Turkish J. Eng. Env. Sci.
27 (2003) , 83 – 93.

Elimination of the Quality Problems Encountered in Mass Production by Using Statistical Quality Control

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Received 09.04.2002

Abstract

Having determined the quality problems in mass production in a medium-size firm chosen as a pilot study, all the processes from casting to machining were investigated. The problem of low quality arising during production was eliminated by the statistical quality control of a given product. The procedure to eliminate the problem of low quality followed a specified procedural sequence. The beginning stage of the problem was analyzed, the type of the quality problem was identified, some short-term corrective measures were sought and the required means of measurement and control were prepared. Samples were chosen randomly during the production process. X-R control charts were used with the support of statistical calculations for the problem of low quality concerning the part and undesired size causing high costs. The underlying reasons for parts not meeting the desired quality were identified and the correct parameters presented.

Key words: Statistical quality control, Process control, X-R control charts

Introduction

It is not always possible to have exact equivalence and correctness in size and manufacturing features in parts. This may be due to the characteristics of the machines, the size of the tools, the quality of the workforce the raw material and working conditions.

What is essential in production is not just eliminating differences in measurements and quality but identifying the maximum and minimum limits and keeping them between these. Divergences must be identified and prevented; otherwise, efficiency decreases and overall costs increase (Bosch, 1994).

Statistical quality control is a general term covering measures and methods to eliminate out-of-control processes. It can be applied in all stages of production, and is superior to classical quality control methods because it possesses effective methods and flexibility (Esin, 1993).

Statistical quality control methods can be grouped under two categories:

- Process control,
- Acceptance sampling.

However, the statistical methods used in quality control processes are not limited to these (Braverman, 1981).

The purpose of statistical quality control is to help managers and employees develop and control production and products. For this purpose all staff should learn about statistical problem-solving. In this way, quality control will not be a simple way of final inspection but a tool for management that can control all the system during the process of production (TMMOB, 1993).

Literature review

Studies in quality control started with the checking of all products and separating art of faulty ones. When the costs of the lack of quality of faulty products are added to those of acceptable products, it increases the cost of normal products and thus prices go up. This increase in prices results in low market share in a climate of of intense competition in the free market economy. In parallel to the increasing pace of production, whether products were accepted or not was decided on a party basis. At this stage, statistical techniques were used. Later it was realized that it would be more beneficial to eliminate the reasons for problems in products rather than identifying faulty ones. It was seen that the purpose of statistical quality control should be prevention, not identification (Boccacino, 1993).

The first study in statistical quality control was carried out by W.A. Shewhart. He developed the theory of statistical quality control and collected his studies in a book (Hoyer and Ellis, 1996).

Once they had been accepted control methods started to be used and statistical quality control gained much more importance. With the increase in the pace of production it became impossible to inspect products individually and costs started to rise. Large quantities started to be evaluated with samples collected via statistical techniques (Özer, 1989).

In 1961, the idea of "Quality Circles" was proposed by Ishikawa et al. (Özer, 1989). It was also argued that many problems could be eliminated by making use of seven statistical techniques in quality control (Özer, 1989).

Freigenbaum has stated that there is a correlation between productivity and quality. He argues that productivity and thus profit are only possible with the application of "Total Quality Management". He also draws attention to the importance of the relationship between purchasing and sub-industry (Özer, 1989).

A statistical experiment design, namely "Minimum Prototyping", has been developed by Taguchi. Arguing that statistical methods help improve the design of the products, he is regarded as the originator of the approach (Özer, 1989).

The number of recent studies in statistical quality control and process control is quite considerable. It has been proved by many researchers that there are similarities and a correlation between predictive approaches and statistical process control. Due to such resemblance statistical process control and predictive approaches have been used by many researchers to establish model-based statistical quality control. Ledolter and Swersey have discussed the pre-control chart, an alternative statistical quality control chart for the processes observed. They have discussed the pre-control and standard statistical quality charts and presented the advantages and limitations of the two (Ledolter and Swersey, 1997).

In "The Optimization of Tolerance Charts in Terms of Quality and Cost", Jeang developed a mathematical model for optimization of the tolerance charts. His model includes the limits of process manufacturability, the limitations of design functionality, the cost of production under the limitations of product quality needs, and the effects of quality losses (Jeang, 1998). The economic statistical design of the S-charts was made by Su through the use of Taguchi loss function (Su, 1997).

In this study, statistical process control was applied to eliminate the quality problems during production in a medium-size company that had never applied statistical quality control. A new statistical model was not developed, but the applicability of X-R charts on identifying quality problems was investigated.

