Simulation model of dispersions in turning process

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Abstract: To control and to optimise the product/process pair, manufacturing companies are more and more directed to use software tools performing virtual simulations. In this way, let us consider that one important aim of the virtual or numerical simulation of process planning is to study and take into account the machining dispersions. The global intend is to predict the intervals of tolerances of a series of manufactured parts and to compare with the specifications due to the design office.
The general objective of this work is to extend the field of application and to increase the knowledge about machining dispersion simulations. This study, based on design of experiment, aims to confirm the hypothesis retained for an initial model designed to help process planning and validate chronology, sequencing, and elementary operations.
In this paper, an extent of the simulation model of dispersions in turning process first exposed in [W1], is developed. This initial work is based on the characterisation and the taking into account of the geometrical default generated by the turning process. An integration of the parameters relative to the cutting conditions and to the machined and cutting materials is now proposed. The link between these parameters and the input data of the initial model is explained. An application is developed to illustrate the associated methodology. The effect of each cutting parameter on machining dispersions has been shown and quantified.

Key words: machining dispersions, geometrical specifications, manufacturing defects, functional tolerancing.

1. Introduction

Figure 1 schematically illustrates the three engineering main stages of a mechanical production from the design to the manufacturing process. The control of geometrical specifications inside a specified range is one of the main difficulties. This is called feedback on Fig.1. The nominal geometry is mainly concerned by the behaviour model used during the design stage (⓪, Fig.1). The design of tolerances of the parts (① Fig.1) must be bring under control according to two other different points of view, the dispersions of manufacturing (② Fig.1) and the geometrical control (③ Fig.1). So a real optimisation of mechanical part tolerancing cannot be managed without the global framework of co-operating engineering between design, manufacture and metrology. In particular, this approach integrates, on one hand, the computation and the treatment of the design of tolerances and, on the other hand, the dispersions due to the manufacturing process.
The simulation of products or manufacturing processes is an important means in the organisations of the CIM (Computer Integrated Manufacturing) [S1]. In this frame, the aim of this application is to determine the manufacturing specifications for each elementary operation of the process plan. Considering dispersions of the manufacturing operations, the tolerances of a set of the manufactured parts can be redict [A1]. After estimating manufacturing dispersions, it is possible to compute these tolerances in a virtual workshop [B1] with the want to validate the manufacturing process according to the tolerances defined by the functional tolerances design.

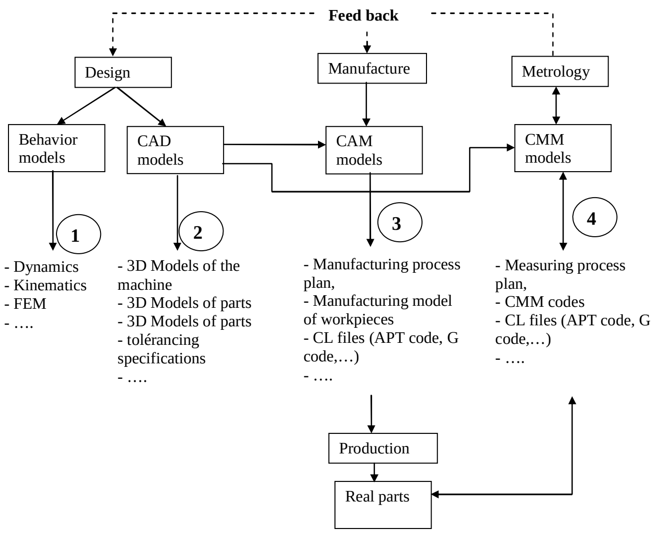


Figure 1 : Engineering stages of a mechanical production

In this paper, the objective is to present a method allowing the characterisation of dispersions and the exploitation in computation applied to numerical controlled lathes. Based on the method of the "Delta L" developed by P. BOURDET [B1], this method has been extended in [W1]. A relation between the three-dimensional ISO tolerancing and specific dispersions of the turning process was then proposed.

The variation effects of the cutting parameters (cutting conditions, type of material, tool wear …) were not analysed in the first model. We propose here a methodology to consider their effects.

An implementation of design of experiment is used to find out the influent parameters on the machining dispersions in turning. After pointing out the dispersions model of the revolution workpieces, a methodology using numerical tools (statistical, Taguchi's table …) is presented. The experimental method is applied to the numerical characterisation of an existing CNC lathe. The analysis of the answers then makes it possible to improve the initial model of simulation so called the "Delta L method".

