U.P.B. Sci. Bull., Series D, Vol. 72, Iss. 3, 2010 ISSN 1454-2358

EVALUATION OF THE FUNCTIONAL STABILITY OF PROCESSING CENTERS WITH CNC

Viorica CIOBANU[1], Alexandru DORIN[2], Nicoleta-Elisabeta PASCU[3]

Comportarea în exploatarea centrelor de prelucrare determină productivitatea acestora şi calitatea pieselor fabriate. Noțiunea de stabilitate în funcționare se referă la menținerea preciziei de prelucrare în timp pe maşinile-unelte cu comandă numerică în limitele prescrise, având în vedere modificarea în timp a preciziei maşinii-unelte şi siguranța în funcționare a echipamentului de comandă numerică. În lucrare se propune o metodă de evaluare a stabilității în funcționare a centrelor de prelucrare care sunt cele mai răspândite maşini-unelte cu comandă numerică folosite în prezent.

The behavior in exploitation of processing centers determines their productivity and the quality of manufactured parts. The term of functional stability refers to the maintenance of processing precision in time on the machines-tool with CNC in the prescribed limits, considering the modification in time of the precision of the machines-tool and the functional safety of the CNC equipment. In this paper, we propose an assessment method for the functional stability of the processing centers which are the best known machines-tool with CNC used today.

Keywords: stability, machines-tool with CNC, processing centers

1. Introduction

The scope of defining a maintenance policy is to improve the machines reliability by increasing their availability and reducing the probability of failure.

This paper discusses maintenance issues. There are many aspects dealing with such function: maintenance strategies, supervision and monitoring, information system diagnostics.

In academic literature, different maintenance policies are mentioned but all of them consider that the corrective and preventive maintenance is the most important one.

[1] PhD, University POLITEHNICA of Bucharest, Romania; e-mail: ciobanu_bratu_viorica@yahoo.com

[2] Prof., Machine and Production System Department, University POLITEHNICA of Bucharest, Romania

[3] PhD, Lecturer, Descriptive Geometry and Engineering Graphics Department, University POLITEHNICA of Bucharest, Romania

a) **Corrective maintenance (CM)**: its role is to restore the deficient element in the shortest time in order to minimize losses to the enterprise due to downtime. There are two forms of corrective maintenance:
- **the palliative maintenance (PCM)**: it is an emergency intervention where the deficient item is brought back to production;
- **the curative maintenance (CCM)**: in this part, the failure is corrected trough a "definitive" intervention. Actions of this kind of maintenance can follow the palliative maintenance ones.

b) **Preventive maintenance (PM)**: in this case, the interventions are planned before the occurrence of failure. It is supposed that we have an idea of the item behavior. In its turn this includes in its turn three other types of maintenance.
- **the systematic preventive maintenance (SPM)**: its activities are a function of lifetime or of the number of units in use. It consists on changing an element systematically, it supposes that we know the item mode degradation and its Mean Time Between Failures (MTBF).
- **the conditional preventive maintenance (CPM):** it consists of the control of the item if possible and change it only if necessary. It is used after a monitoring (and or a diagnostic) of an expansive element.
- **the field inspection (FI)**: it is a regular control of the items on small frequency; it consists of preliminary maintenance activities. It is a kind of a mixed systematic and conditional maintenance [1].

2. Performance analysis

This function is done at off-line stage, evaluates the system production performance and then determines:

a) All the thresholds values (as sensors, one per monitoring operation);

b) Strategies of maintenance as defining on which item such kind of maintenance activities (preventive or corrective) will be applied spare part management, etc.

The performance analysis is first of all a criterion which is fixed by the enterprise objectives (cost, quality and product lead time) and optimized. It is also a function of all production system characteristics such as reliability of each element, their ability for repair and all costs resulting from maintenance activities (repairing, tests).

This analysis is made through various existing methods available in academic literature. Specific work applied to manufacturing systems can be found in [2], [3].

Related to cutting state monitoring, there are many studies to detect other vibration, tool wear and chipping [4].

Sensors must be set on all critical or susceptible elements; the threshold values obtained from the performance analysis is used at this step. On various methods in machine monitoring, fault detection and fault diagnostics are examined in order to introduce a perspective on proactive maintenance (this approach is to use integrated, investigation and corrective practices to significantly extend machinery life).