Materials and Methods

Materials

In this study, a medium-size business cast and manufacture company was chosen and the elimination of quality problems during production via statistical quality control investigated. In addition statistical process control was carried out in the workshop of the company and the outcomes examined.

Methods

Statistical quality control was carried out with the techniques following the sequential procedure shown in Figure 1. First, the problem was determined examining the process, the causes of the problem were investigated and the data obtained analyzed. Having done the necessary works according to the analysis result, the process was reinvestigated and the effect of improving measures was observed. The stages of statistical process control are shown in Figure 1.

The problem and its identification

It is possible by Pareto analysis to classify the mistakes and to determine the most frequent mistake or the reasons behind it (Benjamin and Shaw, 1993).

In the initial stages of the study, the process of production, known only by those concerned and not written as a complete text, was examined to form the schema of process flow and an analysis of the actual production environment was performed.

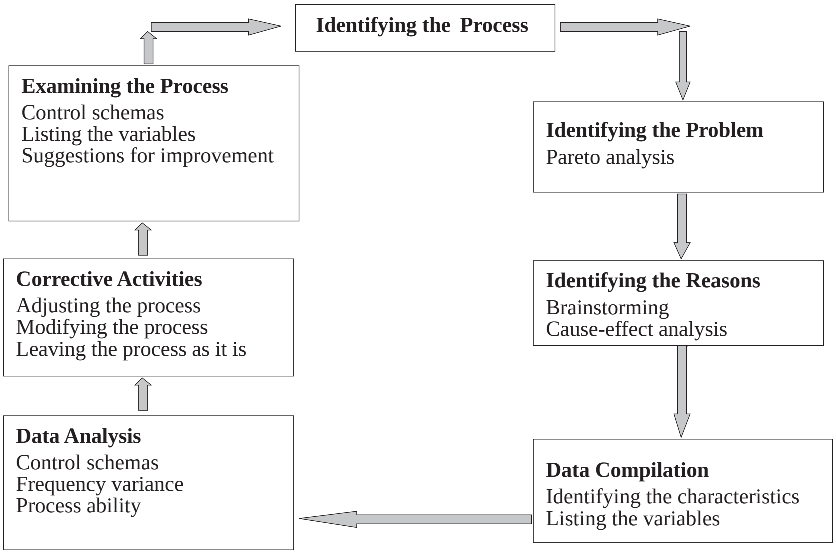

Figure 1. The stages of statistical process control (Benjamin and Shaw, 1993).

