PAPER • OPEN ACCESS

Dimensional analysis of the manufacturing processes of axisymmetric parts

To cite this article: A D Khalimonenko *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **560** 012144

IOP Conf. Series: Materials Science and Engineering **560** (2019) 012144 doi:10.1088/1757-899X/560/1/012144

Dimensional analysis of the manufacturing processes of axisymmetric parts

A D Khalimonenko[1], K P Pompeev[2] and D Yu Timofeev[1]

[1] Saint-Petersburg Mining University, 2, 21st Line, St Petersburg, 199106, Russia
[2] ITMO University, 9, Lomonosova Street, St. Petersburg, 191002, Russia

E-mail: Khalimonenko_AD@pers.spmi.ru

Abstract. The paper considers the issues in and provides recommendations for dimensional analysis performed during the design stage of axisymmetric parts manufacturing processes. Conducting the dimensional analysis with the method proposed in the paper allows: calculating the wobble (rotational error) of the rotating elements that arises during various operations of the manufacturing process; checking for possibilities to ensure the given requirements of mutual spatial arrangement of surfaces for a piece of equipment selected automatically, using verification only where it is justified; determining non-uniformities of machining allowances and performing final calculation of all the machining allowances and intermediate diameter sizes.

1. Introduction

Technical quality of the final product is built and provided at all the stages of the product life cycle. At that, engineering support for the part quality indicators commences at the design stage [1,2].

Ensuring the quality of part manufacturing has always been and will always be a current issue, as long as there is industrial production. Among the main quality indicators are dimensional accuracy; mutual spatial relation requirements, geometric accuracy and surface roughness of the part [1-4].

Modern computational possibilities allow predicting the quality of part manufacture as early as at the design stage of their manufacture processes, that is, it is possible to obtain reliable technologies that provide accuracy and required surface roughness [2,5,6]. Reliability of machining processes is understood as the ability of the process to ensure dimensional accuracy and quality of parts given in the drawing through various stages of its manufacture, on condition of keeping the necessary technical parameters within their predefined limits and accounting for a certain sequence of machining at selected equipment in a required process environment with necessary tools and under given machining modes [2,7-10].

Designing the reliable technologies with the accuracy parameters allows conducting the dimensional analysis of the technologies. The aim of the dimensional analysis is to conduct all the calculations to determine the operational dimensions and analysis of possibility to meet the design dimensions and process requirements for mutual spatial relation with a given accuracy using the selected equipment in the automatic mode with or without verification [3,6,11,12].

2. Materials and methods

Dimensional analysis for axisymmetric parts will require designing a dimensional sketch of wobbles arising throughout the process and a dimensional sketch of the linear dimensions. This paper does not consider designing the linear dimension sketch and subsequent calculations of process linear dimensions and machining allowances for plane surfaces.

The baseline information for the dimensional analysis includes the operational sketches of all the geometry-generation operations, each of them is a Machining System, including a machine, accessories, cutting tool(s) and a blank being processed [6,12-17]. A generalized example of a manufacture process for an axisymmetric part is shown in Figure 1.

