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Statistical Process Control for shearing and punching of metal coils

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Preface

This master thesis was performed at the institution for Industrial Production at the Faculty of Engineering at Lund University in cooperation with the company Alfa Laval Lund AB during the autumn of 2011 and January 2012.

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Martin Jönsson – Six Sigma Engineer at Alfa Laval (at the time of the master thesis)

Examiner:
Jan-Eric Ståhl

A big thanks to the Jan-Eric and Mats. Also big thanks to Martin for taking your time answering all my questions.

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Abstract

This master thesis is on Statistical Process Control (SPC). The objective is to evaluate if SPC can be used in a process that produces plates for heat exchanger, the process evaluated is located at Alfa Laval Lund AB. The products are produced in the process by punching and shearing metal coils. An ambition in the project is also to increase the knowledge about Statistical Process Control at Alfa Laval therefore one part of the project is to hold an in-house education.
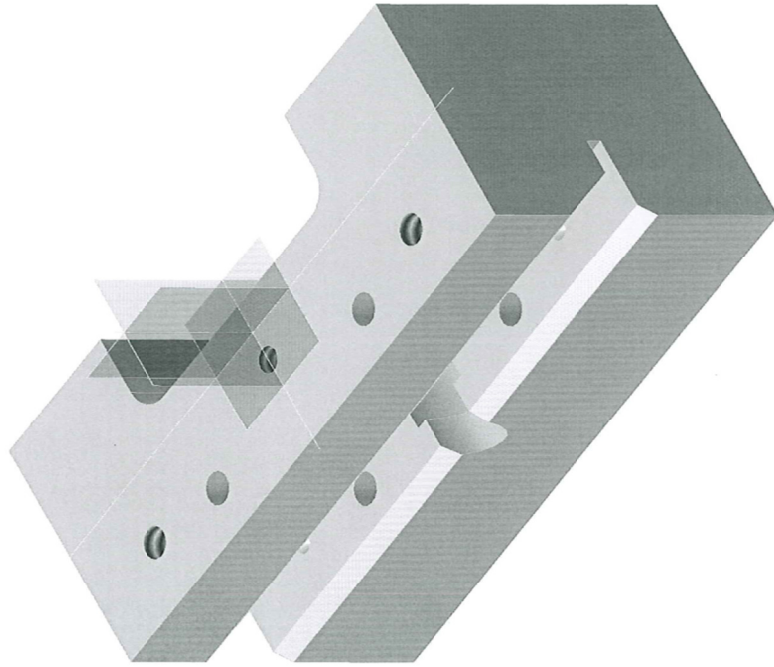
A big part of the thesis consists of theory around Statistical Process Control. This is both for the education and for the understanding of the subject.

Machine capability and process capability tests have been made to evaluate the process. After analysing the test results the values were satisfying. The process can be brought to statistical control and it should not be a problem to implement Statistical Process Control, at least not for capability reasons. The process is greatly complex and there are a lot of different products produced so it will be a lot of work to start up Statistical Process Control.

Content

1. INTRODUCTION

1.1 Background

Alfa Laval is a company that have three focus areas; heat transfer, separation and fluid handling technologies. Alfa Laval Lund AB, where the master thesis is performed, is concentrated on heat transfer. The production lines, where the study has been performed, produce high volumes of plates for plate heat exchangers. It is a fully automated production with many steps and it is greatly complex.

Heat exchangers are used to either cool or heat a medium. The plate heat exchangers are made from a series of corrugated plates that are assembled. In between the plates there are two channels with a cool and a warm medium. The mediums passes on either side of the plates in opposite direction to each other. There are different types of plate heat exchangers:

- Gasketed plate heat exchangers
- Brazed plate heat exchangers
  - o For higher pressures and temperatures
- Welded (semi- and full) plate heat exchangers
  - o For even higher pressures and temperatures

The plate heat exchangers have many applications especially in the energy sector. Larger plate heat exchangers are commonly used in e.g. nuclear plants and smaller ones can be found in distant heating systems of apartment buildings.

In the lines where the study has been performed there are plates produced for all types of plate heat exchangers. They are made in many different sizes, some small and easy to handle by hand and some big and unwieldy.

1.2 Objective

The objective of the thesis is to evaluate if it is possible to use Statistical Process Control in shearing and punching of metal coils which is part of producing the plates. An ambition in the project is also to increase the knowledge about Statistical Process Control at Alfa Laval.