Also it is stated that development in process monitoring of machine degradation and fault is one of the most important research task for increasing machine up-time and improving production quality. In order to make the maintenance of processing centers more efficient, in this paper we present an original method for the evaluation of the positioning precision stability. By using specific test items, we can determine in the right time the evolution of the positioning precision and intervene in order to correct its degradation.

3. The estimation of the functional stability for machine-tools

In case of processing centers, a relevant factor for the evaluation of the positioning precision is the estimation of the geometric precision. This consists in determination of the static and dynamic errors along the coordinate axes.

In the analysis of the precision errors, the following factors are considered:

1. The systematic error;
2. The random error;
3. The minimum movement increment;
4. The insensitivity zone.

The check of the processing centers regarding the positioning precision is done according to the regulations elaborated by the manufacturing companies. The tests performed in order to evaluate these methods are expressed in the regulations elaborated by NMTBA and VDI (American, respective German standards).

In this paper we propose – on one hand to test some hypothesis that are the foundation of the NMTBA-VDI recommendations – and on the other hand to elaborate new methodologies to check the positioning precision of the processing centers that is guaranteed by the manufacturer [5].

The term of functional stability refers to the maintenance of the processing precision in time on the processing centers in the prescribed limits, considering the functional safety of the CNC equipment and the modification in time of the processing center precision.

The importance and the necessity of stability checking in time of the processing centers consist in the fact that it influences the quality of the processed items. The problem of functional stability testing of the processing center consists in examining the statistical hypothesis:

$$H_0 : \sigma_1^2 = \sigma_2^2 = \ldots . = \sigma_\kappa^2 \quad (1)$$

where k represents the number of independent volume selections $n_i(1 \le 1 \le k, n_i > 2)$, extracted from different normal populations $N(m_i;\sigma_i^2)$.

In the case of processing centers, k is the number corresponding to the periods of time for which checking is done, at each check a number of "n" measurements being performed. The first step consists of the verification of the affirmation contained in the regulations mentioned above according to which the positioning errors are subjected to a normal repartition law.

Data normality was verified with D'Agostino test [7]:

1) – order date is: $x_1 \le x_2 \le x_n$

2) – indicators are calculated

$$\bar{x} = n^{-1}\sum x_i \tag{2}$$

$$S = [n^{-1}\sum (x_i - \bar{x})^2]^{1/2} \tag{3}$$

$$T = \sum i x_i - n(n+1)\frac{\bar{x}}{2} \tag{4}$$

$$D = T / n^2 s; as_{\infty} D = 0.02998598 / \sqrt{n} \tag{5}$$

3) – constant decision is calculated:

$$Y_c = D - (2\sqrt{\pi})^{-1} / as_{\infty} D \tag{6}$$

Normality α risk is accepted if:

$$Y_{n;\alpha/2} \le Y_c \le Y_{n;1-\alpha/2} \tag{7}$$

and reject otherwise:

$$Y_{n;\alpha/2} > Y_c sau Y_c > Y_{n;1-\alpha/2} \tag{8}$$

Currently, the risk chosen by the checking person is $\alpha = 0.05$.

The normality checking has been performed for data in Table 1 in which we have completed the positioning errors on the OX axis for processing center.

Calculations led to the following values: $Y_c \approx 0.39781716$

$\bar{x} \approx 13.675; S \approx 3.04867; T \approx 5529; D \approx 0.28337172;$

$as_{\alpha} D \approx 0.00335252; \sqrt{80} \approx 8.9442719$

For : $\alpha = 0.05$; $Y_{80;0.025} = -2.613$; $Y_{80;0.575} = 1.226$

If: $Y_c \in (Y_1, Y_2)$ - and accept the normality values.

The second step consists of the examination of the H_o hypothesis with Bartlett's method [7]; based on this, the following equation is written:

$$\chi_B^2 = \frac{\nu \ln S^2 - \sum_{i=1}^{k} \nu_i \ln S_i^2}{1 + \frac{1}{3(k-1)}\left[\sum_{i=1}^{k} \frac{1}{\nu_i} - \frac{1}{\nu}\right]} \tag{9}$$

where:

$$\nu = \sum_{i=1}^{k}(n_i - 1) = \sum_{i=1}^{k}(n_i - k)\,; \nu_i = n_i - 1 \qquad (10)$$

$$S_i^2 = \frac{1}{\nu_i}\sum_{i=1}^{k}(x_{ij}\,\bar{x}_i)^2 \qquad (11)$$

In formula (11) of the selection dispersion, x_{ij} represents the measurement ”j” from the selection “i” [7].

$$S^2 = \frac{1}{\nu}\sum_{i=1}^{k}\nu_i S_i^2 \qquad (12)$$

The variable χ_B^2 is a random variable which respects the repartition law χ_B^2 (hi– square) with (k-1) degrees of freedom.

