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RESEARCH ARTICLE

A FULL METHOD FOR OPTIMIZING THE QUALITY OF MANUFACTURING BY CNC MACHINE-TOOL.

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Abstract

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In the steering methods of CNC machine tool presented in the literature, none use both the geometry and the cutting parameters to adjust the machine. In the steering methods of machine that we previously presented in our works, we always use an incidence matrix built from linear relationships between a collection of geometric deviations and a collection of correctors available in numerical control (NC). This matrix makes it possible to find the adjustment to be made on the tools which guarantees the geometric quality of the workpiece. Now, more and more machine tools are monitored by sensors (vibration, temperature, load, ...), and it is interesting to watch how we can connect this new collection of parameters to another new collection of possible corrections which would be the feeds, the speeds, the depths of pass, ... In this article, we present new feeds in the field of steering taking into account the relations between new collections of parameters which are, the load, the torque and the feed rate. It is possible to determine from an experimental assembly the linear relationships that exist between these new collections of parameters to apply a more ''global incidence matrix''. If we know the measurement of the parameters obtained thanks to the experimental assembly and the measurement of the geometry of the part, it is then possible to find a more global setting which optimizes the whole of the process on all the parameters and to get the best quality possible regardless of the complexity of the part.

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Introduction:-

Due to the origins of the very complex and very varied manufacturing uncertainties related to the part/tool/machine system, several researchers have worked to try by different ways to maintain the quality of the processes. Some authors such as Sergent et *al.*, 2010 Tichadou et *al.*, 2007 have attempted to solve the problem of machining defects, by modeling the machining defects by torsors of small displacements presented by Clement and Bourdet, 1988. Others authors, such as Girardin, 2010, sought instead to model the dynamic behavior of the machining system in the case of milling, and used a frequency analysis of the cutting force to monitor the machining process. Similar work in monitoring of the machining by monitoring of tool wear has been done by Huseyin et *al.*, 2004, and monitoring of

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tool wear by acoustic emissions has been done by Marinescu et *al.,* 2008, and even work on monitoring of tool wear by electric power has been done by Faleh et *al.,* 2005.

Many other problems with the part / tool / machine system persist, such as the setting of manufacturing process. In this subject, several authors have published approaches to effectively steer the process. Due to the very approximate initial setting of the tools, Kibe et *al.,* 2007 proposed to adjust the initial position of the tools using an in-situ measurement. The authors Bourdet, 1982 and Anselmetti and Bourdet, 1993 have shown that if we can act on the correctors of the machine to reduce the difference between the theoretical part and the machined part, it can also be reduced by acting on the optimal dimensions chosen intelligently. The authors Goldschmidt 2009 and Pairel *et al.,* 2011 implemented the Copilot-Pro® methodology that allows the adjustment of all cutting tools, including roughing tools. Their method determines the "range of setting" or the "range of monitoring" in a manufacturing step and allows determining the manufacturing dimensions to be measured to adjust a maximum of cutting tools per step.

There are methods in the literature to determine the manufacturing dimensions necessary for the good adjustment of the machine, but the methods proposed by Goldschmidt 2009 and Pairel *et al.,* 2011 differs in that because these dimensions are determined taking into account the constraints related to manufacturing process. The authors Goldschmidt *et al.*, 2007, and Boukar *et al.*, 2012, conscious of the interest offered by the geometric tolerancing to ensure the conformity of the products, exploited this tolerance for setting the machines. Pillet *et al.*, 2014 proposed a multivariate setting approach using both Hotelling's T^2 and an incident matrix between the tool correctors and the points probed on the part. However, his method is limited only to the use of column information of the incidence matrix. Pairel et *al.,* 2014 also presented a multivariate setting approach using a linear program. He showed that we can optimize the setting by optimizing a parameter of distance introduced in the program. Work on the matrix setting approach of machines has been conducted in particular by Boukar *et al.,* 2014; Boukar *et al.,* 2015; Boukar *et al.,* 2017; Pillet and Pairel 2011 in the context of inertial tolerancing introduce by Pillet, 2001.

In this article, we propose an extension of the inertial steering method that we previously proposed by going beyond the geometrical parameters of the part to steer the machine. In addition to steering the geometrical parameters, we introduce the control of the cutting force and the torque measured from an experimental assembly.

