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# Double Optimization of Machine-Tool Setting in the Case of Total Inertial Steering (TIS)

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**ABSTRACT:** The traditional machine-tools setting's consists to rend each characteristic independent, it is for example the case of the transfer of dimension starting to the reference surface which allows taking one adjustment parameter (corrector) by one dimension. The setting in this case is trivial, because there is no dependence between characteristics. The modern machines allow henceforth the simultaneous realization of several operations in one manufacturing phase that put in question the traditional setting. In this context, the relations between manufactured characteristics on the part (or probed points on surfaces) and the correctors are complex, because it exist dependence of setting between surfaces. The Total Inertial Steering (TIS) approach that we present in this article allows to establish a direct relationship between the tool offsets available on the machine and the points of the surfaces through an incidence matrix In most cases, this matrix is not square and therefore not invertible, because there are more probed points as correctors to adjust. The Gauss pseudo-inverse allows to find solution that minimize deviations on the next parts. The problem come up when the same cutting tool machine two surfaces with different point values, the resulting solution favors the one with the highest number of points, at the expense of the other surface which can remain not conform. To remedy this problem, we propose in this article an original method to rebalance setting on surfaces, and this regardless of the number of points.

**KEYWORDS:** Balancing surfaces, Corrector, Adjustment, Machining, Total Inertial Steering.

## 1 INTRODUCTION

The machine setting is to position each cutting tool in the machine to realize conform part. The first study on the problem is the one of Grubbs [1] which proposes a rule of setting machines allow to minimize global variability (of the measurement and of the production). He proposes a successive serial of adjustment (1, ½, 1/3 …), to allow adjusting from the distance the first part, then from half of distance the second part … then from 1/n the last part. He extends the approach to adjust group of samples. In this case, we adjust from average the first group, then from half of average the second group… then from 1/k the last group. Del Castillo et al. [2] and Rong [3] proposed an extension of Grubbs rule's for the case of multivariate process. They propose a strategy allow to taking into account correlation between characteristics to calculate the actions to do on adjustment parameters. Melloy et al. [4] too based on Grubbs rule's to determine an optimal correction which minimize the mean square deviation between the measured value and the target value. He complete the rule to taking into account the square lost of part to calculate the optimal setting that guarantee the quality of the final product. Others works based on Grubbs rule are proposed by Trietsch [5] and Lian et al. [6].

Lill et al. [7], proposed a rule of setting for the first manufactured part. But his rule becomes too fixed to be adapting to serial steering.

Because of initial setting very approximate, Kibe et al. [8] developed an adjustment method allowed adjusting the initial position of cutting tools with assistance system of in-situ measure. They put up for place a system of measure allows to determine position of cutting tool relative to the free surface of the part.

Bourdet [9] presented an approach of setting which allows searching for simulation the adjustment parameter allow to put dimension in his tolerance. The approach is situated in a univariate context and supposes that one adjustment parameter impact only but also one manufactured characteristic.

The Total Inertial Steering (TIS) approach that we present in this article is a setting approach which consists to balance in space the whole of cutting tool trajectories to bring closer the machined surfaces to their targets. The approach have done object of many publications presented particularly by Pillet et al. [10] and Boukar et al. [11]. The approach allows establishing the dependence between points of surfaces and tool offsets through an incidence matrix. Given this matrix is not square and then not invertible, The Gauss pseudo-inverse is used to calculate the values of corrections to be made to compensate for measured deviations.

When the same cutting tool machine two surfaces with different number of probed points, two problems come up:

- The first problem comes up when the both surfaces have different values of tolerance; in this case the adjustment favors the one with largest tolerance at the expense of the other surface can remain not conform towards its tolerance. Pillet *et al*. [11] proposed a solution which allows standardizing surfaces by concerned tolerances to rebalance correction on these surfaces in order to have conformed parts.
- The second problem come up when the both machined surfaces have different number of probed points. For the same style, the computing of correction brings by pseudo-inverse favors the surface with highest number of points. We proposed in Boukar *et al.* [12] a first solution which allows rebalancing surfaces by the Least Common Multiple (LCM) of the numbers of points of surfaces. This balancing of the numbers of points can give exactly the same weight to each surface. But this approach increase considerably the number of points when the LCM is big. The solution has consequence the important increasing of computing times. We recently proposed in Boukar *et al.* [13] a second which allow passing by a geometric parametering of surfaces to find adjustment relation to bring closer surfaces to their targets. The problem in this case is that each case is a particular case and then the solution is with difficultly automation. In this article, we propose a third solution which allows rebalancing correction on surfaces without passing by the LCM or by the geometric parametering of surfaces. This solution is passing by a “double optimization” of correction and the computing is immediate. The objective is to improve the quality of the surface with the smaller number of probed points without too deteriorate the one with the highest number of probed points.

