ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume X (XX), 2011, NR1

OPTIMIZING UP TIME

Traian Ionescu[1], Stefan Velicu[1], Alexandru Velicu, Lucian Mihai[1]
[1] Universitatea Politehnica Bucuresti, traiancionescu@gmail.com

Key words: maintenance, calibration, processing capacity.

Abstract: To maximize to up time in a production facility there are well known methods that revolve around systematic maintenance, predictive maintenance and management. Solutions have been proposed in RCM (Reliability Centered Maintenance), TPM (Total Productive Maintenance) and Lean Maintenance management concepts.

This article proposes another way to optimize the up time by properly calibrating machine tools after maintenance repairs or improvement and estimating the processing capacity. Today there are many measurement instruments available for machine tool calibration. The biggest advantage that they offer is that you can also asses the state of the machine tool and base maintenance decisions on calibration results. Estimating processing capacity is a mathematical approach that helps asses the production possibilities of each machine tool in a production line.

1. INTRODUCTION

In the maintenance context the goal is to achieve 100% up time. This can be achieved only if you have no down time. This means you have to eliminate maintenance interventions to fix faults, defects and weaknesses from the production schedule. There is a possibility to achieve this by moving all the maintenance activities outside this schedule. You can inspect the state of each machine tool in the production line each day, after production stops and decide if repairs or improvements are needed. But that means all the maintenance actions will have to be done over night outside working hours. And after that in the morning before production starts you have to check if everything works according to specifications. If you are dealing with 24h production then it's impossible to eliminate down time.

To achieve this goal and maximize your up time you have to be sure that after each maintenance intervention the machine tool works in the specified parameters. Properly calibrating a machine tool is the most important step after part replacement or improvements of any kind.

To maintain this balance it's essential to be aware of the state of each machine tool on the production line. If you are not aware of it you may get unexpected failures that will lower the percentage of up time. One method to achieve this is predictive maintenance. This implies throwing a lot of money on expensive equipment and sensors to supervise the production and also on the personnel that will be responsible with analyzing the data.

This article proposes another approach, estimating the processing capacity.

2. CALIBRATION AND MAINTENANCE TESTS

When you are dealing with small tolerances or in the case of mass production it is very important after a maintenance action and calibration to check the precision of the machine tool. There are different measurement techniques that are well known by now.

The first and oldest type of test is the circle test. The test is pretty simple involving just the drawing of a circle in one plane (XY, XZ or YZ) in two directions (first CW and after CCW), without the involvement of resistance forces that appear in the manufacturing process. So the test is about the interpolation of two axes at one time keeping the others blocked. There are different measurement devices that are available on the market from the oldest type the Double Ball Bar or DBB to the latest Laser Tracer. This type of test uncovers many faults or defects that cause the loss of accuracy.

For this test, first you have to install the measuring device on the machine tool, then according to the position of the measurement device and the measurement's device capabilities generate the program for the test. Run the program on the machine and measure the relative position of the tool tip. This type of test generates a plot that looks like a circle with some imperfections [1]. These imperfections are measured and the plot interpreted. The interpretation of the plot offers information about the possible fault and the measurements offer error quantity information that helps maintenance personnel decide on the possible course of action to correct that error. As conclusion to these tests compensation parameters are established and if the error exceeds limits, correction actions are advised.

These types of tests are always done after eliminating prior compensations as it is very important to have a clear view of the plot.