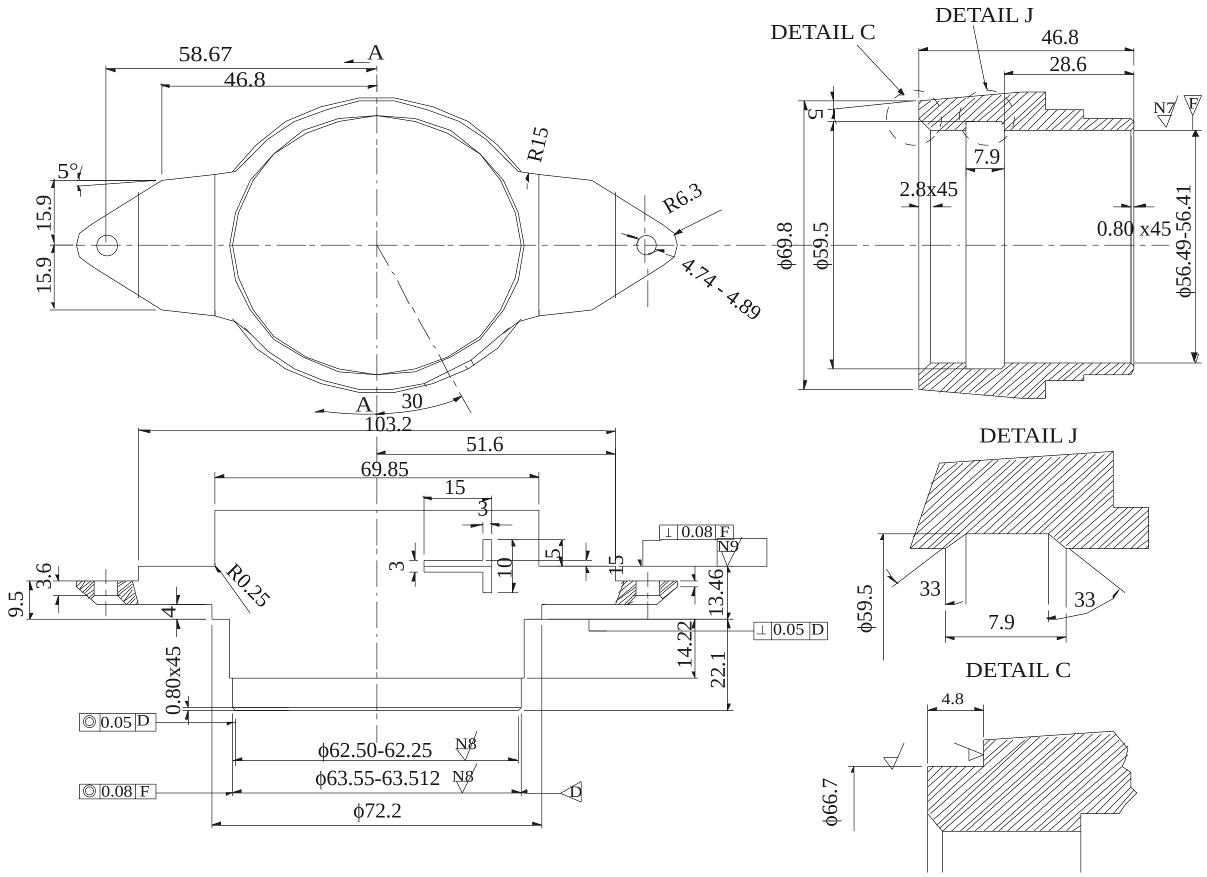

Figure 2. Technical drawing of part "Y1".

Table 1. The desired sizes according to the technical drawing and the wrong measurements of Y1.

Sequence	Size	Drawing Value	Type of Measurement	Key Words Identifying the Problem
1	Diameter	62.500 62.250	Caliper	• Exceeding the tolerance limits, • Oval shape, • Not having the desired value of surface roughness.
2	Diameter	56.410 56.490	Comparator	• Exceeding the tolerance limits, • Oval shape, • Not having the desired value of surface roughness.
3	Diameter	63.512 63.550	Micrometer	• Exceeding the tolerance limits, • Oval shape, • Not having the desired value of surface roughness.
4	Side	46.800	Caliper	• Exceeding the tolerance limits.
5	Side	22.100	Caliper	• Exceeding the tolerance limits.

"Y1", one of the mass production parts as shown in Figure 2, was chosen as the pilot product. For the dimensions, tolerance values and surface roughness of part Y1, its front, top, left views and detail drawings are shown. Y1, which is cast iron with special additives and was machined to give its final shape, is a part of a construction machine.

The size problems of part Y1 as listed in Table 1, were identified and key words were created to identify the problem.

During the quality control of Y1 parts, which were sent to the firm after mass production, the quality problems given in Table 1 were determined. In the quality and rejection reports, which were sent to the company by the main firm, it was stated that the number of faulty products increased continuously. Due to the contract, the quality problem was to be solved by the main firm. It was decided that this would yield poor quality cost for the company and would harm its reputation and statistical process control was decided on.

The analysis of fault causes

In identifying faults, a number of techniques are used, such as fishbone diagrams, brainstorming, and mesh diagrams (Sanigae, 1989). All the causes with their factors affecting the problem in the cause-effect diagrams are taken into consideration schematically. In this way, the cause of the problem is sought through examining all possible reasons. With brainstorming, solutions and suggestions, even of minor importance, that come to people's minds are dealt with and discussed, so that all the factors can be examined. With mesh diagrams, the relationship between two given variables can be established and compared with the desired situation (Kume, 1989).

In order to identify the faults in product Y1, a project team including the owner of the firm as the manager, workshop chiefs, foremen, operators and a quality control expert was formed and brainstorming was carried out with this team. The management supplied the required resources for the study, and all the staff were employed when necessary. The equipment in the firm (machine tools, measuring tools, etc.) was used as the tools and equipment. The study was planned to last for eight days, and at the end of this period it was aimed to assess the ways of eliminating the identified faults. Information that was unknown, incomplete or still not acquired regarding the problem was sought and the cause of the problem was sought through brainstorming. Initially, it was a determined that there was a lack of knowledge concerning casting parts and a failure to achieve the required part hardness. With regard to the fields of activity of the firm, the points of general failure were identified as tools, moulds, machines, people and time.