## 2 TOTAL INERTIAL STEERING (TIS)

### 2.1 PRINCIPLE OF TIS

The principle of TIS is to establish and use direct link between tool offsets and the position of surfaces defined in reference frame of the machine. The machined surfaces on a first part will be probably moved away to their initial position because of the initial adjustment of cutting tools. In TIS approach, this remoteness is materialized by the deviations of measured points on the machined surfaces relative to their target position measured about the local normal to the surface.

Consider $[e^0_{n,1}]$ matrix column of initial deviations measured on the points and $[e^1_{n,1}]$ matrix column of next deviations on these points. The aim of setting is to find the shift to do on the points to minimize the next deviations. This is result in relation of equation *(1)*:

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

With

$[e^1_{n,1}]$ = matrix of final deviations estimated after correction;

$[e^0_{n,1}]$ =matrix of initial deviations compared to target points

$[d_{n,1}]$ = matrix column of shifts on the n points.

The shifts on points can be calculated using the method of small displacements proposed by Bourdet *and* Clément [14] which is calculated the translation of true point according to the displacement {D(O), ?} of the trajectory of cutting tool relative to the part (Eq. 2):

$$d_i = D(P_i') \cdot \vec{n}_i \tag{2}$$

This is express by:

$$\overrightarrow{D(P_i)} \cdot \vec{n}_i = \left(\overrightarrow{D(O)} + \vec{\Omega} \Lambda \overrightarrow{OP_i}\right) \cdot \vec{n}_i$$

With

$$\overrightarrow{D(O)} = \begin{pmatrix} Tx \\ Ty \\ Tz \end{pmatrix}; \quad \vec{\Omega} = \begin{pmatrix} Rx \\ Ry \\ Rz \end{pmatrix}; \quad \vec{n}_i = \begin{pmatrix} ai \\ bi \\ ci \end{pmatrix}$$

Where, O is the origin of reference frame of the trajectories cutting-tools, and rotations *Rx, Ry and Rz* about *X, Y and Z* axes. Development of equation (2) gives equation (3):

$$d_i = a_iT_x + b_iT_y + c_iT_z + L_iR_x + M_iR_y + N_iR_z \quad (3)$$

With

ai, bi, ci = direction cosines of the local normal ni to the target surface;

Li, Mi, Ni = component of the vector;

Ni = Z-component of the vector $\overrightarrow{OPi} \wedge \overrightarrow{ni}$ ;

L = tool length offset;

R = tool radius offset;

Tx, Ty and Tz = X, Y and Z offset;

Rx, Ry and Rz = X, Y and Z rotation;

In addition to parameters of displacement *Tx, Ty, Tz, Rx, Ry* and *Tz*, it is possible to add parameters of form intrinsic to the surface or to the tool, like for example a variation of radius of tool. Equation (3) becomes then (4):

$$d_i = a_iT_x + b_iT_y + c_iT_z + L_iR_x + M_iR_y + N_iR_z + \varphi_iR \quad (4)$$

With $\varphi i = \sqrt{\text{ai} \quad + \text{bi} \quad} = 1$ (= influence of tool radius offset R)

If there are n points on the machined surfaces, a system of n equations is obtained and which can be written in the following matrix form (5):

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

With

$[m_{n,p}]$ = incidence matrix (n lines, p columns);

$[c_{p,1}]$ = matrix (p lines, 1 column) of corrections on the p tool-offsets;

n = number of probed points on the surface.

The setting is to do a shift opposite to the initial deviation to refocus each measured point on his target. This is to give for the set of points the following matrix system (6):

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

This system has no exact solution when the number of points n is higher than the number of correctors p. The Multiple Linear Regression can then obtain the value of $[c_{p,1}]$ that minimizes the sum of squared deviations. It consists, in his simplest presentation, to multiply the matrix of initial deviations $[e^0_{n,1}]$ by the pseudo-inverse matrix $[m_{n,p}]^+$ of the incidence matrix using the following equation (7):

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

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

The corrections calculated by this equation allow compensating for the measured deviations on the points.

