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APPLICATION OF SPC METHODS IN FURNITURE PRODUCTION

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Abstract

After the social and economic changes in Hungary, the Hungarian companies had to face the requirements of the highly developed market economy. To preserve their competitive position many of them have introduced quality systems. Success in the long, however, needs the quality controlling of previously neglected production processes which have a determining influance on product quality. In company life, the lack of experiences and experts leads to several problems in Hungary. The article demonstrates these difficulties by analyzing the production process of a furniture producing company.

Keywords: SPC, measurement system, repeatability and reproducibility, process capability.

As a result of the well-known Eastern European social and economic changes the decisive majority of Hungarian companies suddenly lost their markets in the early 90s. Accommodating to the new situation the companies tried to sell their products on new, solvent, especially Western European markets. On these markets, however, the companies have to meet much higher quality requirements than before. Facing the great market competition, following the European trend – hardly lagging behind the application which began in Western Europe in the late 80s – also in Hungary more and more companies began to introduce the quality assurance system based on ISO 9000 standards. Although regarding the introduction of quality assurance, Hungary does not significantly lag behind, this few year difference indicates significant difference in development. While the companies present on the developed markets are able to produce high quality products, the competitiveness of Hungarian products is still not sufficient just because of poorer quality.

The quality of the product in addition to construction and the quality of the used materials mainly depends on the production process and conditions [1] therefore good quality product can be obtained only in the short run, mostly by chance without the comprehensive knowledge and regulation of the production process, the occurring failures and disorders. In the communist economies, the companies did not place, because of the secure and protected markets, due emphasis on the processes, systematic detection and elimination of failures, in this way on the improvement of the product, on the reduction of losses that is on quality regulation.

The appearance of quality assurance systems following quality regulation is the next phase regarding quality and the basic goal is that the company could produce high quality reliably and on the long run and the market should adopt it. Therefore the establishment of the quality assurance system does not guarantee automatic quality improvement of the product. Consequently most of the Hungarian companies should take steps to improve the product quality in addition to establishing the quality assurance system. To achieve adequate quality, traditional quality control systems are insufficient. the quality capability and regulation of the whole production process is to be improved and it can be achieved by comprehensive, full-scale application of the statistical methods.

The above facts indicate that in Hungary, in addition to the introduction of the quality assurance system. effective quality regulation is also to be developed. Greater attention should be paid to items [2] of ISO 900x which directly or indirectly are related to the establishment of the quality capability and regulation of the processes.

In the early period of quality assurance in Hungary several managers thought that simultaneously with the introduction of the quality assurance system. in this way the market and economic problems of the company will be solved. Many have become disappointed but as the system is spreading recognise more and more the above duality and simultaneously with introduction the survey of the quality performance of the machines and production processes begin. This, however. often causes difficulties for the companies since as we have already mentioned, the analysis requires first of all mathematical, statistical methods and in our experiences. qualified experts in this field are few. Although the tools and methods to be used are not new, articles and studies on their use, application, conditions of their application and introduction of real industrial examples are rarely published. In this way it seems to be a new field for experts at companies. Extensive use of the methods, analysis and surveys based on facts can significantly help the managers to make the right decisions in addition to improve quality.

The following case study therefore introduces a characteristic application of statistical methods and tools through the quality capability and regulation of a producing machine in a furniture factory demonstrating that statistical analysis does not necessarily mean the application of the most complicated mathematical procedure, often a graphical figure is sufficient to detect the failures and to characterise the processes. The experiences show that the following case and the results of the analysis can be regarded as typical. several companies struggle with similar problems.

The test was carried out at a company producing office furniture. The company is trying to export an increasing part of its products primarily developed, to western markets. Experiencing a continuous increase of quality requirements and taking the demands of developed markets into account, the company management decided to introduce a quality assurance system in accordance with standard ISO 9001 which is being set up just now. In course of introduction they soon recognised that the establishment and operation of the quality assurance system in itself does not automatically lead to better quality. In this way they pay great attention to the analysis of machines and production processes and to the regulation of processes.

As a result of the work carried out so far – failure statistics and ABC analyses, test of machine conditions, etc. – list of weak points, failure maps, causality analyses, etc. are ready. Since previously they mainly dealt with characteristics measurable on machines (e.g. radial misalignment of tool axis, plane failure of machine table, etc.) no or little statistically supported information is available on the parameters measurable on the products which basically determine quality. The test therefore continued with the statistical survey of production processes, definition of quality capability and regulation to obtain adequate data for the definition of the necessary interventions and for the elaboration of control and work instructions. In the following the application of statistical methods, procedures are introduced with the machine capability test of a key equipment in the production process.

The tested equipment is an 8 headed planer where the component (50×60 mm cross section and 50 cm long rod) guided on a long table runs with continuous feed while rotating tools with straight and profile edges on the bottom, on both sides and on the top develop the necessary profile. To characterise the accuracy of the working process – also with regard to the parameters determining the subsequent processes and the quality of the end product – the factory experts determined two critical sizes on the component. They are 42 mm, the greatest length and 55 mm, the height (*Fig. 1*).

We have already mentioned that so far the factory has mainly tested the technological parameters measurable on the machines, they had no regular measurement method for the characteristics measurable on the product which guarantees the necessary accuracy with data. Obviously the accuracy of the measurement system is not identical with the accuracy of the measurement device. Accuracy, in addition to the measurement device, is influenced by the environment, the applied method, the measuring person, etc. Therefore, before machine capability test repeatability and reproducibility (R&R) analysis [3] was carried out to control the accuracy of the measurement method.

1. R&R analysis

Repeatability of a measurement method means that in principle we should always get the same result if the same person measures the same size sev-

