Improvement of Tapping Accuracy Through Multicriteria Choice of Technological Parameters

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Abstract

During tapping, it is necessary to choose the technological parameters in order to ensure the desired dimensional accuracy of the thread for all parts machined in series. Under certain machining conditions however, the interaction between these technological parameters eliminates the possibility of improving accuracy by correcting each one separately. A logical relationship between the targeted accuracy and the technological parameters (geometrical, metrological and technological) has been proposed to resolve this problem.

The precision model proposed in this paper considers the following technological parameters : elastic deformation of a technological system, set-up and clamping errors of the raw part to be machined, dimensional wear of the tapping tool and the error in axial alignment between the active part of the tap and the guide hole (a turntable with one fixture was used). These parameters were assembled in a structured set of possible solutions. The procedure for the selection of one of these solutions is based on the multicriteria hierarchy method [1].

A decision directing a change in cutting speed and modification of the metrological conditions of the tap attachment was obtained.

Keywords : multicriteria choice, tapping, precision

1 Introduction

Tap precision has been estimated in previous research as a resultant of geometric errors, without taking into account the causes of these errors (see : the vector model, K. Martincen [2]; the analytical model using double integral by D. Reshetov, and Portman [3]; the TTRS method (Technologically and Topologically Related Surfaces) by A. Clement., A. Riviere, M. Temmerman [4]; and the torseur method by F. Velleneuve, O. Legoff, P. Bourdet [5]). The 'Δl' method presented by P. Bourdet, P. Padilla, B. Anselmetti and M. Roboyeau [6], G. Halevi and D. Weill [7], and E. Dubé [8], permits calculation of the dimensional disparities caused by the dispersion of end surfaces, tool wear, and differences in tool setup. In order to realize an improvement in tapping precision, it is first necessary to establish the critical precision parameters and incorporate these into a valid model of the machining process.

2 Tapping precision model

The tap forms the tool edge and, for this reason, the model can be visualized in the following manner (Figure 1).

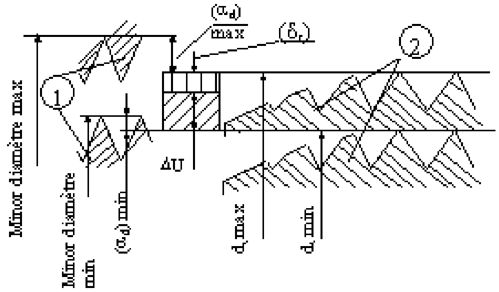

Figure 1. Model of tapping precision.

Where :
Minor diameter max is the maximum value of the minor diameter
Minor diameter min is the minimum value of the minor diameter
α_d *is a derivative of the tapped thread*
ΔU *is the dimensional wear of the guide teeth*
δ_t *is the prescribed tolerance of the tap*
d_t, *the tap diameter*
1 – female part
2 – tap

The tapping precision, Δt, at the tool edge is the tap error and is a function of the tap tolerance - δt and a derivative of the tapped thread - αd. Using the following relations:

$$\Delta_t = (MinorDiameter)_{MAX} - (MinorDiameter)_{MIN} \quad (1)$$

$$(\alpha_d)_{MIN} \le \alpha_d \le (\alpha_d)_{MAX} \quad (2)$$

and, rearranging:

$$\Delta_t = a_{MAX} + \delta_t + \Delta u - a_{MIN} \quad (3)$$

Using the usual relations [9]:

$$a_{MIN} = 5 \quad \grave{a} \quad 10\,\mu m$$

One can express a_{MAX} as follows:

$$a_{MAX} = f(\Delta y, \varepsilon_{mp}, \varepsilon_s, \Delta p) \quad (4)$$

where Δy is the elastic deformation of a technological system (TS) due to a nonequilibrium between the radial component - F_r of the cutting force and the variation of the rigidity of the tap in the tool holder. Furthermore, Δy increases the intensity of the wear in the active section at the entry point of the tap. ε_{mp} is the set up error incurred during initial mounting of the part to be machined. ε_{mp} is determined by the reference surfaces (RS) and describes a small radial displacement (and a lesser angular movement) measured from the center axis of the hole to be tapped. ε_s is the clamping error of the part in the 3 bit concentric spool under the tightening force applied. ε_s describes the small radial displacement of the axis of the hole to be tapped. Δp is the non coaxiality between the active section of the tap and the leading surface of the hole.

