Coherence of Reconfigurable Manufacturing Systems Thermo-Mechanical Fields

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ABSTRACT

The quality of surfaces generated on RMS as well as dimensional and geometrical precision of manufactured pieces is closely tied to the possibility of controlling, in real time, the manufacturing process. To do such a thing, it is necessary to have precise information concerning the manufacturing system fields. Because we aren't able to measure specific parameters values in every point of these fields, we are looking for the possibility of finding functions of field-variable to realize manufacturing fields' accurate modeling. An important fields' property that could ease their modeling is the coherence. This paper suggests a tool to investigate a certain field coherence, simple but effective, to further enable its appropriate modeling.
Keywords: *RMS fields, coherence, modeling, approximation functions.*

1. Reconfigurable Manufacturing Systems Fields

A certain reconfigurable manufacturing system (RMS) may be defined as an ensemble with hard and soft components, conceived on such a manner as it can be used to transform a worked piece into a finite one. The hard components are connected between them such as to form an open frame having at its extremities the tool and the worked piece (Fig.1).

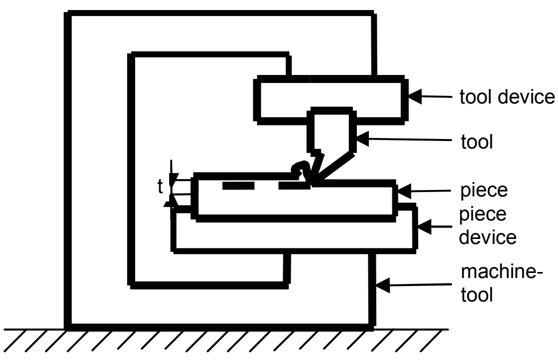


Fig.1 – RMS Hard Components Structure

A mechanical or thermal nature interaction appears between tool and piece, whose effect is the manufacturing process; its consequences are the modifications of worked piece shape, dimensions or properties such as to meet finite product specifications. A RMS conceptual scheme, where major interactions between system components are highlighted is presented in Fig.2.

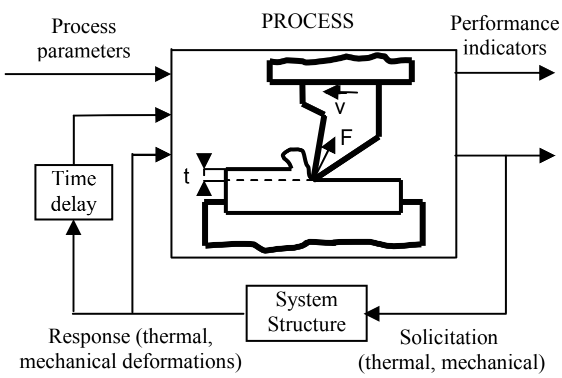


Fig.2 – RMS Conceptual Scheme

At conceptual level, any manufacturing system may be considered as having two components among which specific connections establish; these components are:

- The manufacturing process;
- The system structure.

The manufacturing process has at its input process parameters as cutting speed, v, cutting depth, t and at its output both performance indicators (precision, surface roughness, price, productivity) and structure solicitations (elastic or thermal deformations, wearing etc.). Structure response turns back at process input twice:

- At solicitation moment;
- After a certain time delay from solicitation moment.

The solicitation of manufacturing system structure involves the installation of some specific fields, which will be further named manufacturing system fields. For example, the thermal field, generated because the energy used during the process is transformed in heat and modifies the temperature in different structure points. Another example is structure deformation, meaning that each structure point moves respect to its initial position, generating the displacements field.

The interaction between tool and worked piece is the source (direct or indirect) of three types of fields:

- Mechanical fields: forces field, displacements field, tensions field, mechanical receptances field;
- Geometrical fields: worked piece errors field, system errors field, process errors field, product errors field, manufacturing precision field;
- Thermal fields: system thermal field, thermal deformations field, thermal receptances field.