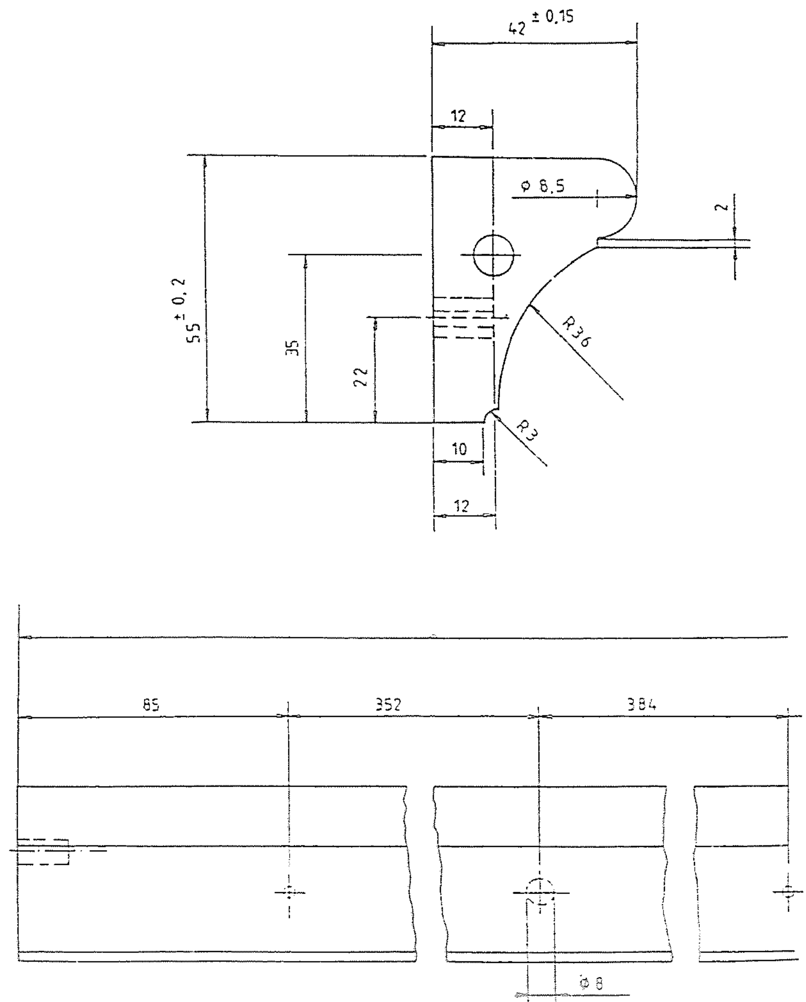


Fig. 1. Profile drawing of the tested component

eral times. Repeating the measurements under the same conditions (person, conditions, measuring device, measurement method, etc.) will of course not give exactly the same result, the measured values fluctuate and differ from each other to smaller or greater extent. This variability is a feature of the measuring system and its magnitude is a component of the accuracy of the measuring system. Another basic requirement of the good measurement method is that the measurement result should be independent of the person carrying out the measurement. If different people measuring the same component by the same measuring device get identical (or practically almost identical) value, the measurement method can be reproduced. The above two features – that is reproducibility and repeatability – influence the accuracy of the measurement system. The magnitude of these components can be estimated by planned experiments and comparing them with the extent of the fluctuation among the measured components, the accuracy of the measurement method or the magnitude of the failure caused by the measurement system can be evaluated.

The measurements were carried out by three persons for the test with a 0.01 mm digital callipers gauge. 10 components have been chosen and all of them measured 55 mm height at a given point of the ten components. The measurements were repeated twice, in this way everybody measured the same point three times. So altogether ninety data were available for the evaluation. *Table 1* shows the descriptive statistical processing of the measured values by persons and components.

Table 1. Descriptive statistical results according to persons and components

Descriptive statistical results grouped by persons $\bar{\bar{X}} = 55.265$; $S^* = 0.049133$					
Name of the persons	Average	Difference	Minimum	Maximum	Standard deviation
K. Zsolt	55.24400	−0.021000	55.14	55.30	0.039793
O. Feri	55.29067	0.025667	55.18	55.44	0.054957
S. Zsolt	55.26033	−0.004667	55.14	55.33	0.040555
Descriptive statistical results grouped by components $\bar{\bar{X}} = 55.265$; $S^* = 0.049133$					
Number of the components	Average	Difference	Minimum	Maximum	Standard deviation
1	55.27444	0.009444	55.21	55.34	0.042459
2	55.28677	0.021667	55.23	55.33	0.029580
3	55.26556	0.000556	55.18	55.31	0.036094
4	55.29444	0.029444	55.22	55.44	0.064053
5	55.25444	−0.010556	55.18	55.29	0.033582
6	55.26000	0.005000	55.23	55.29	0.025000
7	55.30000	0.035000	55.24	55.43	0.060415
8	55.26111	−0.003889	55.19	55.29	0.033333
9	55.25889	−0.006111	55.14	55.30	0.046488
10	55.19444	−0.070556	55.14	55.26	0.036094

In the heading of the tables the average and experienced standard deviation of all the data are given. The column of difference shows the difference between the average of the given line (person or component) and the average of all the data. In general it is difficult to recognise the characteristics by comparing several numbers in tables therefore graphical plotting is useful. First let us see what is the difference among the people carrying out measurements at the measurement points (*Fig. 2*).

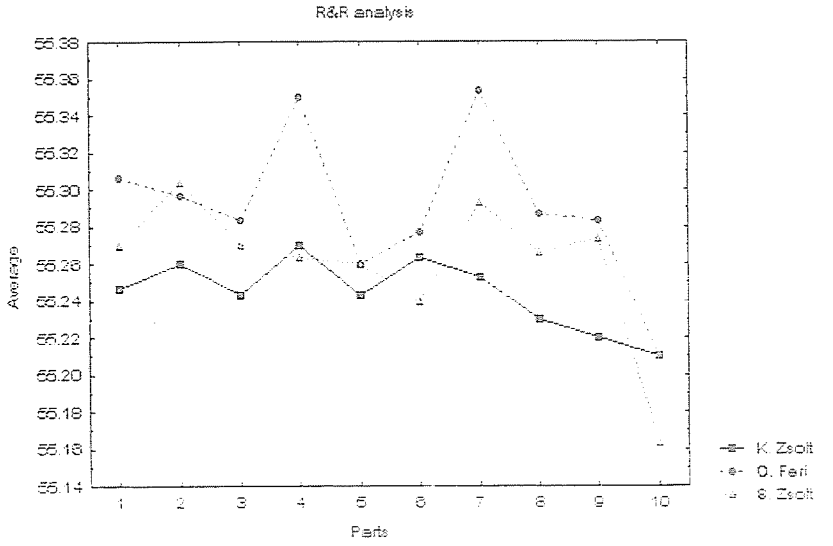


Fig. 2. Averages of measurements at individual measurement places

The result is not too encouraging since differences seem to be quite great at 'first sight'. The figure clearly shows that person 2 (O. Feri) systematically measures greater value than the others. Out of the 10 points he measured slightly lower value only at one point (2). Neither are the high values measured at points 4 and 7 'too reassuring'. The 'pattern' of the lines also provides additional important information. If the measurement can be reproduced well the difference among the lines is little and the shape of the lines should be similar. This is unfortunately only partly true of our results because only sections of the curves are similar. It is clear that in the case of the first 3 points the measurement of K. Zsolt and S. Zsolt, at points 2 and 6 those of K. Zsolt and O. Feri then from point 6 those of S. Zsolt and O. Feri are similar. In the case of perfectly repeatable and reproducible measurement system the figure would show only one line since the measurements results would be independent of the persons and repetitions.

Let us see if the former higher data really indicate the changes of measurement conditions. If the data come from identical multitude, one data will not or most probably will not fall outside the intervention limits when they are plotted on control cards. *Fig. 3* shows the plotting of data on extent card grouped according to persons.

The average extent is 0.6 mm and the upper intervention limit – marked by dashed line – is 0.154 mm. It is clearly shown that one data is outside the limit and another one is very near the limit. It indicates the irregularity of the measurement process. These measurements significantly differ from the other results (statistically: do not come from identical multi-

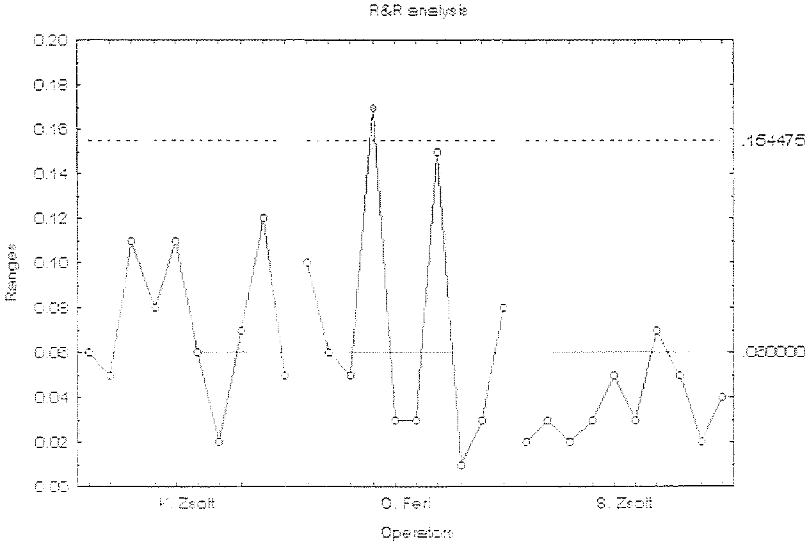


Fig. 3. Plotting data on range card

tude) that is they are the results of some effect or failure (for example: the measuring person is not experienced enough, reading error, insufficient fitting of the measurement device on the surface to be measured, etc.). At the same time the measurements of S. Zsolt are clearly very good, fluctuation is small. It is worth seeing how he handles the measuring device, how he carries out the measurements and others should practice that method and the company should apply it.