Data collection

This is the stage whereby the data concerning the problem were collected through the use of various forms. What is important at this stage is to decide where, how and how often to collect the data. When production is in progress, it is necessary to establish the required size of the sample that is able to represent all the products. The following questions should be answered;

- Do the products meet the desired conditions?
- If so, what is the degree of appropriateness?

- Can this group or pile be accepted according to the quality conditions?

If thenumber of faulty products in the sample taken exceeds the accepted limit, the pile will be rejected; otherwise, it will be accepted. The limits show the highest fault ratio acceptable in relation to the size of the sample. In this respect, the size of the sample taken and the highest fault ratio acceptable in relation to the size of the sample represent the degree of quality (Ercan, 1987).

Since 600-750 products were delivered in each delivery, 75 samples were taken out of the pile to be controlled. The rejection probability was established as 5%. Fifteen parts taken from each production line were measured so that this lot represented all the products manufactured on five production lines. For the five faulty dimensions of product Y1, the measurement values of production line 1 are listed in Table 2. The measurement values were saved for statistical calculations.

Data analysis

At the stage of data analysis, various techniques are used. The most important of these is control graphics, which can be formed in a variety of types. It is essential at this stage to determine which control graphic will be utilized (Bcira, 1989). In this statistical work, X-R graphic charts were used. Statistical calculations were carried out to form the charts.

$$X_{ave} = (X_{ave1} + X_{ave2} + X_{ave3} + X_{ave4} + X_{ave5})/n_g \tag{1}$$

$$R_{ave} = (R_{ave1} + R_{ave2} + R_{ave3} + R_{ave4} + R_{ave5})/n_g \tag{2}$$

$$UCL_1 = X_{ave} + A_2.R_{ave} \tag{3}$$

$$LCL_1 = X_{ave} - A_2.R_{ave} \tag{4}$$

$$UCL_2 = D_4.R_{ave} \tag{5}$$

$$LCL_2 = D_3.R_{ave} \tag{6}$$

($A_2 = 0.223$, $D_4 = 1.652$, $D_3 = 0.348$)

The averages of the averages obtained for each faulty dimension, the average of differences and control limit values for X-R graphic are given in Table 3 using measurement values.

Table 2. The measurement values of the parts in production line 1 examined for five faulty dimensions.

62.500 62.250	56.490 56.410	63.550 63.512	46.800	22.100
62.270	56.450	63.540	46.770	22.085
62.280	56.450	63.540	46.780	22.090
62.255	56.430	63.540	46.790	22.095
62.255	56.450	63.530	46.790	22.080
62.275	56.440	63.540	46.790	22.085
62.265	56.445	63.530	46.785	22.080
62.280	56.435	63.540	46.780	22.090
62.280	56.450	63.535	46.790	22.085
62.265	56.435	63.540	46.770	22.090
62.265	56.450	63.540	46.770	22.085
62.275	56.445	63.540	46.790	22.080
62.265	56.450	63.535	46.785	22.085
62.280	56.440	63.540	46.790	22.090
62.265	56.450	63.540	46.790	22.080
62.270	56.435	63.540	46.790	22.085

When the data in Table 3 are examined it can be seen that the average of the averages (X_{ave}) of the 62.250-62.500 dimension is smaller than the lower dimension ($X_{ave} = 62.247 < 62.500$). It can therefore be said that the products were manufactured with wrong dimensions. Looking at the X_{ave} value in the table, it cannot be determined which production line faulty products are from. There may be some faulty products from one or more production lines that lower the X_{ave} value under the tolerance lower limit. It also can be seen from the table that X_{ave} values of other dimensions lie between the tolerance limits ($56.410 > 56.4360 > 56.490$ etc.). However, it would be wrong to evaluate the process using these values. The X-R graphic charts show whether the average of each group exceeds the control points and what type of distribution the averages show according to the average line.

Table 3. The results of the statistical calculations.

Drawing Value	X_{ave}	R_{ave}	Control Limits for X Graph		Control Limits for R Graph	
			UCL_1	LCL_1	UCL_2	LCL_2
62.500 62.250	62.2470	0.0200	62.2517	62.2427	0.0330	0.0070
56.490 56.410	56.4360	0.0260	56.4425	56.4309	0.0430	0.0090
63.550 63.512	63.5390	0.0140	63.5421	63.5359	0.0231	0.0049
46.800	46.7889	0.0130	46.7918	46.7860	0.0215	0.0045
22.100	22.0884	0.0130	22.091	22.0808	0.0274	0.0000

