STUDY OF SHAPE AND DIMENSIONAL ACCURACY IN THE PRODUCTION OF DUCTILE IRON CASTINGS USING 3D SCANNING

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Abstract

At present, cast iron foundries are facing increasing competition along with increasing demand for ductile iron. Therefore, there is no other way than to improve the technological processes of casting production and use other possibilities for more efficient management of their quality by means of 3D scanning of dimensional accuracy in critical production nodes.

The paper is based on the gained experience with the study of the potential of the method of non-contact 3D measurement of shape and dimensional accuracy of the patterns and castings, which is to be used in optimizing the process parameters of gravity casting of ductile iron castings.

The ROMER Absolute Arm 7525SI portable laser measuring arm is used. The dimensional accuracy of newly manufactured patterns is monitored. Then, it can be confronted with the original 3D model. Subsequently, the patterns are scanned over their life cycles to identify critical dimensional deviations. All in connection with the control of dimensional deviations in molds, but especially in castings. The study of dimensional stability of the patterns, molds, and castings will allow monitoring the actual state in connection with the implementation of our own casting technology. As it turns out, it is possible to identify critical production parameters in terms of compliance with the dimensional accuracy of castings. The entire measuring system is connected to a professional program for measuring, dimensional evaluation according to the GD&T methodology, comparison with 3D objects, fitting, and export to a CAD system as STL 3D objects.

Keywords: Cast iron, castings, mold, quality control, 3D measurement

1. INTRODUCTION

Ensuring shape and dimensional accuracy and other surface and internal quality parameters are critical parameters that must be met to provide the required product quality. It is no different in the case of the production of cast iron castings. These cast irons with nodular graphite are increasingly used as parts of machine units incl. the automotive industry, where they replace more expensive steel products. Authors [1] created an algorithm to predict casting defects based on monitoring various operational data from production in a cast iron foundry [1]. However, creating complex predictive algorithms is somewhat of a black box, albeit with very satisfying results. In addition to the implementation of artificial intelligence methods, the optimization of ductile iron production can also be focused on, for example, the study of shrinkage tendency in ductile cast iron as affected by mold rigidity (green and furan resin sand molds) and inoculant type (FeSi-based alloys) [2]. Attention is increasingly focused on austempered ductile iron (ADI) with increasing demands on material properties and the increased added value of castings [3,4].

There is a wide range of approaches to studying casting quality and casting manufacturing technology. Non-destructive methods are becoming more and more widespread. Strategies focused on 3D measurement and 3D scanning is also integral. The authors [5,6] implement micro-CT scanning methods to study microstructure issues. The authors [7,8] then focus on the study of surface quality/roughness. The authors [9] present a complex 3D defect detection system based on deep learning methods.

However, the work of the authors [10] is closest to the present contribution. Attention is focused on implementing 3D measurement and scanning methods during the preparation of a casting for machining, which is closely related to the output dimensional and quality control of castings in a cast iron foundry.

At the Environmental Research Department of VŠTE in České Budějovice, the methods of using 3D scanning are implemented in a whole range of research and development activities. For example, the specific use of 3D scanning in studying FDU (Foundry Degassing Unit) rotor wears during aluminum alloy refining [11]. As part of the research aimed at optimizing the casting technology of ductile cast iron, there is also an intensive study of shape and dimensional accuracy, especially of the patterns and castings.

This paper focuses on monitoring these key quality parameters using non-contact measurement methods (3D scanning). It presents their importance in the quality control of nodular graphite cast iron (ductile iron) production by the applied standard [12].

2. EXPERIMENTAL PROCEDURE

3D scanning is the one in the group of non-contact measurement methods. During measurement (scanning), there is no contact between the measured part and the scanning head. In the case of the presented paper, it is used with a ROMER Absolute Arm 7525SI 3D measurement laser scanner (**Figure 1**) [13] while applying the Polyworks 202X professional measurement and evaluation software [14].