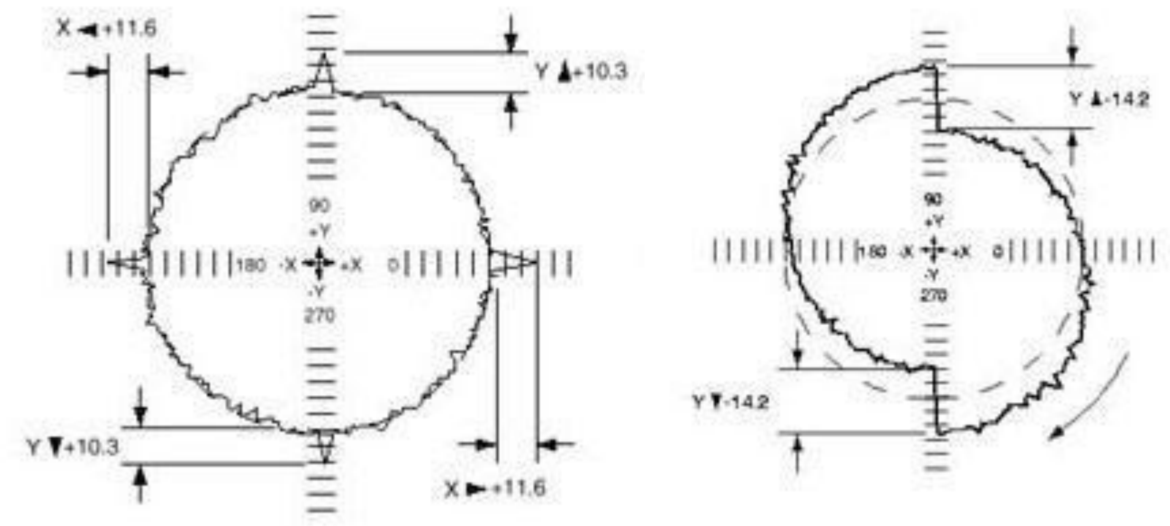

Figure 1 Example of plots for circular test

Another type of test is linear test. This type of test is done only on one axis at a time keeping all other blocked and without a work piece. There are fewer devices available for this type of test and the price is also higher than for the circular one usually because the devices involve laser technology and they involve a bigger scale [2]. For circular tests the scale is smaller that means that if you want to check the entire length of the two axes you have to repeat the test in different positions on the surface. Linear tests are done once on the entire length of the axis or on different parts as the case requires.

In linear tests it is also easier to pinpoint the right fault or defect as you are not dealing with interpolation of two axes. Linear tests offer information about the wear, straightness, orthogonality and also PLC incorrect parameterization. There are also stress tests that can be carried out on each axis at a time to measure the errors that appear due to metal fatigue and expansion [3]. For this you have to load the table with a big enough mass (an example would be 50 Kg) and repeat a movement of back and forth for some time. After a while the backlash error increases to reach a certain limit.

From this test as well conclusions are drawn that involve compensation parameters or, in more serious cases maintenance actions (replacing, improving or different adjustments).

There are also possible free form tests. After the calibration and maintenance actions completed there is a possibility to do also free form tests [3]. In these tests any form can be drown (line, circle, helix, spline) and on any scale or plane. This test is also done without the resisting forces that are met in the manufacturing process (without a work piece). These test are refinement tests that cannot offer many clues as to the causes that lead to loss of accuracy but offer a view about overall precision. The devices available for measurement of this type of test are very expensive and all of them use laser technology.

The last type of test is test work pieces. This test involves generating a work piece that has straight angles, circles (straight angles offer information about orthogonality, circles about interpolation), milling it on the machine tool and then measuring it with a 3D scanner. With this measurement we can compare the work that had to be done and what was actually done on the work piece so we can draw some conclusions as to causes for loss of accuracy. This test is different than the ones before because it takes in consideration all the forces that are present in the manufacturing process. This is also a good test to do after the circular and linear tests are performed and corrections are applied.

All these tests offer information about the precision of movement of the machine tool. If followed on a regular basis these test also offer information about the development of wear and of other problems that lead to loss of accuracy.

3. DETERMINING THE PROCESSING CAPABILITY

Currently there is a general method for determining the capability of processing of an equipment based on direct measurements. Some statistical indicators can be determined from measurements made on machined parts. As a result, developing a unique method and criteria for assessing the current capability of machines is an issue of paramount importance.

The processing capability of an equipment is a global feature that involves:

- defining capacity indicators;
- technical assessment of provisional and then final reception;
- different performance behavior of existing equipment;
- evaluation of wear and maintenance triggers;
- improve and correct operation procedures on the equipment;
- assess the satisfaction of processing requirements on that equipment.

The processing capability is based on the precision and wear of the equipment. The accuracy of the equipment is important for either production of small or large series [4]. When you have a small batch and the work pieces don’t respect the tolerances rework is not going to be cheap and some of them might even be scrap. In the case of mass production the main problem will be maintaining the precision of the equipment from start to finish.

There are different manners to estimate the processing capability:

- by assessing the wear of the equipment;
- by measuring a batch of work pieces.

4. ESTIMATING THE PROCESSING CAPABILITY BY ASSESSING THE WEAR OF THE EQUIPMENT

This criterion indicates the extent to which the machine can provide processing requirements between two repairs.

During machine operation, its mechanisms are subject to wear. Depreciation affects the normal operation of the machine. Thus, reduced power transmission efficiency, increases energy consumption, decreases processing accuracy, increasing noise due to big play, etc..

