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A Method for the Evaluation of the Casting Accuracy of a Cast Iron Body

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Abstract

This paper presents a new methodological premise for accuracy evaluation of cast iron machine tool bodies. The hereby introduced method utilizes a three-dimensional optical scanner and a reference design of the tested machine tool body. The ultimate aim of its implementation is to compare the geometry of the investigated cast iron body with that of its three-dimensional model. The comparison results are presumed to facilitate a considerable improvement in the quality of cast iron bodies.
Preliminary investigation was carried out in a machine tool manufacturing enterprise. Results of the aforementioned comparison of geometric features provided for acceptable accuracy assessment, revealing a slight deformation i.e. a naturally arising technological feature, bearing no influence on final casting efficiency. As a consequence, the investigation results obtained were successfully implemented by the machine tool company for effective quality improvement of the produced cast iron bodies.

Keywords: optical measurement, photogrammetry, accuracy evaluation, casting, marking out, machining allowance minimization.

1 Introduction

Marking out is one of the first technological procedures in manufacturing of large and complex casts. The process allows assessing casting accuracy, as well as determining whether the surplus size of all work surfaces is sufficient for appropriate machining, corresponding to the construction design. Marking out is a manual operation and, depending on the size and complexity, might take from several minutes for simple casts up to several working shifts for prototype casting.

The process of marking out consists in appropriate setting and horizontal leveling of a given object on a marking plate, followed by gouging the machining surfaces (chiseling e.g., orifice centers, cast axes, machined surface edges, etc). In regard to the applied gouges, the machinist works the three basic surfaces, most often oriented in inter-perpendicular directions of the coordinate system of the machined object; the remaining surfaces are then machined according to the construction design. In case of prototype casting, however, marking out encompasses all machined surfaces to ensure determining whether the size of the allowances of all work surfaces is sufficient. Nowadays, marking out is the only cast accuracy assessment method commonly used in machine tool industry. Figure 1 depicts the process of marking out, exemplified upon the basic work surfaces of headstock guideways.

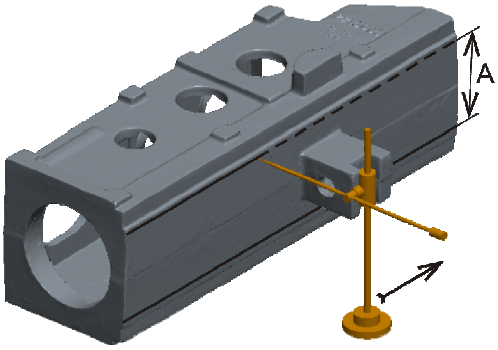

Figure 1: Marking out of headstock guideways:
A – designed dimension (distance between guideway basic work surfaces).

In case of large and elaborate casts, as those of machine tool bodies, marking out is often restricted only to the first cast of the desired body produced in a given casting mould. Such course of action is based on an assumption that casting is reproducible and there is no need to assess each and every individual cast. While this approach saves time, it often results in late detection of casting errors (surplus shifts or insufficiencies) during the actual machining process. That, in turn, leads to considerable losses due to the disruption of the work process and often demands cast repair.

Some modern production enterprises are now gradually introducing selective quality control procedures utilizing optical measuring systems. In most cases, however, due to high cost of equipment and the necessity of individual measurement protocol design for each cast, the geometric cast accuracy assessment is sporadically contracted out to specialized companies [2, 3, 6, 9, 10].

The aim of the hereby presented study is to introduce a new technological premise dispensing with manual marking out as well as allowing fast verification of cast shapes and optimal design of machining datum surfaces [4, 5].

2 Theoretical groundwork

A typical cast, constituting a constructing element of a technological machine (e.g., bed, stand, headstock), encompasses around 15 to 40 work surfaces [7]. These are spatially inter-oriented according to the construction design and dimensionally connected. Each surface is assigned a machining allowance whose size is defined either by PN-ISO 8062:1997 or the individual criterions of the producer. According to the authors' professional experience in machine tool industry, the overall volume of material removed during the machining process generally amounts to approximately 10 - 20% of the entire cast mass. The cast machining time adds up to 10.5 - 11.3 h, and its cost reaches 350 - 450 EUR. The cast machining time should additionally encompass the time of marking out, taking up – depending on the size and complexity of the cast – from several minutes for simple casting series to tens of hours in case of elaborate prototype casting. Even in highly automatized production outfits, marking out is a manual process and constitutes one of most time-consuming operations comprising tool body machining.