2. Evaluation of Thermo-Mechanical Fields Coherence

The quality of surfaces generated on RMS as well as dimensional and geometrical precision of manufactured pieces is closely tied to the possibility of controlling, in real time, the manufacturing process. To do such a thing, it is necessary to have precise information concerning the manufacturing system fields.

Because we aren't able to measure specific parameters values in every point of these fields, we are looking for the possibility of finding functions of field-variable to realize manufacturing fields' accurate modeling. An important fields' property that could ease their modeling is the coherence.

By field coherence we mean that if to a field, having a certain map, we apply a perturbation, the general aspect of the map doesn't change. More specific, the thermo-mechanical field characterizing a RMS, at a certain moment, is considered coherent if being influenced by an additional quantity of heat coming from the cutting process, the hottest points from the field remain the hottest and the coldest remain the coldest (of course at another level and perhaps, at another ratio between them).

To evaluate RMS thermo-mechanical field coherence, the following methodology was imagined:

a. The values of a manufacturing process characteristic parameter, also in connection with RMS thermo-mechanical field, are measured in a number of points.

b. A set of interpolation functions to approximate the variation, in the field, of chosen characteristic parameter is determined, based on values measured before.

c. An additional solicitation, following a known law (linear or harmonic), is applied to RMS.

d. A new set of interpolation functions is determined, under the new conditions.

e. A thoroughly comparison between the two sets of interpolation functions is made, in order to reveal if their modification is relative similar to solicitation modification; if the answer is affirmative, we could conclude that the analyzed field is coherent.

3. Example of Application

To validate the upper-suggested algorithm, a simple application was considered. A file containing manufacturing errors, due to the effect of the manufacturing process thermo-mechanical field, measured along a certain direction, in 200 points is analyzed. Its graphical representation is shown in Fig. 3.

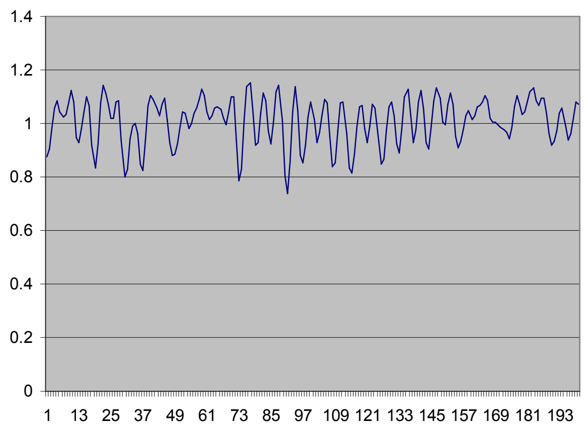
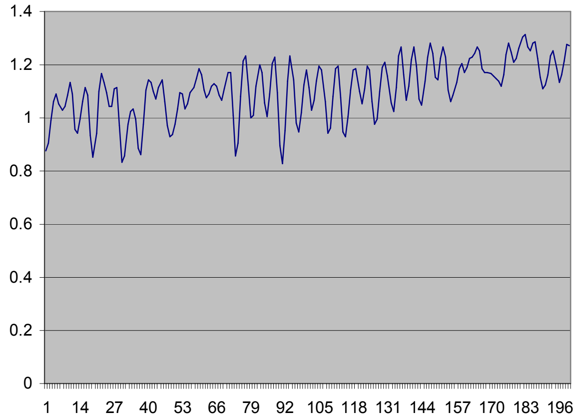


Fig.3 – Manufacturing Errors Evolution along the Chosen Direction

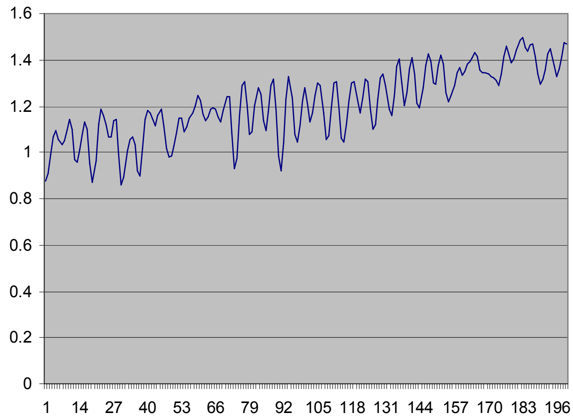
Then we simulate the addition to the manufacturing process normal thermo-mechanical field of a supplementary field, with known variation,