Input / Output System

The quality of the machining depends on the correct configuration setting between the input and output parameters, that is to say on the one hand, between the dynamic parameters (load, torque, ...) and the cutting parameters (depth of pass, feed per revolution, cutting speed, ...) and on the other hand, between the adjustment parameters of the numerical control and the geometry parameters of the part. Figure 1 shows a systemic view of the production system. In this system, we measured δ at the output (δ is a decentering between the target and the measured value) + a variability σ. The goalof the steering is to eliminate, if not to reduce as much as possible the decentering and to control the variability.

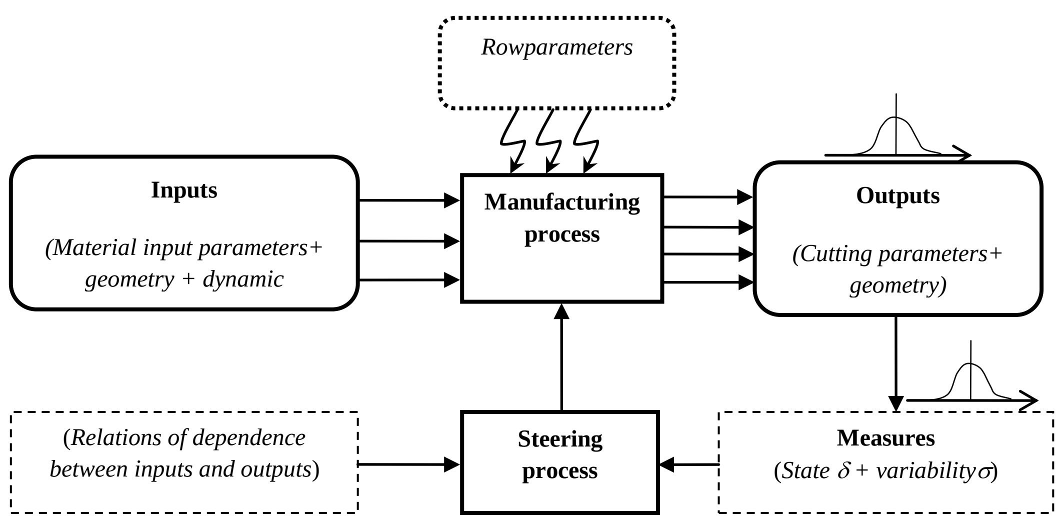
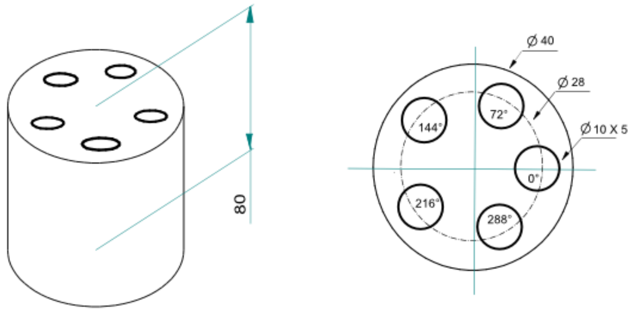


Fig 1:-Systemic view of a production system

To present this work, we base ourselves on the case of drilling of a part chosen voluntarily simple to present the approach. Five (5) holes of 10 mm in diameter are made equidistantly along a circumscribed circle in the part (see Fig.2). The holes were made on XC48 steelof 40 mm in diameter. The depth *h* of the hole is *h* = 12 mm. Figure 2 shows the drilling geometry.



General's tolerances ISO 2768 m-k
Fig 2:-Drawing definition of the part

Steering Methods

Steering by the geometry of the part
The drilling surfaces are generated by the same drill. This drill can be adjusted by acting on its axial position corrector Tz (along the Z axis) which adjusts the position of the h depth of the hole. Its radius corrector (R) is not corrected. If the drill is worn, it is either sharpenedor replaced. Similarly, the angular offset is not corrected, it is an editable parameter in the program. Anyway, displacement variables Tx (translation along the X axis) and Ty (translation along the Y axis) are introduced into the program to allow the machining reference to be repositioned on the part reference to refocus the machined shapes on their targets (Fig. 3).

Thus, to correct the machining we acts on Tx, Ty and Tz. The difference between the target surfaces and the machined surfaces is measured at several points by distances following the normal of the points of the surfaces. Thus, we arbitrarily decided to measure five points on each hole (four on the sidewall that positions the shapes on the circle and one on the bottom that allows correcting the depth of the hole).