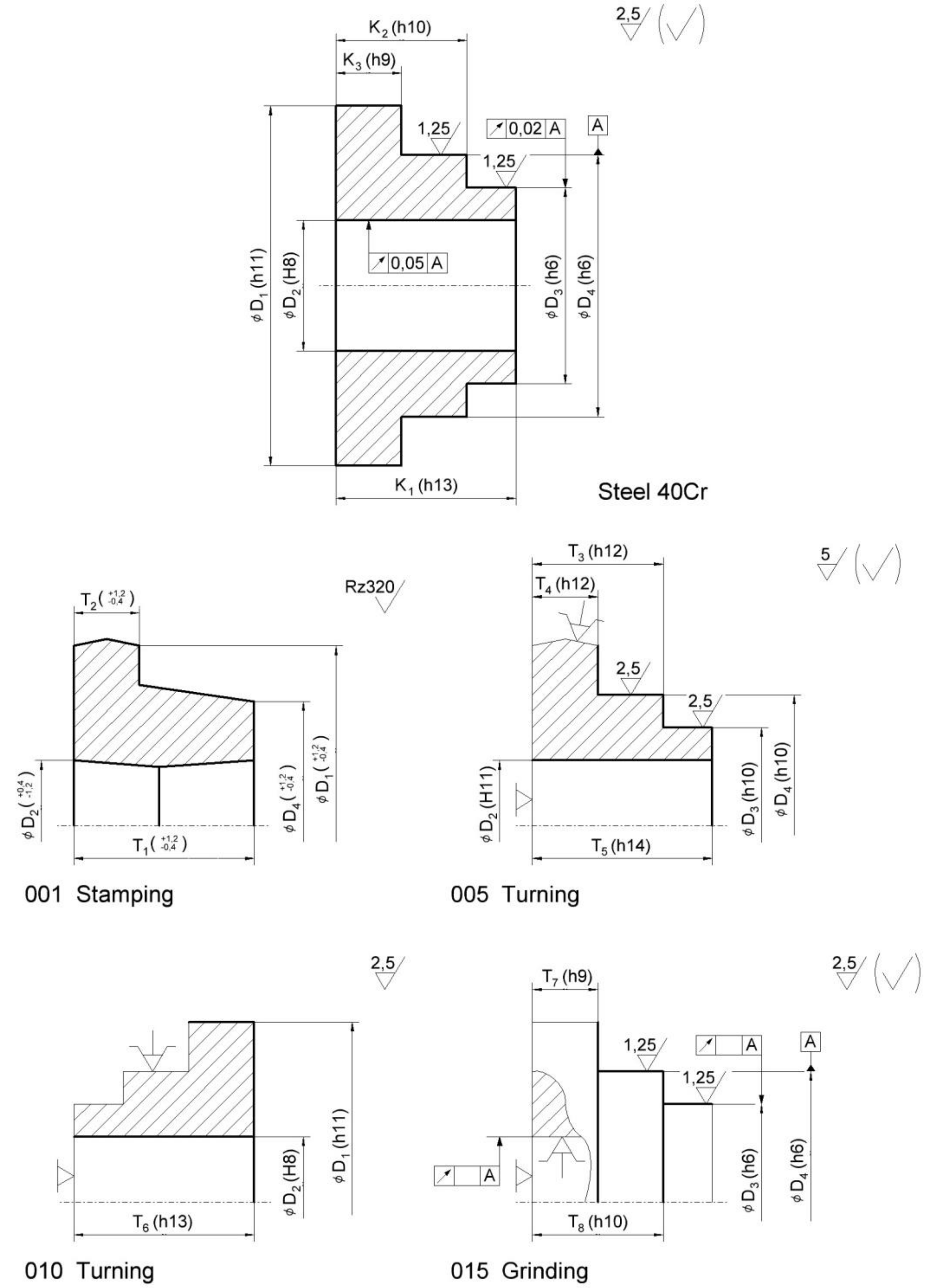

Figure 1. A sketch of an axisymmetrical part, operational sketches with the referencing schemes and the structure of operational dimensions.

Constructing the scheme of the wobbles involves drawing a sketch of the part that is (if necessary) contracted along the main rotational axis and extended transversally to this axis, so that the horizontal lines drawn to the right and corresponding to each state of the rotary surface do not coincide with each other. Machining allowances for each rotary surface are drawn on the sketch of the finished part. Then, for every operation, wobble of rotary elements in the initial blank is indicated with provisional vectors (for cast or stamped blanks), as well as basic, machined and currently being machined rotary elements relatively to a certain ideal rotary surface. At that, the ideal surface in the initial blank may be thought of as a cylindrical surface formed by rotating a certain straight segment around a certain ideal axis of the blank; during the machining stages, the ideal surface may be thought of as a cylindrical surface formed by rotating a certain straight segment around the axis of the machine spindle or the axis of the basic element of the Machining System. If we imagine that the radius of the ideal rotary surface tends to zero, then at a certain moment it attains such a value that it may be neglected. Thus, conditionally, we may consider not the ideal cylindrical surface, but its axis and then continue our reasoning using the term axis when we imply the ideal cylindrical surface. Then, to simplify construction of the scheme of wobbles, we may assume that the vectors of wobbles arising at each process operation will be directed away from the ideal axis of the blank to each element that is produced in the blank, and from the reference bases of the Machining System (from the rotational axis of the machine spindle or from the axis of the basic element of the Machining System) to every reference, currently being machined and already machined element. For rolled blanks, wobbles caused by defects of form are taken into account during the first machining operation and are not stated specifically. The vectors are designated as B , where i is the number of the element and its state; j is the number of operation for which wobble is being determined.

Figure 2 shows a scheme of wobbles for the process shown in the Figure 1.