The analysis so far can be summarised in one figure and from it conclusions can be drawn for the reproducibility and repeatability of the measuring system (*Fig. 4*).

The points in the figure indicate the individual measurements, that is the difference of the individual measurements from the average of the data measured on the given component. Let us see the first (upper left) point (the value is −0.004). This point is the difference of one measurement of K. Zsolt on the first component (55.27 mm) from the average of all the data measured on this component (55.27444 mm). The other two points linked by vertical line indicate the results of K. Zsolt on the same component. The points linked by the next vertical line are the data of K. Zsolt's measurements on the 2. component, and so on. Since the vertical line links the results of one person measured on the same component, the length of the line indicates accuracy, repeatability. The measurements of the individual persons are in a rectangle. The dashed line in the rectangles indicates the average of the individual persons and the height of the rectangle indicates the variability of the measurements. In the case of perfectly repeatable measurements all the

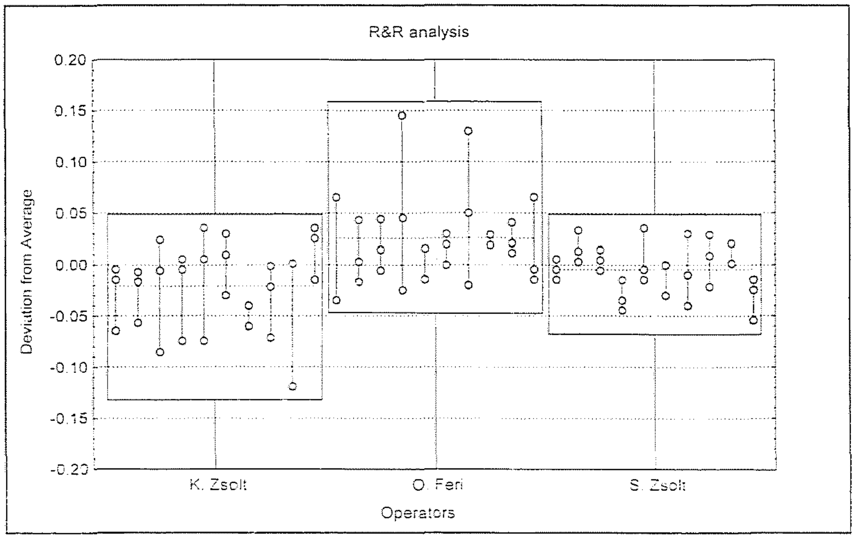


Fig. 4. R & R analysis

measurements on one component would give identical result, there would not be vertical line and in the case of perfect reproducibility the measurements of the operators would be identical and consequently all rectangles would be identical and their average (dashed line) would be 0.

Now let us see our results. As it is visible the height and the position of the 'boxes' are different which refers to difference among the measuring persons. The dashed lines indicating the average of the rectangles (that is the operators) – except for S. Zsolt – differ from 0. The difference, however, does not seem to be great at least compared to the height of the 'boxes' and the length of the vertical lines. This indicates that the accuracy of the measurements (more precisely their inaccuracy) is determined by uncertainty coming from repeatability. To judge the suitability of the measuring system, we should know how big the error is comparing to the total fluctuation of the process. The size can be concluded from the figure. Let's see S. Zsolt's measurements. It is clear that the height of the rectangle is determined by the difference among the components and compared to the height, the length of the vertical lines is relatively small. In the case of the other two operators the length of the lines, however, can be compared to the height of the 'boxes' that is the proportion of failures coming from repetitions is bigger in the total fluctuation.

The comparison of the magnitude of fluctuation can determine the proportion of failures numerically. Resulting from the type of the test, to estimate the extent of fluctuation caused by the failures, usually the standard deviation estimated from the extent of the patterns and not the corrected experienced standard deviation is used [3]. If extents come from identical distribution (multitude) – on the extent card all the data are between the intervention limits – standard deviation can be estimated from the average of extents by formula ($\bar{R}$) the $\bar{R}/d_2$. (Constant value of d_2 is in the tables). If extent was calculated from the difference between measurements, this standard deviation (σ_{rep}) is the estimation of the failure of repeatability and the standard deviation estimated by experienced standard deviation calculated from all the data (σ_t) contains both the fluctuation of the process and the measurement error. The failure of repeatability ($rep\%$) then can be determined by the following formula: $rep\% = 100\frac{\sigma_{rep}^2}{\sigma_t^2}$.

The previous analyses showed that one point on the extent card was outside the intervention limit. Ignoring this measurement the next greatest extent is also above the upper limit when the card is redrawn. Except for this point already all the points are under the limit, in this way calculations can be carried out.

The average of extent: $\bar{R} = 0.052857$ mm. $d_2 = 1.693$

Estimation of the standard deviation: $\sigma_{rep} = 0.052857/1.693 = 0.031221$ $\sigma_{rep}^2 = 0.031221^2 = 9.7475 \cdot 10^{-4}$

Estimating the standard deviation characteristic of the process by the corrected experienced standard deviation $\sigma_t = 0.04117$, $\sigma_t^2 = 0.001695$

The error of repeatability:
$Rep\% = 100(9.7475 \cdot 10^{-4}/0.001695) = 57.5\%$.

Although clear decision can be made on the measurement system on the basis of repeatability we also introduce the definition of the error of reproducibility. If extent is calculated from all the measurements on one component (Part 2 of *Table 1*) the standard deviation estimated from their average ($\sigma_{rep+repro}$) contains fluctuation caused both by people (reproducibility) and difference among measurements (repeatability). Since standard deviation characteristic of repeatability is already known standard deviation of reproducibility can be calculated (σ_{repro}) and from this the error of reproducibility ($Repro\%$). Data of components 4 and 7 were already excluded from the data base during the calculation of repeatability, in this way they are ignored also this time. Plotting the other data on control card, there is no value outside the intervention limit therefore standard deviation can be estimated from the average of extent.

Average of extent: $\bar{R} = 0.11375$ mm, $d_2 = 2.97$

Estimation of standard deviation: $\sigma_{rep+repro} = 0.11375 \;/\; 2.97 = 0.0383$

$\sigma_{rep+repro}^2 = 0.001467 = \sigma_{rep}^2 + \sigma_{repro}^2$

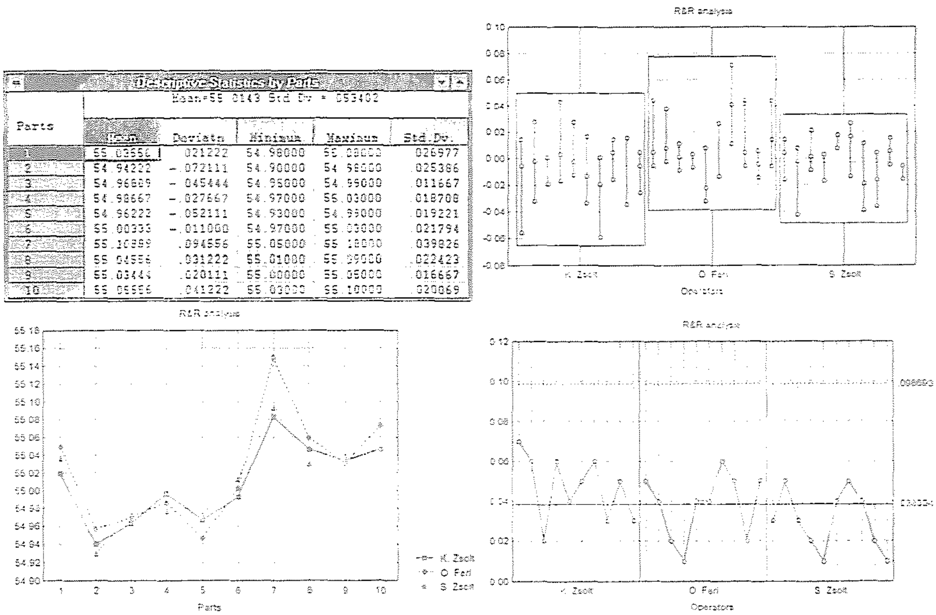
$\sigma_{repro}^2 = 0.001467 - 9.7475.10^{-4} = 4.921.10^{-4}$

The error of reproducibility: $Repro\% = 100\, 4.921.10^{-4}/0.001695 = 29.0\%$.