1.3 Deliverables and Delimitations

The main deliverables of the project are:

- To evaluate how Statistical Process Control works in general
- How can it be applied on shearing and punching of metal coils
  - Which measurement/measurements are critical and suitable to measure
  - How should that measurement/those measurements be measured
  - How should the control limits be set
  - A reality test of Statistical Process Control should be performed during a limited time
- Education material
- Education of assigned personal

The delimitations of the project include:

- The economical aspect is not to be included in the master thesis.
- There is no goal to have Statistical Process Control up and running in the production at the end of the project.

1.4 The process

The shearing and punching process is complex. The products made in the process are metal plates, of different sizes and with different patterns of holes, to heat exchangers. Here comes a short introduction to the process so the reader has some understanding of what is done.

The process is fed with raw material consisting of metal coils. The material has different widths and thickness for different products. The metal coil is unwounded as it goes into to the punching and shearing part of the process. The material goes into the machine where holes in a specific pattern are punched in it. It is of particular importance that the symmetry in the pattern is correct.

The pattern and the length is punched and sheared in a specific sequence. This sequence is decided in advance, it is complex and specific for each product. Because the sequence includes both the shearing of the length and punching, the shearing of the length will affect the pattern symmetry in length direction of the product. The order in which the pattern is punched and the plates are sheared off is different for different products. After the products are sheared off at both sides they are transported away for further processing.

The entire process is automated which is a big part of its complexity. But in Statistical Process Control this can be an advantage in the sense that human error can only be made in the computer input and the maintenance of the tools.

The process output varies a bit depending on the type of product. In general smaller products go faster through the process while larger products take a bit more time.

2. THEORY

2.1 Variation

All processes have variations, which come from multiple sources, such as equipment, tools and material. The variations can never be entirely removed. There are two categories of variations; random and assignable.

Random variations are variations that will always be present in the process. These variations are hard to do anything about without revising the entire process. Random variations can be due to environmental factors, the operator, electrical fluctuations, vibrations and/or gaps between parts in the machine/machines. When there are only random variations present in a process it is said to be *in statistical control*.

Assignable variations are usually relatively large compared to random ones. With an assignable cause of variation present the process variability will be excessive and it will therefore be said to be *out of statistical control*.

Assignable causes for process variations can be located with control charts. Some of them can be removed, others such as tool wear are a part of the process. To investigate if the process is capable the assignable causes needs to be brought to control. Process capability will be described further later on in the text.

There can also be variations in the tools measuring the process these variations needs to be known and the tools need to be exact enough to show the assignable and random variations in the process.

2.2 Statistical Process Control

To be able to use Statistical Process Control (SPC) the process must be in statistical control and the outcome is preferably normally distributed. Other statistical distributions can be used e.g. Weibull distributions but normal distributions are simpler to handle.

For the process to be capable the machine in the process needs to be capable. To determine if the machine is capable a machine capability test is performed. During such a test everything must be as good as possible. The values in the outcome of the test need to be normally distributed.

To further decide if it is possible to use SPC a process capability test needs to be performed. This test evaluates if the process is in statistical control.

The purpose of using Statistical Process Control is to prevent the process from manufacturing default products. It is not to detected faulty products.

A list of terms, and their abbreviations, for SPC and that will be used in the thesis is to be found in Appendix A.

2.2.1 Normal distribution

Normal distribution is a commonly used statistical distribution which is used in SPC. The distribution is continuous and symmetrical and in theory it includes all real numbers, see Figure 2-1. The tails in the figure is cut off at the red lines representing $\pm 3\sigma$, in reality the tales continue to infinity. Normal distribution is described with the density function in Equation 2-1.
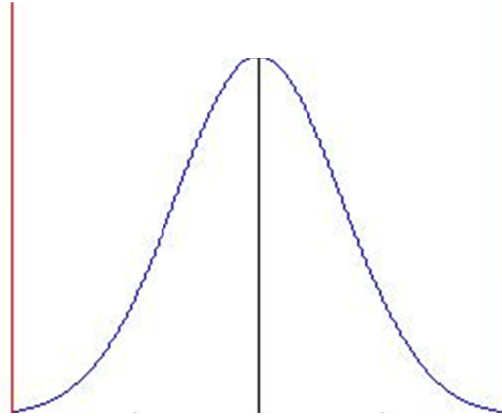
Figure 2-1: Normal distribution.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{\sigma^2}}$$

Equation 2-1

The distribution is divided into standard deviations. The most commonly used number of standard deviations is six, $\pm 3\sigma$. It will look like in Figure 2-2. To calculate σ Equation 2-2 is used.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N}}$$

Equation 2-2: σ, where x_i is the value of individual number i in the population.