Herein the authors propose a new technological solution including shape verification of all machined cast surfaces by means of an optical contactless scanning system. The information provided by the scanning system enables the development of a 3D cast model, while the accompanying software allows detailed analysis of the conducted measurements. Moreover, the system facilitates optimal planning of cast machining aiming at minimization of the removed material volume. It has been estimated that the reduction could amount to 15 - 30% [8].

3 Measurement methodology

Initial investigation focused on headstock cast geometry measurement and comprised extrinsic machining allowance specification according to the technological construction design, minimized surplus determination in line with the proposed and recently patented protocol [5], as well as the overall evaluation of geometric accuracy of the cast. Selection of the milling machine headstock as the investigated element was due to authors' close cooperation with a machine tool corporation. Nevertheless, the hereby proposed accuracy assessment and allowance minimization approach can be applied to a wide spectrum of machine tool casts.

In the first experimental phase the cast was labeled with reference markers and photographed by Tritop HR (GOM, Braunschweig, Germany) along with the length standards (Figure 2a), allowing the development of a spatial marker map. Subsequently, consecutive geometric cast areas were scanned by means of the optical system GOM ATOS II (Figure 2b). The size of the scanned surface and the number of essential photographic shots were dependent on the measurement area and the detection range of the camera system utilized.

Obtaining the full geometric images necessitated shifting/turning of the investigated cast. The previously acquired photogrammetric map of markers enabled the proper integration of all scanned surfaces.

Thus performed optical scanning resulted in obtaining the complete spatial model of the investigated cast (Figure 2c). The scanner software enabled the assessment of casting quality through calculation of shape errors of selected surfaces, as well as the comparative analysis of the cast and its reference model designed by means of Pro/ENGINEER (PTC, Needham, MA, USA) body system.

