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Simulation of Machining Allowance Mass Minimization of Iron Castings

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Abstract

The study, presented in this paper, deals with the issue of machining allowances for volume minimization of machine tool body cast iron elements by means of two methods: individual and global. It offers initial efficacy estimations of both methods resulting from simulation analyses, as well as comprehensive optimization protocols. The constant increase in the cost of machining, which (along foundry) constitutes the main machine tool body production process, provided the rationale for the investigation. Minimizing the volume of machining allowances affords not only machining time reduction, but directly alleviates tool overexploitation and energy use. The proposed implementation of modern visual measurement techniques of contactless three-dimensional scanning and photogrammetry will considerably facilitate the machining design process, which in most machine tool production enterprises relies on laborious and time-consuming procedures of marking out applied to each and every individual cast. Both the discussed surplus minimization methods involve pending patent applications.

Keywords: machining allowance, volume minimization, iron casting, machine tool, simulation, contactless three-dimensional scanning, photogrammetry

1 Introduction

The modern machine tool design development aims predominantly at the improvement of their operating efficacy and accuracy with simultaneous machining cost reduction [1, 2]. The said development is therefore based on multifaceted optimization of machine tool construction (increase in accuracy and machining efficiency, as well as reduction of manufacturing cost). Unfortunately, in most cases the three aforementioned factors are mutually exclusive [3]. Machining efficiency can be effectively enhanced through perfecting kinematic parameters of the machine tool by implementation of innovative and dynamic drives (electro-spindles, direct drives, etc.), which in turn entails its higher price. Furthermore, achieving higher cut-machining velocities does not facilitate accuracy, as it generates vibrations and reduces tool stability. Only High Speed Machining (HSM) technology provides for effective improvement of surface quality and dimensional accuracy [3], as extremely high centrifugal velocities entail constraining frequencies exceeding the inherent oscillation frequencies of the machined element, thus reducing the overall vibration. As for cost reduction, it should be sought for in areas bearing no direct influence on machine tool efficiency and accuracy.

Hereby we wish to propose an innovative machining allowance volume minimization system for machine tool casting. Thus implied reduction of swarf by-production promises to bring about considerable cuts in energy consumption, an alleviation of machining difficulties, and a decrease in tool overexploitation [4], directly influencing production expenditure. We present initial efficacy evaluation, as determined by simulation analysis, of machine tool body cast system machining allowance minimization by means of two methods: individual and global. Both discussed methods are based on modern visual measurement techniques and involve two pending patent applications.

2 Machine tool bodies

Modern machine tool design involves mainly bodies made of steel (welded), polymer concrete, and cast-iron. The mass of steel, welded bodies is considerably lower, relative to the alternative solutions, while the same stiffness parameters are maintained, which results from the high modulus of elasticity inherent to steel (approx. 210 GPa). Figure 1 shows comparative beam sections of equivalent stiffness made of the three aforementioned materials.