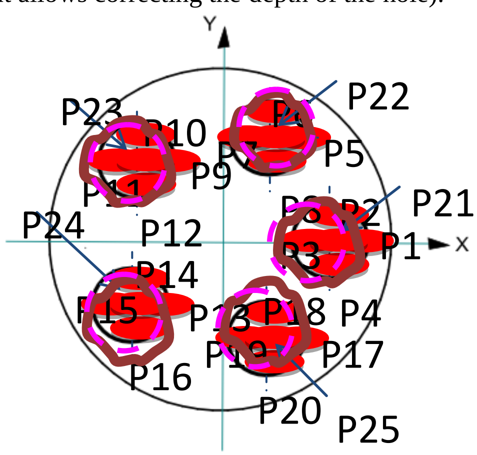


Fig 3:-Representation of the target holes and offsetting machined holes

Table 1 gives the coordinates of the probed points and the components of the local normals expressed in the part reference as well as the deviations measured at these points according to the normals (column e^0_i).

Table 1:-Expression of points in the part reference

Point	X	Y	Z	ai	bi	ci	e^0_i
P1	19	0	-4	-1	0	0	-0.1818
P2	14	5	-4	0	-1	0	-0.1807
P3	9	0	-4	1	0	0	0.1847
P4	14	-5	-4	0	1	0	0.2106

P5	9.33	13.32	-4	-1	0	0	-0.1933
P6	4.33	18.32	-4	0	-1	0	-0.1940
P7	0.67	13.32	-4	1	0	0	0.1950
P8	4.33	8.32	-4	0	1	0	0.1959
P9	-6.33	8.23	-4	-1	0	0	-0.1878
P10	-11.33	13.23	-4	0	-1	0	-0.1947
P11	-16.33	8.23	-4	1	0	0	0.1936
P12	-11.33	3.23	-4	0	1	0	0.1936
P13	-6.33	-8.23	-4	-1	0	0	-0.1868
P14	-11.33	-13.23	-4	0	-1	0	-0.1906
P15	-16.33	-8.23	-4	1	0	0	0.1859
P16	-11.33	-3.23	-4	0	1	0	0.1946
P17	-9.33	-13.32	-4	-1	0	0	-0.1860
P18	-4.33	-18.32	-4	0	-1	0	-0.1880
P19	-0.67	-13.32	-4	1	0	0	0.1859
P20	-4.33	-8.32	-4	0	1	0	0.1912
P21	14	0	-8	0	0	1	0.1802
P22	4.33	13.32	-8	0	0	1	0.1925
P23	-11.33	8.23	-8	0	0	1	0.2014
P24	-11.33	-8.23	-8	0	0	1	0.1931
P25	4.33	-13.32	-8	0	0	1	0.1879

To steer the machining by the drill, we uses the approach of Total Inertial Steering presented by Boukar *et al.,* 2014 which makes it possible to establish and to use the direct link between the correctors and the position of the machined surfaces defined in a reference linked to the machine. So we use all the raw information on the points without going through a geometric parameter by dimension which makes us lose the precision of setting. If we consider $[\mathbf{e}^{0}_{n,1}]$ the matrix of initial deviations measured on the points and $[\mathbf{e}^{1}_{n,1}]$the matrix of the next deviations (after setting) on these points. The goal of the setting is to find the offset to be made on the points to minimize $[\mathbf{e}^{1}_{n,1}]$. This results in the relation of equation (1):

$$[\mathbf{e}^{1}_{n,1}] = [\mathbf{e}^{0}_{n,1}] + [\mathbf{d}_{n,1}] \tag{1}$$

With $[\mathbf{d}_{n,1}]$: matrix of offsetson *n* points

The offsets on the points are computed by the method of small displacements proposed by Bourdet and Clément 1988 which consists in calculating the translation of the real point according to the displacement {D(O), □} of the trajectory of the tool relative to the part (equation 2):

$$d_i = \overrightarrow{\boldsymbol{D}(\boldsymbol{P}_i)}.\overrightarrow{\boldsymbol{n}_i} \tag{2}$$

This is expressed by:

$$\overrightarrow{\boldsymbol{D}(\boldsymbol{P}_i)}.\overrightarrow{\boldsymbol{n}_i} = \left(\overrightarrow{\boldsymbol{D}(\boldsymbol{O})} + \vec{\Omega}\wedge\overrightarrow{\boldsymbol{OP}_i}\right).\overrightarrow{\boldsymbol{n}_i}$$

$$\overrightarrow{\boldsymbol{D}(\boldsymbol{O})} = \begin{pmatrix} T_X \\ T_y \\ T_z \end{pmatrix}; \qquad \vec{\Omega} = \begin{pmatrix} R_X \\ R_y \\ r_z \end{pmatrix}; \qquad \overrightarrow{\boldsymbol{n}_i} = \begin{pmatrix} a_i \\ b_i \\ c_i \end{pmatrix}.$$