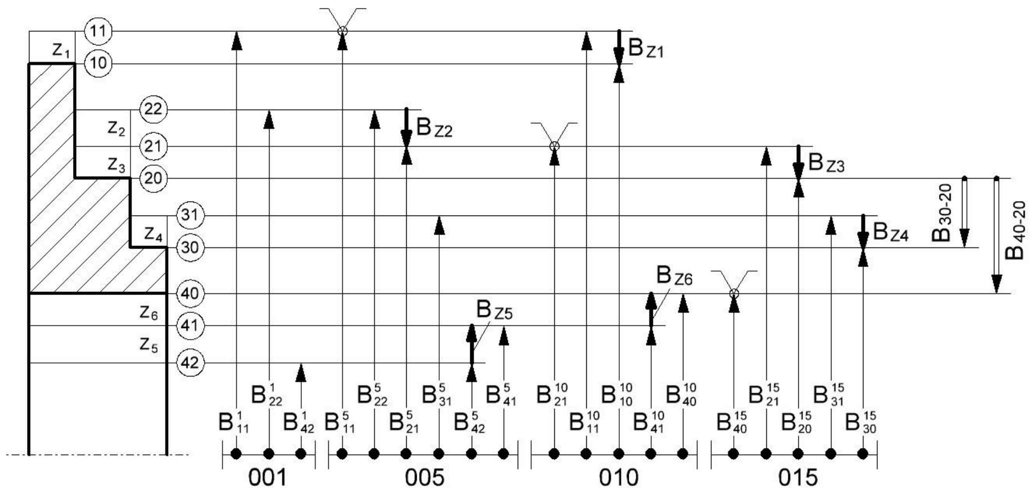

Figure 2. A scheme of wobbles arising when implementing the previously shown technology.

After constructing the dimensional scheme, the values of wobble are calculated for the elements of the initial blank, both currently being machined and already machined, relative to the machining reference and between themselves, non-uniformity of allowances; the possibility of meeting the technical requirements for mutual spatial layout of the elements is checked for the selected referencing scheme and for the selected devices, following the algorithm given below.

1. The wobbles of elements of the initial blanks with respect to its ideal axis due to defects of form and spatial deviations are determined with the formulas

– for a cast blank

$$B_i^j = 2 \cdot \sqrt{(\Delta_w)^2 + (\Delta_{disp})^2 + (\Delta_{dist})^2} \ ;$$

– for a stamped blank

$$B_i^j = 2 \cdot \sqrt{(\Delta_w)^2 + (\Delta_{disp})^2}\ ;$$

where Δ_w is the surface distortion in casting or stamping; Δ_{disp} is the displacement of surface axis from its nominal position; Δ_{dist} is the misalignment of the orifice axis in casting.

The values of Δ_w , Δ_{disp} , Δ_{dist} are determined from reference data given in [5].

2. The wobbles of the basic elements are determined with respect to the basic reference of the Machining System (the axis of the spindle) for all the operations, caused by inaccuracy of the setup, using the reference data [5] or the following empiric formulas [6], given in Table 1.

Table 1. Wobble of basic elements (B_i^j) depending on type and precision of employed devices

Types of devices	Formula to calculate B_i^j	Values of coefficients a_i and b for device precision		
		normal	increased	high
Three-jaw chuck and piston mandrels	$2 \cdot a_1 \cdot \sqrt{IT_b} \cdot (1 + 0.02 \cdot l)$	$a_1 = 0.17$	$a_1 = 0.11$	$a_1 = 0.08$
Collet chucks and mandrels	$2 \cdot a_2 \cdot \sqrt{IT_b} \cdot (1 + 0.01 \cdot l)$	$a_2 = 0.12$	$a_2 = 0.09$	$a_2 = 0.06$
Chucks and mandrels with hydroplast, membrane chucks and mandrels	$0.08 \cdot \sqrt{IT_b} \cdot (1 + 0.01 \cdot l)$	–	–	(0.04)
Centers	$2 \cdot (a_3 \cdot \sqrt{D} + b \cdot L)$	$a_3 = 0.006$ $b = 0.00005$	$a_3 = 0.0018$ $b = 0.000015$	$a_3 = 0.0009$ $b = 0.000007$
Rigid mandrels with clearance	Doubled maximum radial clearance		–	

IT_b is the allowance for diameter of the basic surface;
l is the length of the area of the basic surface used for referencing the blank;
D is a diameter of the central bevel;
L is the total length of the blank

3. The wobble of the machined elements is determined relative to the references of the Machining System. First, dimension chains of wobbles are constructed that take the target wobbles as master links. Construction and solution of such chains has some peculiarities. As the links of the dimensional chains are parameters, whose nominal values are zero, there is no need to determine the nominal and limiting values of the master link – only the allowance equation is constructed, which is subsequently resolved with a quadratic summation method applicable due to the vector properties of the chain links

$$B_i^j = \sqrt{\sum_q^1 (B_s)^2}\ , \qquad (1)$$

where q is the number of constituent links.

5. If necessary, a check is performed against the drawing requirements (radial wobbles or axial misalignment between the machined surfaces) using the formula (1). The calculated wobble(s) shall be less or equal to the given requirement. As soon as this fact is established, calculation of allowance non-uniformities and intermediate diameter dimensions starts.

If this condition is not met, a correction is performed, involving either precision of the basic accessories, or type and/or precision of applied accessories, or the structure of the process as a whole. After that, the calculations in items 1…5 of the algorithm are repeated until acceptable results are obtained that ensure the requirements of mutual spacial location of the surfaces.