Figure 2-2: normal distribution curve with 3σ lines (red), 2σ lines (blue) and 1σ lines (cyan).

If there aren't data for the entire population, as is the normal case in production, the estimated standard deviation is calculated, this is done according to Equation 2-3.
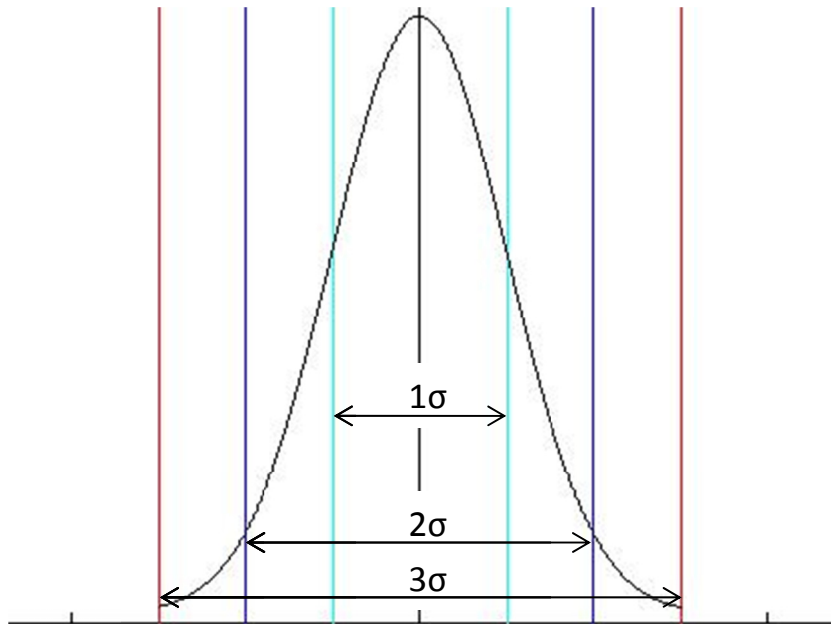
$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

Equation 2-3: where x_i is the value of sample number i.

Sample x_i can be either the value of an individual sample or the mean value of a small sample group. In SPC sample groups are used.

2.2.2 Capability

2.2.2.1 Machine capability

Machine capability measures how well the machine performs. In other words; If everything is set to optimum how good is the machine? For a new machine this should be included in the specification from the supplier of the machine.

The test is performed by manufacturing a sample of products under as perfect conditions as possible. The material should be known to be good, the machine shall be set to optimum values and no external conditions may affect the manufacturing. After these conditions are fulfilled the production of the products starts. Then the sample of products, e.g. 50 pieces, is measured.

To calculate the machine capability:

