IMPROVEMENT OF TURNING PERFORMANCE THROUGH STATISTICAL PROCESS CONTROL

Cristian PISARCIUC, Dragoș CĂȚEANU
Transilvania University of Brasov, Romania

Abstract. This work presents some steps related to the implementation of statistical process control on a CNC turning centre. Due to the increasing need for a fast and reliable quality control system and in order to cope with the high output rates achievable in manufacturing industry today, some actions must be taken in order to a remain competitive on global market. The article is using data collected in turning process, presented through histograms and control charts, to improve the accuracy in order to reduce scrap. Several methods could be implemented, in order to accomplish the goal of satisfying the customer's demands, the detailed being the one with feed variation.

Keywords: turning, feed, dimensional accuracy, statistical process control

1. Introduction

In manufacturing processes, quality is defined in concordance with technical specifications. However, there are no two identical products, since all processes are containing multiple sources of variation. In mass production, traditionally, products quality is assured by postproduction inspection. Each product or batch can be accepted or rejected depending on how much closer is to design specifications. In contrast, Statistical Control Process - SPC use statistical methods to observe the performance of manufacturing process in such way that major variations to be detected before they translate into defective products.

The most recent development in statistical quality control - SQC methods is Motorola’s Six Sigma [1]. According to traditional SQC, a process is in control if the variation measured in standard deviations (σ or sigma) is less than one-third the difference between the control limits and the process mean; i.e., the traditional distance between the mean and any control limit is at least 3σ. However, Motorola concluded that quality leaders achieved fewer defects by reducing process variations. They estimated that defects would be cut 1000-fold if the process variation could be held to one-sixth the difference between process mean and control limits, or 6σ variation control [2].

The term six sigma (6σ) initiated as a performance measure or a measure of quality. Using six sigma, process goals are set in parts per million in all areas of the production process. Since its origin, six sigma has now evolved into a methodology for improving business efficiency and effectiveness by focusing on productivity, cost reduction, and enhanced quality [3]. The name six sigma comes from the statistical use of the sigma (σ) symbol, which denotes standard deviations. The six identifies the number of standard deviations around the mean. A process is six sigma when the values of collected data for process stability analysis is at distance 3σ from upper specification limit (USL) and lower specification limit (LSL) and the average absolute data set is at a distance 6σ from LSL to USL (assuming that σ is the standard deviation). Statistical Process Control (SPC), and Statistical Quality Control (SQC), are tools utilized by a six-sigma process. In conclusion, either SPC or SQC are, after all, methods of reducing the costs associated with production activities.

Sources of variability detected in a process can be classified as:

- Common cause variations that refer to multiple sources of variation that causes constant effects on processes;
- Special cause variations are caused by such factors that affect only some of the processes being most often intermittent and unpredictable.

Identifying these causes is related to the possibilities of revealing the scrap occurring in manufacturing processes. This is the reason why SPC is used frequently. Motivation is related to the fact that SPC generates savings by reducing the number of interventions in the process, or reducing the waste caused by faulty adjustment operations.

Variation data are monitoring through control diagrams. They are used to highlight common and special causes of variations. The data collection activity and drawing up control charts should have a continuing character in time because when the process does not trigger any detection rule (from control graphics) then the process is stable. The histograms are used as they are the graphical representation of a phenomenon, in this case, process stability. Consequently, effective planning of product quality involves measuring the capability of the production process, which involves determining the indices Cp (Process Capability) and Cpk (Process

Capability Index). In order to assess the process capability the minimal values recommended for Cpk are 1.33 or 1.67 for safety or critical parameter [4].

2. Process presentation

Rotor subassembly is the main component of an electric motor, ensuring the transfer of mechanical energy from engine to connected devices. Good quality of the production is vital to the long-lasting evolution and to parameters of the final product, the electric motor.

Figure 1 shows a cutaway view through an electric motor highlighting the important parts, shaft being the one that will be analysed in this article.