Where, O is the origin of the reference of trajectory of the tools and rotations Rx, Ry and Rz, respectively around the X, Y and Z axes. The development of equation (2) gives equation (3):

$$d_i = a_iT_x + b_iT_y + c_iT_z + L_iR_x + M_iR_y + N_iR_z \tag{3}$$

With:
ai, bi, ci: direction cosines of the local normal $n_i$to the target surface;
Li, Mi, Ni: components of the vector $\overrightarrow{\boldsymbol{OP}_i}\wedge\overrightarrow{\boldsymbol{n}_i}$;
Tx, Ty, Tz: translation respectively along X, Y and Z axes;
Rx, Ry, Rz: rotations along X, Y and Z axes.

Since for the part, only Tx, Ty and Tz are corrected, equation (3) is simplified and becomes (4):

$$d_i = a_iT_x + b_iT_y + c_iT_z \tag{4}$$

This equation can be written in the following matrix form (see equation 5):

$$[\mathbf{d_{n,1}}] = [\mathbf{m_{n,p}}].\ [\mathbf{c_{p,1}}] \quad (5)$$

With:

$[\mathbf{m_{n,p}}]$: matrix of incidence of the correctors on the points (n lines, p columns);

$[\mathbf{c_{p,1}}]$: matrix of corrections on the correctors (p rows, 1 column).

The adjustment consists of making an offset opposite to the initial deviation to cancel the deviation of each point and to bring back the machined surfaces on their target. This gives for all the points the following matrix system (6):

$$[\mathbf{-e^0_{n,1}}] = [\mathbf{m_{n,p}}].\ [\mathbf{c_{p,1}}] \quad (6)$$

This matrix system (with 25 rows and 3 columns) has no exact solution because the number of points (n = 25) is greater than the number of correctors (p = 3). The multi-linear regression then makes it possible to obtain the values of Tx, Ty and Tz which minimize the sum of the squares of the next offsets. It consists in its simplest presentation, to multiply the matrix of initial deviations $[e^0_{n,1}]$ by the pseudo-inverse $[m_{n,p}]^+$ of the incidence matrix according to equation (7):

$$[\mathbf{c_{p,1}}] = [\mathbf{m_{n,p}}]^+.\ [\mathbf{-e^0_{n,1}}] \quad (7)$$

With:

$$[\mathbf{m_{n,p}}]^+ = \{[\mathbf{m_{n,p}}]^T.\ [\mathbf{m_{n,p}}]\}^{-1}.\ [\mathbf{m_{n,p}}]^T$$

Knowing the deviations of the points reported in Table 1, we obtain the values of Tx = - 0.188, that of Ty = -0.193 and that of Tz = -0.191 which minimize the geometric differences on the next piece. The corrections obtained make it possible to estimate the new deviation values on the next part thanks to equation 8.

$$[\mathbf{e^1_{n,1}}] = [\mathbf{e^0_{n,1}}] + [\mathbf{m_{n,p}}].[\mathbf{c_{p,1}}] \quad (8)$$

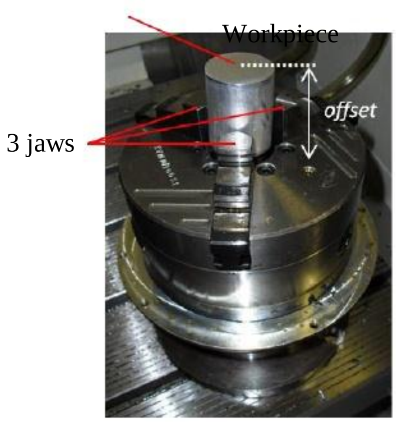
Figure 7 presented below shows the deviations before and after adjustment of the geometry.

Steering by cutting parameters

To take into account the loads and the cutting conditions in the incidence matrix, measurements are made using an experimental assembly.

Experimental assembly for measuring cutting force and torque

For drilling, we used a DECKEL MAHO milling center: DMC 635V and a HSS drill ("High Speed Steel") without cutting in the center. Figure 4 shows the machining assembly of the part.



The steel sections are placed and tightened between the 3jaws of the vice.
Then the depth between the top of the test part and the base is measured with vernier caliper in order to perform the offset of the machine and to inform the position of its origin (0, 0, 0).