Single point repeatability	0.027 mm / 0.0011 in
Volumetric accuracy	± 0.038 mm / 0.0015 in
Scanning system accuracy (RS4)	0.063 mm / 0.0025 in
Arm weight	8.9 kg / 19.6lbs

Scanning Sensor Specifications: Integrated Scanner RS4		
Point acquisition rate		752 000 points/s
Points per line		Max. 7520
Line rate		Max. 100 Hz
Line width	min.	80 mm
	mid.	115 mm
	max.	150 mm
Stand off		165 ± 50 mm
Accuracy		0.028 mm (2σ)
Minimum point spacing		0.011mm (line)
System scanning certification		Yes
Laser class		2M
Operating temperature		5–40°C

Figure 1 ROMER Absolute Arm 7525SI and its specifications based on [13]

The principle of laser scanning consists in scanning tens of thousands of points per second (after filtering) from a laser line that passes over the scanned object. Millions of points result from a specific scanned object, the so-called point cloud, which creates a virtualized 3D object. The recording is performed in the appropriate control and evaluation SW, here Polyworks. Importing the CAD model of the given scanned object/part is necessary for dimensional and shape inspection. After scanning the object, it is possible to perform alignment on the existing CAD model according to the required parameters. Automatic alignment to the reference object (imported CAD model), the so-called Best Fit, is used in the studied case. Subsequently, it is possible to perform a dimensional and shape check of the scanned part against the reference CAD model and perform the required evaluation of the detected deviations.

One of the shaped and dimensionally studied castings with feedback for optimization of production technology is KARDAN A type castings (material EN GJS 600-3 [15]). Castings are gravity cast into bentonite molds. Due to the limited scope of the paper, attention focuses on the demonstration of the use of checking the dimensional stability of the pattern and, at the same time, on the study of critical dimensions that are difficult to control using the contact probe of a contact coordinate measuring machine (CMM).

3. RESULTS AND DISCUSSION

Attention focuses on verifying the accuracy of the production of the pattern for casting type KARDAN A, see CAD model in **Figure 2**, where dimensions out of tolerance detected as part of the 3D measurement.

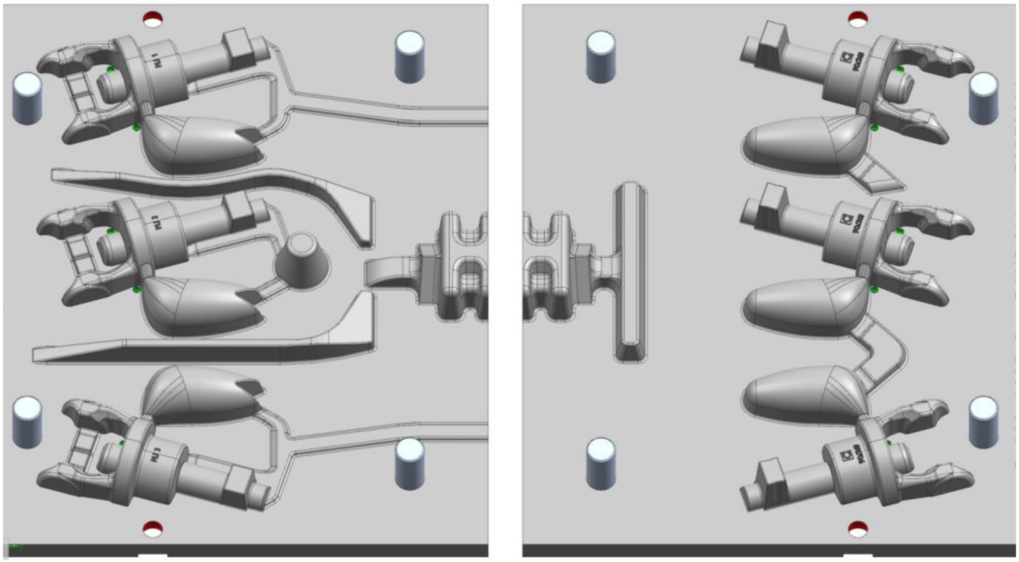


Figure 2 CAD model of pattern KARDAN A

In the first phase, a scan of the pattern was carried out and a comparison of the measured deviations with the CAD input of the model (**Figure 3**) and a comparison of the resulting values on the castings (**Figure 4**) was done.