The decision regarding the acceptance or rejection of the H_o hypothesis is made in the following manner:

a) H_0 is accepted if: $\chi_B^2 \le \chi_\alpha^2 ; k-1$ (13)

which means that the processing center was stable during the considered time frame;

b) H_0 is rejected if: $\chi_B^2 > \chi_\alpha^2 ; k-1$ (14)

meaning the processing center was not stable during the considered time frame.

Table 1

Positioning errors

Positioning dimension on the OX axes [mm]	Values of positioning errors [µm]							
50	9	9	9	8	12	8	9	7
150	18	18	16	16	18	19	17	16
250	13	14	14	11	13	14	12	11
350	15	16	16	18	15	16	16	16
450	14	15	14	12	15	14	12	12
500	16	17	18	16	16	17	17	16
600	10	10	11	3	10	10	10	8
700	17	15	17	16	18	16	17	16
850	17	14	14	12	14	14	14	8
950	8	13	12	14	9	13	12	14

The application of Bartlett’s method for the functional stability check of the processing center requires:

- The stability of the standard type part which is the subject of processing and which will be measured: the configuration of the part and dimensions to be measured are of interest;

- The precision stability which must be imposed for the execution of the standard type part, precision according the requests of the beneficiary;
- The stability of “k” time intervals after which will be performed the „n_i” measurements on the standard type part is performed.

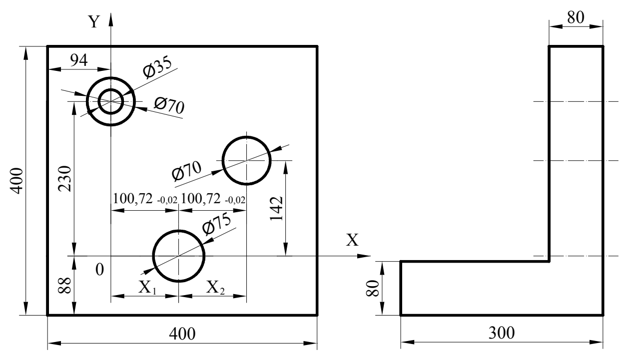

Fig. 1. The standard type part

Below we present an example of application for the Bartlett method for checking the functional stability of a processing center model MCU 200 Speed (Czech Republic) with movements on the X/Y/Z axes = 2000/1200/800 mm. The standard type part which has been processed is shown in Figure 1.

In Table 2, the deviations in micrometers (µm) recorded on the precision check on the OX axe are given.

The check has been performed in a 30 days interval, the processing cycle being repeated seven times.

Issue $k = 7$; $n_i = 14$ $(i = 1,\dots 7)$ so $\nu_i = n_i - 1 = 13$ (15)

The selection mean values calculated are given in Table 3 and the selection dispersions in Table 4.

Table 2

Deviation measured current k issue

Deviation measured [µm]	Number of groups / Current k issue	1	2	3	4	5	6	7
X_1	1	6	0	16	17	8	10	1
	2	12	16	10	16	14	15	10
	3	8	4	9	10	0	4	7
	4	6	4	0	6	4	10	9
	5	4	3	3	6	4	4	7
	6	3	0	16	6	12	0	3
	7	11	14	3	12	6	15	10

X_2	1	0	6	13	5	10	3	4
	2	18	12	0	0	19	8	6
	3	7	5	10	12	0	13	15
	4	0	10	5	8	5	4	3
	5	7	10	3	12	17	14	18
	6	0	5	4	0	0	0	0
	7	5	8	6	12	7	5	3

Table 3

Selection mean values

i	1	2	3	4	5	6	7
$\overline{X}_i$	6,2142	6,9285	7,0000	8,7100	7,5700	7,5000	6,8571

Table 4

Selection dispersion

i	1	2	3	4	5	6	7
S_i^2	25,5581	24,2179	29,2220	27,2885	37,9446	28,7221	26,8930

Data necessary for calculation of χ_B^2 according to the formula (9) are:

$$\sum_{i=1}^{7} v_i = 91;\ \ln\frac{\sum_{i=1}^{7} v_i S_i^2}{\sum_{i=1}^{7} v_i} = 3.354 \qquad \sum_{i=1}^{7}\frac{1}{v_i} = 0.5383;\ \sum_{i=1}^{7} v_i \ln S_i^2 = 304.1142$$

A value $\chi_B^2 = 1.0497$ is obtained.