Fig 4:-Machining assembly of the workpiece

The acquisition chain

The input parameters that we measure experimentally are the cutting force F and the torque C. The measurement of the loads (F and C) is carried out by an acquisition chain consisting of four (4) main elements (1-Dynamometer, 2-charge amplifiers, 3-multimeters, 4-card and PC-based processing software) shown in Figure 5. The acquisition system used is the UNIGOR SET 304 PC.

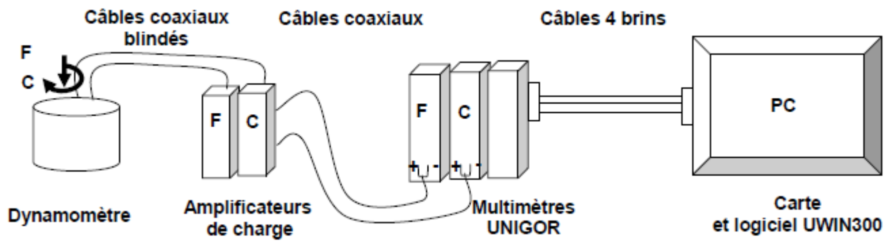


Fig 5:-Acquisition chaine (Installation of INSA Lyon-France)

The well-known setting parameters for the drill operation are the cutting speed and the feed per revolution. The cutting speed characterizes the relative speed between the workpiece and the tool at the point of contact, while the feed per revolution naturally characterizes the state of surface obtained (see Chibane *et al.*, 2011).

During machining, the cutting speed was set at 10 m / min and the values of the cutting force and the torque were measured by varying the spindle feed rate and the depth of the hole h = 4, +2, +2, +2, +2 (= 12 mm). The program allows recovering the values of the force and the torque provided by the machine. These values are given in Volt thanks to the amplifiers, a coefficient of 20000 to obtain the torque in (N.mm) and 5000 for the force in (N) as given in Table 2.

Table 2:-Measures of cutting force and torque according to the feed rate.

Voltmeters			**Dynamometric table**	
			Coefficient	
			5000	**20000**
f (mm/rev)	**F (Volt)**	**C (Volt)**	**F (N)**	**C (N mm)**
0,080	0,294	0,075	1470,000	1500,000
0,100	0,316	0,097	1580,000	1940,000
0,125	0,353	0,112	1765,000	2240,000
0,160	0,397	0,126	**1985,000**	**2520,000**
0,200	0,412	0,139	2060,000	2780,000

Figure 6 shows the influence of the feed rate on the cutting force and torque provided by the machine. The cutting force and the torque increase according to the feed rate, which requires a better adjustment of the latter.

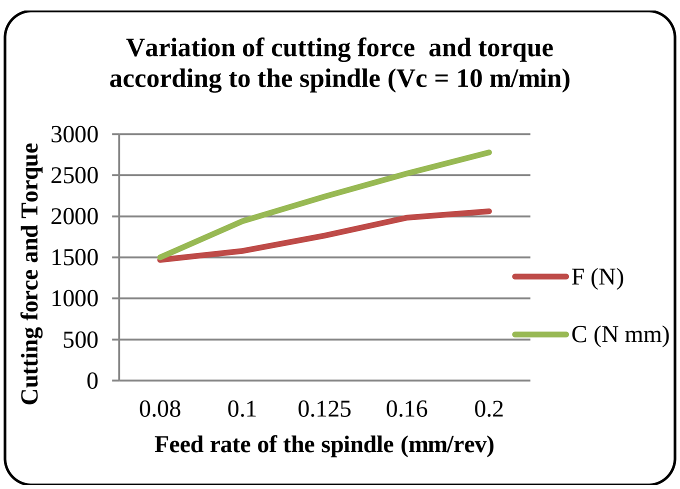


Fig 6:-Influence of feed rate on cutting force and torque

Relationship of dependence between cutting force, torque and feed rate

The relationships between cutting force, torque and feed rate in the case of drilling are given respectively by equation (9) for the cutting force and by equation (10) for the torque:

$$F = Kca .f. d \tag{9}$$
$$C = Kcc. f. d^2 \tag{10}$$

With:
f: spindle feed rate (mm / rev).
d: tool diameter (mm).
Kcc: specific cutting force coefficient (N / mm²)
Kca: specific axial force coefficient (N / mm²)

Equations (9) and (10) can respectively be simplified by the following equations (11) and (12):

$$F = K1. f \tag{11}$$
$$C = K2. f \tag{12}$$

Where K1 = Kca .d, and K2 = Kcc .d²

The specific force coefficient Kca and Kcc indicate the criterion of machinability of the material, they vary according to the cutting parameters and the geometry of the section. In our case, these parameters were determined experimentally as a function of the feed rate for a diameter of 10 mm, for the drill HSS (see Table 3).