Considering U_{max} wear reached during operation between two repairs in T time, equipment’s capability function by this criterion is given by:

$$C_U = C_{U0}\left[1 - \frac{U_{(t)}}{U_{\max}}\right], \qquad (1)$$

where C_{U0} is the capability of the machine at the time $\sigma = 0$, and $U(t)$ is the wear at time $\sigma = t$.

The function U (t) is determined graphically or analytically for each machine, by theory or experiment. For the calculation of the capability is necessary to take into account a statistical parameter such as the arithmetic mean of the wears of all machine parts, not wear of the mechanisms with the lowest durability.

For a simplified calculation can be regarded as a linear function to approximate the shape of equipment capability:

$$C_U = C_{U0}\left[1 - \tau/T\right] \qquad (2)$$

Most times, after repair or overhaul environments, decrease some essential characteristics for the purposes of processing, such as rigidity, durability camps, resistance, etc. [4]. In these cases, after repair, machine capability is different from the original and usually less, it depends on technological factors, operating factors and number of repairs.

Illustrated in Figure 2 you can see how the graph for equipment capability changes over time. It is essential, from this point of view, that machine tool be fitted with a reserve of capability, so after every repair, replacement of parts or necessary adjustments and implementation the equipment would still be within that reserve.

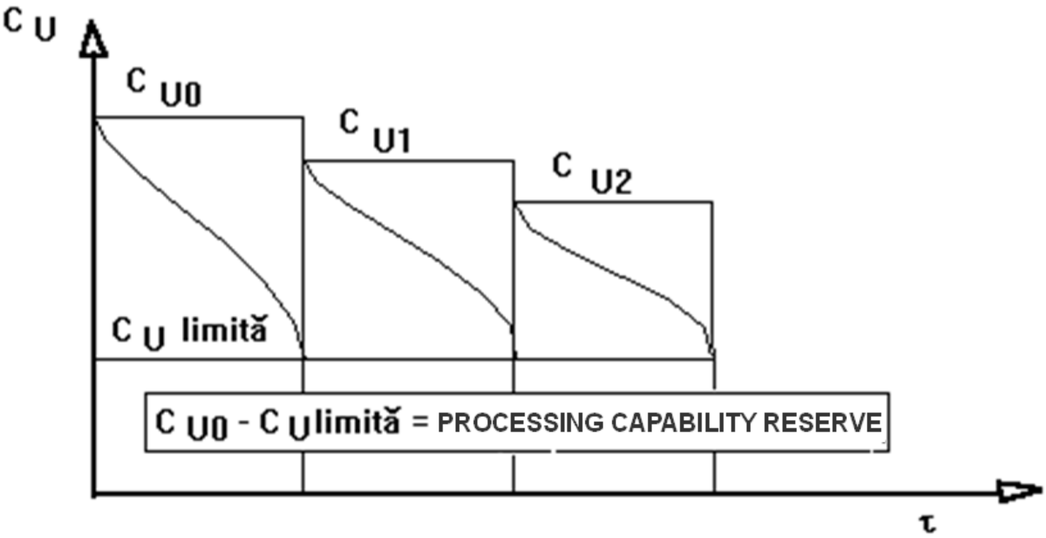

Figure 2 Equipment processing capability

5. ESTIMATING THE PROCESSING CAPABILITY BY MEASURING A BATCH OF WORK PIECES

When dealing with mass production you have to be sure that the machine tools respect the precision standards required for the production of the desired work piece and that they can maintain those standards in the stress situation that is brought on by the production requirements [4]. There is a method to check this by measuring the processing capability.

Processing capability calculation using as a criterion accuracy of processing must take into account the dynamic behavior of machines, unlike the internal rules and existing standards that are based on static accuracy.

Due to the large number of factors that influence the accuracy of the equipment, some of them having even a random occurrence, to evaluate the capability of the equipment we must resort to means and methods of mathematical statistics.

For this we can take in consideration the work piece that we have to produce or a test piece that has special characteristics [4]. For this we have to take in consideration at least 50 work pieces and it is very important to remember the order for the work pieces so we can follow the loss of accuracy.

After the work pieces are produced we have to measure them with a 3D scanner and gather the data.