$$C_m = \frac{USL - LSL}{6s}$$

Equation 2-4

Figure 2-3 to Figure 2-6 shows a representation of the normal distribution curves for different C_m values. The red lines in the figures represent LSL and USL. All of the figures have the mean value 10, LSL=6 and USL=14.
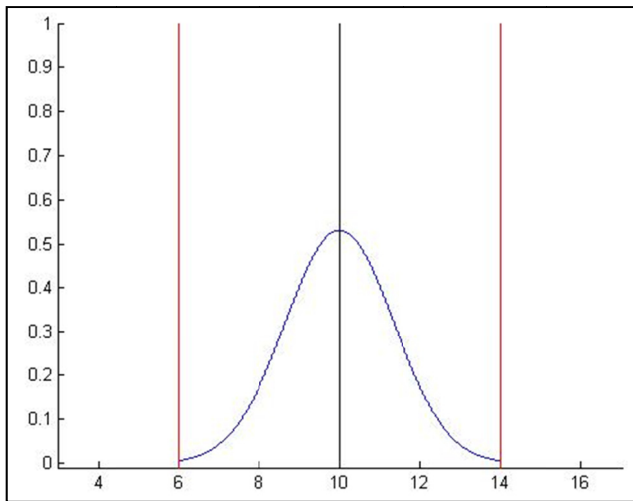
Figure 2-3: s=1.333 C_m=1.
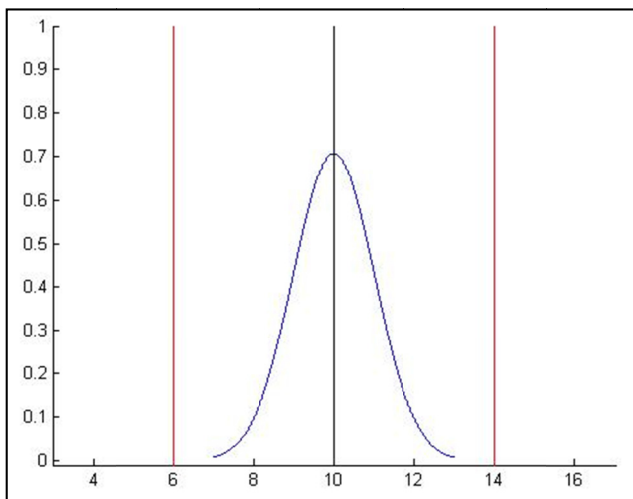
Figure 2-4: s=1 C_m=1.333.
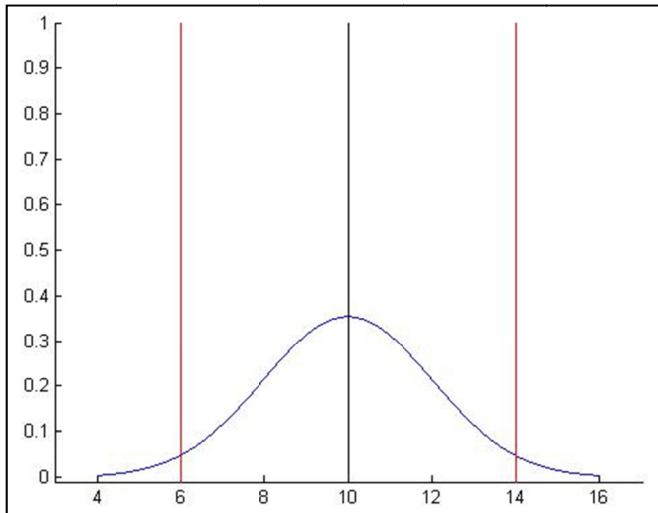
Figure 2-5: s=2 Cₘ=0.667.
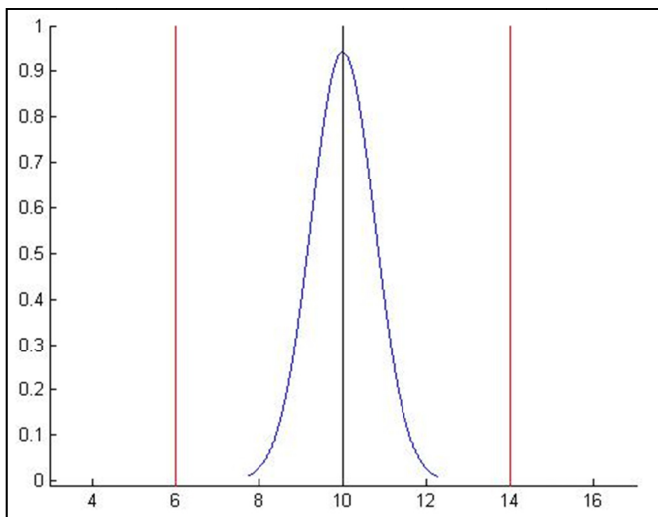
Figure 2-6: s=0.75 Cₘ=1.778.

As can be seen in
Figure 2-3: s=1.333 C_m=1 to Figure 2-6 larger values of C_m gives wider margins to the specification limits. To be sure that the machine is capable certain values of C_m needs to be fulfilled, see Table 2-1 for some guidelines. With C_m equal to one the machine will not be capable. The spread will be within the tolerance width but the machine capability is only for a small part of the process. When the entire process is added up, it will probably not produce products within the specification limits.

Sample Size	Requirements for C_m alt. C_{mk}
25	>1.5
50	>1.4
500	>1.35

Table 2-1: Table of required values for C_m and C_{mk}[1].

These values for C_m and C_{mk} are not exact but can be seen as guidelines. Every company have to decide which values to use.

When the process is not centred the C_m value doesn´t say much more than it might be interesting to calculate how well it performs with consideration taken to the target value of the process. The value to calculate then is the adjusted machine capability. C_{mk} is a value that takes both the process spread and the normal distribution curves offset from the desired curve in the x direction.