In this way our 'guesses' are proved also numerically. The results support the earlier assumptions relating to the analysis of *Fig. 4*. The error of reproducibility is really smaller than the error of repeatability, about half of it but it is still quite big. This measurement method is not suitable to analyse machine capability. The error of measurements is too big, the data from machine capability tests would be highly unreliable. There is no exact specification for the size of the acceptable error, it depends on the tested characteristic, the measurement conditions, possibilities, the quality requirements and naturally on costs, etc. As a general requirement, however, it can be stated that the measurement system can be regarded as good if the total measurement error is not bigger than 10% and is still acceptable if the error is below 20%. In our case only the error of repeatability is over 50%.

Another measurement procedure is to be elaborated. The conclusion from the measurement method is that repeatability is wrong not because of the measuring device but it comes from the interaction of the measurement device and the workpiece. According to our assumptions the two facts – the surface can be pressed slightly because of the hardness, more precisely softness of the wood and the supporting surface of the measuring device is narrow – result in subjectivity in reading the measuring device therefore it measures a distance between not perfectly parallel surfaces. In our opinion subjectivity, in this way the measurement error can be greatly reduced by using other, for instance foot-type thickness gauge, by precise definition of the measurement and practising the use of the measurement device. In the case of measurement with foot-type thickness gauge the workpiece can be placed on greater surface more precisely, the jaw is pressed by a spring on the surface to be measured by constant force and reading is more reliable since the contact between the workpiece and the measuring device is more stable. Since the operator does not hold the measuring device in hand, it does not move and the numbers do not 'run' on the display. To prove these assumptions about the new measuring device and measurement method the repeatability and reproducibility tests were repeated. The graphs used for the analysis so far are in *Fig. 5*.

As the figures indicate the test methods have not been changed, the same three persons measured 10 components three times. In the case of the repeated test there was no possibility to measure the same workpieces, in this way 10 new part samples were taken. The figures indicate that the reproducibility and repeatability of the measurements have improved. Carrying out the calculations, the error of repeatability is $Rep\% = 17.97\%$, that of reproducibility is $Repro\% = 1.75\%$. The two together $\approx 20\%$, that is carrying out measurements in this way the extent of measurement error is just acceptable.



Descriptive Statistics by Parts

Mean=55 0143 Std Dv = 053402

Parts	Mean	Deviatn	Minimum	Maximum	Std.Dv.
1	55.03556	.021222	54.98000	55.08000	.026977
2	54.94222	-.072111	54.90000	54.98000	.025386
3	54.96889	-.045444	54.95000	54.99000	.011667
4	54.98667	-.027667	54.97000	55.03000	.018708
5	54.96222	-.052111	54.93000	54.99000	.019221
6	55.00333	-.011000	54.97000	55.03000	.021794
7	55.10889	.094556	55.05000	55.18000	.039826
8	55.04556	.031222	55.01000	55.09000	.022423
9	55.03444	.020111	55.00000	55.05000	.016667
10	55.05556	.041222	55.03000	55.10000	.020069

Fig. 5. Results of new R & R analysis

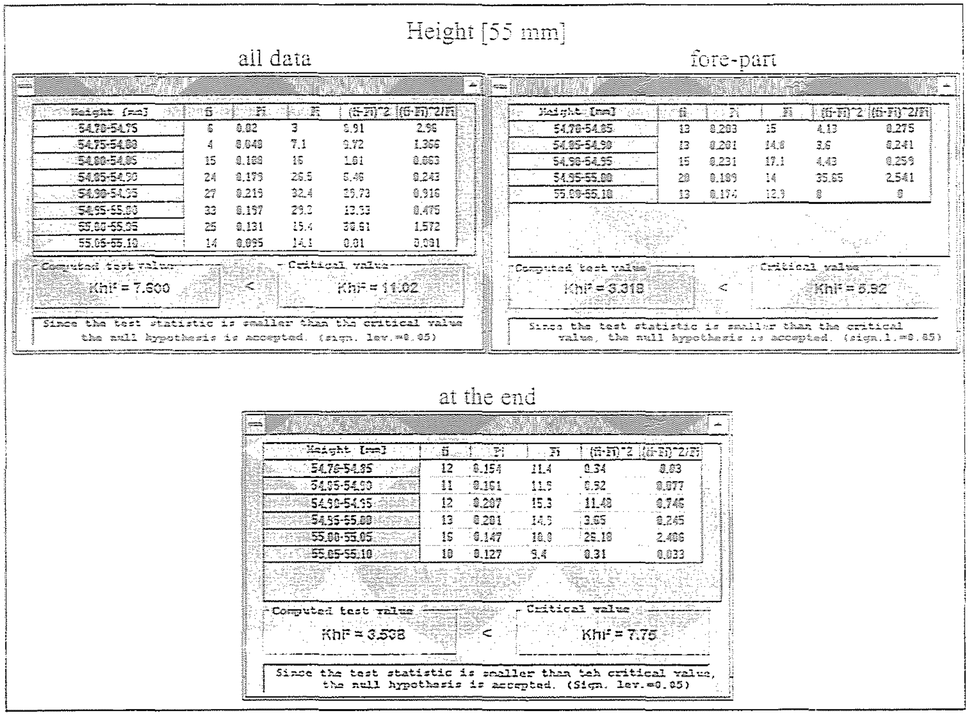
2. Machine Capability Test

The process or machine capability tests indicates the character or extent of disturbances affecting the production process. Disturbances have two main groups: the dangerous (regular) errors and accidental errors [3, 4]. If definable disturbances (regular errors) are eliminated from the production process or operation we can say that the production process is stable (regulated). In connection with the stabilised operation or process, however, the question is raised whether it can meet the customers' expectations. In other words whether the capability of the process, operation or machine is within the specifications. Quality capability analysis is used to answer this question. Quality capability analysis in fact has two types: machine capability and process capability analyses. Statistical methods used for machine and process capability analyses are in fact identical. The difference between them is how the measurement results are obtained.

Machine capability analysis is carried out on one machine or operation. The measured parameters (characteristics) which are used to measure capability should indicate only the changes which are caused by the machine or the operation and not those which are caused by another part of the process (e.g. machine operators, procedures, materials or the environment). During machine capability test we try to reduce or hinder the changes of these factors (e.g. work is done by the same machine operator, in the same shift with the same input material, etc.). In addition to ensuring homogeneous production conditions, data collection in relatively short period of time is also useful for minimising the changes of factors. [1]

Since the goal now is to survey machine capability, sampling was carried out according to the above principles. The expert operating the planer following the change of tools (putting newly sharpened tools) adjusted the machine according to specifications. The adjustment of the machine is checked by specimens and if necessary the positions of the axes of the tools are adjusted. It is carried out until he deems the adjustment of the machine 'perfect'. Following the new adjustment 75 workpieces were taken out of continuous production one after the other during sampling.