2. A methodology to characterize dispersions

2.1. Proposed geometrical model

The ISO tolerancing standards, grouped under the term of GPS (Geometrical Specification of the Products), propose a packed language for the mechanical engineers. This GPS is widespread today among the industrialists. This geometrical model is designed for accompanying the evolution of the product from design stages to manufacturing ones. First steps seem simple to apply, but complexity appears rather quickly with the treatment of tolerances. This is why dispersions on manufactured part series are not seen with a unique point of view according to the step of the production process evolution. To avoid this difficulty, the geometrical model with tolerances proposed in this paper, has been designed to allow the follow-up of the geometry of the part during the machining process phases. This model is wanted to be able of realistic simulation to help each choice of the process planning in respect with the ISO GPS standard.

The objective is to carry out a systematic treatment for the tolerancing of dimension, orientation and form, based on the principles of the "ΔL" method due to P. Boudet [B2]. In its initial development this method was applied to one dimension problems. It allows analyzing only one direction of the workpiece. Whereas, the axial defects of the revolution geometry workpieces, are often considered as well in design for functional reasons, as in manufacturing for turning operations. This is why this paper proposes to integrate these defects in the computing model for simulation of machining and for helping process planning. More generally, considering effective axial and radial manufacturing dispersions, the initial method has been extended in order to take on into account the orientation defaults in addition to the radial and the axial defaults usually and mainly considered to define the capability of a process plan.

2.1.1. Extension of ΔL method (generalised ΔL method)

For a simple axis symmetric workpiece, the number of parameters P to a complete geometrical description is fixed at five. When manufacturing work piece series, each parameter P is associated with a dispersion value ΔP. The dispersions of these 5 parameters are illustrated on the figure 2.

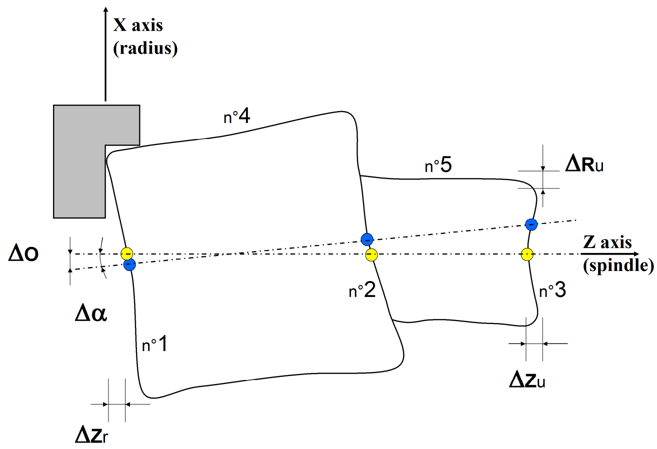


Figure 2 : manufacturing dispersions during turning process

First, to take into account the tolerances and machining dispersions in the axial and the radial directions, on X (radial) and Z (axial), the traditional "Delta L method" axes has been used. Concerning the machined surfaces 3 and 5 (Fig.2) dispersions are indicated by ΔZu (axial), ΔRu (radial). ΔZr (axial) measures the dispersion of the surface 1 used to define the setting (supposed realised with a self-centring chuck). Secondly, to take into account the specifications of GPS tolerancing on the default of orientation and position (coaxiality, perpendicularity…), the use of two new parameters is proposed:

$(\alpha, \Delta\alpha)$,$(O, \Delta O)$.
$\Delta\alpha$ represents the angular default of part setting in the jaws. ΔO correspond to the concentricity default measured in the plane defined by the shoulders of the jaws, between the axis of the workpiece and the spindle rotation axis.

2.1.2. Geometrical default and machining simulation for coaxiality

In the next sub paragraph, the method to link the five manufacturing parameters and their dispersions (P, ΔP) to the tolerances defined according ISO GPS Standards is described.
The ISO definition of the coaxiality and its interpretation are given on figure 3. The coaxiality of two cylinders relates to the relative position of the real axis of the indicated tolerance and the datum axis of the reference. Let us note that it does not relate to surfaces but only to axes.

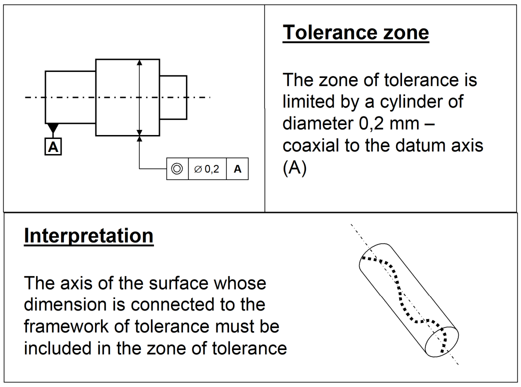


Figure 3 : Coaxiality ISO definition

This definition must be interpreted the most exactly possible. In the global process from design to production or manufacturing, a measuring controlling has to be considered. So, it needs also to have correspondence between the meanings of measurement on measuring machine (CMM) on the one hand, and of the specifications of the design drawing on the other hand.