To calculate the adjusted machine capability:

$$C_{mk} = min\left[\frac{USL - \bar{x}}{3s}, \frac{\bar{x} - LSL}{3s}\right]$$

Equation 2-5

Figure 2-7 through Figure 2-9 shows different values for C_{mk} when it is not equal to C_m. All of the figures have the mean value 10, LSL=6 and USL=14 and C_m=1.333.
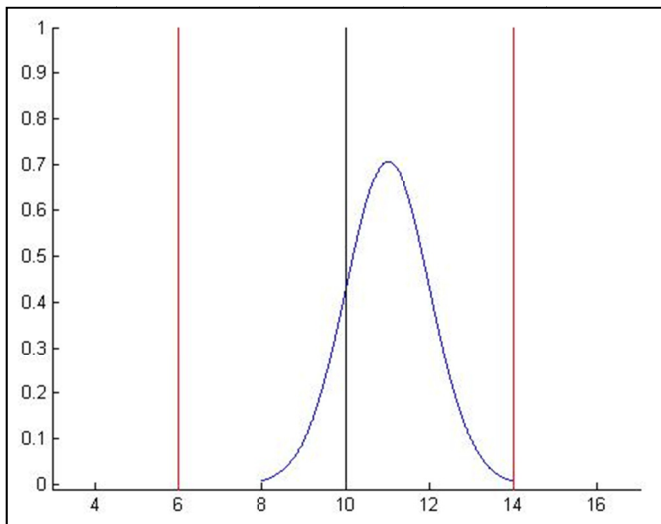
Figure 2-7: x-bar=11, s=1, C_{mk}=1.

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[1] Scania TFP 2009
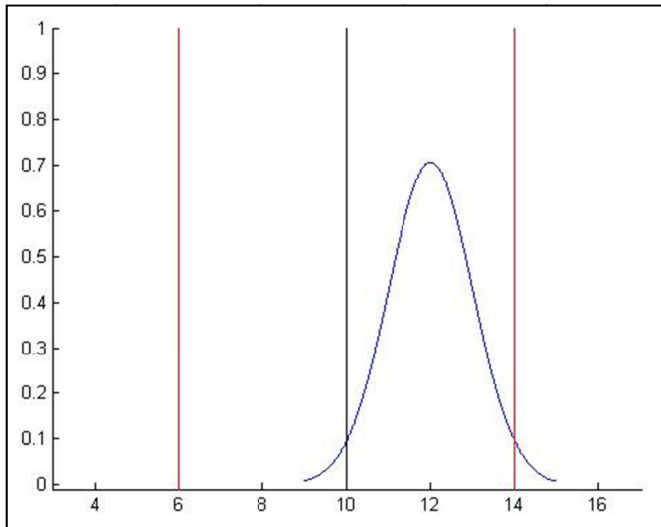
Figure 2-8: x-bar=12, s=1, C_{mk}=0.667.
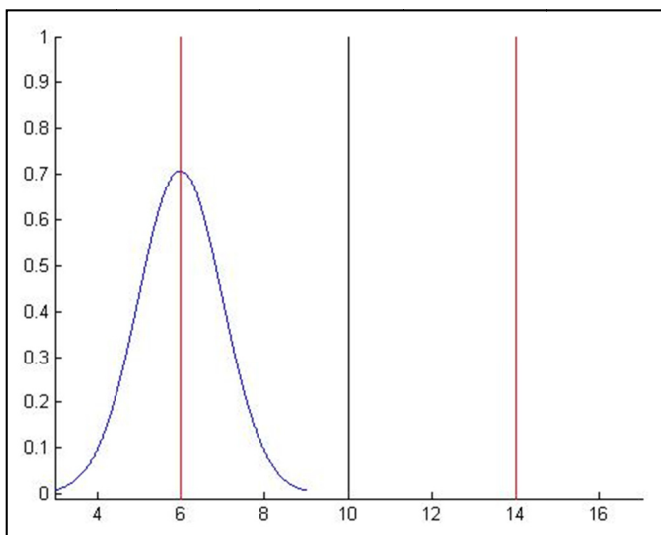
Figure 2-9: x-bar=6, s=1, C_{mk}=0.

With a value of C_{mk} equal to zero, 50% of the products produced by the machine will be below the LSL or above the USL. Example for 50% below LSL can be seen in Figure 2-9. Figure 2-7: x-bar=11, s=1 shows a C_{mk} value equal to 1 which would mean that only 0,135% of the produced products would fall outside the specification limit. This is still not a satisfying value since the process is not centred on the desired process mean.

There is little literature on machine capability, especially in English, Swedish sources is a little bit easier to find. Why there is so little is hard to figure out. It is important to know that your machines capability in good conditions before you start to do more extensive tests.