We have already mentioned that during machine capability analysis we try to accomplish data collection in the possible shortest time. In our case it becomes possible since the machine makes the profile in *Fig. 1* on both ends of the workpiece, in this way we can have two measured values about a workpiece and the number of samples necessary to get adequate number of data can be reduced. The data from the two ends of the workpiece, however, can be handled uniformly only if we are convinced that the data come from



Height [55 mm]

all data

Height [mm]	fi	pi	Fi	(fi-Fi)^2	(fi-Fi)^2/Fi
54.70-54.75	6	0.02	3	9.91	2.96
54.75-54.80	4	0.048	7.1	9.72	1.366
54.80-54.85	15	0.108	16	1.01	0.063
54.85-54.90	24	0.173	25.5	6.46	0.243
54.90-54.95	27	0.219	32.4	29.73	0.916
54.95-55.00	33	0.197	29.2	13.33	0.475
55.00-55.05	25	0.131	19.4	30.61	1.572
55.05-55.10	14	0.095	14.1	0.01	0.001

Computed test value: KhI² = 7.600 < Critical value: KhI² = 11.02

Since the test statistic is smaller than the critical value the null hypothesis is accepted. (sign. lev.=0.05)

fore-part

Height [mm]	fi	pi	Fi	(fi-Fi)^2	(fi-Fi)^2/Fi
54.70-54.85	13	0.203	15	4.13	0.275
54.85-54.90	13	0.201	14.8	3.6	0.241
54.90-54.95	15	0.231	17.1	4.43	0.259
54.95-55.00	20	0.189	14	35.65	2.541
55.00-55.10	13	0.174	12.9	0	0

Computed test value: KhI² = 3.318 < Critical value: KhI² = 5.92

Since the test statistic is smaller than the critical value, the null hypothesis is accepted. (sign.l.=0.05)

at the end

Height [mm]	fi	pi	Fi	(fi-Fi)^2	(fi-Fi)^2/Fi
54.70-54.85	12	0.154	11.4	0.34	0.03
54.85-54.90	11	0.161	11.9	0.92	0.077
54.90-54.95	12	0.207	15.3	11.40	0.746
54.95-55.00	13	0.201	14.9	3.65	0.245
55.00-55.05	15	0.147	10.0	25.10	2.406
55.05-55.10	10	0.127	9.4	0.31	0.033

Computed test value: KhI² = 3.538 < Critical value: KhI² = 7.75

Since the test statistic is smaller than teh critical value, the null hypothesis is accepted. (Sign. lev.=0.05)

Fig. 6. Fitting test – 1

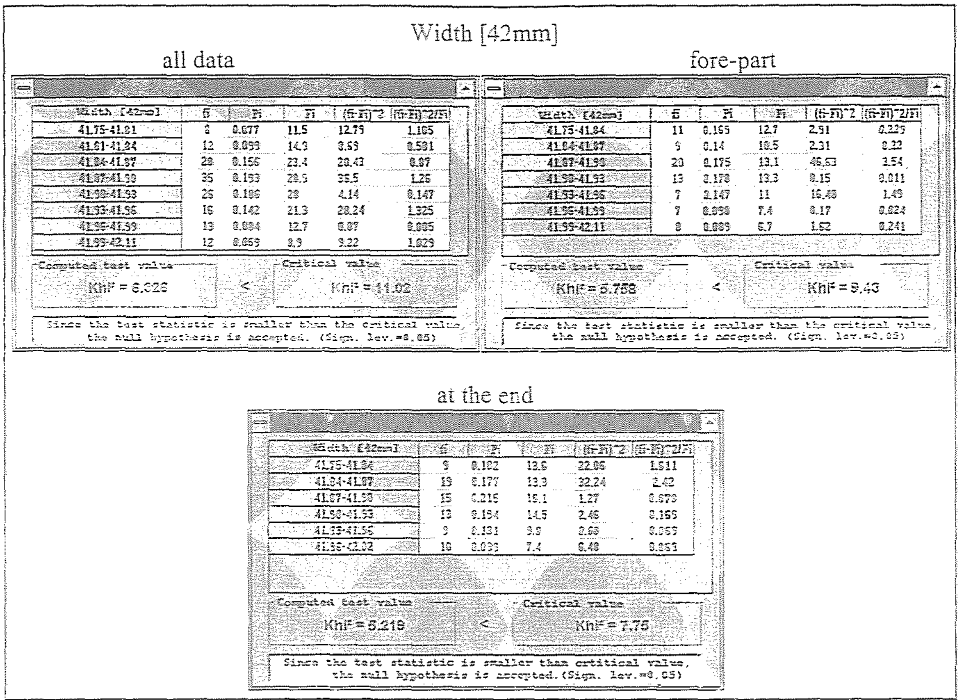


Fig. 7. Fitting test – 2

identical multitude – that is assuming normal distribution, from distribution of identical expectable value and standard deviation. Therefore, the test of the production process should begin with this control.

First let us see whether the data come from normal distribution. *Figs. 6* and *7* indicate the results of fitting tests carried out by k^2 test.

It is clear that on 95% reliability level, the origin of both characteristics from normal distribution is acceptable. It is true not only of all the 150 data but also for the 75–75 data measured at the front and the end for the rod (the data measured at the front are in partial distribution 1 and the ones at the end in partial distribution 2). The results of the tests indicate that there is/are no dangerous error(s) in the process which would spoil normality. Continuing the test let us compare the standard deviations first and if they do not differ let us control the agreement of average. To test standard deviations F test can be used. The final result of the calculations (also on 95% reliability level) is in *Fig. 8*.

In the case of the two tested characteristics the standard deviations and the average are identical, that is there is no difference between the data measured at the front and the end, they come from identical basic multitude. Therefore, to analyse machine capability, the two data aggregates can be

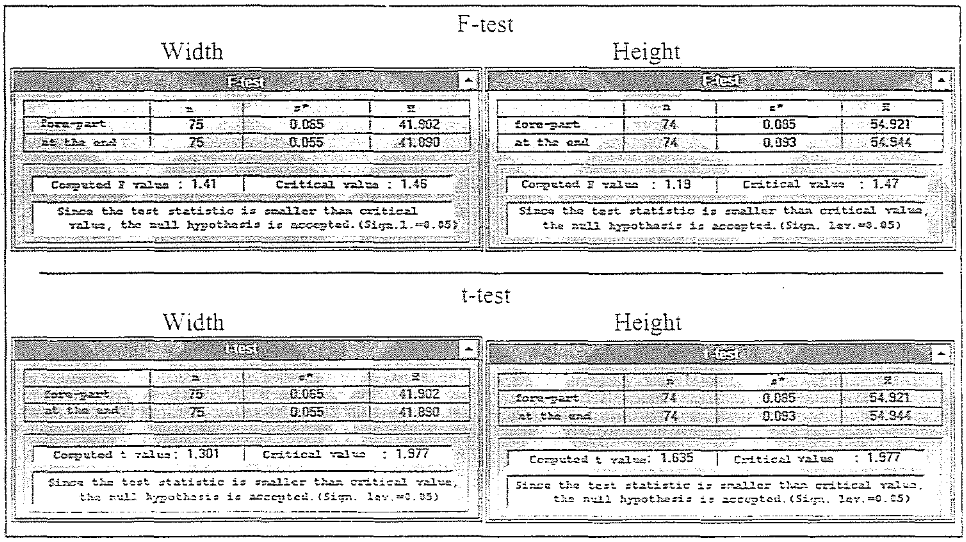


Fig. 8. Results of F- and t-test

combined. In this way there are 150–150 data on both characteristics which is sufficient to carry out machine capability analysis.