Scanning confirmed (**Figure 3**) that the pattern was manufactured with the required accuracy. The measured deviations on the pattern were within a maximum variance of 0.2 mm. Given the standard tolerance of manufactured castings according to ISO 8062 CT9 [12], these deviations are acceptable. However, a problem can arise with specific characteristics (dimensions tightened and required by the customer), where this variance can make up more than 20 % of the total tolerance of the casting, regardless of additional variability in the casting process.

In the subsequent step, a comparison was made of the measured values on the casting, the pattern, and the designed value according to the CAD model (**Figure 4**). When designing the pattern for this casting, a shrinkage value of 5 ‰ was calculated. The resulting deviations measured on the castings do not correlate with the values of the pattern. According to the results from the 3D scanning of the castings, a dimensional correction will propose a dimensional revision of the pattern, followed by repeated sampling and measurement.

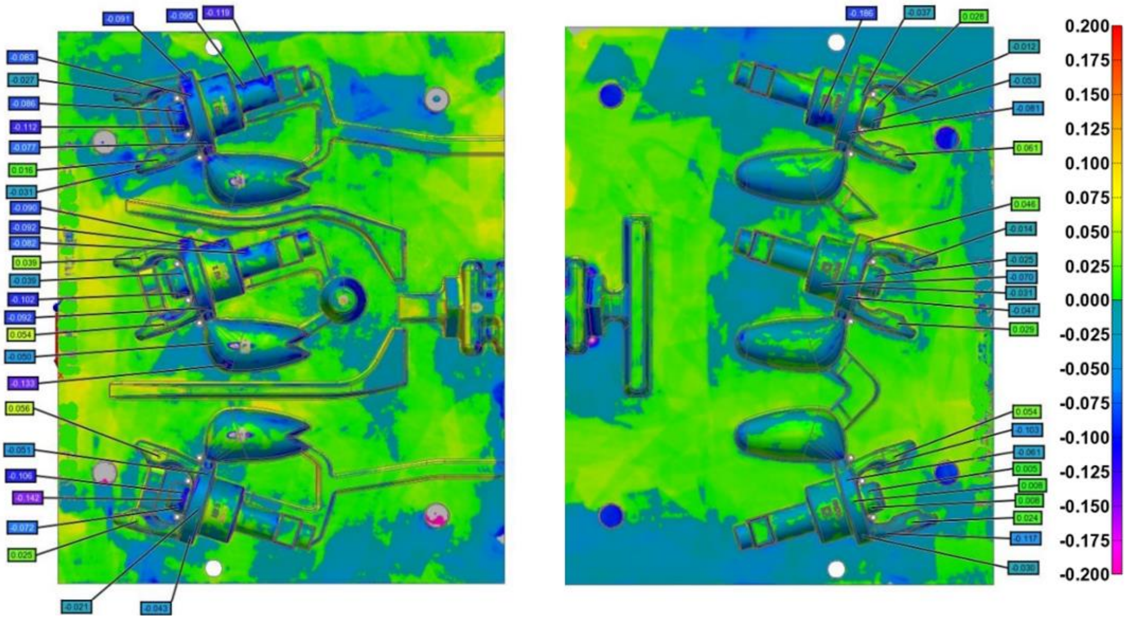
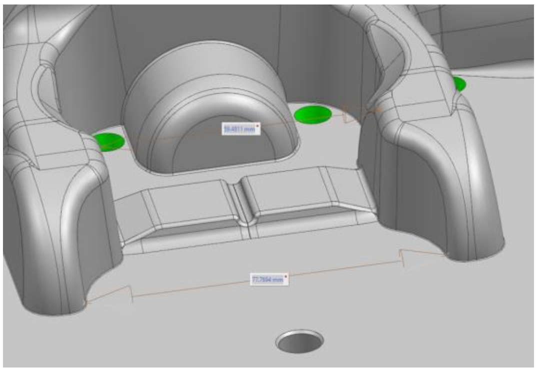
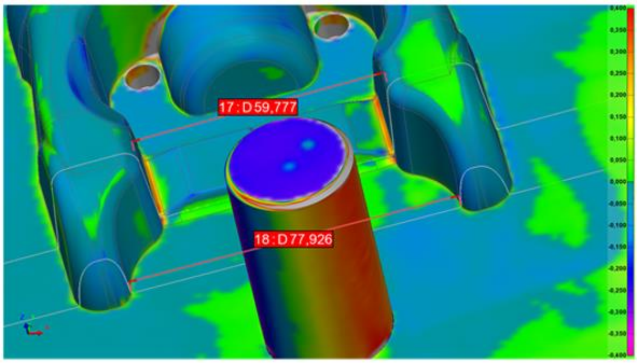