Table 3:-Specific cutting forces according to the feed rate

		Foret HSS	
f (mm/rev)	**D (mm)**	**Kca (N/mm²)**	**Kcc (N/mm²)**
0,080	10	2056,25	480
0,100	10	1745	460
0,125	10	1544	430,4
0,160	10	1303,13	381,25
0,200	10	1107,5	338

Global Optimization Of Manufacturing

The overall setting of the machine involves both the adjustment of the workpiece geometry and the setting of the cutting condition for overall optimization of production. The "overall" incidence matrix between deviations of the points probed on the part and the tool correctors, on the one hand, and between the loads and the feeds, on the other hand, can be expressed by the following matrix relation (see equation 13):

$$\begin{Bmatrix} [-\mathbf{e}^{0}_{n,1}] \\ [-\mathbf{F}_{i,1}] \\ [-\mathbf{C}_{i,1}] \end{Bmatrix} = \begin{Bmatrix} [\mathbf{m}_{n,p}] & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & [\mathbf{K1}_{i,j}] & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & [\mathbf{K2}_{i,j}] \end{Bmatrix} \begin{Bmatrix} [\mathbf{c}_{p,1}] \\ [\mathbf{f}_{j,1}] \\ [\mathbf{f}_{j,1}] \end{Bmatrix} \tag{13}$$

With:
$[\mathbf{F}_{i,1}]$ = Matrix of cutting forces
$[\mathbf{C}_{i,1}]$ = Matrix of torques
$[\mathbf{f}_{j,1}]$ = Matrix of feed per revolution.
$[\mathbf{K1}_{i,j}]$, $[\mathbf{K2}_{i,j}]$ = respectively, Matrices of the specific axial force coefficients and specific cutting force coefficients.

Discussions:-

Determination of the best feed adjustment

The overall optimization of the process is done on all the collections of parameters. The approach for optimization by geometry is presented in section III (in point A), which is simply reported its incidence matrix in the "Overall" incidence matrix obtained by equation 13 (see Table 4). As for the geometry parameters, the measured values of F, C, K1 and K2 are also reported in the "Overall" incidence matrix that is given in Table 4.

Table 4:-"Overall" Incidence Matrix

		Tool offsets			**Feed per revolution**				
		Tx	Ty	Tz	f1	f2	f3	f4	f5

Measured points on the workpiece	P1=-0.1818	-1	0	0	0	0	0	0	0
	P2 = -0.1807	0	-1	0	0	0	0	0	0
	P3 = 0.1847	1	0	0	0	0	0	0	0
	P4 = 0.2106	0	1	0	0	0	0	0	0
	P5 = -0.1933	-1	0	0	0	0	0	0	0
	P6 = -0.1940	0	-1	0	0	0	0	0	0
	P7 = 0.1950	1	0	0	0	0	0	0	0
	P8 = 0.1959	0	1	0	0	0	0	0	0
	P9 = -0.1878	-1	0	0	0	0	0	0	0
	P10 = -0.1947	0	-1	0	0	0	0	0	0
	P11 = 0.1936	1	0	0	0	0	0	0	0
	P12 = 0.1936	0	1	0	0	0	0	0	0
	P13 = -0.1868	-1	0	0	0	0	0	0	0
	P14 = -0.1906	0	-1	0	0	0	0	0	0
	P15 = 0.1859	1	0	0	0	0	0	0	0
	P16 = 0.1946	0	1	0	0	0	0	0	0
	P17 = -0.1860	-1	0	0	0	0	0	0	0
	P18 = -0.1880	0	-1	0	0	0	0	0	0
	P19 = 0.1859	1	0	0	0	0	0	0	0
	P20 = 0.1912	0	1	0	0	0	0	0	0
	P21 = 0.1802	0	0	1	0	0	0	0	0
	P22 = 0.1925	0	0	1	0	0	0	0	0
	P23 = 0.2014	0	0	1	0	0	0	0	0
	P24 = 0.1931	0	0	1	0	0	0	0	0
	P25 = 0.1879	0	0	1	0	0	0	0	0
Cutting force	F1 = -1470	0	0	0	20563	0	0	0	0
	F2 = -1580	0	0	0	0	17450	0	0	0
	F3 = -1765	0	0	0	0	0	15440	0	0
	F4 = -1985	0	0	0	0	0	0	13031	0
	F5 = -2060	0	0	0	0	0	0	0	11075
Torque	C1 = -1500	0	0	0	48000	0	0	0	0
	C2 = -1940	0	0	0	0	46000	0	0	0
	C3 = -2240	0	0	0	0	0	43040	0	0
	C4 = -2520	0	0	0	0	0	0	38125	0
	C5 = -2780	0	0	0	0	0	0	0	33800