In course of quality capability analyses the fluctuation characterising the process or the machine can be compared with tolerance. The simplest way of comparison is graphical plotting of the data. The data can be plotted both on histogram or line diagram [5]. *Fig. 9* shows plotting by line diagram.

Tolerance: for width 42 ± 0.15 mm, height 55 ± 0.2 mm. We can see that the process is not in the middle, the values of both tested parameters fluctuate between the lower tolerance and nominal value. Therefore the instructions for machine adjustments are to be revised. The extent of fluctuation also seems to be great compared to the tolerance field. Several data got outside the lower tolerance and fluctuation 'fills' the areas among the limits. On this basis we can conclude that the machine capability is not satisfactory, the production operation cannot meet the given specifications. The values of quality capability indexes also confirm this assumption (*Fig. 10*).

Since now we are carrying out machine capability analysis values of C_m and C_{mk} are authoritative for us. A minimum requirement for capability index is to achieve value 1 since $\pm 4\sigma$ limits were used for their calculation as the basis of comparison [2,3]. We can see that in our case this expectation has not been met with any of the parameters. Even the values of indexes C_m are smaller than one and because of the shift of the mean value, values of C_{mk} are even smaller.

Another, relatively simple method of capability tests is the Gauss paper

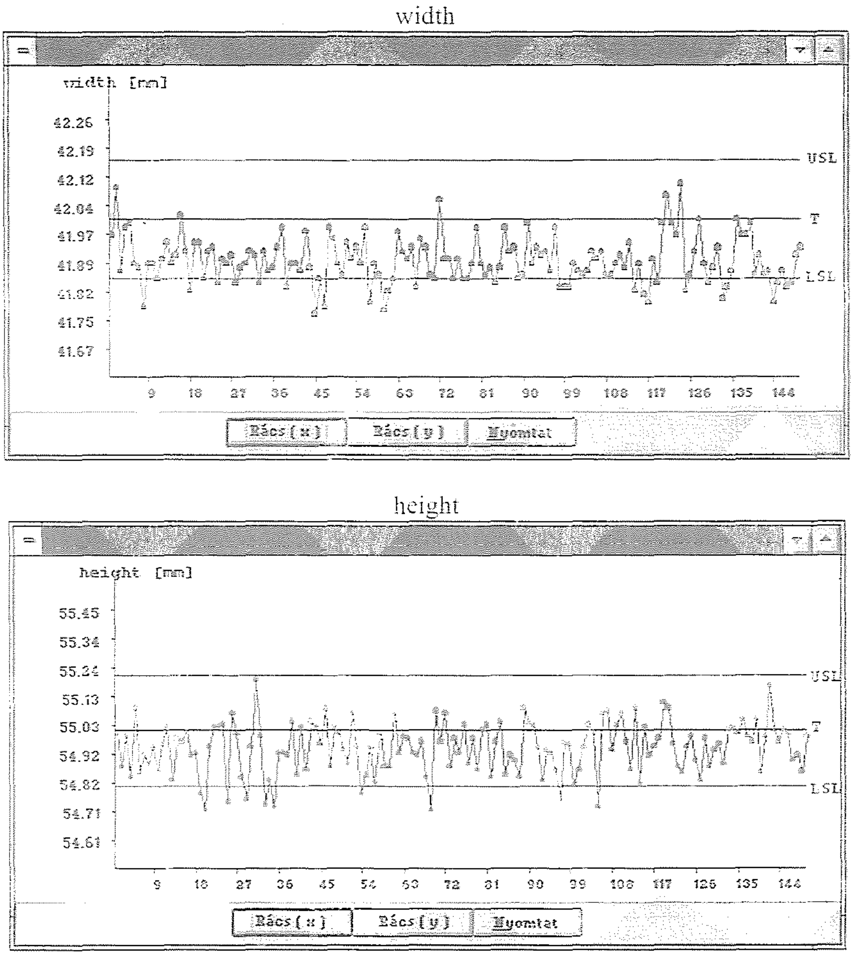


Fig. 9. Plotting data on line diagram

plotting [3]. This is also an easy, graphical analysis method, the essence is that the data are plotted on so-called normal paper or Gauss paper and drawing tolerance, it graphically shows how the straight line fitted on the points – representing theoretical distribution – is compared to the limits. *Figs. 11* and *12* show the plotting of the two characteristics we tested on Gauss paper.

Let us see first the location of the points. If the data come from normal distribution, the points plotted give a straight line. The character of the distribution was already tested by a statistical test but the figures indicate that the points in fact are along a straight line. The comparison of the