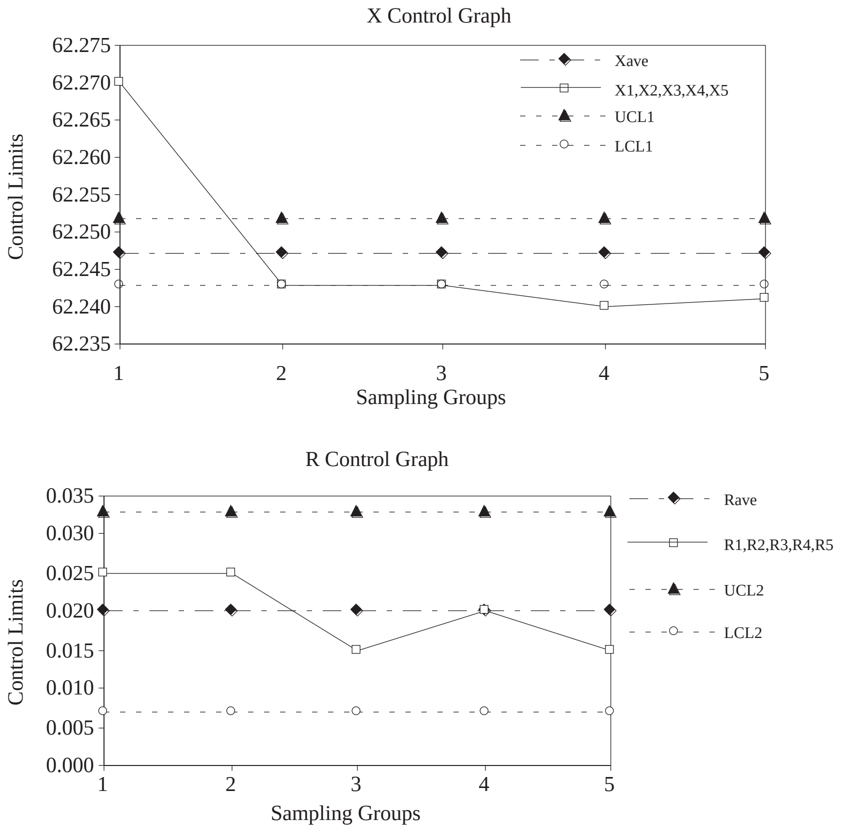

Figure 3. X-R graphic charts for the 62.250-62.500 mm diameter dimensions.

Using the data obtained from the statistical calculations in Table 3, X-R control graphics were prepared. In Figures 3-5, X-R graphics are presented and evaluated for the dimensions of 62.250-62.500, 56.410-56.490 and 63.512-63.550 respectively. For the 46.800 and 22.100 dimensions only X-R graphics are evaluated.

When Figure 3 is examined, it can be seen in the X-control graphic that the averages of the sample groups 2 and 3 approach the control limits, and that the averages of the sample groups 1, 4 and 5 exceed the control limits. Since some values stay within the control limits and some exceed the control limits, after stopping production the production line must be taken under control by resetting the machine tool and machining parameters. Furthermore, since the average of averages (X_{ave}) of the 62.250-62.500 dimension is smaller than the lower value of the dimension ($X_{ave} = 62.247 < 62.500$), it can be said that all the dimensions of the products manufactured are faulty.

When Figure 4 is examined for the 56.410-56.490 dimension, it can be seen that the average of sample group 2 approaches the upper control limit, and that the averages of sample groups 1 and 2 exceed the control limits. Thus, after stopping production, the production line must be taken under control by resetting the machine tool and machining parameters. Since the averages of production line, 4 and 5 are near the X_{ave} line, it can be said that production is normal. Furthermore, since the average of averages (X_{ave}) of the 56.410-56.490 dimension stays between the upper and lower values of the dimension ($56.410 < X_{ave} = 56.436 < 56.490$), even though no faulty product was manufactured lines 1, 2 and 3 must be brought under control.

When Figure 5 is examined for the dimension of 63.512-63.550, it can be seen that in the control graphic the average of sample group 2 approaches that the lower control limit and the averages of sample groups 4 and 5 exceed the control limits. Thus, after stopping production, the production line must be taken under control by resetting the machine tool and machining parameters. Since the averages of production lines 1 and 3 are near the X_{ave} line, it can be said that the production from these lines normal. Furthermore, since the average of averages (X_{ave}) of the 63.513-63.550 dimension stays between the lower and upper value of this dimension ($63.512 < X_{ave} = 63.539 < 63.550$), even though no faulty product was manufactured the process parameters of the production line brought reorganized and must be under control.

