -0.1000 mm min(52) = -0.4992 max(101) = 0.0006

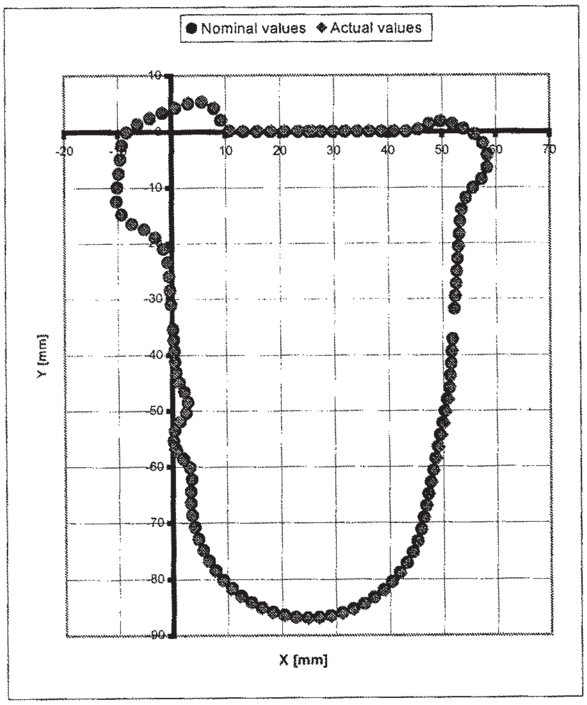

Fig. 9. The measurement data of the profile

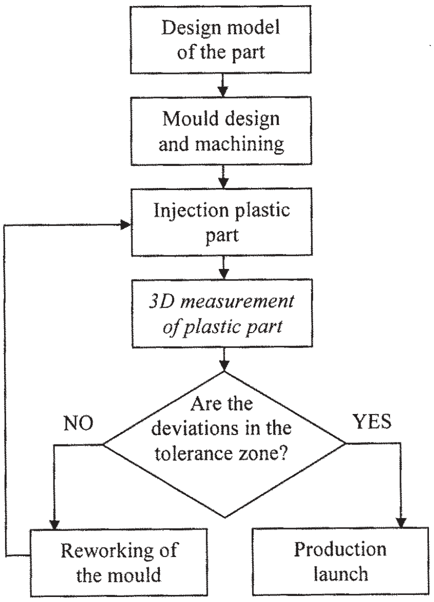

Fig.10. The try-out phase and production launch

If the part does not meet the expectations, the quality team has to identify the area of concern and define the cause of the problem. In our example it can be seen that the deviations in some areas of the part are out of the tolerance zone. The maximum deviation is 0.006mm and the minimum deviation is –0.4992mm. The standard deviation is 0.2444mm at a tolerance zone of 0.200mm.

The complete cycle from the “Designed” part to the production launch, with the modifications during the try-out phase is presented in figure 10. After the reworking of the mould, the new parts will be measured and compared with the CAD model in a reverse engineering cycle.

Conclusions

Dimensional parameters are the most commonly encountered quality characteristics of injected plastic parts. The measuring process for testing conformance of those characteristics contains the important sub-process of probing the surface. Coordinate measuring machines (CMMs) are essential for quality assurance and production control in injection molding process. Compared to metal machining parts, the injected plastic parts show bigger deviations of dimensions and shape against the CAD data.

The augmentation of mechanical resistance performances of new polymers lead the industry to use frequently these new polymers to make parts with functional role which impose high accuracy of dimensions and shapes and more stability.

In this way, the reverse engineering technique offers a good prediction for injected plastic parts, from design phase, digitizing, up to the final accurate part and production launch.

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