## 2.2 EXAMPLE

To illustrate the problem, we base on example of 3D part. Figure 1 gives a geometrical specification of the finished part. The notch (in green) has a tolerance lower than the elliptical pocket (in yellow). We will measure different point value on these surfaces to illustrate our words.

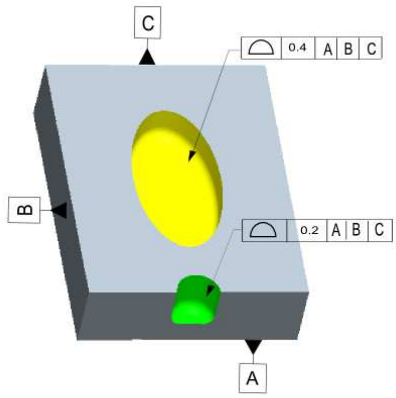


*Fig. 1. Specification of the finished part*

A block of rectangular material with dimensions 25 mm x 20 mm is machined on a CNC milling machine. It is fixed to the milling machine table. Three stops are used to position the block on the table of the milling machine. A clamping system ensures its fixation (see figure 2). An elliptical pocket is realized in the block by contour milling and a notch by diving of the same tool (toric milling cutter).

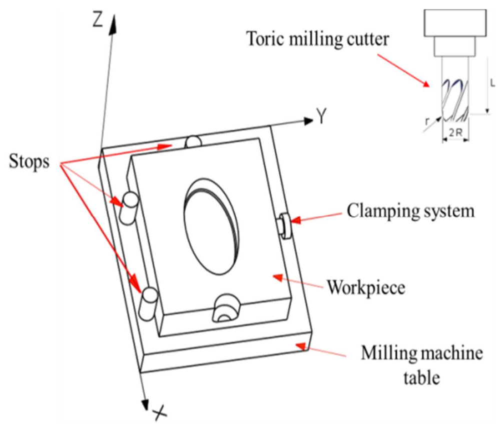


*Fig. 2. Defining of action axis of the tool – machining assembly*

To adjust the cutting tool, we arbitrarily measured the points on the workpiece. The deviation between the target surfaces and machined surfaces is measured on several points by distances along the normal to the surfaces at these points.

Eight points are measured on the side of elliptical pocket S1 and three points on the notch S2 to adjust the tool. The points (P1, P2 ... P8) of S1 are precisely measured for each 45° angle relative to the axes of the ellipse in the center of the ellipse. The points on the notch are measured on its cylindrical portion to allow repositioning the notch relative to the ellipse. Surfaces of the fillets radiuses generated by the end milling radius and surfaces of the bottom of the notch and ellipse are not probed to simplify the presentation. If the fillets radiuses are not the good shape, the tool will regrind or replace. But in the case of this paper, the fillets radiuses are not corrected.

Table 1 gives the coordinates of points and the local normals expressed in the part reference frame which correspond with datum system and the deviations of these points along the normal to the surfaces (column $e^0_i$).

*Table 1. Points expressed in the part reference frame*

| Surface | Tolerance | Point | X | Y | Z | ai | bi | ci | $e^0_i$ |
|---|---|---|---|---|---|---|---|---|---|
| S1 | 0.4 | P1 | 20 | 10 | 5 | -1 | 0 | 0 | -0.1 |
| | | P2 | 12.5 | 14 | 5 | 0 | -1 | 0 | 0.1 |
| | | P3 | 5 | 10 | 5 | 1 | 0 | 0 | 0.3 |
| | | P4 | 12.5 | 6 | 5 | 0 | 1 | 0 | 0.1 |
| | | P5 | 17.8 | 12.83 | 5 | -0.5 | -0.866 | 0 | 0 |
| | | P6 | 7.2 | 12.83 | 5 | 0.5 | -0.866 | 0 | 0.2 |
| | | P7 | 7.2 | 7.17 | 5 | -0.5 | 0.866 | 0 | 0 |
| | | P8 | 17.8 | 7.17 | 5 | 0.5 | 0.866 | 0 | 0.2 |
| S2 | 0.2 | P12 | 24 | 12 | 4 | -0.5 | -0.866 | 0 | -0.1 |
| | | P13 | 24 | 8 | 4 | -0.5 | 0.866 | 0 | 0.12 |
| | | P14 | 22.5 | 10 | 4 | 1 | 0 | 0 | 0.37 |