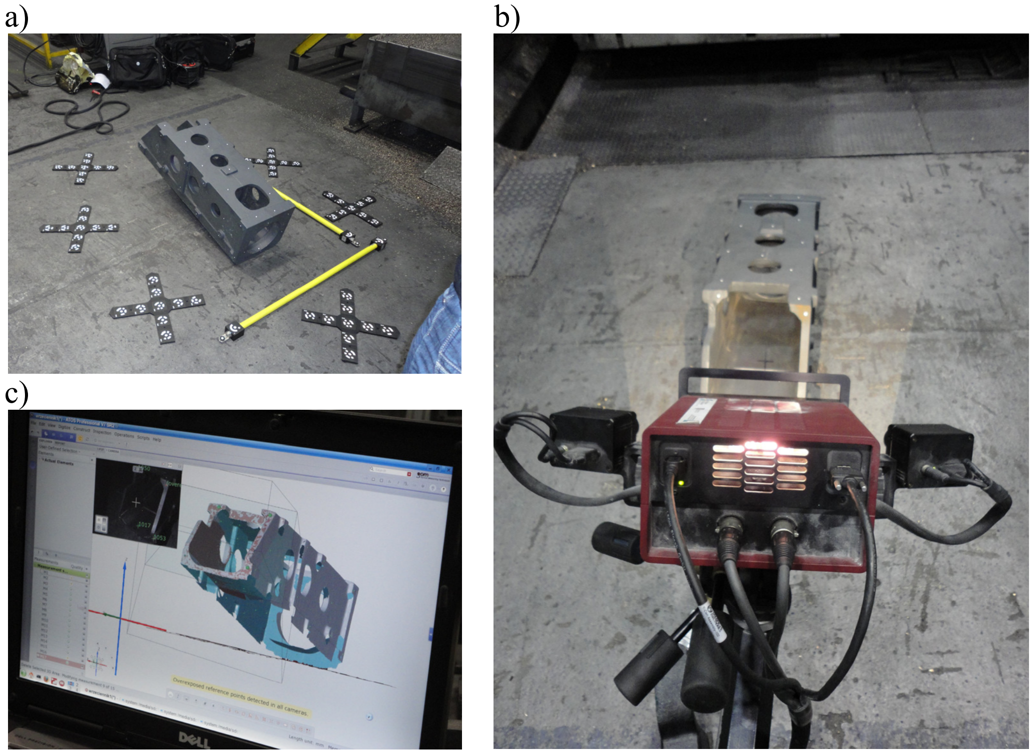

Figure 2: Marker-labeled cast with length standards – a), optical scanning system GOM Atos II during measurement – b), partially scanned geometry – c).

The size of machining allowances in the investigated cast was assigned in accordance with the internal company norms, and amounted to approximately 6 mm. Theoretical calculations, taking into account the surplus surfaces, resulted in surplus mass of 22.3 kg, constituting 15% of the milling machine headstock total cast mass.

4 Measurement results, casting accuracy assessment, and minimization of allowances

Initial casting quality assessment was performed by allotting the flatness parameter for selected surfaces. The scanning software analyzed the area surrounding the indicated point and denoted the area restricted by the furthermost points, according to the established criterions and the software algorithm.

Figure 3 depicts the investigation outcome, giving clear evidence for surface quality consistent with quality control requirements and allowing effortless mechanical treatment. The flatness parameter of poorer quality was recorded only for the surfaces characterized by casting inclinations due to mould division (Figure 3b). That, however, is a naturally arising, technological effect, having no influence on the casting quality.

Subsequently, the shape assessment of the investigated cast was performed, involving appropriate relative alignment of the cast and its 3D model design. The scanning system software affords several alignment methods [1]. The herein presented shape assessment involved:

- *bestfit* method taking all scanned surfaces into account,
- *bestfit* method basing on selected surfaces.

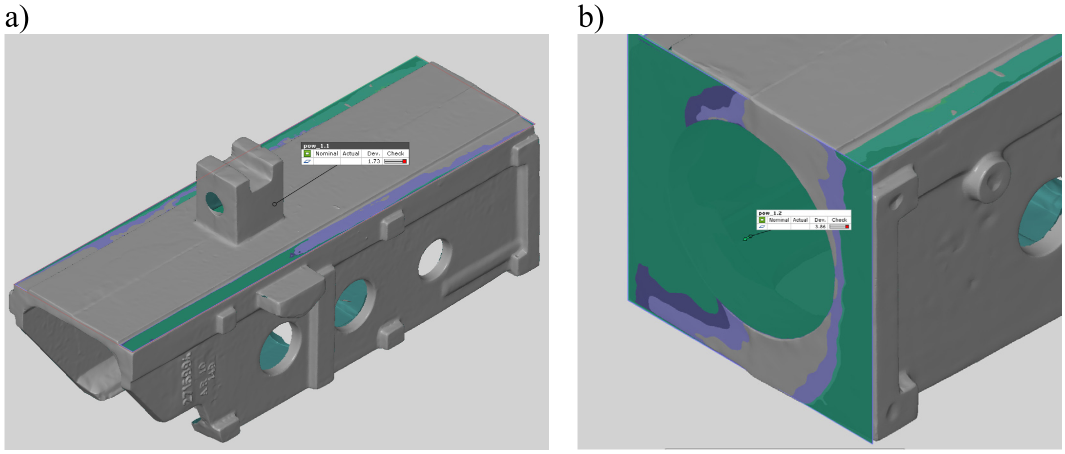

Figure 3: Surface flatness assessment of the investigated headstock: a) base surfaces for guideways, b) base surface for spindle

The *bestfit* method, matching the scanned geometry to that of the original design, aims at the alignment of both models resulting in minimal sum of normal distances, as recorded in measurement points, between all their corresponding surfaces. The differences between the compared models are illustrated by means of color maps, marked either on the scanned or the reference model, with colors indicating appropriate distances in the given measurement/test points (Figure 4). Green corresponds to the highest compatibility (distance near zero). Light- to dark-blue indicates negative distance values, which may be interpreted as casting faults due to lack of material. Yellow merging into red designates positive distance values, corresponding to the machining surplus sizes of the investigated surfaces.