Linear, $y = i \cdot m + n$, or (1)

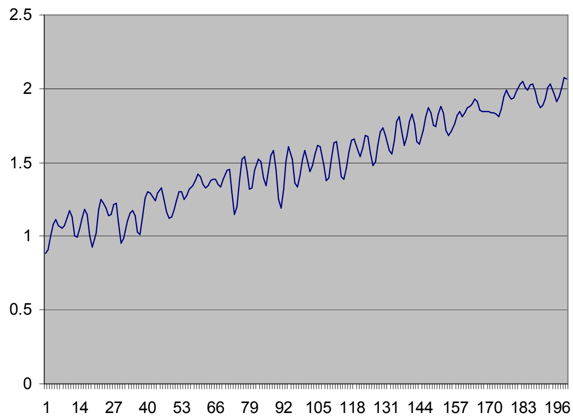
Sinusoidal, $y = a \sin \frac{i \cdot \pi}{200}$, (2) where i means current point order number, i = 1 … 200, m, n and a being constants concerning straight line (1) direction respective sinusoidal curve (2) amplitude. Graphical representations of manufacturing errors in these cases are shown in Fig. 4 (linear supplementary field) and 5 (sinusoidal supplementary field.



a) $m = 0.1$, $n = 0$



b) $m = 0.2$, $n = 0$

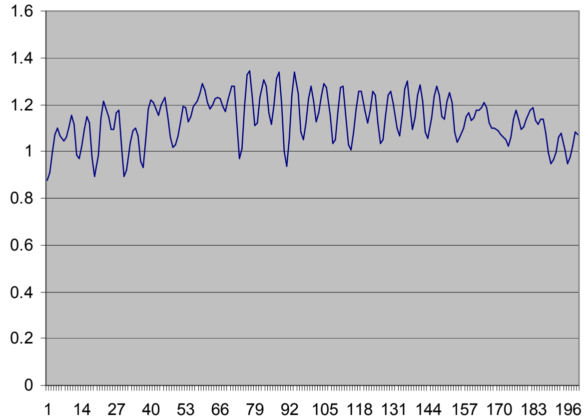


c) $m = 0.5$, $n = 0$

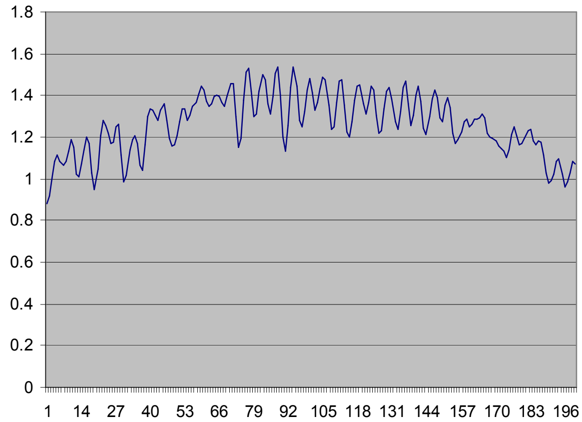
Fig.4 – Addition of Linear Supplementary Field

In each of presented cases, the evolution of manufacturing errors field was modeled by approximating through a system of 3rd degree functions.