This matrix contains 35 rows and eight (8) columns, so it is not invertible. The system does not have an exact solution. The pseudo-inverse of Gauss given by the equation 14 thus makes it possible to find an approximate solution of setting of the values of the correctors and feeds which optimizes at the best the production.

$$\begin{Bmatrix} [\mathbf{c}_{\mathbf{p},\mathbf{1}}] \\ [\mathbf{f}_{\mathbf{j},\mathbf{1}}] \\ [\mathbf{f}_{\mathbf{j},\mathbf{1}}] \end{Bmatrix} = \begin{Bmatrix} [\mathbf{m}_{\mathbf{n},\mathbf{p}}]^{+} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & [\mathbf{K1}_{\mathbf{i},\mathbf{j}}]^{+} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & [\mathbf{K2}_{\mathbf{i},\mathbf{j}}]^{+} \end{Bmatrix} \begin{Bmatrix} [-\mathbf{e}^{\mathbf{0}}_{\mathbf{n},\mathbf{1}}] \\ [-\mathbf{F}_{\mathbf{i},\mathbf{1}}] \\ [-\mathbf{C}_{\mathbf{i},\mathbf{1}}] \end{Bmatrix} \quad (14)$$

With:

$[\mathbf{m}_{n,\,p}]^{+} = \{[\mathbf{m}_{n,\,p}]^{T}.\,[\mathbf{m}_{n,\,p}]\}^{-1}.\,[\mathbf{m}_{n,\,p}]^{T}$

$[\mathbf{K1}_{i,\,j}]^{+} = \{[\mathbf{k1}_{i,\,j}]^{T}.\,[\mathbf{K1}_{i,\,j}]\}^{-1}.\,[\mathbf{K1}_{i,\,j}]^{T}$

$[\mathbf{K2}_{i,\,j}]^{+} = \{[\mathbf{k2}_{ni,\,j}]^{T}.\,[\mathbf{K2}_{i,\,j}]\}^{-1}.\,[\mathbf{K2}_{i,\,j}]^{T}$

Knowing the deviations measured on the points, the measured cutting forces and the torques reported in Table 4, we obtain the values of the adjustment parameters given in Table 5.

Table 5:-Values of the adjustment parameters to be made

Tool offsets			Feed per revolution				
Tx	Ty	Tz	f1	f2	f3	f4	f5
- 0.188	**-0.193**	**-0.191**	**0.037**	**0.048**	**0.059**	**0.075**	**0.092**

The corrections obtained make it possible to estimate the new deviation values on the next workpiece which is calculated by equation 8 and the next values of cutting forces and torques given in Table 6.

Figure 7 shows the deviations before and after adjustment of the geometry. It is also noted in this figure that the geometric deviations after adjustment have been greatly reduced and therefore we have a better quality of the part.

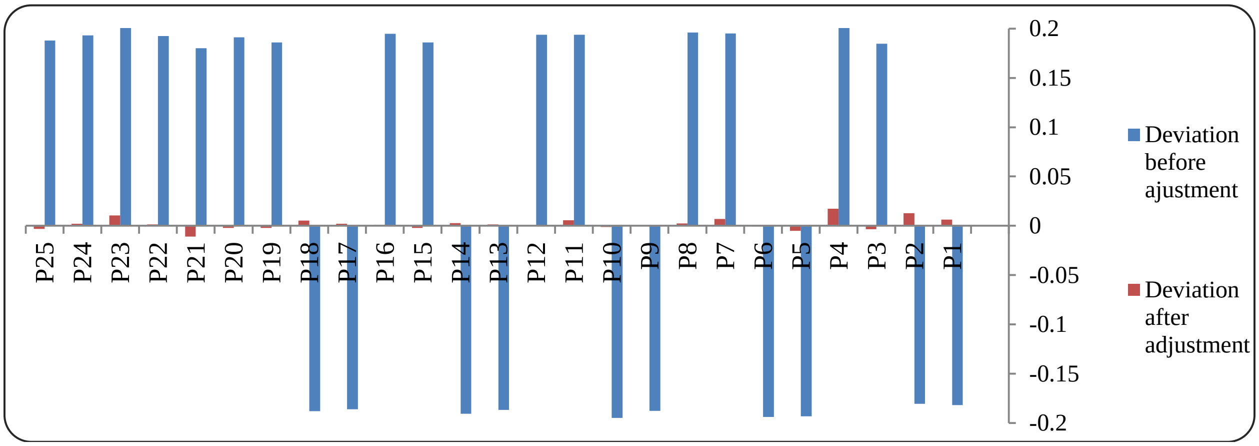


Fig 7:-Representation of the measured deviations before and after adjusting the machine

Table 6 gives the values of cutting forces and torques before and after adjustment according to the feed rate.