Measurement on a CMM machine makes it possible to compute the positions of Oi points defined like the intersections of the axes of the two cylinders with the plane ends. According to the ISO standard, the real axis is concerned with this coaxiality specification. That brings now to a model where the real axis is a rectilinear segment which is obviously, different from the ensemble of the various sections centres. With this rectilinear model, the coaxiality control is limited to the calculus of the two bases centres radial distances for a comparison with the tolerance value defined in the standard.
On the example, in figure 4, the coaxiality value is the diameter of a cylinder coaxial with (O4 O5) segment and including O2 and O3 centre points.
The coaxiality default value is

t = 2 (max. [dist. (O2 O4); dist. (O3 O5)])

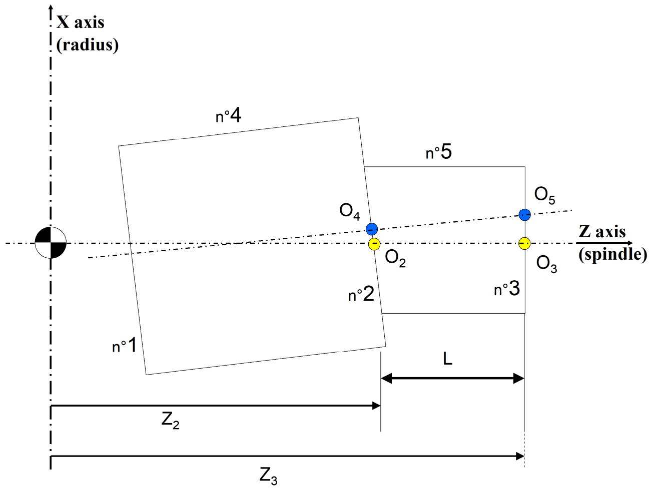


Figure 4 : geometrical parameters concerned in coaxiality

To calculate the coaxiality default produced by dispersions induced by a turning operation, the next geometrical parameters have to be considered:

- The axial positioning defect of the clamping Zr,
- The radial dispersion dues to the setting and to the clamping ΔO (See fig.2).
- The absolute orientation dispersion dues to the setting and to the clamping $\Delta\alpha$ (See fig.2).
- The axial length of the concerned surface, measured from the coordinate system origin, Zi = Z2, Z3… and L = absolute (Z2 - Z3).

The machining dispersions terms are summed up to compute coaxiality default. Several surfaces types (plane, conical, cylindrical, and unnamed or complex) can be considered as only associated setting dispersions (ΔO, $\Delta\alpha$) and axial length Zi are concerned.
For a machined surface Si, the angular coaxiality dispersion ($\Delta\alpha$) is equal to the angular dispersion due to the setting and the clamping.
To compute the corresponding radial defect (ΔOi), for a comparison with the tolerance specification, the furthest point from the setting surface is considered in the following equation:

$$\Delta O_i = L \times \Delta\alpha$$

For the surface Sj concerned by the setting, the dispersion inducing a coaxiality defect is the radial dispersion ΔOj. So, the total dispersion is the sum of ΔOi and of ΔOj dispersions (See details in [B2] and [W1]).

$$\Sigma\ [\ \Delta Oi\ ] \quad + \quad \Sigma\ [\ \Delta O\,j\ ] \quad = t\ ,$$

with index i relatives to machined surfaces and j relatives to the setting surface

To qualify a process plan, this sum has to be compared with the interval of tolerance valued by the design office.

$$t \quad < \quad IT$$

If this inequality is verified for each tolerance specification, the process plan is theoretically able to perform a good production.

2.2. Experimental methodology to quantify dispersions in turning

The machining dispersions have several origins in particular related to the control systems and the geometrical defects of the machine tool, the cutting pressures and the deflection of the tools … It is commonly accepted that stochastic laws characterize the behaviour of the source of each dispersion. These laws have various forms (normal, bimodal…). So the assumption that the resulting machining dispersions follow a normal law has been made (fig.5)