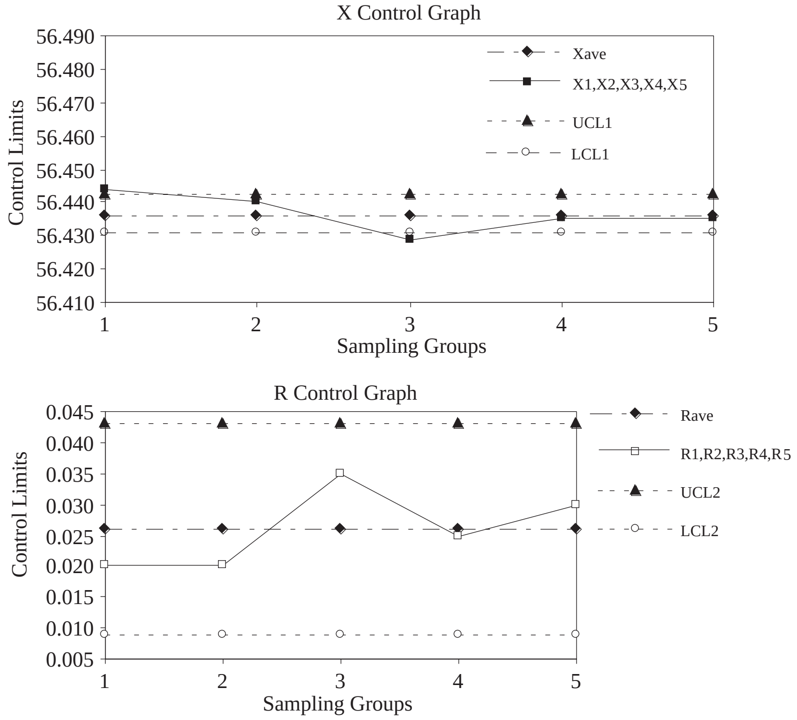

Figure 4. X-R graphic charts for the 56.410-56.490 mm diameter dimensions.

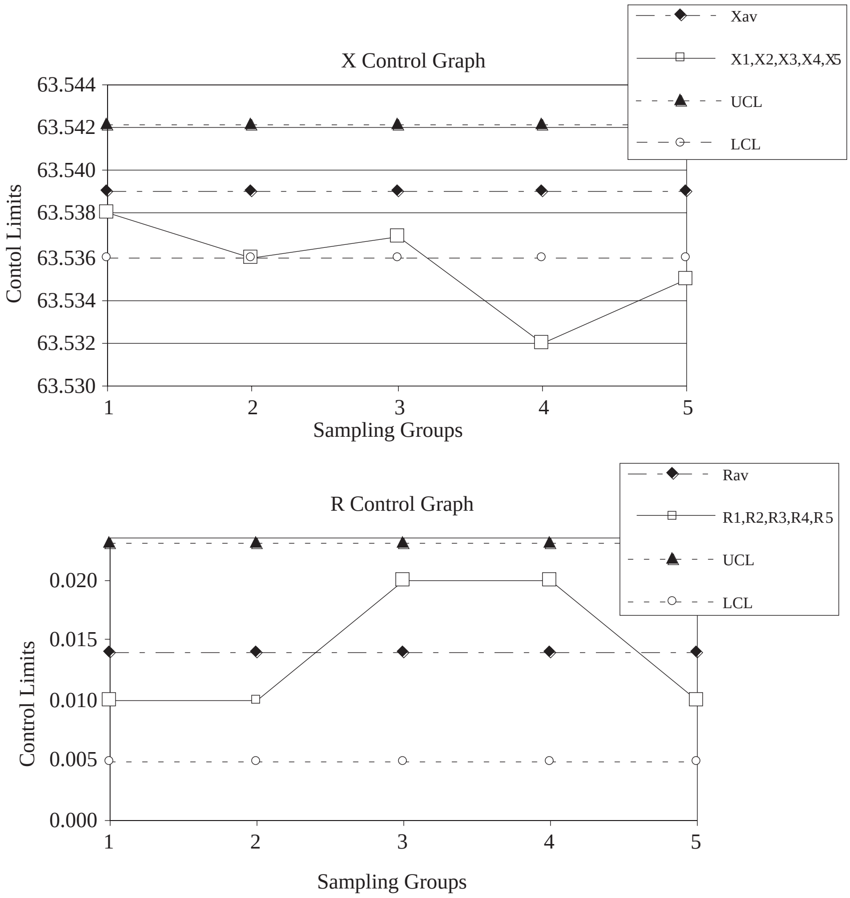

Figure 5. X-R Graphic Charts for the 63.512-63.550 mm diameter dimensions.