2.2.2.2 Process capability

When a machine capability test is done and the machine or machines in a process is known to be capable a process capability test can be done. Process capability is a measurement of what we actually produce in our process. It includes everything in the process not just the machines.

$$C_p = \frac{USL - LSL}{6s}$$

Equation 2-6

As you can see Equation 2-6 is identical to Equation 2-4, the difference is that a new value for the standard deviation have been calculated from a process capability test instead off one from a machine capability test.

A value of C_p below one means that the process is not in statistical control, it looks the same as in Figure 2-5. C_p equal to one shows that the natural spread of the process is equal to the tolerance width, see
Figure 2-3: s=1.333 C_m=1, even a small shift of the mean value of such a process would cause it to produce defect products. $C_p \geq 1.33$ makes USL-LSL $\geq 8\sigma$ this means the process can shift a little before it starts to produce faulty products, see Figure 2-4.

C_p>1.33 is a common limit for deciding to start up using Statistical Process Control. This means that there is less than 64 products out of 1 000 000 that falls outside the specification limits. This might sound like a lot but keep in mind that this is for a test that is performed with good conditions.

As in the case for C_m, C_p needs a complement to know if the process is centred on target. This complement is the adjusted process capability C_{pk}.

C_{pk} measures the difference between the mean of the process outcome and the USL and LSL.

$$C_{pk} = min\left[\frac{USL - \bar{x}}{3\sigma}, \frac{\bar{x} - LSL}{3\sigma}\right]$$

Equation 2-7

A value of C_{pk} less than one indicates that the process is incapable; it means that the tail of the normal distribution curve for the outcome of the process is outside the USL or LSL, see Figure 2-8.

If the process is centred C_p and C_{pk} will be equal. If they differ and C_{pk} is less than one while C_p is greater than one the process can be made capable by, if possible, centring it. Increasing values of C_{pk} indicates a higher process capability.

If $C_{pk} \geq 1.33$ the difference between the mean value and the specification limit furthest away from tit (if not centred) $\geq 4\sigma$ which means that it is less chance of the outcome to be outside the specification limits than 64 in 1 000 000. The process can then move a little and still manufacture products well within the specification limits.

2.2.3 Control charts

In SPC Control charts are used to monitor the outcome of the process. There are three types of control charts normally used in production processes; Shewart, CUSUM and EWMA according to Wiklund[2]. But it seems to be more common to use x-bar and R charts in modern literature. The decision to use x-bar and R charts in the report and at Alfa Laval has been made, therefore only those charts will be described here.

Before you can start using control charts three parameters needs to be set; the sampling interval, number of observations in every sample and the control limits. The control limits is normally calculated from historic data.

2.2.4 X-bar and R charts

X-bar and R-charts are two charts that are commonly used in Statistical Process Control. They are used when samples of more than one product is in use. The X-bar (comes from $\bar{x}$, the mean value) chart is a way to register the mean value of samples. It is complemented with an R-chart, in which the range of the sample is plotted.

Advantages with these two plots are that there is two ways to follow if the process is in statistical control. The x-bar chart will show if the process is centred on the target and the R-chart will show if the process spread remains the same.

2.2.4.1   X-bar chart

The x-bar chart is used to show if the process is centred on the target value. It has an upper control limit and a lower control limit. These are normally set to:

$$UCL = \bar{x} + 3s$$

Equation 2-8: upper control limit

$$LCL = \bar{x} - 3s$$

Equation 2-9: lower control limit

If a point falls outside these control limits there is statistical certainty that something has happen, that there is an assignable cause. The points in an x-bar chart comes from a sample in the process. A sample has a sample size n. This sample size can vary between normally three to eight products, for more information read under heading "Sample size and interval".

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[2] Control Charts and process adjustments, Wiklund, p. 5

Example off a x-bar chart see Chart 2-1
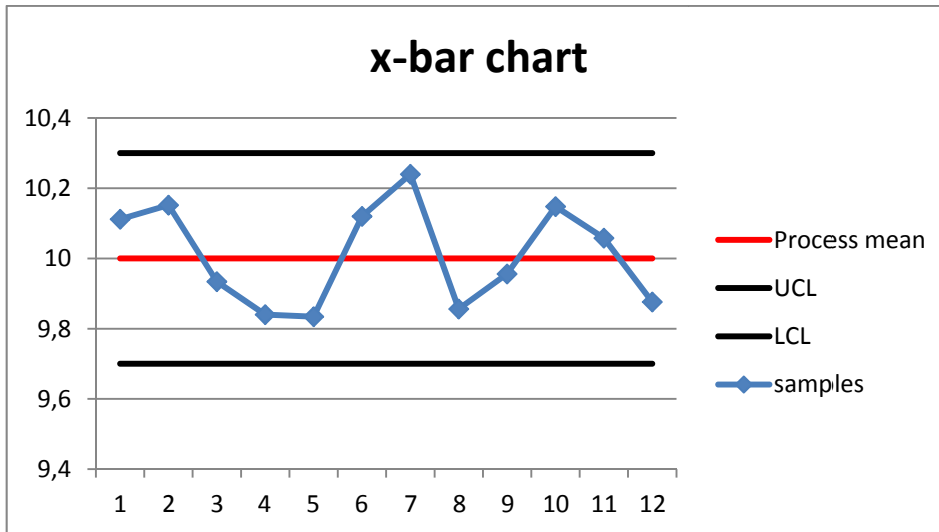
Chart 2-1: x-bar chart, s=0.3, process mean=10 and all sample within UCL and LCL.