Interactions between the parameters noted in Figure 2 will be presented using the values of δ_t and a_{min} (see (3)), which can be established by the designer and the production engineer.

The values of parameters Δy, ε_{mp}, ε_s, Δp, and Δu cannot be calculated directly from the analytical precision model. Δy, ε_{mp}, ε_s, and Δu are primary errors, however Δp does not exercise a direct influence on the tapping precision and is affected by a number of factors, including the geometric imprecision of the turntable attachment and the conception of the tap holder.

As relations are established between each parameter in question and the logical conditions (geometrical, metrological, technological) it becomes possible to determine the attributes and the parameters for managing them (on Figure 3), where Δy, ε_{mp}, ε_s, Δp and Δu are those parameters to be managed.

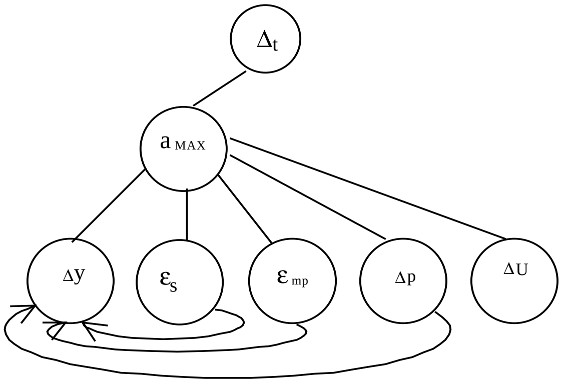

Figure 2. *Interactions of tapping parameters.*

In other words, a set of possible solutions will be identified. For the moment, these solutions will be studied by applying them to reduce tapping waste. This can also be interpreted as increasing tapping precision.

This reasoning can be expressed mathematically. It is essential to guarantee that:

$$\delta_f \le \delta_{des} \quad (5)$$

δ_f is the total fabrication error and, δ_{des} is the design tolerance.

$$\delta_f = \Delta_t \quad (6)$$

where Δ_t is the tapping precision

It follows that the solution that is adopted from among those described would be the one that offers the largest reduction of components. In other words:

$$\Delta_y \downarrow, \varepsilon_{mp} \downarrow, \varepsilon_s \downarrow, \Delta_p \downarrow \quad (7)$$

3 Improvement of tapping precision

Figure 3 is used as a reference to propose three possible solutions for improving precision of the tapping operation. These solution possibilities are presented in Table 1.

The summary presented in Table 2 was developed following our analysis and shows the influence of the possible solution alternatives, S1, S2, S3 on the tapping precision parameters. This allows us to consider all criteria when making a choice on the type of solution.

Table 1. Three possible solutions for improving precision of the tapping operation.

N	Designation	Content	Advantage	Disadvantage
1	S1	*Change the parameters of the active part of the tap (γ, de, ω)*	Simplicity: the fabricator of the taps can make the changes required upon request	Increased cost of the tap
2	S2	Change the alignment and tightening of the pulley	A simple change that is easily made.	Small improvement of the clamping jaws
3	S3	Change Vm/min and the metrological conditions of the tapping attachment	Simplicity	One must analyze existing types of attachment to verify if it is possible to use one of these.