From tables [8] one extracts the value: $\chi_{0.05,6}^2 = 12.6$

Note that: $\chi_B^2 < \chi_{0.05,6}^2$ so, the positioning precision on the OX axe of the processing center have been established in the considered time interval (seven months).

6. Conclusions

Manufacturing products of high quality and low cost depend on the reliability and maintainability of the manufacturing system [9].

The proposed method has the advantage that the appreciation of the processing center quality using the functional stability is done globally, both on the machine-tool and the CNC equipment based on effective processing.

If one compares, taken into account the results obtained with the above mentioned two methods for testing the accuracy of processing centers it can be concluded that the NMTBA method recommends data collection for 20 different quotas at each point making seven measurements. Therefore, one must determined 140 positioning error data.

It is obvious that the procedure is tedious since a great deal of effort must be paid for collecting processed data.

The method imagined in this paper is simpler due to the fact that the acceptance of the hypothesis concerning the homogeneity of the mean errors implies that the positioning error does not depend on the quota.

Other advantage of this method is that relatively small amount of data is used, offering the possibility to quickly obtain the quality of the processing center for its exploitation.

The results may serve for test planning and periodical adjustments of the processing centers considering their maintenance. Also, the methodology may be used with maximum efficiency for the reception of this kind of machine-tool with CNC.

R E F E R E N C E S

[1] *Al. Dorin and T. Dobrescu,* Maintenance on – line in manufacturing systems, in TSTMJ – Romanian Academy, 2001, pp 150-155

[2] *J. Lee,* Machine performance monitoring and proactive maintenance in computer manufacturing, review & perspective, in J. Computer Integrated Manufacturing, vol.8, no. 5, 1995, pp 370-380

[3] *F. Peres,* Outils d'analyse de performances pour strategie de maintenance dans les systemes de production, PhD Thesis, Universite de Bordeaux, 1996

[4] *G. Byrne, D. Dornfeld, K. Inasaki, G. Ketteler, G. Konig and R. Teti,* Tool condition monitoring (TCM) – the status of research and industrial application, Annals of the CIRP 44/2, 1995, pp 541-567

[5] *P. Salmon,* Vers la reception des machines outils a commande numerique, Usine automation, nr. 42, 1970, pp 27-35

[6] *R.B. Duffey and J. W. Saul* , Risk prediction for modern technological systems, R&RATA, vol. 1, no. 2/2008, pp 52-60

[7] *L. Tovissi and Gh. V. Vodă,* Metode statistice. Aplicații în producție (Statistical methods. Production application), Editura Ştiințifică şi Enciclopedică, Bucureşti, 1982, (in Romanian)

[8] *H. Ionescu,* "Statistica matematică" (Mathematical statistics), Editura didactică şi pedagogic, Bucureşti, 1962, (in Romanian)

[9] *G.B. Williams and R.S. Hirani* , A Delay time multilevel on condition preventive maintenance inspection model based on constant base interval risk – when inspection detects pending failure, Int. J.Mach. Tool Manufact. Vol. 37, no.6, 1997, pp 823-836

[10] *M. Pospisilik, J. Puchar, and M. Adamek* , Wifi module for autonomous monitoring system, in Annals of DAAAM for 2009 and Proceedings of the 20th International DAAAM Symposium, Vol. 20, No. 1, 2009, pp1325-1326

[11] *M. Dosedla* , Machine tool life-cycle, in Annals of DAAAM for 2009 and Proceedings of the 20th International DAAAM Symposium, Vol. 20, No. 1, 2009, pp 0075-0076

[12] *I. Popescu and S. Tonoiu*, Static stiffness of turning tools, Scientific Bulletin, Series D, vol. 72, Iss. 2, pp. 115-122, 2010