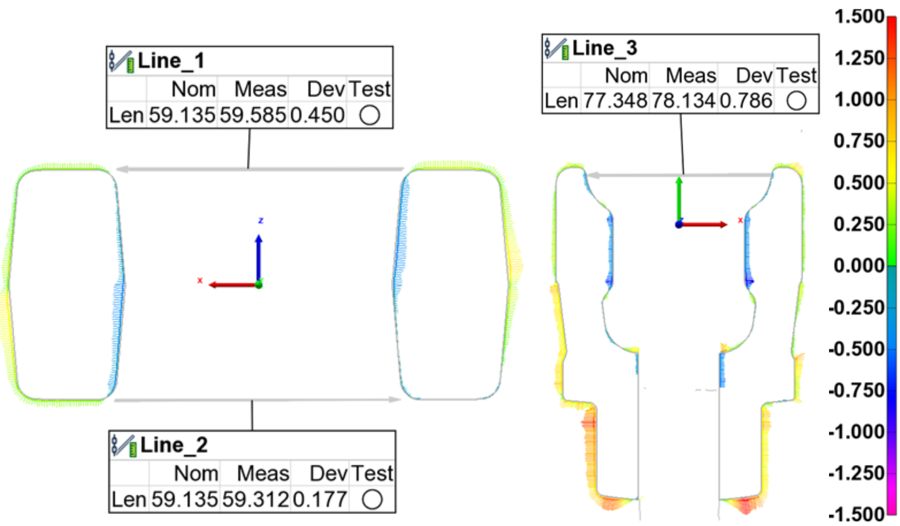
Figure 3 Scan results for the pattern KARDAN A



a) designed values on the CAD model



b) measured values on the manufactured pattern



c) measured values on the part/casting after casting

Figure 4 Scan results - comparison of the design value of the model, the actual value on the manufactured pattern, and the resulting value on the cast part (KARDAN A; cavity 1)

It is worth noting that the observed dimensions in **Figure 4** are complicated to measure by standard touch measurement accurately. On the other hand, 3D scanning can identify with a high degree of accuracy the points where the shape changes and where the necessary dimension needs to be specified. It is best shown in the sections from the cast in **Figure 4c)**.

4. CONCLUSION

Presented paper was devoted to the study of the potential of the method of non-contact 3D measurement of shape and dimensional accuracy of the patterns and castings, which is to be used in optimizing the process parameters of gravity casting of ductile iron castings.

The use of 3D scanning in the discussed foundry practice has mainly demonstrated the following advantages:

- ✓ obtaining a complex cloud of millions of points with dimensional deviations from the design of the CAD model;
- ✓ the possibility of measuring with a CMM barely identifiable dimensions;
- ✓ the use of virtual sections in the evaluation SW assesses the shape and dimensional accuracy as needed.

Shape and dimensional deviations of the patterns and castings are monitored similarly, and the resulting castings' quality is continuously monitored and evaluated. Based on the results, it is possible to operationally approach adjustments in cast iron production technology with nodular graphite. Obtained 3D scans can be archived for later use, for example, when optimizing the process of numerical simulations, where stress states and resulting deformations of castings are also studied.