## 3 OPTIMIZATION BY THE GAUSS PSEUDO-INVERSE

Surfaces S1 and S2 are generated by the same cutting tool. This tool can be adjusted by acting on the tool radius offset (R). Its tool length offset (L) along the Z axis is not correct to simplify the problem. Further, the displacement variables Tx (translation about the X axis), Ty (translation about the Y axis), and Rz (rotation about the Z axis) are introduced in the program to enable repositioning the program reference frame on workpiece reference frame to refocus the machined shapes on their targets. Correctors Tx, Ty and Rz have the effect of moving the machined surfaces while R has the effect of changing their "sizes". Tz, Rx and Ry offset are not correct in this example.

The incidence matrix is obtained by reduction of equation (4) is given in table 2. Starting on this matrix, we can determine corrections on correctors *R,* Tx*, Ty and Rz*, by calculated the pseudo-inverse of this matrix through equation *(7).* The new matrix obtained is given in table 3. It is called “global steering matrix”.

*Table 2. Global incidence matrix*

| Surface | Point | R | Tx | Ty | Rz |
|---|---|---|---|---|---|
| S1 | P1 | 1 | -1 | 0 | 10 |
| | P2 | 1 | 0 | -1 | -12.50 |
| | P3 | 1 | 1 | 0 | -10 |
| | P4 | 1 | 0 | 1 | 12.50 |
| | P5 | 1 | -0.5 | -0.866 | -9 |
| | P6 | 1 | 0.5 | -0.866 | -12.65 |
| | P7 | 1 | -0.5 | 0.866 | 9.82 |
| | P8 | 1 | 0.5 | 0.866 | 11.83 |
| S2 | P9 | 1 | -0.5 | -0.866 | -14.78 |
| | P10 | 1 | -0.5 | 0.866 | 24.78 |
| | P11 | 1 | 1 | 0 | -10 |

*Table 3. Global steering matrix*

| | P1=-0.1 | P2 = 0.1 | P3 = 0.3 | P4 = 0.1 | P5 = 0 | P6 = 0.2 | P7 = 0 | P8 = 0.2 | P9 = -0.10 | P10 =0.12 | P11 = 0.37 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **R** | 0.091 | 0.091 | 0.091 | 0.091 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| **Tx** | -0.140 | 0.096 | 0.140 | -0.096 | -0.11 | 0.28 | -0.40 | 0.23 | -0.35 | 0.21 | 0.14 |
| **Ty** | -0.154 | -0.334 | 0.154 | 0.334 | -0.13 | -0.45 | 0.67 | -0.09 | 0.31 | -0.46 | 0.15 |
| **Rz** | 0.010 | 0.012 | -0.010 | -0.012 | 0.00 | 0.02 | -0.04 | 0.01 | -0.03 | 0.04 | -0.01 |

Knowing the deviations $e_{0i}$ on the points P1... P12, we calculate corrections R, Tx, Ty et Rz which allow to compensate for the next deviations of two surfaces S1 and S2. Table 4 gives the corrections values.

*Table 4. Correction value obtained by the Gauss Pseudo-inverse*

| Corrector | R | Tx | Ty | Rz |
|---|---|---|---|---|
| **Value** | -0.108 | -0.269 | 0.074 | -0.007 |

## 4 Method of Double Optimization

This method is to do two optimizations to avoid the problem of number of points: a first optimization is to calculate independently setting on each surface. Then a second optimization allows to do synthesis of two previous settings and to pass by a "**interdependence matrix**" between settings to calculate corrections to do on the tool.

### 4.1 First Optimization

For this optimization, we extract two incidence matrixes (one by surface) to the global incidence matrix. We then obtained two reduces matrixes gives in table 5 and table 6, and their pseudo-inverse respectively in table 7 and table 8.