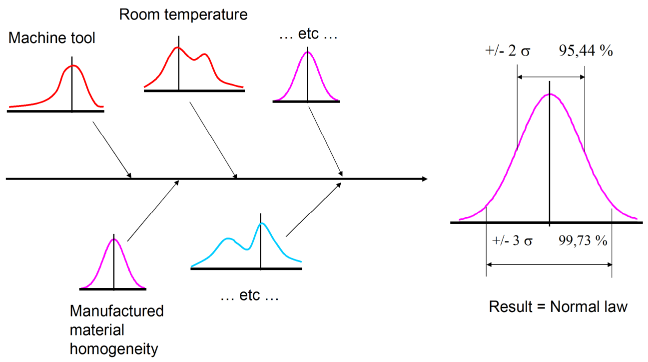


Figure 5 : Dispersion model: Normal law

The application presented here concern:

- The characterization of a single machine (HES300 CNC lathe)
- The characterization of 3 different setting and clamping systems (sets of different jaws)
- A set of fixed cutting conditions (tools and cutting parameters)

For the design of experiment, the choice was made on simple work piece geometry (Fig. 6), with a minimum number of surfaces (3 plans and 2 cylinders). This number (five) is necessary and sufficient to determine the five machining dispersions ΔP with the help of the proposed method.

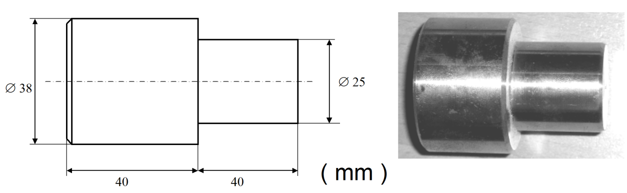


Figure 6 : Work piece nominal geometry and photo

This work piece was machined in three phases. The first one was a roughing operation consisting in preparing the initial bases for setting and clamping. It was carried out on a traditional parallel lathe. The two next were realized on CNC lathe. One of them carries out the diameter ϕ38, the other the diameter ϕ25 and the shoulder after work piece reversal.

3. Extension of the model

3.1. Taking into account of the cutting parameters

The initial model [W1] allows interesting forecasts. The tolerances associated with the manufactured geometries are computed starting from the input values of the dispersions. In practice, these values change in time for various reasons: evolution of the work piece material, variation of the tool supplier products, tools wear … etc…. Then a link has to be proposed to evaluate the capabilities of the model in respect with these variations. For that, it is proposed to take into account of the variability of cutting parameters which are defined during the process planning. It is commonly known that they involve dispersion variations of manufactured geometries.
For practical reasons, only five cutting parameters have been considered, the ISO grade of the insert (N), the insert nose radius (Rε), the cutting speed (Vc), the manufactured material (M), the feed rate (f). The method of the experimental designs was applied here to quantify the influence of them on manufactured dispersions on the basis two modalities.

Parameter	Label	Type	Modality 0	Modality 1
ISO insert grade (N)	N	Discrete	P15	P35
Insert nose radius (Rε, mm)	Rε	Discrete	0.4	0.8
Cutting speed (Vc, m min^{-1})	Vc	Continued	150	280
Manufactured material (M)	M	Discrete	NF-E 335	NF C35
Feed rate (f, mm)	f	Continued	0.1	0.3

Tableau 1: Factors of the experiment design

A batch of minimum 30 samples is usually required for a good use of traditional statistical tools. To allow a fast and economic method, our study is based on a number of samples reduced to five. Only five work pieces have been manufactured for each set of the experimental design. The appropriated statistical laws have been applied. On the base of expertise certain particular interactions are taken into account in the design of the plans. They are shown in table 2.

Interactions	
ISO insert grade – Cutting speed	N-Vc
Manufactured material - Feed rate	M-f
Manufactured material - Cutting speed	M-Vc
ISO insert grade - Feed rate	N-f

Tableau 2: interactions entre paramètres

In accordance with the initial method for the calculation of the total dispersion values in turning, considering axial dispersion ΔZu, the two values ΔZu_1 and ΔZu_2 respectively associated with the surfaces 1 and 2 were considered. They are measurable on the part test. The corresponding machined surfaces are obtained by two different edges of the insert (see fig.7). For the surface 1, the facing operation was made according the usual rules, from the outside towards the axis. For the surface 2, facing the shoulder is associated with a slide-lathing operation and cutting is realised from the axis towards outside.

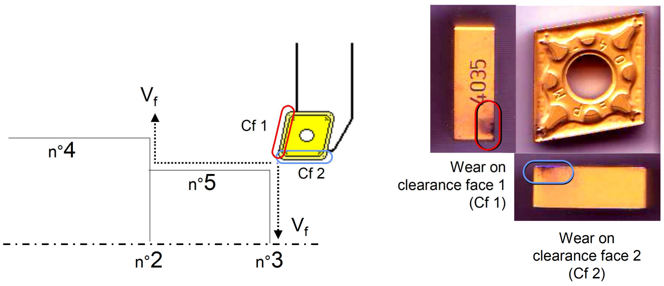


Figure 7 : Wear areas in facing and cylindrical turning

The analysis further developed uses designation "ΔZu_facing" for $\Delta Z\ u_1$ and "ΔZ u_facing up" for ΔZu_2.
To characterize the radial dispersion, ΔRu, two machined diameters are measurable, the 25 mm and the 38 mm diameter.
Figure 8 shows the variations of these diameters for the 16 machined work pieces. A similarity of evolution of the defects is observable.