The model alignment derived from the comparison of all scanned surfaces affords the overall shape assessment of the obtained cast as well as the determination of machining allowances adequacy on all surfaces. The ready access to a 3D model featuring the color map illustrating the compatibility of a cast with its reference design will enable quick evaluation of machining surplus sufficiency (yellow merging into red), and will consequently facilitate ultimate elimination of the inconvenient manual marking out process from the technological procedure.

According to the authors' professional experience in machine tool industry, the casting accuracy depends, to a large extent, on the quality and efficiency of the available foundry and oscillates around ± 5 mm. Furthermore, the shape of the non-treated surfaces is not monitored at all, which often precludes appropriate machining of surfaces additionally introduced during machine production. Therefore, the possibility of prompt cast shape control prior to machining could help avoid unnecessary interruptions and minimize losses.

a) b)

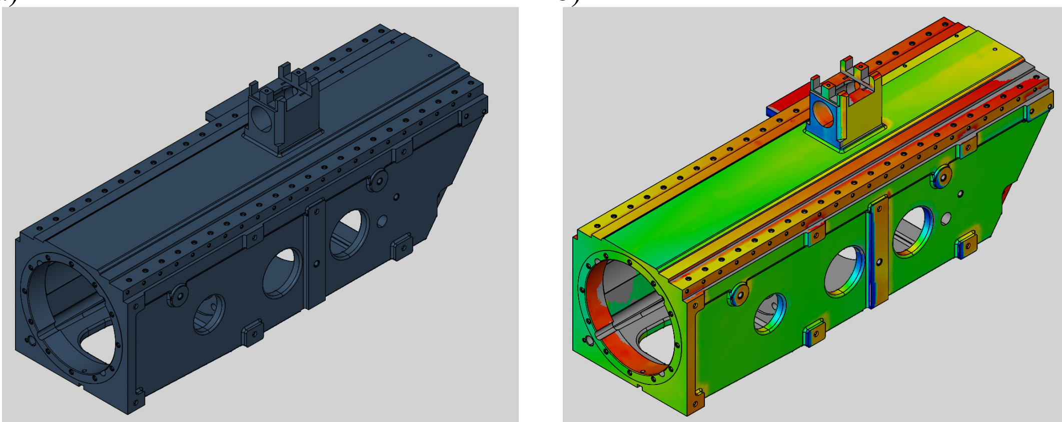

Figure 4: Reference headstock model: a) after machining, b) shape comparison of the scanned cast and the reference model.

Modern machine tool engineering utilizes FEM (Finite Element Method), providing for optimal cross-section design in terms of strength, stiffness, stability, and resonance frequencies. Thus, the highest possible shape compatibility of the cast with its reference design model is vital for the obtained machine tool to fulfill the technical requirements for spindle-end vibrations.

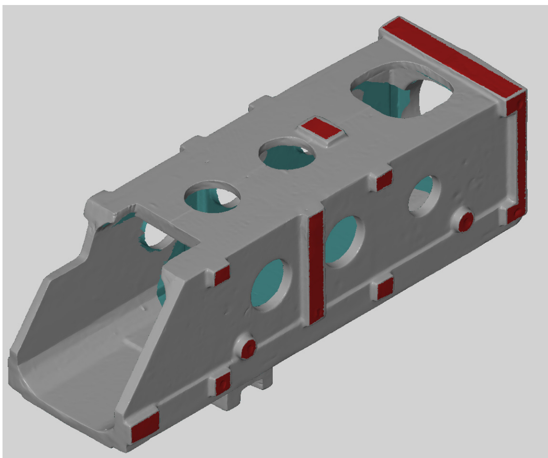

Figure 5: Cast model with selected machining allowance areas.