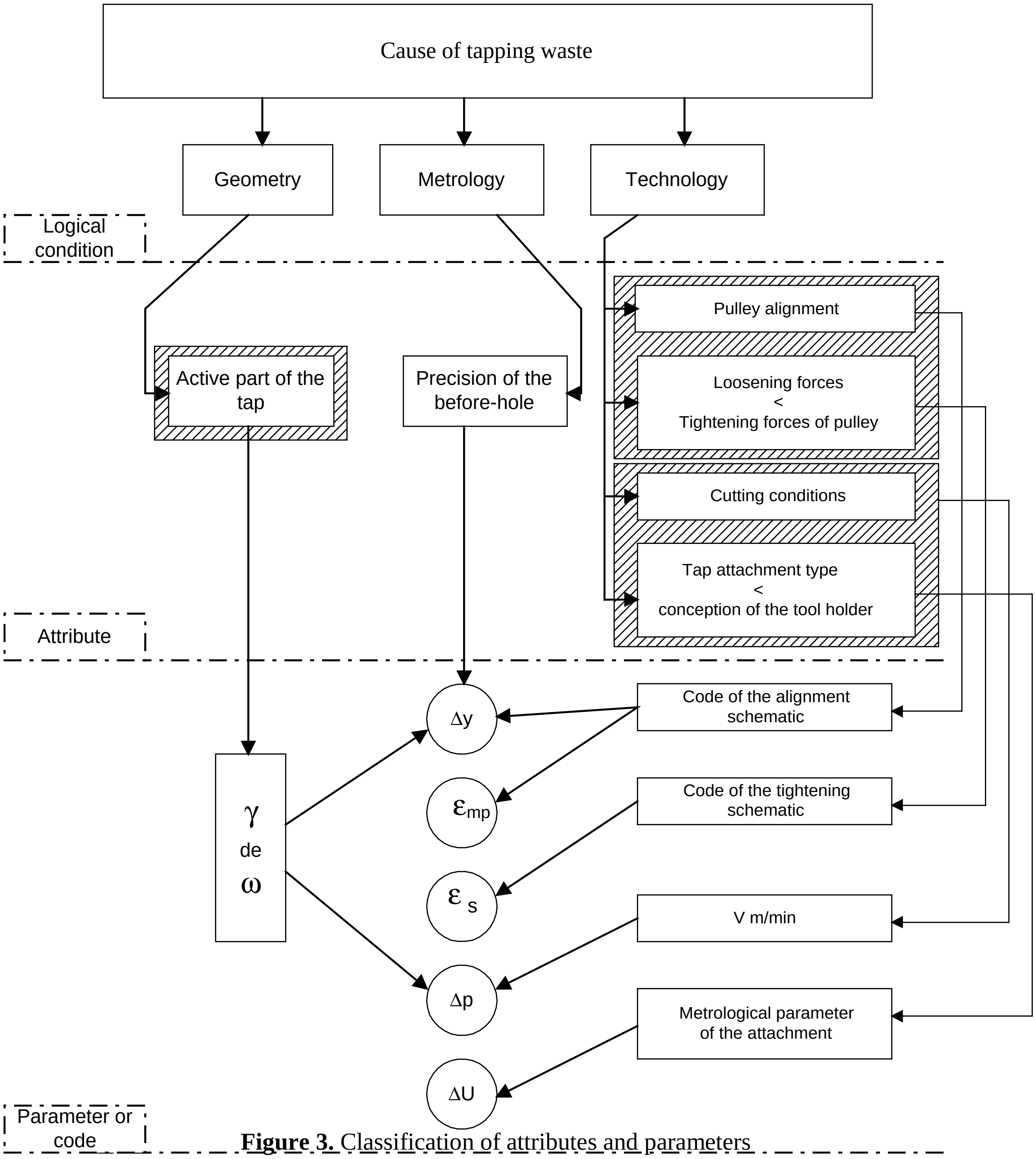

Figure 3. Classification of attributes and parameters

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Table 2. Influence of the alternative solutions on tapping precision parameters.

N	Possible solution	Parameters of precision to the tapping				
		Δy	ε_{mp}	ε_S	Δu	Δp
1	S1	xxx $\gamma_r, (d_e)_r, (\omega')_r \uparrow\rightarrow\Delta y\downarrow$	-	stronger than x $F_r\downarrow$, $F_{ax}\downarrow\rightarrow Q\downarrow\rightarrow\varepsilon_S\downarrow$	xx	-
2	S2	xx $M.P.\rightarrow F_r\downarrow\rightarrow\Delta y\downarrow$	xxx $M.P.\rightarrow\varepsilon_{mp}\downarrow$	X $M.P.\rightarrow(F_r,F_{ax})\downarrow\rightarrow Q\downarrow\rightarrow\varepsilon_S$	x $M.P.\rightarrow(F_r,F_{ax})\rightarrow\Delta u\downarrow$	-
3	S3	xxx $A_t\rightarrow\Delta p\downarrow\rightarrow(F_r,F_{ax})\downarrow,\Delta y\downarrow$	-	stronger than x $A_t\rightarrow(F_r,F_{ax})\downarrow\rightarrow Q\downarrow\rightarrow\varepsilon_S$	stronger than x $A_t\rightarrow(F_r,F_{ax})\rightarrow\Delta u\downarrow$	xxx $A_t\rightarrow\Delta p\downarrow$