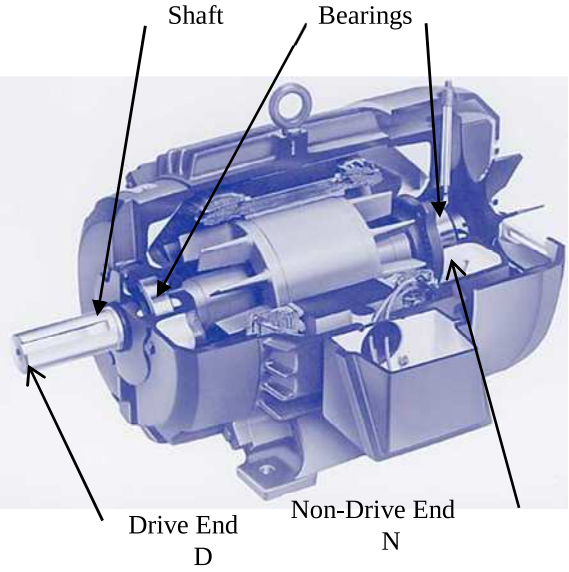

Figure 1. Cutaway view of a generic AC motor. Adaptation from [5]

The shaft passes to several machining stages until last one being the drive shaft finishing, more exactly the final processing for bearings mounting diameters (on both drive and non-drive end), finishing the sealing beds and the drive end, where usually is already machined a keyway.

Attaching rotors to CNC machine tool (Okuma LB 3000 EX-II) is done using two centres method for faster change. The machines is fitted with a headgear drive mounted in chuck and centering devices of different sizes in order to accommodate all kind of shaft sizes. On tailstock are used ROHM OHM MK5 live centres [6] (revolving), as presented in Figure 2.

To finish the diameters on shaft, Sandvik tool holders are used, model SVJBR 2020K, to support VBMT 16 04 04-PF 4325 [7] cutting inserts (Figure 3).

Figure 2. Shaft mounted before machining

Figure 3. Tool holder and cutting insert used for finishing

3. Initial assessment

The specific model selected for analysis was the one with 15 mm diameter for inner ball bearing ring and 14 mm at drive end. The numeric values are the average of the processed shafts. The 15 mm diameter is also the one with the tightest tolerance (+0.009, +0.001).

In order to assess the initial process stability of shaft's finishing, 50 parts were analysed and measured with a micrometre calibrated every five measurements.

In the initial phase, the machining regime for cutting inserts was set-up according to manufacturer recommendations (feed 0.1 mm/rot (0.05-0.2), speed 460 m/min (395-480)) [7], as follows: cutting feed 0.12 mm/rot, cutting speed 425 m/min and spindle speed 3800 rot/min.

The data was collected using an Excel spreadsheet template available from [8]. Using the formulae already embedded in Excel spreadsheet, the results for statistical control parameters were as follows:

- for 14 mm diameter for drive shaft (DS), Cpk = 1.168
- for 15 mm ball bearing diameter at drive end (DE), Cpk = 0.895
- for 15 mm ball bearing diameter at non-drive end (DN), Cpk = 0.862

The first evident conclusion is the fact that process is not adequate from quality point of view, and needs substantial improvements. However, it is interesting to note the importance of tolerance in Cpk's results. The DS diameter of 14 mm having 13 micron tolerance has a better result against DE and

DS diameters that have only 8 µm tolerance range, although they were machined with the same cutting conditions and cutting tools.

The histograms that illustrate graphically the initial situation are presented in Figures 4-6.

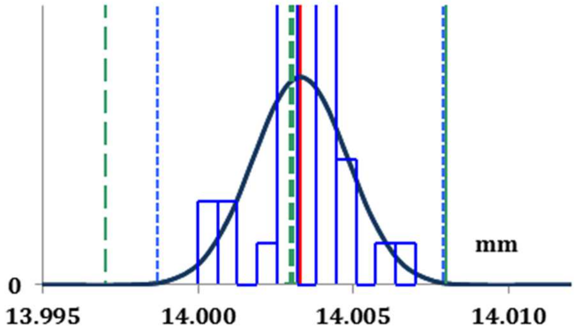

Figure 4. Histogram for DS ϕ14 (+0.008, -0.003)

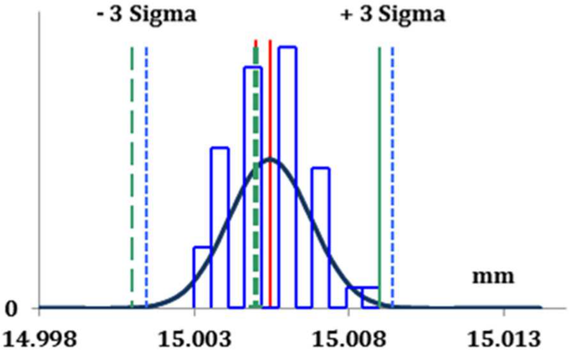

Figure 5. Histogram for DE ϕ 15 (+0.009, +0.001)