The alignment of the cast model relative to its reference model resulting in minimal sum of normal distances between all surplus surfaces and machined surfaces can be accomplished successfully by means of *bestfit* orientation applied to chosen areas (Figure 5). The method provides reliable means for appropriate cast machining set-up ascertaining surplus minimization. Since the shape accuracy of cast surfaces tends to be relatively low, it was necessary to determine the minimal value of machining allowances at the approximate level of 3 mm. As the extrinsic surplus values equaled 6 mm, the acceptable allowance modification totaled up to ± 3 mm.

Comparative masses of extrinsic machining allowances, determined according to the construction design, and minimized surpluses, as measured by *bestfit* method for selected surfaces of the investigated cast, are presented in Figure 6. The implementation of the hereby proposed technological solution resulted in achieving machining allowance mass reduction of 11%. This, in turn, will directly contribute to machining time reduction, a decrease in machine tool and cutting device overexploitation, as well as considerable cuts in energy consumption. Since the casting geometric reproducibility is relatively low, as conditioned by cast model deterioration, individual determination of minimized surplus values based on geometry measurement of each cast comes highly recommended.

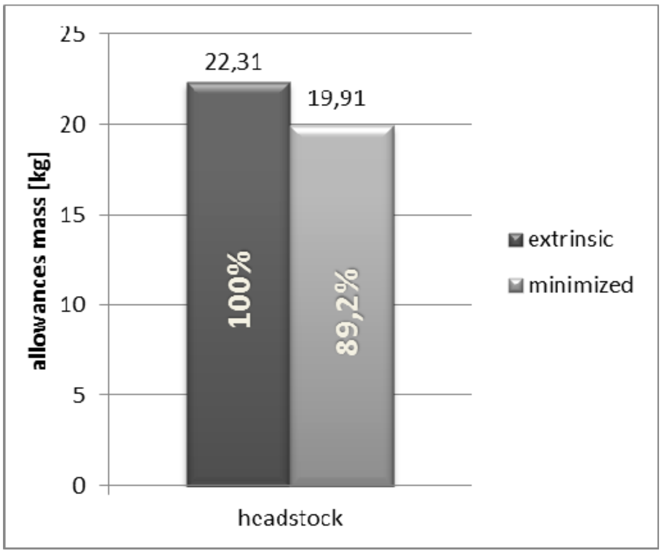

Figure 6: Surplus masses of the investigated cast before and after minimization.

The geometric accuracy assessment, relying on comparative alignment analysis of the scanned cast and its reference design, proved high consistency between the two models. Nonetheless, some substantial discrepancies concerning the basic vent cylindrical element of the headstock were detected. The nature of the observed deviation, depicted in Figure 7, identified insufficient cleansing of the forming substance from the founding core vent as the source of the exposed inconsistencies. The quality control units are usually not able to detect such flaws, as the casts are painted. Further machining of the deficient areas can cause not only faster over-exploitation of the cutting tools, but also their utter damage. Therefore, the measurement record interpreting the character of the aforementioned technological flaw was sent back to the foundry, thus ascertaining the quality improvement.

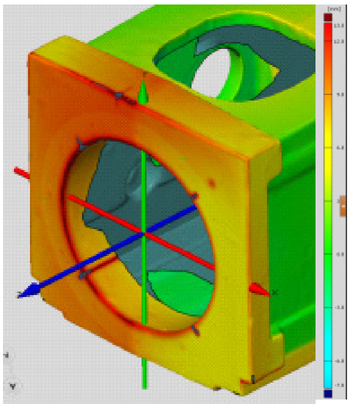

Figure 7: Geometric alignment of the investigated cast and its reference model; considerable positive deviation on the vent edge indicates insufficient cast cleansing of the core remnants.

Figure 8 demonstrates the initial protocol of geometric accuracy assessment and machining allowance minimization of the hereby investigated cast.