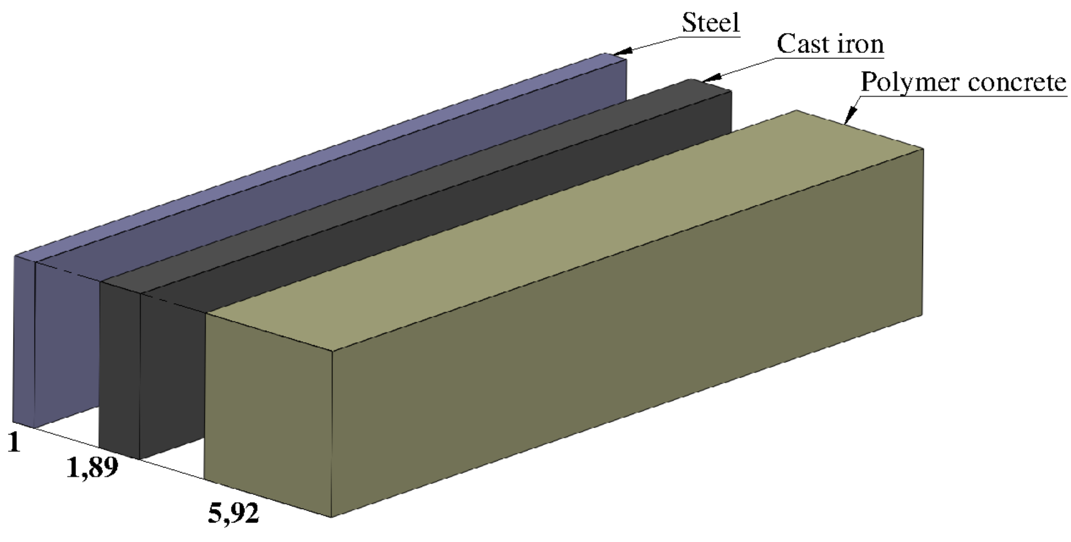

Figure 1: Comparison of beam sections of equivalent stiffness made of steel, cast iron, and polymer concrete [5].

In contrast, low value of logarithmic damping decrement and manufacturing arduousness constitute disadvantages of the steel machine tool bodies. Polymer concrete bodies are characterized by the highest damping capacity, as their logarithmic decrement values exceed 10-fold those of grey cast iron. They are also thermally stable and, due to post-casting machining limitations, are ready-formed.

However, machine tool body casting relies most heavily on cast iron. Advantages of cast iron bodies, as compared to the alternative solutions, are:

- relatively low cost of production,
- high value of logarithmic damping decrement, providing for adequate dissipation properties,
- complex shaping possibility,
- appropriate machining capacity.

The bodies are cast in sand molds and require the introduction of machining allowances of sizes depending on applied technology and casting accuracy. Cast iron machine tool body casting technology design is a difficult task, requiring considerable experience. Allowing high values of machining allowances increases the probability of appropriate body casting; it leads, however, to protracted machining and tool overexploitation.

3 Machining allowance size analysis

Publications of the past few years indicated that the machine tool body cast should be seasoned for approximately one year after stress relief annealing process [5]. Nowadays, however, a one-month period of cast delivery to the machine tool enterprise from the moment of placing an order turns out to be too long.

After casting and cast delivery to the recipient, it is necessary to design the mechanical processing (machining). At present the process entails a laborious and time-consuming procedure of marking out applied to each and every individual cast. Marking out does not allow machining surplus minimization and, when faulty, may prevent appropriate cast machining.

Hereby we propose replacing the arduous cast marking out procedure with an innovative implementation of visual measurement technology. Introducing TRITOP and Atos (GOM) measuring systems, as depicted in Figure 2, we postulate the critical advantage of cast geometry scanning resulting in rapid acquisition of virtual models of investigated casts [6, 7].

Figure 2: Measuring system comprising Atos three-dimensional scanner and TRITOP optical machine (GOM).

Appropriate processing of the obtained scan images allows their comparison with the construction model designs of individual machine tool body elements [8, 9]. The juxtaposition of the ideal body model, as designed by its constructor, and the experimental three-dimensional scan affords identification of positive deviations (overcasting, casting inclinations, insufficient cast cleansing from the forming substance, etc.), negative deviations (misrun casting), and errors arising, among others, from faults in forming core manufacturing or assembly.

With the appropriate three-dimensional machine tool cast model at hand, machining design involving a marking out plate can be abandoned and successfully replaced by computer-based technological solutions. Consequently, machining allowance minimization can be readily attained.

4 Individual method of machining allowance volume minimization

According to this method, each cast is subjected to the machining allowance volume minimization individually [10, 11]. The machining surpluses of a given cast are divided into three groups, according to the axes directions of the cartesian coordinate system. Each directional set is then represented as a multiplication product of machined surface areas and their respective allowances. Figure 3 exemplifies a directional set.