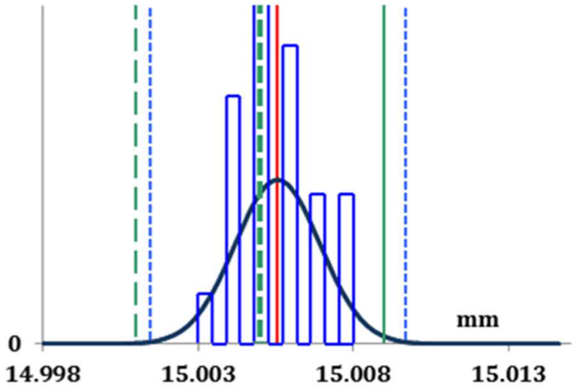

Figure 6. Histogram for DN ϕ 15 (+0.009, +0.001)

It can be seen with ease that finishing processes are centred. However, it requires increasing the precision of processing, in order to decrease the number of not conforming parts.

Analysis of control charts is attesting the fact that there are no unexpected external or disruptive elements on the system. Major influence on the processing capability analysis result is thus internal, most likely processing technology, cutting conditions, or the tools and devices do not meet the process requirements (Figures 7-9).

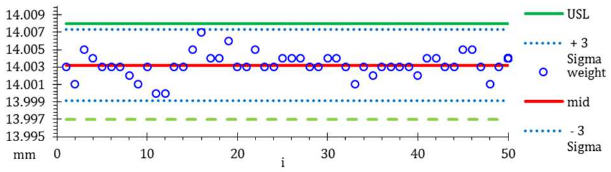

Figure 7. Control diagram for ϕ14 (+0.008, -0.003), initial situation

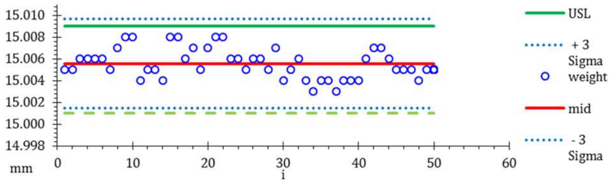

Figure 8. Control diagram for ϕ 15 (+0.009, +0.001), initial situation

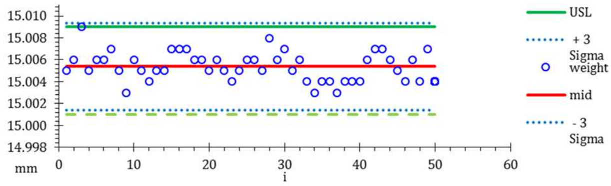

Figure 9. Control diagram for ϕ 15 (+0.009, +0.001), initial situation

4 Experimental research

The machining parameters for shaft finishing, as mention above, were: cutting feed 0.12 mm/rot, cutting speed 425 m/min and spindle speed 3800 rot/min.

Given that the maximum spindle speed for Okuma lathe is 4200 rot/min, raising this speed is not a recommended solution. In the same way, modifying the cutting speed over or under the recommended value of 425 m/min is neither indicated.

The only substantial change that could be relevant is related to feed and was decided to test with values of 0.16 mm/rot and 0.08 mm/rot (plus and minus 0.4 mm versus initial parameter).

For 0.16 mm/rot the results obtained were:

- for 14 mm diameter for drive shaft (DS), Cpk = 0.79
- for 15 mm ball bearing diameter at drive end (DE), Cpk = 0.72
- for 15 mm ball bearing diameter at non-drive end (DN), Cpk = 0.92

Histograms for feed = 0.16 mm/rot are presented in Figures 10-11.