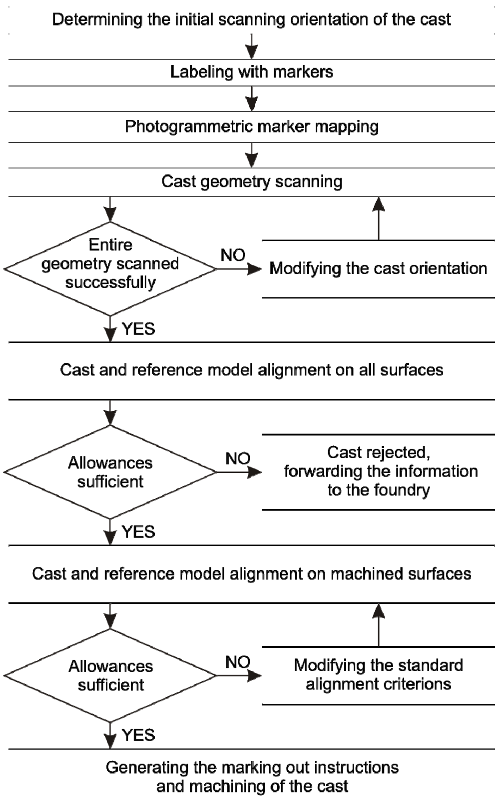

Figure 8: Methodology of cast assessment and surplus minimization by means of optical measuring system

5 Summary and conclusions

This paper demonstrates a new technology enabling prompt and accurate assessment of casting quality utilizing an optical measuring system. Its ultimate practical advantage is the elimination of the inconvenient cast marking out process from the technological procedure.

The presented results confirm the modification feasibility of extrinsic machining allowances, ultimately affording reduction of their total mass. The geometric cast accuracy is largely dependent on operating standards of a given foundry as well as on the degree of exploitation of cast models, and is, therefore, not constant. Accordingly, individual machining allowance minimization for each cast is highly recommended. In case of the investigated cast, a surplus mass reduction of 11% was obtained.

Further advantages of the proposed technology include machining time reduction, a decrease in machine tool and cutting device overexploitation, and preventing unnecessary interruptions in production due to faulty casting. This further entails considerable cuts in manufacturing costs. Assuming that the proposed surplus minimization procedure was extended to all casts machined in a given enterprise (approx. 10 000 tons per year), the overall yearly swarf by-production would decrease by 150 tons. 100% verification of the cast shape geometry constitutes an additional and vital benefit.

The issue of cast machining set-up according to the *bestfit* orientation, not discussed herein, constitutes an independent subject and is currently under investigation (including the development of a new patent application).

Acknowledgement

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References

[1] ATOS GOM II, user information.

[2] Cuypers W., Van Gestel N., Voet A., Kruth J.-P., Mingneau J., Bleys P., “Optical measurement techniques for mobile and large-scale dimensional metrology”, Optics and Lasers in Engineering 47, 292-300, 2009.

[3] Galanulis K., Reich C., Thesing J., Winter D., “Optical digitizing by ATOS for press parts and tools”, Internal publication, GOM, Braunschweig, 2005.

[4] Gessner A., Patent application No. P-390364 (5.02.2010), “Method of preparing cast iron for machining” (in Polish).

[5] Gessner A., Patent application No. P-390852 (31.03.2010), “Method of preparing cast iron for machining with minimized machining allowances” (in Polish).

[6] Grzelka M., Chajda J., Budzik G., Gessner A., Wieczorowski M., Staniek R., Gapiński B., Koteras R., Krasicki P., Marciniak L., “Optical coordinate scanners applied for the inspection of large scale housings produced in foundry technology”, Archives of Foundry Engineering, 10, 255-260, 2010.
[7] Matusiak-Szaraniec A., “Technology and design analysis of machine tool bodies”, Archives of Mechanical Technology and Automation, 27/2, Poznan, 121-129, 2007 (in Polish).
[8] Mrozek K., Gessner A., “Optimization of machining allowances in large scale cast iron”, Advances in Science and Technology, 6, Lublin, 96-103, 2011 (in Polish).
[9] Wieczorowski M., Ruciński M., Koteras R., “Application of optical scanning for measurement of castings and cores”, Archives of Foundry Engineering, 10, 265-268, 2010.
[10] Sanz-Ablanedo E., Rodríguez-Pérez J. R., Arias-Sánchez P., Armesto J., “Metric potential of a 3D measurement system based on digital compact cameras”, Sensors, 9, 4178-4194, 2009; doi:10.3390/s90604178.