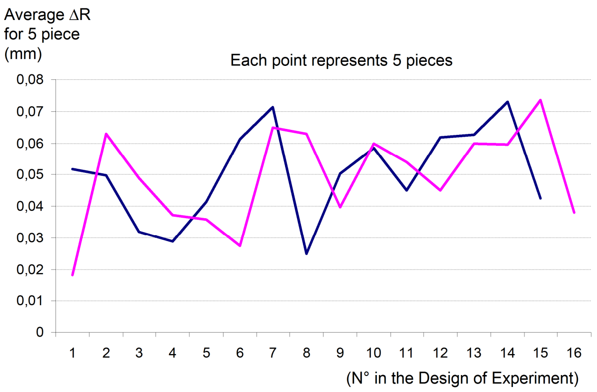


Figure 8 : variation of ΔR default for two different diameters

To preserve homogeneity on the number of measurements used for statistical calculations, only the parameter of dispersion corresponding to diameter 25, noted ΔRu_25 has been considered.

3.2. Design of experiment

3.2.1. Choice of the plan

In order to limit the number of tests to be realized and taking into account times of machining and control, and in agreement with literature [V1][WLR1], a Taguchi method has been applied.

The number of unknown factors of the model *Nddl* is given by :

$$N_{ddl} = I + \sum N_{ddl\ \text{paramètres}} + \sum N_{dll\ \text{interaction s}}$$

In this application: $N_{ddl} = 10$.

The number of tests must be higher than *Nddl*. Consequently, the table L16 (2^{15}) was selected. The graph of the interactions of figure 9 was built from one of the graphs proposed for this table L16 (2^{15}). The effects of the various factors and the effects of their interactions on the answers are calculated via this table with the index given in the figure.

Factors / Interactions	Index
ISO insert grade (N)	1
Insert nose radius (Rε, mm)	2
Cutting speed (Vc, m min^{-1})	4
Manufactured material (M)	8
Feed rate (f, mm)	15
Cutting speed - Manufactured material (Vc-M)	12
ISO insert grade - Cutting speed (N-Vc)	5
Manufactured material - Feed rate (M-f)	7
ISO insert grade - Feed rate (N-f)	14

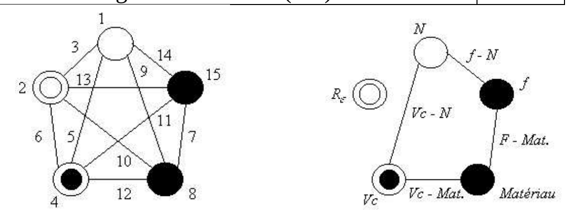


Figure 9: Factors and interactions of the Taguchi projected plan

For each studied answer, the order of the tests, as well as, the combinations of the parameters are given in table 2, in accordance with the table L16 (2^{15}).

Facteurs N°	Nuance N	Géométrie R_ε	Vitesse V_c	Matériau M	Avance f
1	P15	0.4	150	A60	0.1
2	P15	0.4	150	XC38	0.3
3	P15	0.4	280	A60	0.3
…	…	…	…	…	…
16	P35	0.8	280	XC38	0.1

Tableau 3: List of experiments

A reduced sample of five parts is sufficient. The plan will be thus of type L16 (215) repeated 5 times. Dispersions are related to the standard deviations of the obtained answers. These answers are due to the initial input parameters measured on the set of manufactured workpieces. That makes it possible to valuate manufacturing dispersions ΔO, Δα, ΔRu, ΔZr and ΔZu.

Two cases of computing occur because of dispersion is calculable starting from the standard deviation obtained by measurements of only one or several dimensions:

The first case, for only one dimension, relates to dispersionsOΔ, Δα, ΔRu. For example the following relation gives the radial dispersion calculation:

$$\Delta Ru = \left[\frac{6 \times (\sigma_{diameter})_{sample}}{C_4} \right] / 2$$

Where $\sigma_{diameter}$ is the variance of the measured series and C_4 is the factor taken in the statistical table given for a reduced number of samples [PIL 96].