In the statistical work for the dimension of 46.800 with no value of tolerance indicated in the technical drawing, the average of the averages was 46.788. Since the upper and lower control limits were all below the given dimension, production had to be stopped urgently and radical changes made by revising the parameters of the machine tool and cutting tool, otherwise the products would be discarded. Since the measurement of 22.100 has no tolerance value, it is necessary for production to be made in the desired size. However, the average of the averages was 22.088 from the data obtained through the statistical work. The upper and lower control limits were between the tolerance values of the given dimension. The ascending and descending differences between the measurement groups showed that it was necessary to stop production and to rearrange the machine tool and the process.

The data from the statistical work showed that there were serious problems in production. From a general evaluation of the statistical work, it was determined that the process of production must be reorganized and that radical changes were necessary.

Corrective measures

Several changes have now been implemented according to the results obtained after the evaluation of the data. Some investigations must be made to eliminate the problems.

Since the company has two sections, a casting section and a machining section, a two-way investigation was carried out to eliminate the problems. The first investigation was in the casting section. The casting stages were examined and the processes in each stage controlled. The problems of surface roughness could not be eliminated in the machining workshop because the parts cast were taken out of the mould rather early. Although under normal circumstances the cast parts are left to cool for about 40-45 min, shell hardening occurs on the outer surface of the cast parts because the cast moulds are dismantled earlier, since there are not enough of them.

Likewise, shell hardening varies since the temperature of the workshop varies. This causes a problem with machining in the workshop. It was suggested that additional moulds be fabricated and moulds be dismantled in time to eliminate the problem.

The second investigation was carried out in the machining workshop where the pieces are formed through machining. The following work was undertaken to examine the machining factors affecting the surface roughness and the cutting parameters in the CNC machine tools in the machining workshop and to bring them under control.

1. When the last finishing operation is reached in the rough machining of the part, the importance of production cost increases. In rough machining and semi-finishing operations, machining sub-time and machining ratios determine economic factors. In the final machining operations, cutting speed (V), depth of cut (t), feed rate (F) and tool tip nose radius (r) affect the surface properties (Motorcu, 2001). Cutting speed is the distance taken by the cutting tool in millimeters per revolution or per minute during cutting. Recessions and protrusions on the surface are called surface roughness.

The evaluation of the surface roughness of the machined surface is caried out according to certain criteria. The surface roughness is determined according to the profile mean line in a distance chosen to a certain sample value and amount and in a direction vertical to the machining surface lines. Generally, a geometric profile is taken as a reference profile. The location of the profile mean line is determined so that the total areas staying over and under this line are equal. The maximum roughness according to the reference profile (Rt) and the average absolute value of recessions and protrusions according to the mean line (Ra) are used for the evaluation of surface roughness. For turned and milled parts Rt $\cong$ 3.5 x Ra (Motorcu, 2001). The cutting speed and feed values were changed to eliminate the problem of surface roughness occurring on the parts, so that the desired values of surface roughness could be achieved. However, this practice caused an increase in part production time. The desired surface roughness values of the dimensions with the problem of surface roughness were identified in the technical drawing (Table 3).

2. The parameters of cutting tools were examined to obtain the desired surface roughness values. The cutting tool codes used for the machining of each dimension were found from a cutting tools catalogue (e.g. NTK-HCDNGA443TN). Cutting tool tip radii were determined (e.g. r = 1.2, r = 1.2 mm) (Table 4). The values of the cutting tool tip radius were used for the calculation of feed rate (F).

3. The feed rates (F) in CNC part programs were calculated according to insert tip radius (r) and the desired surface roughness (Rt) criteria, and the spindle speeds (N) were obtained from cutting speed (V) values.

Feed rate (F)

$$F = \sqrt{8.Rt.r} \tag{7}$$

is expressed by this equation and its unit is mm/rev. Using the surface roughness values (Rt) in Table 3 and the cutting tool tip radius values (r) in Table 4 in equation 7, the feed rates were calculated as 0.163 mm/rev, 0.130 mm/rev and 0.130 mm/rev respectively for the dimensions of 56.410-56.490, 62.250-62.500 and 63.512-63.550.

Spindle speed (N)

$$N = \frac{1000.V}{\pi.D} \tag{8}$$

is expressed by this equation and its unit is mm/rev. The cutting speed used for cast iron was 100 m/min. According to the diameters (D) of the machined part, the spindle speeds (N) were calculated as 568 rev/min, 505 rev/min and 497 rev/min respectively for the dimensions of 56.410-56.490, 62.250-62.500 and 63.512-63.550.