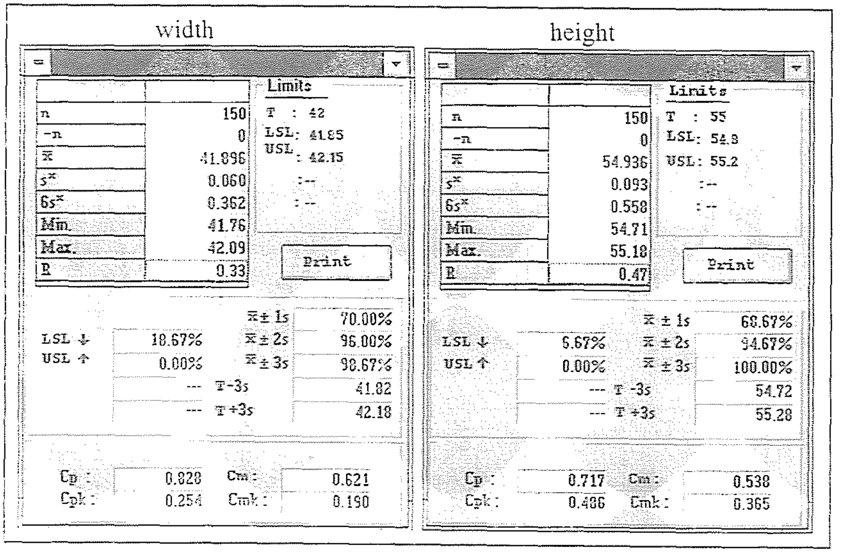


Fig. 10. Statistical data

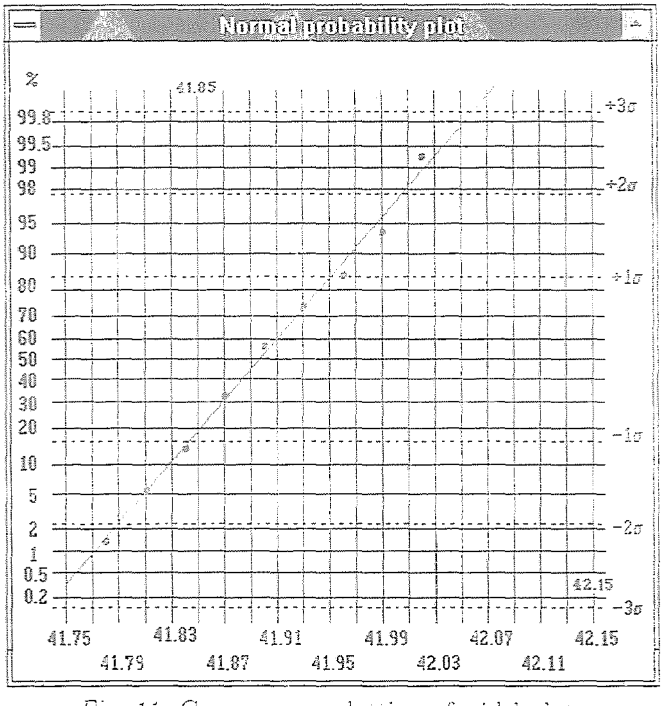


Fig. 11. Gauss paper plotting of width data

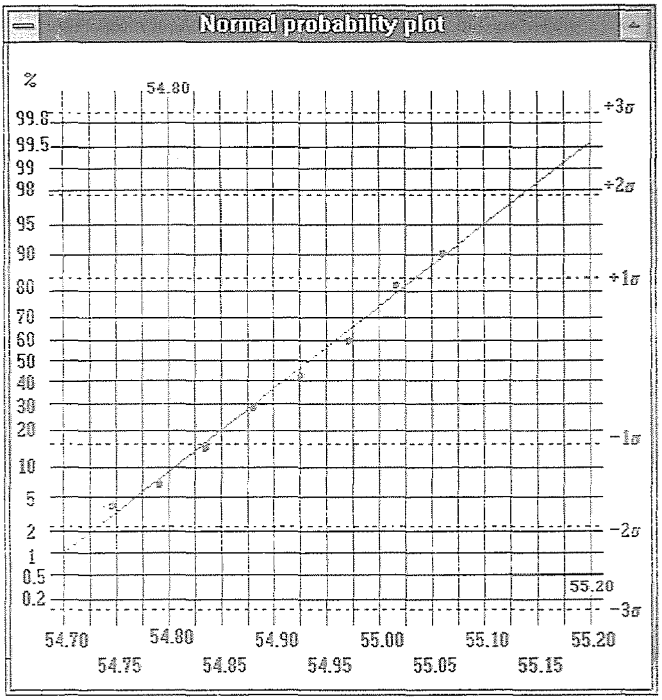
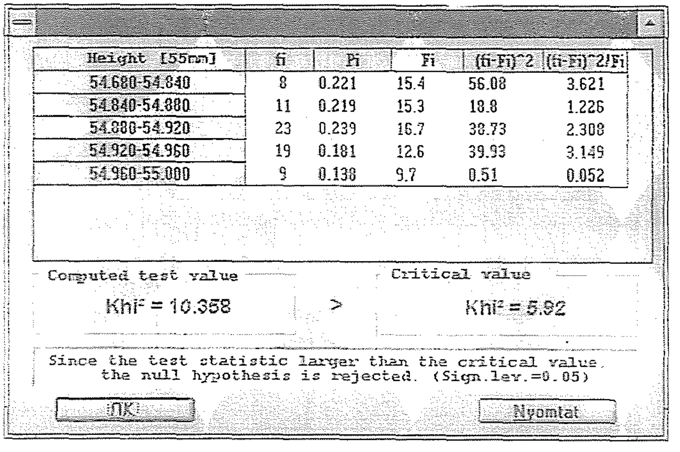


Fig. 12. Gauss paper plotting of height data

position of the straight line with the tolerance will lead to results identical with our conclusion that is the machine does not meet the specifications regarding quality capability. In the case of suitable machine capability the straight line should 'fit into' the $\pm 4\sigma$ range before the intersection of the tolerances. It is fulfilled neither in the case of width, nor height, in fact they 'fit' not even into the $\pm 3\sigma$ range. Both characteristics show that the mean value (the intersection of the 50% line and the straight line) is nearer to the lower limit which indicates the shift of the process. Consequently, the probability of falling below the lower limit – which is clearly indicated in the figure, at the intersection of the straight line and the limit – is big. In the case of width it is about 20% while in the case of height is smaller, about 9%. Obviously, the shift of the process has primary role in the great probability of falling outside the limit. The figure shows that following the elimination of the adjustment error – if the straight line is shifted to the middle – the production still does not meet the expectations, the probability of falling outside the limit (now above the upper limit) is over 4% in the case of height and about 1% for width and they today, taking into account quality requirements, are regarded as high.

At this phase of the analysis we have to raise the issue of measurement methods and tools. The shift of the process – that is the location of the mean value under the target value – is related to the use of the callipers gauge applied to check the adjustment. The measurement of the distance between two opposite. wide and narrow surfaces is uncertain especially if they are not exactly parallel. In this way using a callipers gauge there is a great chance that the operator will measure greater than the real distance. It seems to be the case in the case of data recording with measuring gauge following adjustment.

The probability of falling outside the tolerance in the case of good adjustment requires the supervision of the machine condition since the type of machine should ensure great accuracy in the case of good condition.



Height [55mm]	fi	Pi	Fi	(fi-Fi)^2	(fi-Fi)^2/Fi
54.680-54.840	8	0.221	15.4	56.08	3.621
54.840-54.880	11	0.219	15.3	18.8	1.226
54.880-54.920	23	0.239	16.7	38.73	2.308
54.920-54.960	19	0.181	12.6	39.93	3.149
54.960-55.000	9	0.138	9.7	0.51	0.052

Fig. 13. Fitting test of repeated sampling (Height. 55 mm)

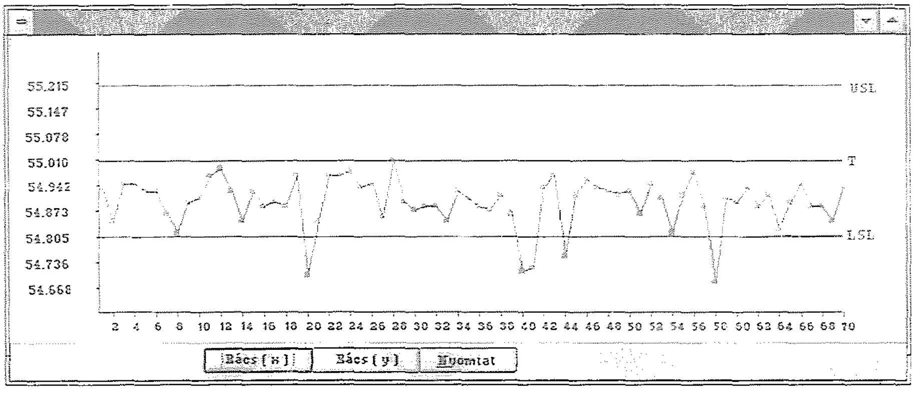


Fig. 14. Graphical plotting of data (Height, 55 mm)

3. Repeated Machine Capability Test Following Overhaul

On the basis of the condition of the studied machine the managers in the plant decided about the overhaul of the machine. Following the overhaul. machine capability test was carried out again during the production of the same type of component which was produced by the machine during the first capability test. During this second test 70–70 measurements were carried out on all critical values of the component, on the components coming from the machine one by one. The way of analysing the data was identical with the one described above. The result of the analysis is, however, basically different.

The result of the 55 mm size fitting test does not prove the assumption of normal distribution. This is shown in *Fig. 13*.

The line diagram of *Fig. 14* indicates that the adjustment of the process was clearly shifted towards the lower tolerance. Both descriptive statistical processing and capability indicators show the shift of the process:

Table 2. Descriptive statistical results

Nr. of data	70
Average	54.890
Std. dev.	0.065
6σ std. dev.	0.388
Minimum	54.68
Maximum	55.00
Range	0.32
below LSL	7.14%
above USL	0.00%
$\bar{x} \pm 1s$	75.71%
$\bar{x} \pm 2s$	92.86%
$\bar{x} \pm 3s$	98.57%
Cm	0.769
Cmk	0.346

It is clear that the indicator of machine capability (C_m) does not meet 4σ expectations. its value is below 1. Even the worse value of C_{mk} indicator shows a strong shift in adjustment. *Fig. 14.* however, also shows that the five data falling below the lower tolerance, most probably 'responsible' for the poor results 'do not fit into' the other measured values which according to the detection of error was most probably caused by measurement error.