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REFERENCES

[1] SIKA, R., SZAJEWSKI, D., HAJKOWSKI, J., POPIELARSKI, P. Application of Instance-bBsed Learning for Cast Iron Casting Defects Prediction. *Management Production Engineering Review*. 2019, vol. 10, no. 4, pp. 101-107.

[2] RIPOSAN, I., STAN, S., CHISAMERA, M., NEACSU, L., COJOCARU, A.M., STEFAN, E., STAN, I. Simultaneous thermal and contraction / expansion curves analysis for solidification control of cast irons. *China Foundry*. 2020, vol. 17, no. 2, pp. 96-110.

[3] SAMADDAR, S., DAS, T., CHOWDHURY, A.K., SINGH, M. Manufacturing of Engineering components with Austempered Ductile Iron - A Review. *Materials Today: Proceedings*. 2018, vol. 5, no. 11, part 3, pp. 25615-25624.

[4] CATIPOVIC, N., ZIVKOVIC, D., DADIC, Z. The Effects of Molybdenum and Manganese on the Mechanical Properties of Austempered Ductile Iron. *Technical Gazette*. 2018, vol. 25, no. 2, pp. 635-642.

[5] LEKAKH, S.N., ZHANG, X.L., TUCKER, W., LEE, H.K., SELLY, T., SCHIFFBAUER, J.D. *Materials Characterization*. 2019, vol. 158, 8 p.

[6] LEKAKH, S.N., ZHANG, X.L., TUCKER, W., LEE, H.K., SELLY, T. SCHIFFBAUER, J.D. Micro-CT Quantitative Evaluation of Graphite Nodules in SGI. *International Journal of Metalcasting*. 2020, vol. 14, no. 2, pp. 318-327.

[7] SCHIMPF, D.W., PETERS, F.E. 3D Analysis of Casting Surface Characterization Based on the Variogram Roughness Method. *International Journal of Metalcasting*. 2022, vol. 16, pp. 1079–1090.

[8] SCHIMPF, D.W., PETERS, F.E. Variogram Roughness Method for Casting Surface Characterization. *International Journal of Metalcasting*. 2021, vol. 15, no. 1, pp. 17–28.

[9] LEE, J.H., OH, H.M., KIM, M.Y. Deep learning based 3D defect detection system using photometric stereo illumination. In: *1st International Conference on Artificial Intelligence in Information and Communication (ICAIIC)*. Okinawa: IEEE, 2019, pp. 484-487.

[10] GESSNER, A., PTASZYNSKI, W., ADAM, W. Accuracy of the New Method of Alignment of Workpiece Using Structural-Light 3D Scanner. *Advances in Science and Technology Research Journal*. 2022, vol. 16, no. 1, 14 p.

[11] PRÁŠIL, T. SOCHA, L., GRYC, K., SVIŽELOVÁ, J., SATERNUS, M., MERDER, T., PIEPRZYCA, J., GRÁF, M. Impact of Rotor Material Wear on the Aluminum Refining Process. *Materials*. 2022, vol. 15, 12 p.

[12] ISO 8062-3:2007. *Geometrical product specifications (GPS) — Dimensional and geometrical tolerances for moulded parts — Part 3: General dimensional and geometrical tolerances and machining allowances for castings*. Charlottenlund, Denmark: Technical Committee ISO/TC 213, Dimensional and geometrical product specifications and verification, 2007.

[13] HEXAGON, Manufacturing Intelligence Division. *ROMER Absolute Arm Overview Brochure* [online]. 2018 [viewed: 2022-03-20]. Available from: https://www.hexagonmi.com/-/media/Hexagon%20MI%20Legacy/hxrom/romer/general/brochures/ROMER%20Absolute%20Arm_overview_brochure_en.ashx

[13] InnovMetric Software. PolyWorks Inspector [online]. 2022. [viewed: 2022-03-20]. Available from: https://www.innovmetric.com/products/polyworks-inspector

[14] EN 1563:1997. Founding - Spheroidal Graphite Cast Irons. CEN/TC 190 - Foundry technology, 1997.