The values calculated were discussed with the workshop chief and were found to be applicable. The operators using machine tools were informed about the work done.

Examining the process

Data must be evaluated to see what the results of the corrective measures are. In this way, process control is applied with a specific systemic approach. It is not enough for the features under investigation to be in the specification limits. The purpose is to obtain values close to the intended values and to reach zero faults, if possible.

As a result of the examinations, corrective measures to eliminate the problem were applied, remeasured and evaluated. After evaluation, it was found that production was within the desired tolerance limits. However, the shell-hardening problem continued, as the required waiting for molding was not applied

Table 3. Tolerance intervals, Ra and Rt values for diameters.

Diameters	Tolerance Interval	Ra Values	Rt Values
56.410 – 56.490	N7 (0.8-1.6)	$R_{a1} = 0.8/1000 = 0.0008$ mm	$R_{t1} = 0.0028$mm
62.250 – 62.500	N8 (1.6-3.2)	$R_{a2} = 1.6/1000 = 0.0016$ mm	$R_{t2} = 0.0056$ mm
63.512 – 63.550	N8 (1.6-3.2)	$R_{a3} = 1.6/1000 = 0.0016$ mm	$R_{t3} = 0.0056$ mm

Table 4. The codes and characteristics of the cutting tools used.

Diameters	Cutting tool used	Insert tip radius
56.410 – 56.490	NTK – HC2DNGA 443TN	$r_1 = 1.2$ mm
62.250 – 62.500	TAEGUTEC – CCGT09T304	$r_2 = 0.4$ mm
63.512 – 63.550	TAEGUTEC – CCGT09T304	$r_3 = 0.4$ mm

in the casting section. The required values of surface roughness were not achieved because the casting elements were not efficient enough and the medium-size firm did not have the financial resources to eliminate this problem. The parameters obtained through the calculations made on the machine tools where the statistical measurement differences were greatest yielded good results, and it was observed that the processed dimensions stayed within the limits of tolerance and exhibited normal distribution. The problem of surface roughness occurring as a result of the wear on the tip radius of the cutting tool and the problem of ovalness were eliminated.

Conclusions and Discussion

In this study, the aim was that a quality control system and statistical quality control could be established and operated in medium-size companies. To achieve this, statistical quality control was applied in a medium-size firm as a model. As a result of the work done:

1. The need for written documents in the elimination of the problem of quality in a sample product was stated and new additional documents were formed.
2. The process was defined and flowcharts prepared.
3. The quality control points in the process were identified, and samples were taken from certain processes by determining the size of sampling.
4. Statistical calculations were carried out on the sample and the measures to be taken to eliminate the problem were resolved by drawing control charts.
5. The points out of control were identified.
6. Suggestions for the improvement of the out-of-control process point were made and new values were evaluated after the application of the suggestions.
7. The problem of quality was eliminated within the limits of the firm's capabilities.

It was observed that the firm had implemented quality control measures. However, quality control was carried out in purchasing the raw material and at the end of the production process. Although statistical quality control is the most frequently used method in industry, as it is both reliable and economical, it is not used by this firm because there are no trained staff to apply it which is the biggest problem in the business. However, today quality is not regarded as the final inspection but a method used by anyone concerned during production. Consequently, it is necessary for the company to allocate resources for statistical quality control and to apply it widely and continuously.

Nomenclature

A_2	the factor for calculating the third sigma control limits according to the part number of the sample
D	diameters of machined parts (mm)
D_3	the factor for calculating the third sigma control limits according to the part number of the sample

D_4	the factor for calculating the third sigma control limits according to the part number of the sample
F	feed rate values (mm/rev)
LCL_1	the lower control limit for X graphic
LCL_2	the lower control limit for R graphic
N	spindle speed values (rev/min)
n_g	the number of measurements in each group
$R_{ave1}, \ldots, R_{ave5}$	the differences of each group
$r, r_1, \ldots, r_3$	insert tip radius (mm)
$R_{a1}, \ldots, R_{a3}$	surface roughness values (μm)
R_{ave}	the average of the differences
$R_{t1}, \ldots R_{t3}$	surface roughness values (μm)
t	depth of cut (mm)
UCL_1	the upper control limit for X graphic
UCL_2	the upper control limit for R graphic
V	cutting speed values (m/min)
X_{ave}	the average of the averages
X_{ave1} ,..., X_{ave5}	the average of each group

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