In the second case several manufactured and measured dimensions are concerned to compute the dispersion. These dimensions are noted $di(\sigma j)$. The variance of required dispersion di is related to the sum of the variances σj of concerned manufactured dimensions. That relates to dispersions ΔZr and ΔZu. For example, the relations used for ΔZr are the following ones:

$$\Delta Zr = \frac{(\sigma_{setting})_{sample}}{C_4} \times 6,$$

$$\text{where} \qquad \sigma_{reprise} = \frac{\sqrt{\sum \pm \sigma_i^{\,2}}}{\sqrt{2}}$$

The manufactured dimensions which are input data for calculations of various dispersions are measured directly on the manufactured part series using a three-dimensional measuring machine (CMM).

Starting from measurements, each set of 5 parts allows calculating the standard deviation of each ΔZρ answer, ΔO, Δα, ΔRu, ΔZr and ΔZu.

The experimental design thus provides 16 values for each studied answer.

3.2.2. Summary of the results

The following table 3 gathers the results for the 5 dispersions studied during the experimental design. In the first column, the results are appeared as charts associated with the different parameters or interactions of the experimental design. In the second column, the coefficient of multiple regressions R^2 is given. His numerical value makes it possible to estimate the percentage of data explained by the model. The higher the R^2 is, and the more exploitable the model is in predictive mode, subject to tests of confirmation. A coefficient R^2 between ~70 and ~ 90% usually corresponds to an acceptable model.
The third column indicates the list of the parameters which were identified like having a significant influence on studied dispersion. The variance analysis based on the value of this parameter p indicates that a parameter is statistically significant on the answer. For example, as soon as p is higher than 0.05. the trust level is higher than 95%.

4. Interpretation of the results

In this paragraph, the results are analyzed for the 5 dispersions considered in table 3. For this study, considering the machining on a lathe, 3 categories were considered.
The work piece setting dispersions,
The axial dispersions,
The radial dispersions.

4.1. Setting dispersions (ΔO, Δα and ΔZr)

ΔO represents the dispersion of concentricity due to the setting. According to the statistical model, this dispersion is only and lightly controlled by the “Feed rate” (f) parameter. Note that this result is very difficult to explain because, from a usual point of view, there is no evident link between these two physical events.
ΔZr and Δα do not statistically depend on any selected input parameters. This result is easier to appreciate. Usually, the setting and the cutting conditions are supposed non dependant.

4.2. Axial dispersions (ΔZu)

Axial dispersions have been measured for the surfaces 2 and 3 defined in figure 2. The manufacturing conditions are given in figure 7.
In the first case concerning the surface No 2, while going up along X axis, the cutting conditions are maintained constant during facing. For simplicity of the presentation the statistical results obtained for this Zu_2 dispersion are not given in table 3. Nevertheless a statistical analysis has been performed and no parameter (among those selected in entry) has been found statistically influential on Zu_2 dispersion. The interaction manufactured material-feed rate has the grater influence . The coefficient p is very near the value limit selected ($p>0,05$). So, complementary tests will be necessary in order to validate the influence of this interaction.
In the second case concerning the surface No 3, the statistical results are given on table 3, where $Zu = Zu_3$. According to the results $R^2 = 0.74$ and $p>0,05$, it is possible to write the following equation explaining that this dispersion is mainly function of the cutting speed Vc:
$\Delta Zu_3 = \Delta Zu = F(Vc)$

The complete numerical equation is :

$\Delta Zu = 0.02148 - 0.00477\ N - 0.00512\ R\varepsilon - 0.00004\ Vc + 0.00151\ M + 0.007\ f + 0.000013\ N.Vc$

From a practical point of view, note that during the facing operation, the edge which generates the surface with an important variation of the cutting speed beyond the range given by the provider for the given ISO grade of the insert. Indeed the constant cutting speed function controls the number of revolutions according to the radial position of the tool. But limits according to the capacities of the machine are reached when the cutting tool nose is near the centre. Inside a limiting diameter, cutting speed decreases until tending towards 0. This insufficient cutting speed involves an acceleration of the phenomena of the tool wear and thus explains the origin of the observed variation of the dispersions.