*Table 5. Incidence Matrix reduce to surface 1*

| Surface | Point | R1 | Tx1 | Ty1 | Rz1 |
|---|---|---|---|---|---|
| **S1** | **P1** | 1 | -1 | 0 | 10 |
| | **P2** | 1 | 0 | -1 | -12.50 |
| | **P3** | 1 | 1 | 0 | -10 |
| | **P4** | 1 | 0 | 1 | 12.50 |
| | **P5** | 1 | -0.5 | -0.866 | -9 |
| | **P6** | 1 | 0.5 | -0.866 | -12.65 |
| | **P7** | 1 | -0.5 | 0.866 | 9.82 |
| | **P8** | 1 | 0.5 | 0.866 | 11.83 |

*Table 6. Incidence Matrix reduce to surface 2*

| Surface | Point | R2 | Tx2 | Ty2 | Rz2 |
|---|---|---|---|---|---|
| S2 | P9 | 1 | -0.5 | -0.866 | -14.78 |
| | P10 | 1 | -0.5 | 0.866 | 24.78 |
| | P11 | 1 | 1 | 0 | -10 |

*Table 7. Steering Matrix of surface 1*

| | P1= -0.1 | P2=0.1 | P3=0.3 | P4=0.1 | P5=0 | P6=0.2 | P7=0 | P8= 0.2 |
|---|---|---|---|---|---|---|---|---|
| Tx1 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 |
| Ty1 | 0.00 | 0.00 | 0.00 | 0.00 | -0.34 | 0.34 | -0.65 | 0.65 |
| R1 | -0.60 | -0.20 | 0.60 | 0.20 | 0.15 | -0.49 | 1.04 | -0.70 |
| Rz1 | 0.05 | 0.00 | -0.05 | 0.00 | -0.03 | 0.03 | -0.07 | 0.07 |

*Table 8. Steering Matrix of surface 2*

| | P9 = -0.10 | P10 = 0.12 | P11 = 0.37 |
|---|---|---|---|
| Tx2 | 0.200 | -0.100 | -0.200 |
| Ty2 | 0.400 | -0.200 | -0.400 |
| R2 | 0.250 | 0.250 | 0.250 |
| Rz2 | 0.002 | 0.005 | -0.002 |

Using the steering matrixes of tables 7 and 8 and knowing the deviations given in these tables, we calculate the value of corrections R1, Tx1, Ty1, Rz1 and R2, Tx2, Ty2, Rz2. The corrections values are given in the table 9.

*Table 9. Correction value of each surface with Rz rotation*

| Corrector | R1 | Tx1 | Ty1 | Rz1 | R2 | Tx2 | Ty2 | Rz2 |
|---|---|---|---|---|---|---|---|---|
| Value | -0.1 | -0.2 | 0 | 0 | -0.130 | -0.247 | -0.108 | -0.001 |

These corrections don't taking into account interdependence of correctors between the both surfaces. You have to take into account these dependences through an interdependence matrix to calculate the global setting to do on surfaces. This is explaining in below section (second optimization).

### 4.2 SECOND OPTIMIZATION

In the first optimization, we have calculated for each the value of corrections R1, Tx1, Ty1, Rz1 for the surface 1, and R2, Tx2, Ty2, Rz2 for the surface 2. In this section, we do the second optimization that consists to pass by an interdependence matrix that you have to determine to calculate the global setting to do. This matrix is established by calculating influence of one corrector on others.

The procedure is illustrated to calculate interdependence of Rz on Tx1 for the surface 1:

a. We calculate effect of unitary correction of Rz on each point of surface 1. It is simply the column of Rz of the incidence matrix of surface 1.

b. We take Tx1 = 1 and all others correctors R, Ty1, Rz1 = 0, to have influence of Rz only on Tx1 (see Table 10).

c. Then we calculate the Gauss pseudo-inverse (steering matrix reduce to Tx1) which gives the influence of Rz on Tx1 (see Table 11). Coefficients of column of Rz of the incidence matrix will serve like deviations on each point to calculate the value of Tx1, and, as well as the influence of Rz on R1, Ty1 and Rz1.