The points plotted in Chart 2-1 are taken from fictive data samples; each point is the mean value of a sample group of five fictive products. As shown all samples are within UCL and LCL, this means that this process is in statistical control. If points are outside the UCL or LCL the process is not in statistical control and the normal distribution curves could look like in Figure 2-10. It would mean that the process has moved away from the target.

Figure 2-10: The black curve is on target, the blue curve is of target..

2.2.4.2   R chart

The R chart is used to show the range within the sample groups.

Example: if the sample size is n=5 and the values of the five samples are as follows:

Sample	Value
1	10,5
2	10
3	12
4	9
5	9,5

Table 2-2: Example of measurements, n_{max}=12 and n_{min}=9.

$$R = n_{max} - n_{min} = 12 - 9 = 3$$

Equation 2-10: To calculate R and then calculation from Table 2-2
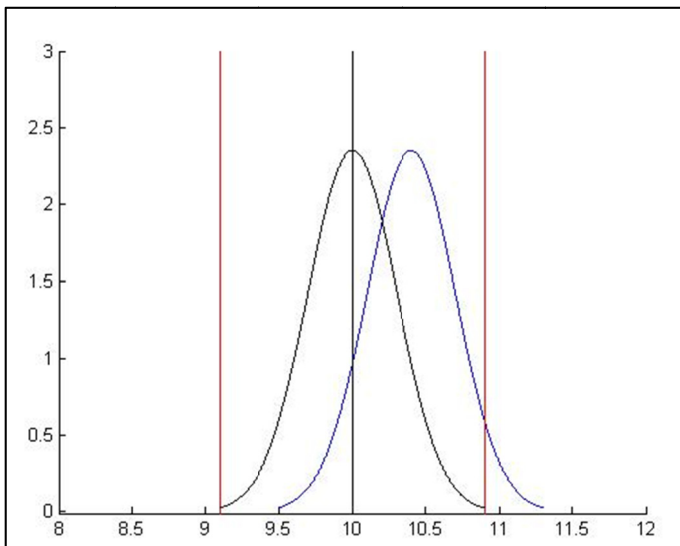
If this was sample one the first point in the diagram would be set at y=3.

To have limits for alarms (for more information about alarms see headline 2.2.6 Rules and alarms) values of R_{max} and in some cases R_{min} are calculated.

$$R_{max} = D_4\bar{R}$$

Equation 2-11

$$R_{min} = D_3\bar{R}$$

Equation 2-12

For values of D_3 and D_4 see Appendix B The reason for calculating R_{min} and not setting it to zero is because the probability of the difference between several samples being zero is not likely. If the difference between for example a number of eight samples is zero there is probably something wrong in the measuring. R_{min} is not calculated for sample sizes smaller than seven, this because the smaller the sample size the more likely it is that all the samples have the same value.

Example of R-chart see Chart 2-2.
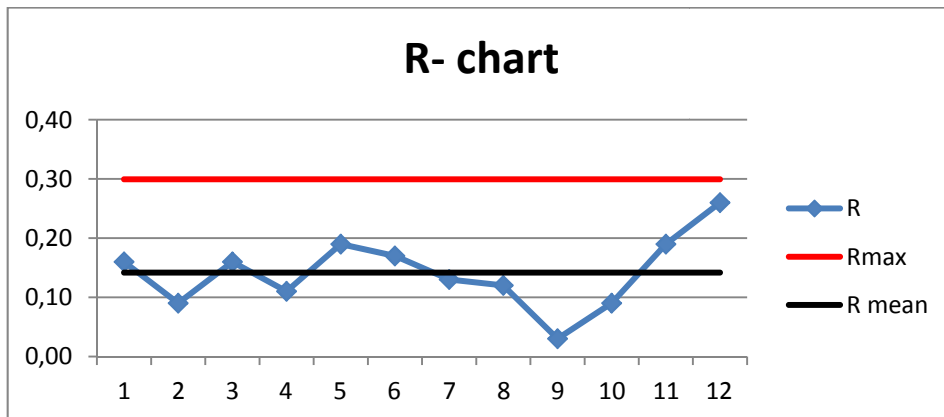
Chart 2-2: R-chart with R_{max}=0.3 and R mean equal to 0.14.