Note: degrees of influence: xxx = high, xx = medium, x = weak, - = no effect
M.P.=alignment, Q=tightening force, At=tap attachment, Fr=radial effort of tapping, Fax= axial effort of tapping, γr, (de)r, (ω')r are the parameters indicated by the active part of the tap, γ - sharpening angle, de - Calibration for an angle of 30 degrees, ω' - obliqueness of the tap entry

4 Selection of the solution using the multicriteria hierarchy method (MHM)

Discrepancies in tapping quality are caused by a number of parameters. It is interesting to note the many relationships between these parameters. The existence of these inter-relationships allows the possibility to implement MHM [1] and use it to analyze pairs of parameters and regroup them according to their characteristics. Two approaches are used simultaneously in MHM. The first systematic is called upon by the hierarchical structure of the parameters, while the second is used to develop and describe based on linear comparisons of hierarchical parameters and by synthesis.

The condensed form of MHM is presented here, as it is better adapted to our problem and clearly demonstrates the steps of the method.

Given a targeted tapping precision, one must determine the preferences of the industrial framework for the three possible solutions: S1, S2, S3.

We have now developed a hierarchy, the scientific preferences, the normalized matrices, the degrees of influence and priorities for each parameter (Δy*,* εmp*,* εS*,* Δu*,* Δp*) with* λmax*) and IC, the vector of degrees of preference for each parameter. This completes steps one to six, and we are ready for step 7.*

Table 3. Regrouping of degrees of influence for each tapping parameter.

Solution	(0.5135) Δy	(0.1340) ε_{mp}	(0.0718) ε_S	(0.0410) Δu	(0.2396) Δp
S1	0.556	0.1	0.638	0.649	0.1
S2	0.09	0.8	0.089	0.905	0.1
S3	0.358	0.1	0.273	0.253	0.8

Table 4. Pondered priority vector.

Solution	(0.5135) Δy	(0.1340) ε_{mp}	(0.0718) ε_S	(0.0410) Δu	(0.2396) Δp
S1	0.2855	0.0134	0.0458	0.0266	0.0240
S2	0.0462	0.1072	0.0064	0.0039	0.0240
S3	0.1838	0.0134	0.0196	0.0104	0.1917

Step 7 involves regrouping the priorities of the three solutions as a function of the degree of influence for each parameter. The degrees of influence for each parameter are placed in the columns of Table 3 and the normalized priority is indicated above the heading of each column.

The degree of influence values in each column of Table 3 are next multiplied by the normalized priority of the corresponding parameter in order to obtain the pondered vectors of priority for each solution. These vectors are presented as the rows of Table 4.

The sum of the entries in the rows of Table 4 is calculated in step 8 to obtain the global priorities for the three alternate solutions. This synthesis produces the following priorities:

$$S1 = 0.3953;\ S2 = 0.1877;\ S3 = 0.4189$$

Solution S3 is chosen as it has the largest influence on the parameters of tapping precision.

It becomes important at this point to consider the costs involved with changing the active part (entry point) of the tap. Depending on economic considerations, the addition of a supplementary solution, S2, may be recommended. A combination of solutions S3 and S2 should assure that the targeted tapping precision is achieved.

*This model of solution selection, MHM, was verified during the tapping of a series of parts made from metallic powder using a DORMER USA 1-¼*16NS tap, NSS CH55992 on a semiautomatic machine with a single turntable.*

5 Conclusion

The impossibility to distinguish primary errors as parameters for machining precision effectively eliminates the application of vectorial or analytical models to describe this process. Alternative approaches are required to determine the best solutions for improving precision.

The study presented here demonstrates the advantages of the multicriteria hierarchy method to group diverse combinations of inter-related parameters in a selection strategy. The optimum solution, or combination of solutions, is chosen from among the alternatives. The objective in this case was to improve the precision of the tapping operation.

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