***Table 10. Matrix of influence of Rz on Tx1***

| | | | | | | Tx1 | | | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R1 | Tx1 | Ty1 | Rz1 | | Erase the table | R1 | Tx1 | Ty1 | Rz1 | R | Tx | Ty | Rz |
| □ | □ | □ | □ | | P1 | □ | □ | □ | □ | 1 | -1 | 0 | 10 |
| □ | □ | □ | □ | | P2 | □ | □ | □ | □ | 1 | 0 | -1 | -12.5 |
| □ | □ | □ | □ | | P3 | □ | □ | □ | □ | 1 | 1 | 0 | -10 |
| □ | □ | □ | □ | | P4 | □ | □ | □ | □ | 1 | 0 | 1 | 12.5 |
| □ | □ | □ | □ | | P5 | □ | □ | □ | □ | 1 | -0.5 | -0.866 | -9 |
| □ | □ | □ | □ | | P6 | □ | □ | □ | □ | 1 | 0.5 | -0.866 | -12.65 |
| □ | □ | □ | □ | | P7 | □ | □ | □ | □ | 1 | -0.5 | 0.866 | 9.82 |
| □ | □ | □ | □ | | P8 | □ | □ | □ | □ | 1 | 0.5 | 0.866 | 11.83 |

***Table 11. Influence Matrix of Rz on Tx1***

| | **P1 = 10** | **P2 = - 12.5** | **P3 = -10** | **P4 = 12.5** | **P5 = - 9** | **P6 = - 12.5** | **P7 = -9.82** | **P8 = 11.83** |
|---|---|---|---|---|---|---|---|---|
| **Tx1** | -0.333 | 0.000 | 0.333 | 0.000 | -0.167 | 0.167 | -0.167 | 0.167 |

This procedure is valid to determine influence of each of corrector on others on surface 1. Idem for the surface 2. To proceed to numerical compute of all influences between correctors, we obtain the interdependence matrix given in Table 12.

***Table 12. Interdependence between correctors***

| | **R** | **Tx** | **Ty** | **Rz** |
|---|---|---|---|---|
| **R1 = 0.100** | 1 | 0 | 0 | 0 |
| **Tx1 = 0.200** | 0 | 1 | 0 | -6.940 |
| **Ty1 = 0** | 0 | 0 | 1 | 12.5 |
| **Rz1 = 0** | 0 | -0.021 | 0.0631 | 1 |
| **R2 = 0.130** | 1 | 0 | 0 | 0 |
| **Tx2 = 0.247** | 0 | 1 | 0 | -10 |
| **Ty2 = 0.108** | 0 | 0 | 1 | 22.841 |
| **Rz2 = 0.001** | 0 | -0.0161 | 0.0367 | 1 |

The pseudo-inverse of this matrix allow to calculate corrections on R, Tx, Ty et Rz (see Table 13) which allow to better correct surfaces independently of number of points of surfaces.

***Table 13. Corrections values of double optimization***

| Corrector | R | Tx | Ty | Rz |
|---|---|---|---|---|
| Value | -0.115 | -0.294 | 0.094 | -0.008 |

## 5 DISCUSSION

To compare the both methods, we evaluate quality of setting obtained on each surface. We have to find a quality criterion. In our case, we have chosen inertia defined by *Pillet* [15] and *ISO 14253-1:1998* [16] because inertia is justly a criterion of optimization to minimize by pseudo-inverse. It is calculate for the surface through equation *(8)* :

$$I_i = \sqrt{\frac{\sum_{i=1}^{n}(e_i^2)}{n}} \quad (8)$$

We compare then the G gain on inertia of each surface which is calculated through equation *(9)*:

$$I_i = \frac{I_{i(before)} - I_{i(after)}}{I_{i(before)}} \quad (9)$$

With

Ii (before) = inertia before setting of the i surface;

Ii (after) = inertia after setting of the i surface.

The below Table 14 gives for the both approaches the corrections value R, Tx, Ty and Rz, and the inertia before and after setting and the gains on inertia of each surface.

***Table 14. Comparative study of two methods***

| Method | Corrector | Correction Value | Surface | Inertia before correction | Inertia after correction | G Gain on the inertia |
|---|---|---|---|---|---|---|
| Case #1. Optimization by pseudo-inverse | R | -0.105 | S1 | 0.158 | 0.027 | 83.24% |
| | Tx | -0.269 | | | | |
| | Ty | 0.093 | S2 | 0.231 | 0.046 | 79.99% |
| | Rz | -0.007 | | | | |
| Case #2. Double Optimization | R | -0.110 | S1 | 0.158 | 0.037 | 76.79% |
| | Tx | -0.294 | | | | |
| | Ty | 0.094 | S2 | 0.231 | 0.032 | 86.17% |
| | Rz | -0.008 | | | | |

This table shows the benefit in terms of gain on inertia of surface that we can obtained using one or other method. The double optimization searches a compromise of quality between the both surfaces. We remark in the case #2, when we apply double optimization, it more improve the quality of surface 2 which have a less probed points than surface 1 which have eight points. Given than surface 2 is functional with quality requirement more high (tolerance t=0.2) than surface 1 (t =0.4), it is naturally privileged in order to guarantee its conformity. We pass then to gain on inertia of 79.99% in the case #1 to a gain of 86.17% in the case #2.