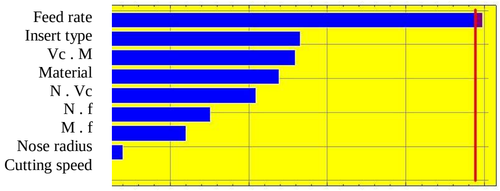
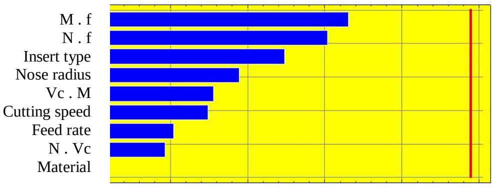
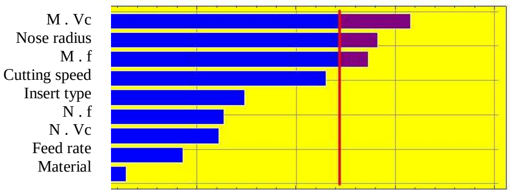
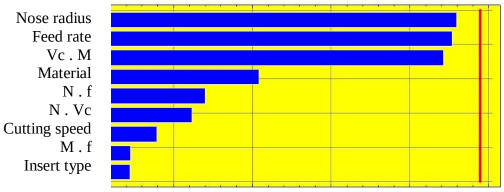
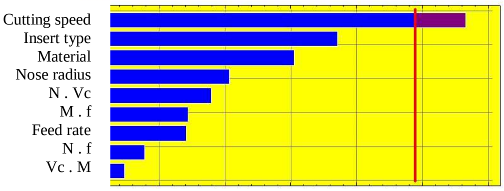
<table>
<tr><td rowspan="2">PARETO charts</td><td colspan="2">Variance analysis</td></tr>
<tr><td>R-squared statistic R^2</td><td>influential parameters (p_i)
$p > 0,05$</td></tr>
<tr><td>ΔO 
</td><td>0,68</td><td>Feed rate (f)</td></tr>
<tr><td>Δα 
</td><td>0,60</td><td></td></tr>
<tr><td>ΔR_u 
</td><td>0,86</td><td>Nose radius (Rε)
Material – Cutting speed (M.Vc)
Material – Feed rate (M.f)</td></tr>
<tr><td>ΔZr 
</td><td>0,74</td><td></td></tr>
<tr><td>ΔZu 
</td><td>0,74</td><td>Cutting speed (Vc)</td></tr>
</table>

Tableau 4: Influence of the parameters

4.3. Radial dispersions (ΔRu)

Radial dispersions have been measured for the surface 4 (38mm diameter) and for the surface 5 (25 mm diameter). Only the resulted obtained for the surface 5 are given in the table 3 and named ΔRu dispersions.

These results show that, the (Rε) nose radius is the only one statistically significant independent parameter. This parameter represents the effective geometry of the tool insert.

The interactions machined material-cutting speed and machined material-feed rate (M-Vc and M-f) are also significant.

The R^2 value, about 86% confirms the possible use of the model for predictions. The Radial dispersion is function of the nose radius and of the interactions machined material-cutting speed and machined material-feed rate,

$\Delta Ru = F(R\varepsilon, M\text{-}Vc , M\text{-}f)$

The complete numerical equation is :

$\Delta Ru = 0.02789 + 0.01822\ N + 0.00637\ R\varepsilon, + 0.00008\ Vc + 0.01187\ M + 0.01941\ f + 0.00004\ N.Vc - 0.02873\ N.f - 0.00010\ M.Vc + 0.06160\ M.f$

From a practical point of view note that these interactions controlling the radial dispersion are composed up from the parameters M (machined material) , Vc (cutting speed) and f (feed rate) which take part with the evolution of the cutting force and the power necessary for the cut:

The Fc cutting force is expressed by $Fc = Ks * S$ where S is the chip section $S = ap*f$.

The specific cutting force Ks is usually related to the machined material (M), ap is the depth of cut. A constant depth of cut has been use for machining samples. In this case the feed rate f alone controls the chip section S.

On an other hand, the Pc cutting power is calculated by $Pc = Fc * Vc$

According to a model of equal distribution of the efforts along the edge of cut [RPB1] in turning, the interface tool/material can be associated to a linear segment AB representing a virtual edge. The cutting force component in the reference plane is supposed to be acting normally and in the middle of this segment (fig. 16). Note that the direction of the effort mainly evolved with the (Rε) nose radius and with ap depth of cut.

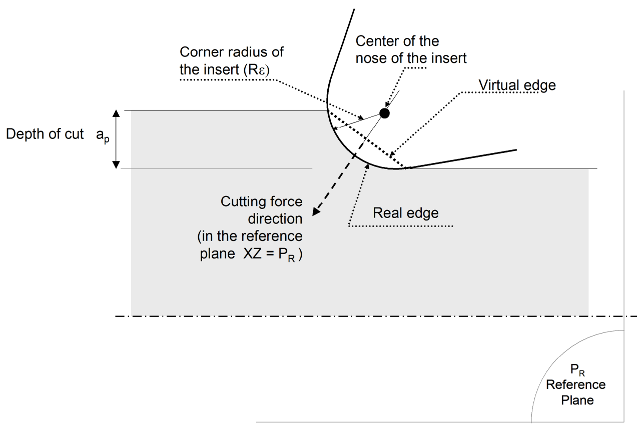


Figure 10: Cutting force direction in the reference plane

More, typical values of the nose radius are associated with specific geometry of the chips breaker by the tool providers. This is to elaborate different tools types designed for rouging, finishing… operations. In our case only the nose radius was an identifiable parameter. It characterizes alone the type of tool. This hypothesis excludes therefore the influence of the chip breaker on the direction and the value from the cutting pressures. Taking in account the ship breaker and quantifying is influence on manufactured dispersion is a perspective of future works