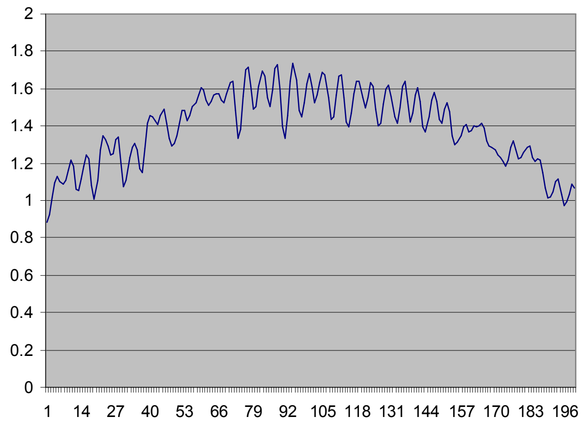
First of all, the evolution curve was divided into a number of segments, each one including 7 … 12 points, on such a manner as each segment should be as similar as possible to the general image of a 3rd degree function graphic; 22 segments were obtained. This division was kept the same in each different curve case.



a) $a = 0.2$



b) $a = 0.4$



c) $a = 0.6$

Fig.5 – Addition of Sinusoidal Supplementary Field

Then, each segment was replaced by a 3rd degree function,

$$f = a_3x^3 + a_2x^2 + a_1x + a_0, \quad (3)$$

chosen by imposing it to pass through two of curve segment points and to have minimum medium squared deviation respect to the rest of segment points.

In Fig. 6 is shown an example of such approximation functions, determined in the case of two consecutive curve segments.

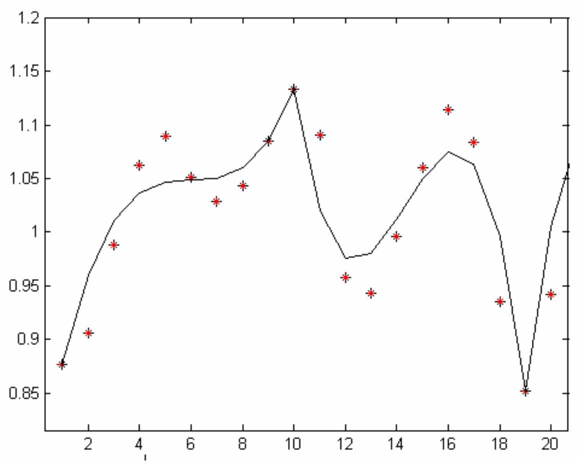


Fig.5 – Manufacturing Errors Curve Substitution by using 3rd Degree Polynomial Functions

In Tab.1 is presented *a0* coefficients evolution, in the case of curves shown in Fig. 3, and in Tab.2, same coefficients evolution, in the case of curves from Fig.4.

By thoroughly examining the results from Tab.1, it is obvious that between linear additional field inclination and a_0 values there is a close connection: when angular coefficient m increases, a_0 also increases; more than that, if m growing increment is higher, a_0 growing increment is also higher.

The values presented in Tab.2 are leading to similar conclusions, but now we are looking for a similarity between sinusoidal additional field amplitude, a, and a_0 coefficient magnitude. The similarity exists and goes further than a simple correspondence between increasing or decreasing tendencies. At the curve extremities segments, the effect of the additional field is smaller than in the case of the middle segments; a_0 coefficients are also less changing if passing from a case to another at the extremities and more changing at the middle of the substituted curve.

We can now affirm, having in view the criterion upper suggested to evaluate thermo-mechanical fields coherence, that the manufacturing errors field considered in this example is coherent.

By considering the results of the upper presented example and also the results from other fields analyzed, we can draw the following conclusions:

Table 1

Segment Crt. No.	a_0		
	m=0.1	m=0.2	m=0.5
1	0.753259	0.753259	0.753259
2	1.336760	1.345760	1.372760
3	0.616744	0.634744	0.688744
4	1.375328	1.402328	1.483328
5	0.621303	0.657303	0.765303
6	1.344929	1.388929	1.520929
7	0.960907	1.013907	1.172907
8	1.256487	1.320487	1.512487
9	0.572965	0.644965	0.860965
10	1.373916	1.454916	1.697916
11	0.491832	0.581832	0.851832
12	1.384882	1.483882	1.780882
13	0.787696	0.894696	1.215696
14	1.391646	1.509646	1.863646
15	0.805707	0.930707	1.305707
16	1.473929	1.608929	2.013929
17	0.823241	0.966241	1.395241
18	1.440999	1.591999	2.044999
19	1.115919	1.274919	1.751919
20	1.381350	1.557350	2.085350
21	1.212697	1.396697	1.948697
22	1.442270	1.635270	2.214270