Table 6:-Cutting forces and torques before and after adjustment of the feed rate

Before adjustment			**After adjustment**		
f (mm/rev)	**Cutting force (N)**	**Torque (N.mm)**	**f (mm/rev)**	**Cutting force (N)**	**Torque (N.mm)**
0,080	1470	1500	0.037	699,123	299,494
0,100	1580	1940	0.048	737,881	279,913
0,125	1765	2240	0.059	851,810	305,575
0,160	1985	2520	0.075	1006,108	343,892
0,200	2060	2780	**0.092**	**1037,688**	**340,012**

It can be seen here that the cutting force and the torque increase according to the feed rate. The question is to determine among the configurations of feed rate obtained for the adjustment, which is the best solution of adjustment of the feed rate to use for the machining of the part?

The authors Chibane *et al.* 2011 and Dib *et al.* 2015 seeking to optimize the cutting parameters have shown that the most influential parameter on the surface quality of the workpiece is the feed rate, followed by tool nose radius presented by Dib *et al.* 2015, or depth of pass and output of the tool presented by Chibane *et al.* 2011. They show that when the feed rate is high, the surface quality is better. Too much feed rate increases the force and may damage the cutting tool. Too little feed rate tends to degrade the surface quality of the part. On the one hand, on their work, and on the other hand, on the result obtained given in Table 6, we retain the value of **0.092 mm/rev** calculated by the incidence matrix for the machining of this part. Because, it seems to be a compromise between the experienced feeds of **0.08 mm/rev** and **0.100 mm/rev**.

Possibility Of Monitoring The Cutting Force By The Shewhart Control Chart

Knowing the values of the fixed feeds, the cutting force and the torque, it is interesting to monitor the cutting force to avoid a sudden increase in its value which would be due for example to the tool wear which disturbs the process. To this end, a “Shewhart control chart” presented by Shewhart, 1931 is designed to judge the importance of variability. It is considered that the process is under control if it is subjected only to random variations (sum of small variations which with the central limit theorem lead to adistribution law of Gauss).In this case it is not necessary to intervene on the process. The zone of random variation is determined by the "control limits". These control limits are traditionally set within ±3σ of the target value, so we takes a risk α = 2 x 0.135% = 0.27% of disrupting a well-centered process. The control limits are calculated for n = 1, by equation 15:

$$\begin{cases} LCI_F = cible - u_\alpha \sigma \\ LCS_F = cible + u_\alpha \sigma \end{cases} \quad (15)$$

With $u_\alpha = 3$, standard Gauss variable for the risk α = 0, 27%

LCI_F: Lower control limit of cutting force,

LCS_F: upper control limit of cutting force.

The Shewhart control chart amounts to considering that the cutting force is negligible within the control limits. The standard deviation is to be estimated by measuring the cutting force on some machined parts. If we consider that the standard deviation is equal to **10 Newton** for example, the limits of control of the cutting force for the feed rate chooses of **0.092 mm/rev** are calculated:

$$\begin{cases} LCI_F = 1037.688 - 3 * 10 = 737.688 \text{ Newton} \\ LCS_F = 1037.688 + 3 * 10 = 1337.688 \text{ Newton} \end{cases}$$

Between 737,688 Newton and 1337,688 Newton, there is no risk of decentering the process due to special causes, for example the wear of the cutting tool. Beyond these limits, the process would be out of order and must be corrected.

Conclusion:-

In this paper, we have proposed an original approach to more global setting machine to optimize all parameters throughout the manufacturing process. The approach was presented based on a part made by milling. However in this article, we open two research perspectives to improve this work:

1. The first on the control of the cutting force by the control charts, because here we arbitrarily chose the standard deviation on the effort, it would be interesting to calculate a true standard deviation from the measurements of the cutting force.
2. The second perspective would be to also consider in the study the quality parameters of the piece such as roughness ... to obtain a much global incidence matrix.

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