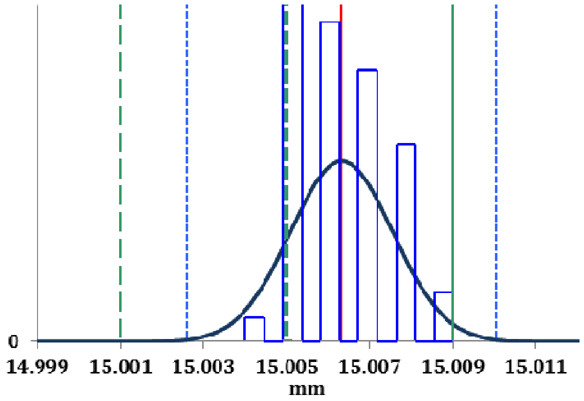

Figure 10. Histogram for DE ϕ 15, f = 0.16 mm/rot

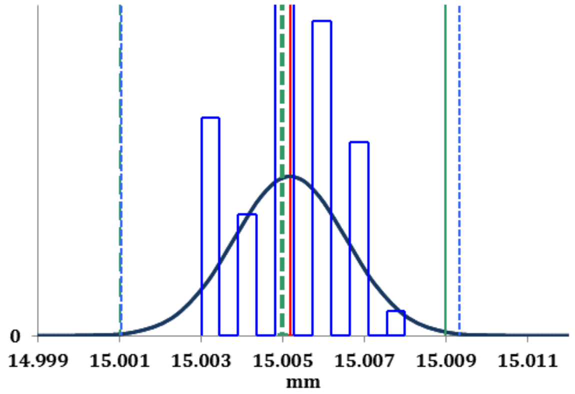

Figure 11. Histogram for DN ϕ 15, f = 0.16 mm/rot

Straightaway could be noticed that there is a difference between the results for diameter from non-drive end and the drive bearing diameter, the difference that was not seen in the initial tests. Histograms show that the distribution is no longer centred for the two diameters on the drive, and the cutting tip wear has increased significantly here. On non-drive end could be noticed a little higher value (0.86 compared to 0.92), but this is not so relevant, as the machining precision is not influenced.

The results were not as favourable from process stability point of view, but based on them could be draw some relevant conclusions about other influences in terms of machining precision. In this stage, only the open keyway could explain the higher wear of cutting. The conclusion can be considered authentic because the two diameters, 14, and 15 mm, are machined by the same tool, in the same cutting conditions but with tools that are mounted in different stations. Consequently, it was discovered a major influence on processing accuracy, more precisely the interrupted turning on drive side of the shaft. Histograms for feed 0.16 mm/rot, shows this effect as the distribution is on the right side, due to wear of cutting tool. Control diagrams presents, more clearly, the wear of cutting insert (Figures 12-14).

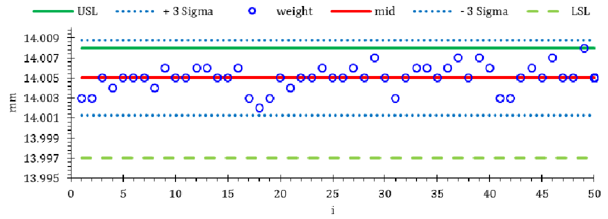

Figure 12. Control diagram for DS ϕ14, f = 0.16 mm/rot

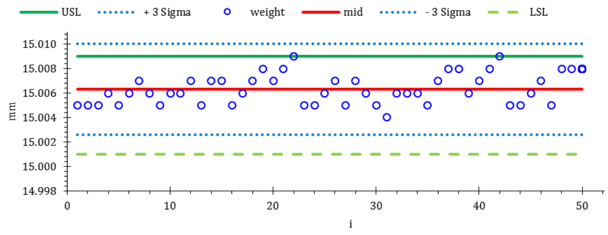

Figure 13. Control diagram for DE ϕ15, f = 0.16 mm/rot

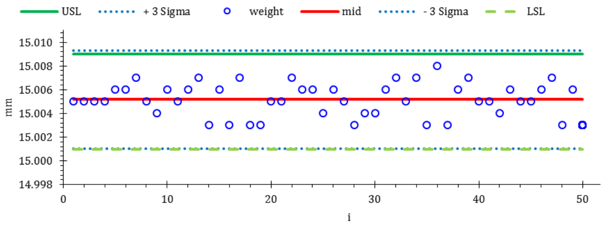

Figure 14. Control diagram for DN ϕ15, f = 0.16 mm/rot

For feed 0.08 mm/rot the results obtained were:

- for 14 mm diameter for drive shaft (DS), Cpk = 1.10
- for 15 mm ball bearing diameter at drive end (DE), Cpk = 1.03
- for 15 mm ball bearing diameter at non-drive end (DN), Cpk = 1.09

This is the first positive result of the tests, but only for the finishing of 15 mm diameters. The Cpk for drive side of shaft remains the same as the initial situation. The process reaches the natural 3-sigma threshold. Histograms (Figures 15-17) and control charts (Figures 18-20) show a better positioning of the average diameter value on 15.005 mm and 14.003 mm. In order to bypass the problem for 14 mm diameter the only solution is to remake the technological order of machining phases and put the milling of keyway as a last operation. The operation will be done on the same lathe as well.

5. Conclusions and further development

Implementation of presented studies proved to be useful for improving the quality of final products as the number of complaints from customers has decreased considerably, so the purpose of the study to improve the production capability related to customer quality requirements was reached.