Since these measurement results are not characteristic of the process, these five points were excluded from the data series – naturally keeping in mind the measures which might prevent the occurrence of similar cases – fitting tests were carried out again which this time proved that they come from the normal distribution of data. The results are given in *Fig. 15*.

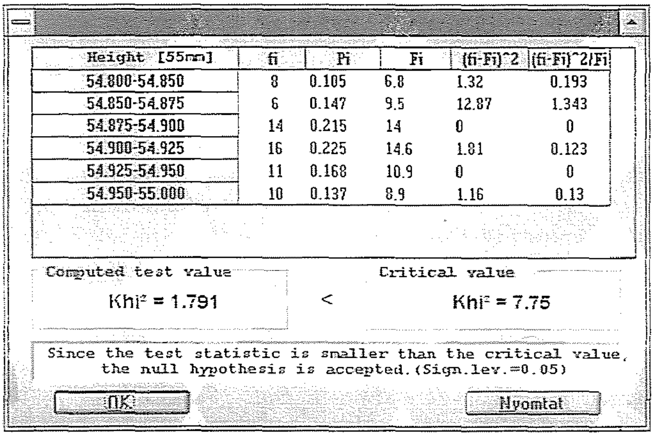


Fig. 15. Fitting test following exclusion (Height, 55 mm)

The new line diagram was also plotted which this time shows fluctuation becoming regular (*Fig. 16*). The calculated statistical data and capability indicators are the following:

Excluding the five data, measurement results were taken out of the data series which can be attributed to extraordinary (in our case measurement) error, in this way they can be eliminated. Their removal results in a condition which is characteristic of the real capability of the process. In this condition the process is regulated and the machine capability indicator is much better than the minimum requirement with value of $C_m = 1.163$. The indicator of the medium adjustment of the process has also improved but still indicates shift.

The analysis on the accuracy of the 42 mm size does not refer to the presence of extraordinary disturbances. The results in *Fig. 17* prove the normal distribution of all the data. *Fig. 18* (line diagram) shows regular fluctuation but again process adjustment shifted under the lower tolerance is given. The statistical data listed below also confirm this fact. The value of the machine capability indicator is very good $C_m = 1.331$, much higher than the expected minimum 1. At the same time centrality is still problematic, the value of C_{mk} is much smaller than C_m indicating that the machine adjustment is to be corrected by all means.

The condition following machine overhaul altogether has improved by several orders of magnitude. In the case of both worked sizes, the quality capability indicators are well above 1.0 requirement value. The analysis on the other hand clearly indicates that adjustment is still problematic. In the case of both measured characteristics the process fluctuates between the nominal value and the lower tolerance. Consequently, the indexes C_{mk}, measuring the real performance of the process, record poor values. The error of adjustment can be traced back to the same reasons which were stated during the first capability test before the overhaul.

Nr. of data	65
Average	54.903
Std. dev.	0.043
6* std. dev.	0.256
Minimum	54.81
Maximum	55.00
Range	0.19
below LSL	0.00%
above USL	0.00%
$\bar{x}\pm1s$	66.15%
$\bar{x}\pm2s$	95.38%
$\bar{x}\pm3s$	100.00%
Cm	1.163
Cmk	0.599

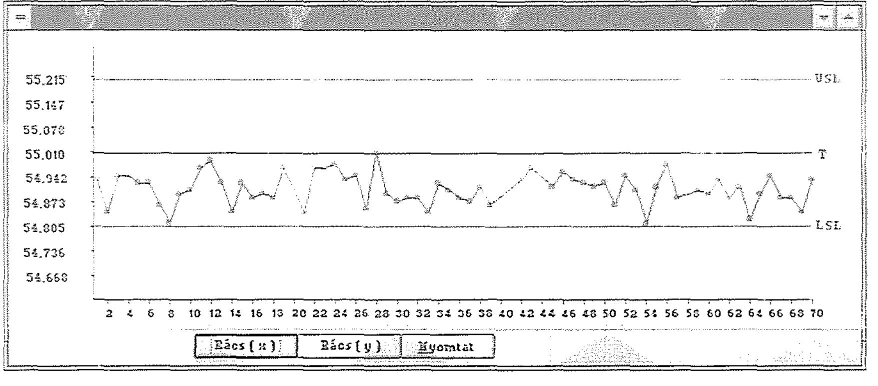
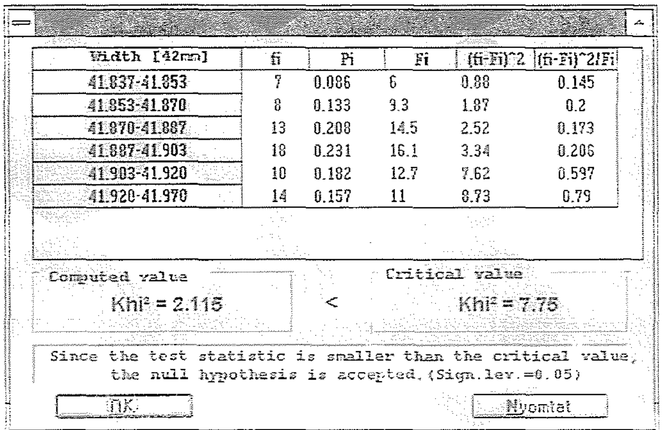


Fig. 16. Graphical plotting of data following exclusion (Height, 55 mm)

Nr. of data	70
Average	41.892
Std. dev.	0.028
6* std. dev.	0.169
Minimum	41.84
Maximum	41.97
Range	0.13
below LSL	4.29%
above USL	0.00%
$\bar{x}\pm1s$	58.57%
$\bar{x}\pm2s$	97.14%
$\bar{x}\pm3s$	100.00%
Cm	1.331
Cmk	0.370



Width [42mm]	fi	Pi	Fi	(fi-Fi)^2	(fi-Fi)^2/Fi
41.837-41.853	7	0.086	6	0.88	0.145
41.853-41.870	8	0.133	9.3	1.87	0.2
41.870-41.887	13	0.208	14.5	2.52	0.173
41.887-41.903	18	0.231	16.1	3.34	0.206
41.903-41.920	10	0.182	12.7	7.62	0.597
41.920-41.970	14	0.157	11	8.73	0.79

Computed value

Khi² = 2.115

<

Critical value

Khi² = 7.75

Since the test statistic is smaller than the critical value, the null hypothesis is accepted. (Sign.lev.=0.05)

OK

Nyomtat

Fig. 17. Fitting test and statistical data of repeated sampling (Width, 42 mm

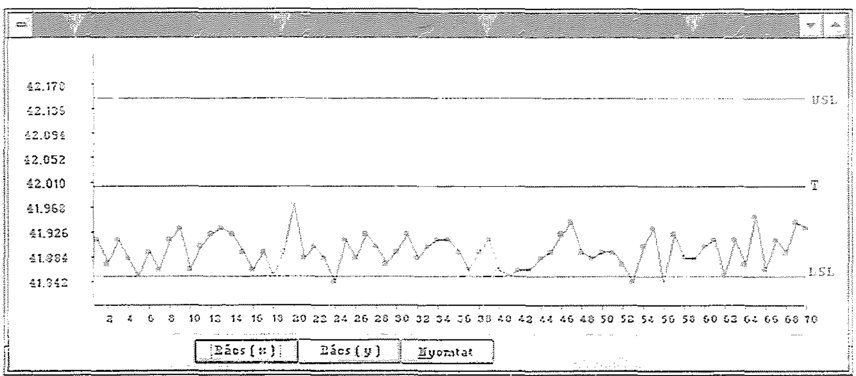


Fig. 18. Graphical plotting of data (Width, 42 mm)

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