Table 2

Segment Crt. No.	a_0		
	a=0.2	a=0.4	a=0.6
1	0.753168	0.753294	0.753170
2	1.355945	1.384136	1.412362
3	0.654509	0.710312	0.766076
4	1.430704	1.512885	1.595261
5	0.692435	0.799641	0.906715
6	1.428421	1.555984	1.683465
7	1.055813	1.203639	1.351735
8	1.361311	1.530263	1.699122
9	0.681915	0.862939	1.043756
10	1.484145	1.675225	1.866481
11	0.599375	0.796918	0.994389
12	1.485848	1.685814	1.885828
13	0.879454	1.078198	1.277103
14	1.465817	1.657766	1.849858
15	0.865528	1.050284	1.235127
16	1.509520	1.679961	1.850552
17	0.836333	0.992400	1.148484
18	1.429126	1.568356	1.707450
19	1.077058	1.197073	1.317208
20	1.278993	1.352590	1.426232
21	1.078444	1.128198	1.177933
22	1.271102	1.293096	1.315101

4. Conclusions

First of all we must highlight that an instrument, simple but effective, to evaluate fields (generally speaking) and especially RMS thermo-mechanical fields coherence. This instrument was imagined in order to facilitate the modeling of manufacturing systems fields dynamics. By measuring a field specific parameter values in a certain number of points (not very large), with a certain time step, we could have a consistent and precise enough information about field dynamics. Thus, it will become possible to control, in real time, the manufacturing process, with direct application in manufacturing process stability control. The ultimate aim is a complete exploitation of Reconfigurable Manufacturing Systems resources of productivity, by working with cutting regimes more intense, to the limit of stability domain.

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Coerența câmpurilor termo-mecanice ale sistemelor de fabricație reconfigurabile

Rezumat

Atât calitatea suprafețelor generate cu ajutorul sistemelor de fabricație reconfigurabile, cât şi precizia geometrică şi dimensională a pieselor prelucrate sunt strâns legate de posibilitatea de a controla, în timp real, procesul de prelucrare. Pentru a îndeplini un astfel de obiectiv, sunt necesare informații precise referitoare la câmpurile sistemului de prelucrare. Deoarece nu este posibilă măsurarea valorilor parametrilor specifici în toate punctele acestor câmpuri, ar fi utilă evidențierea unor funcții de variabilă – câmp, care să permită modelarea precisă a câmpurilor sistemului de prelucrare. O proprietate importantă a câmpurilor, care facilitează modelarea acestora, este coerența. Lucrarea de față sugerează un instrument simplu şi eficient, posibil de utilizat pentru evaluarea coerenței unui câmp, în vederea unei modelări ulterioare corecte.

Coerence des champs termo-mécaniques des systèmes de fabrication réconfigurables

Résumé

La qualité des surfaces générées a l'aide des systèmes de fabrication reconfigurables, en même temps avec la précision géométrique et dimensionale des pièces obtenues sont directement liées de la possibilité de contrôler, en temps réel, le processus d'usinage. Pour accomplir tel un objectif, ils sont nécessaires des informations précises concernant les champs du système d'usinage. Parce' qu'il n'est pas possible de mesurer les valeurs des paramètres spécifiques dans tous les points de ce champs, il sera utile de mettre en évidence certaines fonctions de variable – champ, pour permettre la modélisation précise des champs du système d'usinage. Une propriété remarquable des champs, qui peut faciliter leur modélisation, c'est la cohérence. Ce papier sugere un instrument simple et efficient, possible d'être utilise pour l'évaluation de la cohérence d'un certain champ, qui permettra ainsi une modélisation ultérieure appropriée.