For the calculation of processing capability we must take in consideration the following formulas:

- The average value of selection

$$\overline{X} = \sum X_i / n \tag{3}$$

- The square deviation average of the processed dimension

$$s = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1}} \tag{4}$$

- The C_{pv} index

$$C_{pv} = \frac{L_{ss} - L_{si}}{6 \times s} \tag{5}$$

where: C_{pv} is the machine capability index that compares the machine's own variation to the variation of measured maximum allowable rate, L_{SS} is upper specified limit and L_{SI} lower specified limit;

- The C_{pc} index

$$C_{pc} = \min\left[C_{pc(i)}; C_{pc(s)}\right] \tag{6}$$

where:

$$C_{pc(i)} = \left(\overline{X} - L_{si}\right) / 3 \times s \tag{7}$$

$$C_{pcs} = (L_{ss} - \overline{X}) / 3 \times s \tag{8}$$

This index assesses centering the dispersion. It measures the potential of the equipment to produce good pieces, taking into account the dispersion and centering its position to the specified limits of the measured quota.

The analytical expression of processing capability based on equipment accuracy is as follows:

$$C_p = C_{pv} \cdot C_{pc} \tag{9}$$

To analyze the results reflected by the capability indexes it is useful a graphical approach to assess the position of the dispersion curve in relation to the imposed limits. In Fig. 3, a and b are two graphs of normal distribution.

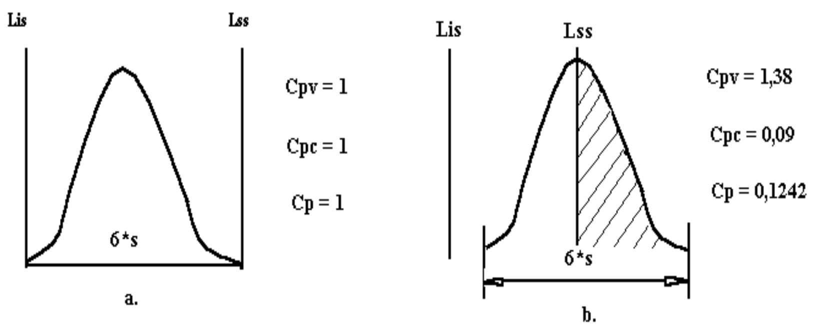

Figure 3 Possible normal distributions

It is estimated that normal processing takes place when the assembly center and dispersion size falls within the confidence interval [L_{SI}, L_{SS}]. Thus, for the distribution of Figure 3, it is assessed that the machine was well chosen and well calibrated as on the distribution in Fig. 3, b shows that the machine wouldn't be a good choice for manufacturing (the possibility of scrap is very high) and calibration has been poorly done so that a large part of pieces leaves are out of desired tolerance range.

Overall capability of the equipment C is defined as a partial product of partial capabilities and can expressed in a relationship of the form:

$$C = 100 \cdot (K_u \cdot C_u)^{\alpha_u} \cdot (K_p \cdot C_p)^{\alpha_p} [\%] \tag{10}$$

For the machine tool that meets 100% of all technological requirements, capability is 100. For some machine tools the processing capability is the product of partial capabilities weighted by proportionality coefficients and exponents according to criteria priority.

6. CONCLUSION

The goal of reaching 100% up time can be achieved by the RCM, TPM or Lean Maintenance methods. These maintenance concepts help eliminate waste, reach a high level of efficiency and concentrate on the equipment's needs. But it doesn't offer very many information about the state of the machine tools so you are not sure when the machine tool brakes down. Implementing predictive maintenance for this has some short comings like high price for implementation and for maintaining system online.

There is another way to assure a high level of productivity by coupling calibration and the calculation of processing capacity. One you calibrate and the machines are working at high level capacity you assess the production capacity once in a while to be sure that you get 100 % of processing capacity. If you get lower than 100% then another calibration will help you regain that level and eliminate possible faults that might appear.

References

1. Measuring machine tools with ball bars
   http://www.gagesite.com/documents/Metrology%20Toolbox/Machine%20Calibration.PDF
2. Seppo TORVINEN, Jouni HÖLSÄ A software system for analysing machine tool circular tests
3. S. Ibaraki, Y. Kakino, K. Lee, Y. Ihara, J. Braasch, A.Eberherr Diagnosis and compensation of motion errors in NC machine tools by arbitrary shape contouring error measurement
4. Prof. Dr. Ing. Velicu Ştefan, Ing. Stanciu Ion, Dr. Ing. Pleşca Marcel Capabilitatea utilajelor de prelucrare