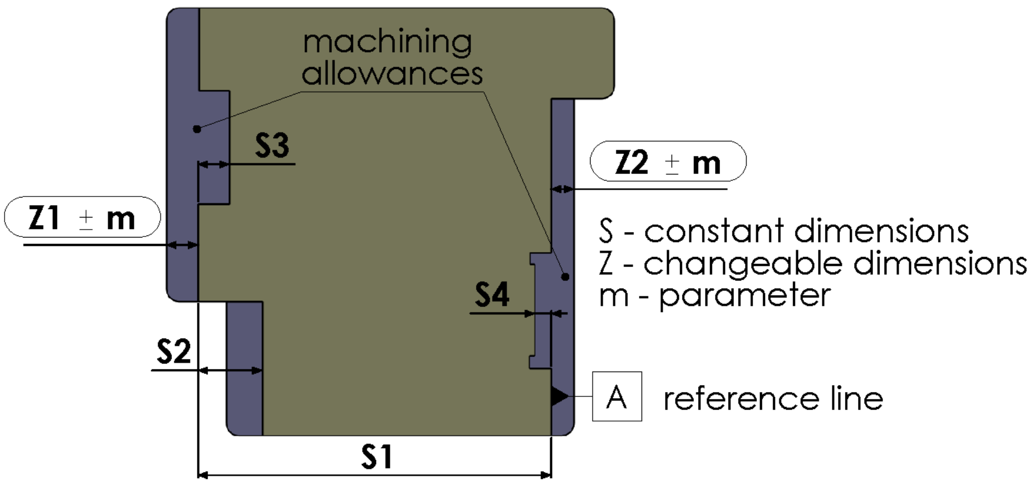

Figure 3: Cast cross-section (indicated: machining allowances, datum surface, as well as constant and changeable dimensions).

Shift of the machining datum surface in the direction ascertaining minimal multiplication product of the machined surface areas and the thickness of the layer subjected to machining constitutes the subsequent step of the proposed methodology. The base shift range is limited by construction design. Figure 4 depicts the method simulation outline, as exemplified upon a cast fragment cross-section.

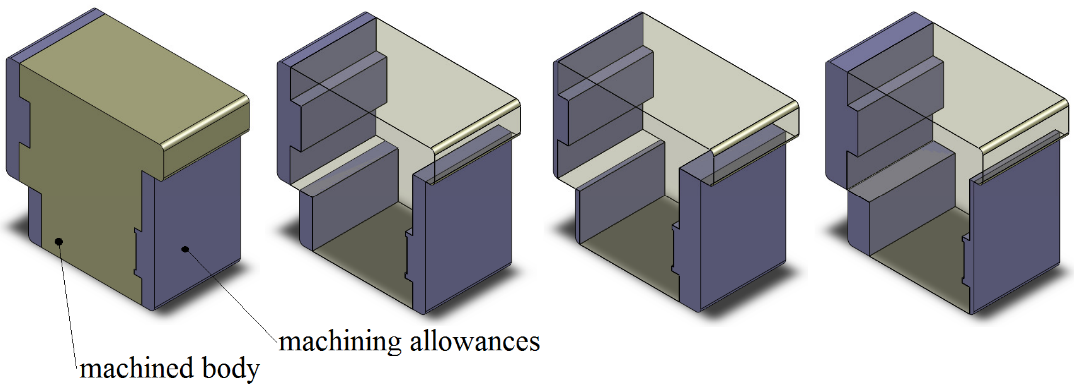

Figure 4: Individual machining allowance volume minimization: outline for a cast cross-section.

5 Global method of machining allowance volume minimization

As opposed to the aforementioned individual method, the global mode of surplus minimization involves creating a virtual system of all scanned casts comprising a given machine tool, inter-connected by a chain of dimension [12]. A layout of the intertwined body casts is presented in Figure 5.