4.4. Global results

For the ranges given in table 1, the dispersions ranges obtained from the statistical analysis of the results obtained The simulation of products or manufacturing processes is an important means in the organisations of the CIM on the CNC lathe are given below:

ΔO (mm) ≤ 0,141; $\Delta\alpha$, (angle °) ≤ 0,11;
ΔZr (mm) ≤ 0,179; 0.020 ≤ ΔRu (mm) ≤ 0.068 ;
0.0060 ≤ ΔZu(mm) ≤ 0.015

From a practical point of view the values associated with the cutting process are in a normal range. The values associated with the setting and the clamping seems to be big. This is related with the clamping jaw system used for experiment.

4.5. Conclusion about dispersions

The results of the integration and the valuation of manufacturing dispersions presented here and the application confirm the assumptions of the development of the first model so called . “Delta L method”.

This application based on the method of the experimental designs shows that setting and clamping dispersions ΔO, $\Delta\alpha$ and ΔZr are independent of the cutting parameters. This conclusion resulting from the application confirms the usual known of the experts.

In the form of numerical equation, this method allows the quantification of important links between manufacturing dispersion and cutting parameters:

- For the axial dispersion ΔZu, the control of the type of machining: facing up to the axis, or not has been observed and the important influence of the Vc cutting speed on the result has been numerically expressed.
- For the radial dispersions ΔRu, the influence of the geometry of the insert, the interaction machined material-cutting speed and the interaction material-feed rate, have been highlighted. The result has been numerically expressed for a given lathe and a given range of parameters.

5. Conclusion

To sum up, this application shows the performance of the “Delta L method” in the case of revolution workpiece manufactured on lathes. When geometrical specifications are carefully considered, a link between manufacturing dispersions and tolerance of the design can bee quantified on the base of plan of experiment. More of that, the presented results, give important indications to optimize the cutting parameters and the production with respect to the objective of the design office. More generally, this shows that the integration, of the dispersions due to the manufacturing process in the computation and the treatment of the design of tolerances is possible. The simulation of products and of manufacturing processes is an important mean available for cooperative engineering.

The principal prospects considered relate to the evolution of the method suggested to adapt it to other means of productions. For example, the study of dispersions during machining by the techniques of high speed machining, or applications related to the more complex machines tools (milling with 3,4, or 5 axes).

6. References

[A1] Anselmetti B., Cotation de fabrication et métrologie, Volume 3, Editions Hermès, Avril 2003.

[S1] Sohlenius G, “Concurrent engineering”, Annals of CIRP, 1992, volume 41/2, pp 645-655

[B1] Bourdet P, « Chaîne de cotes de fabrication », l’ITET L’Ingénieur et le Technicien de l’enseignement Technique, Paris, Dec. 1973

[B2] Bourdet P, « Introduction générale : la cotation, un outil d’aide au tolérancement géométrique normalisé des pièces », colloque « Tolérancement et chaînes de cotes », ENS Cachan, 8-9 février 1995, pp 9-24.

[MA1] Martin P., D’Acunto A., « Method of determining the process applied for feature machining: experimental validation of a slot», The International Journal of Advanced Manufacturing Technology, on line 15 06 2007

[RPB1] Rigal JF, Pupasa C, Bedrin C, « A model for simulation of vibrations during boring operations of complex surfaces. » , vol 47/1 , CIRP Annals , 1998

[V1] Vigier M., Pratique des plans d’expériences (Méthodologie Taguchi), Les Editions d’Organisation, 1988

[V2] VILLENEUVE F., « Optimization of end milling roughing operation sequence», 2nd IDMME, Compiegne – Volume III, pp 835-642, 1998.

[W1] Wolff V., Le suivi de la cotation des pièces fabriquées pour la conception coopérante en mécanique, Thèse de doctorat, INSA de Lyon, 2000

[WLR1] Wolff V, Lefebvre A, Renaud J, « Maps of dispersions for machining processes », CERA Vol 14, ISSN 1063 293X, pp. 129-139, June 2006