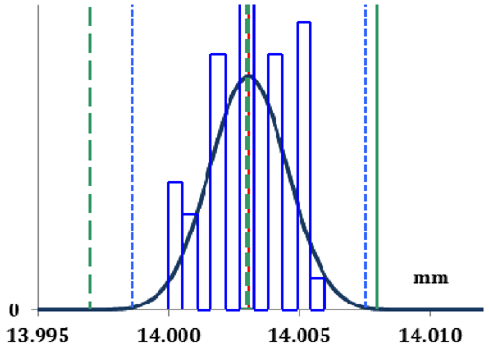

Figure 15. Histogram for DS ϕ14, f = 0.08 mm/rot

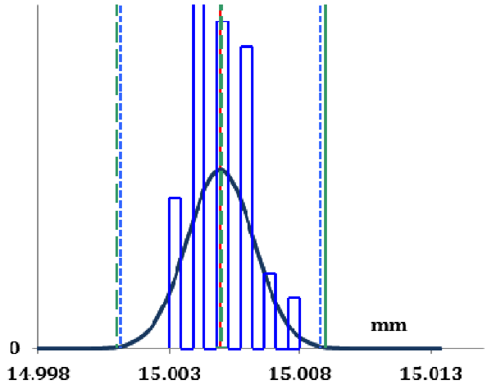

Figure 16. Histogram for DE ϕ 15, f = 0.08 mm/rot

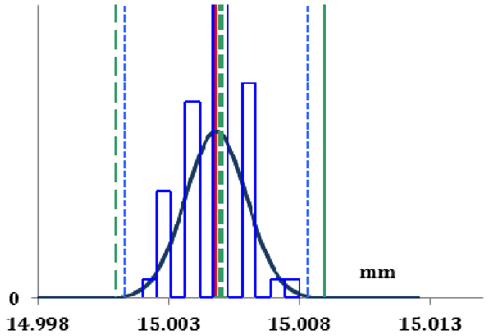

Figure 17. Histogram for DN ϕ 15, f = 0.08 mm/rot

Applied solution involves modifying the technological stages in order to put the milling of the keyway last and lowering the feed to 0.08 mm/rot. This solution does not involve any additional costs but cause a decrease of overall productivity due to longer finishing times.

Because the cutting tools are common carbide turning inserts, in order to maintain the actual productivity, or to raise it, is possible to use cubic boron nitride - CBN inserts. The high hardness of CBN enables it to machine hard materials at high speeds and/or feeds. CBN is chemically inert in ferrous materials and retains its hardness at temperatures over 1000 °C. Of course, this raised performance it will be reflected in costs. This could be reduced by increased machining parameters.

It can be said that the project, against the prevailing classical engineering, brings a new insight into the methodology in finding solutions to improve the various production sectors and customer assurance that quality requirements will still be met.

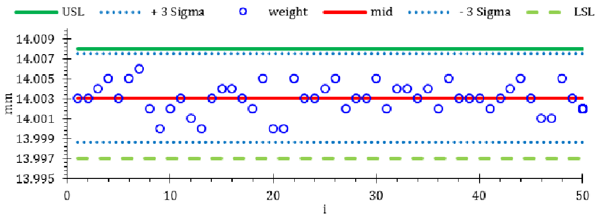

Figure 18. Control diagram for DS ϕ14, f = 0.08 mm/rot

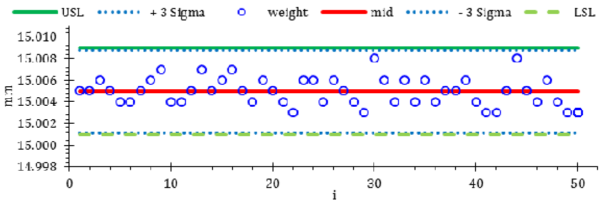

Figure 19. Control diagram for DE ϕ15, f = 0.08 mm/rot

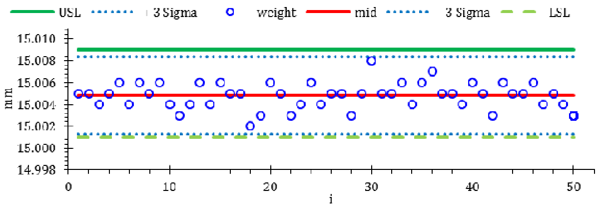

Figure 20. Control diagram for DN ϕ15, f = 0.08 mm/rot

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