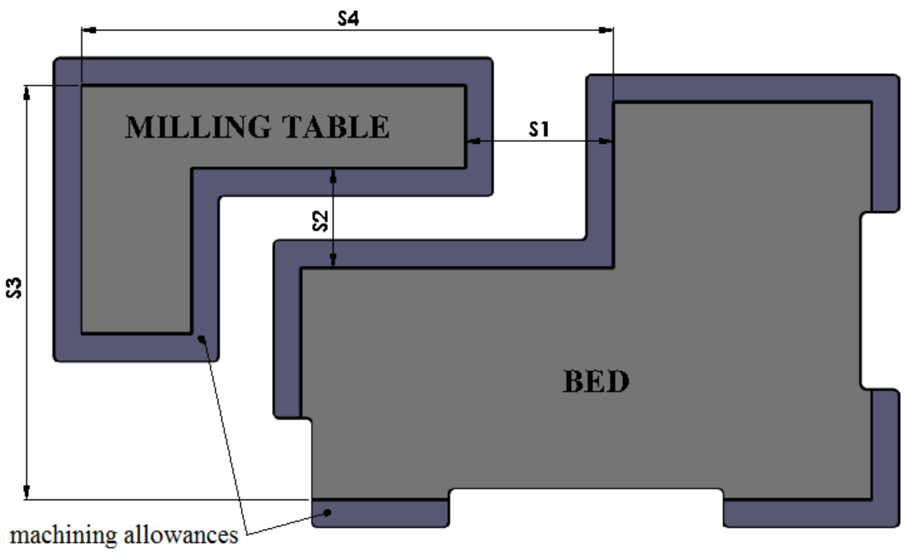

Figure 5: Layout of inter-connected machine tool body elements depicting selected (constant) design dimensions.

Subsequently, the sum of all cast surplus values undergoes minimization, accounting for the inherent construction design limitations (Figure 6).

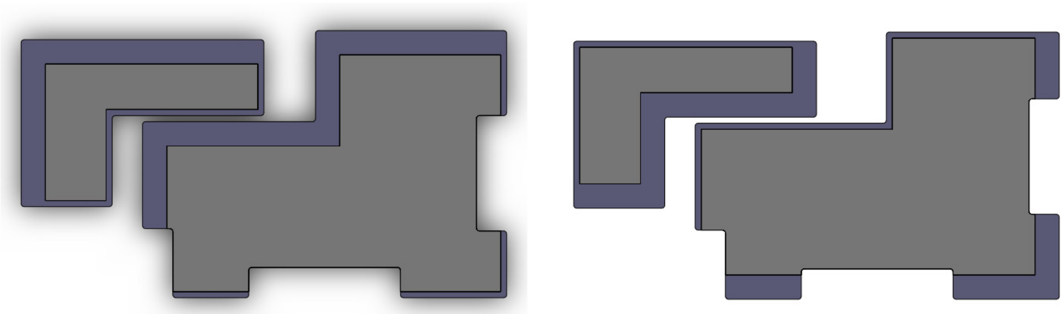

Figure 6: Shift of machining bases in the cast body system.

The global machining allowance volume minimization method influences not only the area of machine processing, but also the technology of machine tool assembly. Simultaneous machining design development for all casts incorporated in a given machine tool will considerably facilitate its assembly process, as all crucial surfaces of individual parts will be dimensioned according to a common base of the entire system.

6 Analysis and results

Figure 7 demonstrates the milling machine cast body models utilized in the simulation of both, the individual and the global machining allowance volume minimization.