The biggest surface (S1) is then put at a disadvantage by the double optimization, but given that it have large tolerance, the setting allow to have residuals deviations included in the tolerances. If necessary we apply standardization (Pillet *et al.* [10], Boukar *et al.* [11]) of surfaces by their tolerances to guarantee the conformity.

The corrections values obtained in Table 14 allow estimating the new value of deviations of the points through equation (10).

$$[e^{1}_{n,1}] = [e^{0}_{n,1}] + [m_{n,p}].[c_{p,1}] \quad (10)$$

Figure 3 and 4 show graphically deviations before setting (in blue) and after setting (in red) respectively obtained by the simple and double optimization.

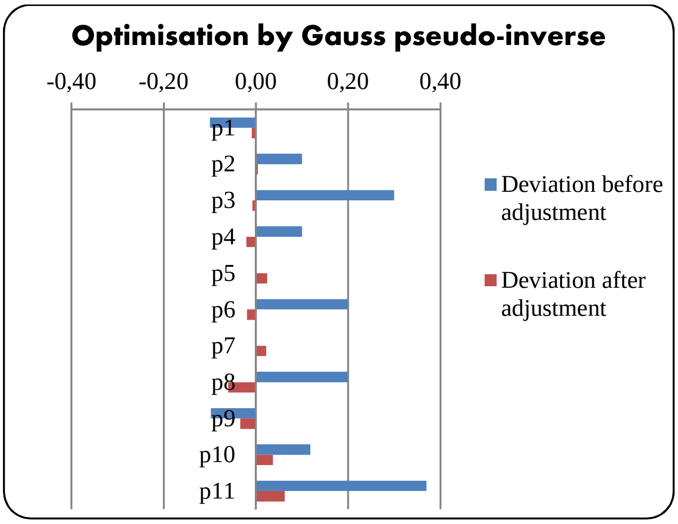


***Fig. 3. Deviations before and after setting for simple optimization***

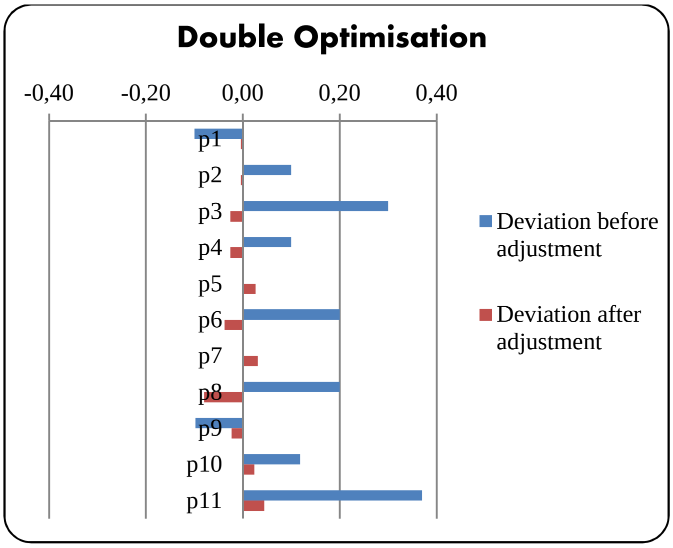


***Fig. 4. Deviations before and after setting for double optimization***

## 6 CONCLUSION

The solution of setting machine by double optimization is to calculate independently the corrections on each surface and to use an interdependence matrix between correctors. This matrix does the synthesis of corrections proposed on each surfaces to find the good compromise of setting on each concerned surface without passing by the average of corrections, neither taking into account the number of points by the LCM. The double optimization allow to get around the problem of increasing dimension of the matrix in order to avoid in some case the important increasing of number of points. The theoretical result of simulation show sure enough when we apply this method, we improve the surface with smaller number of points without too deteriorate the one with the highest number of points. The method present the advantage to be general to all type of surface and to be able to take into account all type of corrector.

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