6. Wobbles between the element being machined and an already machined element is determined (doubled non-uniformity of allowance $2e_{max}$) with a formula

$$B_{Zi} = B^{j}_{i-1} - B^{j}_{i},$$

that is, the following is taken into account: residual wobble does not increase, but actually decreases the dimension of the allowance non-uniformity [3, 6].

7. Intermediate dimensions and allowances are calculated for the rotary elements following the technique detailed in [1, 2].

Calculation of the inter-operational diameters as per [1, 6] may be performed in a tabled form.

Calculation of minimum machining allowances are conducted on condition of guaranteed satisfaction of machined surface roughness requirements [6].

3. Conclusion

Thus, dimensional analysis of the process for the rotary elements of axisymmetric parts allows:

– calculating wobble (axial misalignment) of the rotary elements arising during the process operations;

– checking a possibility to meet given requirements for mutual spatial arrangement of surfaces with a selected set of equipment, using assumed accessories automatically (without verification) or with verification (where justified);

– determining non-uniformity of machining allowances;

– calculating all machining allowance and intermediate diameter values.

References

[1] Pompeev K P, Timofeev D Yu 2018 Precision dimensional analysis in CAD design of reliable technologies. *IOP Conf. Ser.: Earth and Envir. Sci.* **194(2)** 022028

[2] Khalimonenko A D, Pompeev K P, Timofeev D Y 2017 Method of Calculating Intermediate Diametral Sizes and Allowances for Designing Technology of Manufacture of Details. *AER-Adv. in Eng. Res.* **133(1)** 312–317

[3] Matalin A A 2010 *Technology of mechanical engineering: textbook for high schools* (Saint Petersburg: Lan) 512 p

[4] Andreev Y S, Isaev R M, Lubiviy A V 2018 Improvement of piezoelectric vibration sensors' performance characteristics via optimization of details' functional surfaces roughness *J. of Phys.: Conf. Ser.* **1015(5)** 052010

[5] Dalsky A M, Kosilova A G, Meshcheryakov R K and Suslova A G 2001 *Handbook of the technologist – machine builder* (Moscow: Mashinostroenie-1) 912 p

[6] Valetov V A, Pompeev K P 2013 *Technology of instrument making* (Saint Petersburg: NIU ITMO) 234 p

[7] Maksarov V V, Krasn**yy** V A, Viushin R V 2018 Simulation of dynamic processes when machining transition surfaces of stepped shafts. *IOP Conf. Ser.: Mater. Sci. Eng.* **327** 022047

[8] Mavliutov A R, Zlotnikov E G 2018 Optimization of cutting parameters for machining time in turning process. *IOP Conf. Ser.: Mater. Sci. Eng.* **327(4)** 042069

[9] Vasiliev A S, Goncharov A A 2018 Some aspects of problematics in designing technological complexes. *IOP Conf. Ser.: Earth and Envir. Sci.* **194(6)** 062033

[10] Vasilkov D V, Nikitin A V, Cherdakova V S 2018 Dynamic System Stability when Machining with Cutter. *IOP Conf. Ser.: Earth and Envir. Sci.* **194(2)** 022045

[11] Maksarov V, Krasn**yy** V 2017 The Formation of Surface Roughness of Piston Rings for the Purpose of Improving the Adhesion of Wear-Resistant Coatings. *Key Eng. Mater.* **736** 73–78

[12] Maksarov V V., Efimov A E 2018 Simulation modeling of dynamic characteristics of machining in NI LabView software environment to improve processing technique of a rod component. *IOP Conf. Ser.: Earth and Envir. Sci.* **194(2)** 022021

[13] Ershov D Y, Zlotnikov E G, Koboyankwe L E 2017 Analysis of causes and mathematical description of process of manufacturing errors and local defects in mechanical system nodes

IOP Conf. Ser.: Earth and Envir. Sci. **87(8)** 082015
[14] Bezyazychny V F, Sutyagin A N, Bolotein, A N 2018 Modeling a 3D surface roughness of mating parts produced with lathe turning. *IOP Conf. Ser.: Earth and Envir. Sci.* **194(2)** 022005
[15] Ardashkin I B, Martyushev N V, Drozdov Y Yu 2016 Methodological aspects of evaluation of foundry technologies effectiveness. *Key Eng. Mater*. **685** 445–449
[16] Khalimonenko A D, Viushin R V 2014 Accuracy of the machining turning process of the workpieces when cutting tool equipped with removable ceramic inserts. *J. of Mining Institute* **209** 99–103
[17] Krasn**yy** V A, Maksarov V V, Olt J 2015 The use of polymer composite materials in the friction nodes downhole oil pumps. *J. of Mining Institute* **211** 71–79