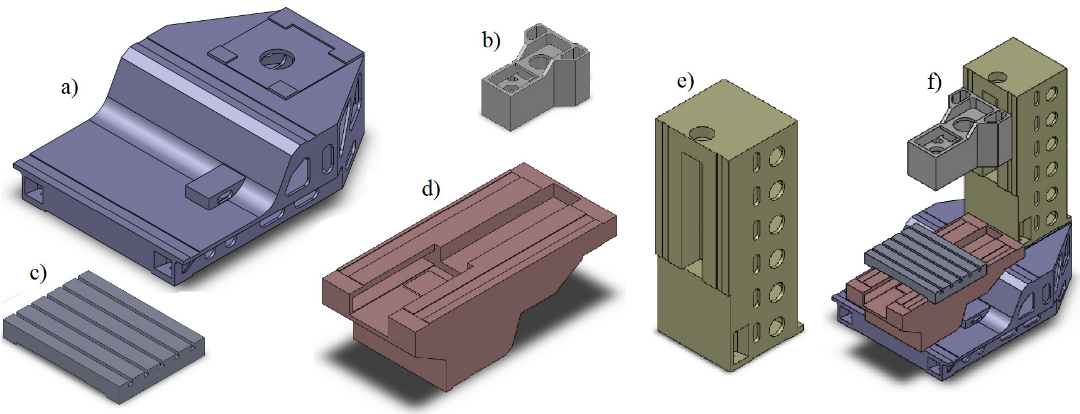

Figure 7: Milling machine cast body elements used in simulative analyses: a) bed, b) headstock, c) axis Y table, d) axis X table, e) stand, f) assembled components.

Each model was assigned normalized casting allowances and machining bases. Simulative analyses of surplus minimization according to both discussed methods followed. Optimization results of the individual minimization method are shown in Figure 8, while Figure 9 demonstrates the outcomes of the global procedure.

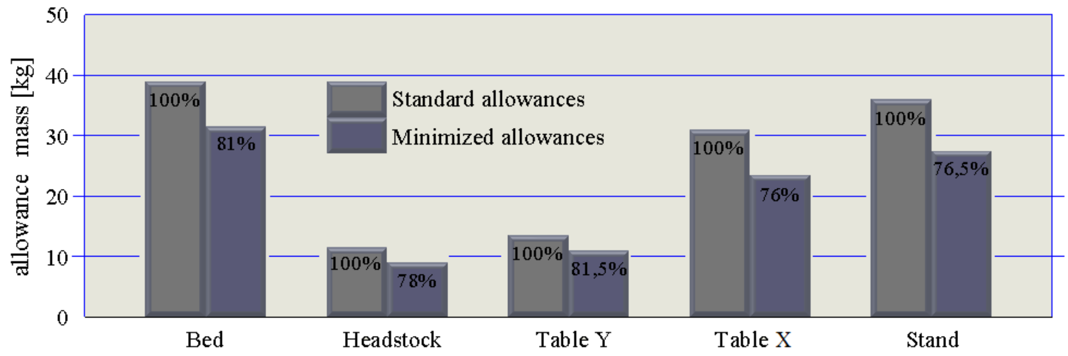

Figure 8: Results of individual allowance minimization simulation.

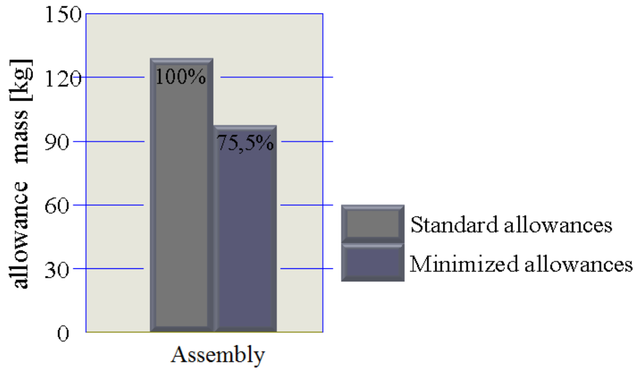

Figure 9: Outcomes of global allowance volume minimization.

The total standard machining allowance mass of the investigated casts was 131 kg. Individual minimization yielded a decrease of 28.5 kg, corresponding to swarf mass reduction of 22%. Global minimization method resulted in swarf mass cutback of 24.5%.

7 Summary

Both investigated machining allowance minimization methods proved to considerably facilitate cuts in machine tool component production costs. Our simulative experiments established the global minimization procedure as more effective; however, its practical implementation seems well-founded only for the case of large-gauge machine tools.

Automation difficulties and the high cost of visual measuring systems is indispensable for three-dimensional cast model generation constitute some of the few shortcomings of the proposed minimization methods.

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