Chart 2-2 is an example of an R- chart. In this chart all points are below R_{max}, the points are calculated from a sample of five products and thus there are no R_{min}. If a point should turn up above R_{max} the process would probably be out of statistical control, the process spread has probably increased, see Figure 2-11 for behaviour of the normal distribution curve.
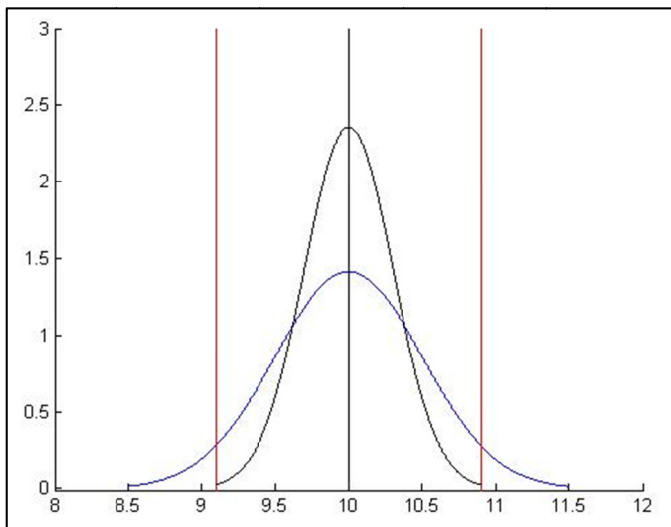
Figure 2-11: the black curve is inside the UCL and LCL, the blue curve have a wider spread.

2.2.5 Sample size and interval

The sample size preferably consists of more than two items. The sample size one is not used because the interesting thing is not how one individual product fulfil the tolerance requirements. If there are more than one sample in a group the range can also be calculated which gives an extra measurement to evaluate the process.

The sample size two should also be avoided. This is because it will become hard to detect changes in process spread since it only will be the range between two products plotted. A common sample size in the industry is n=5, this is because it is considered easy to calculate with and gives a good statistical range. More samples give higher statistical certainty. It is a question of priorities, which is more important to detect every indication that the process is not in control or to keep down the time and work it takes to collect samples. When it comes to big sample sizes e.g. n=8, it is better from a statistical point of view to take samples twice as often and use the sample size n=4. At larger sample sizes the R-chart does not give a good estimation of the standard deviation; this can be solved by using standard deviation charts instead. A standard deviation chart plots the calculated standard deviation within the sample group instead of the range.

The interval between samples can be either a specific amount of products or a specific time. E.g. take a sample of four products every 30min or take a sample of four products every 100 products. The interval used should be decided for every production line or machine. The general rule though is that the samples should be taken more frequent in the beginning of a process capability assessment and when the Statistical Process Control is first up and running. Over time the samples can be taken less frequently if the process is regarded stable.

2.2.6 Rules and alarms

In SPC an alarm goes off when a rule is broken. There are two rules that are always used; an alarm goes if a sample falls outside the UCL or the LCL in the x-bar chart or above the R_{max} line in an R-chart. If the process only gives an alarm in these two cases the process can go longer than necessary out of statistical control. The cause of the assignable variation that affects the process will be able to affect the process longer. Therefore additional rules to trigger alarms are beneficial.

The alarms are to warn the operator that the process is not in statistical control. This, as written earlier, means that the process either isn´t centred on target any more or that the process spread has increased.

2.2.6.1   Rules for the process being of centre

If the process is off centred this will always show in the x-bar chart. The commonly used rules of for x-bar charts are represented here (all σ in the rules can be replaced with s if σ is unknown):

1.   The first rule still is if one point is outside the 3σ line on either side or, as in Chart 2-3, one point above UCL or one point below the LCL. The probability that it gets over the UCL is 1-0.99865=0.135% (0.99865 can be read in a normal distribution table or calculated). So the probability of a point turning up below or above either UCL or LCL is 1-0.9973=0.27%.

Example, if a point gets outside the UCL in an X-bar chart it would look like this:
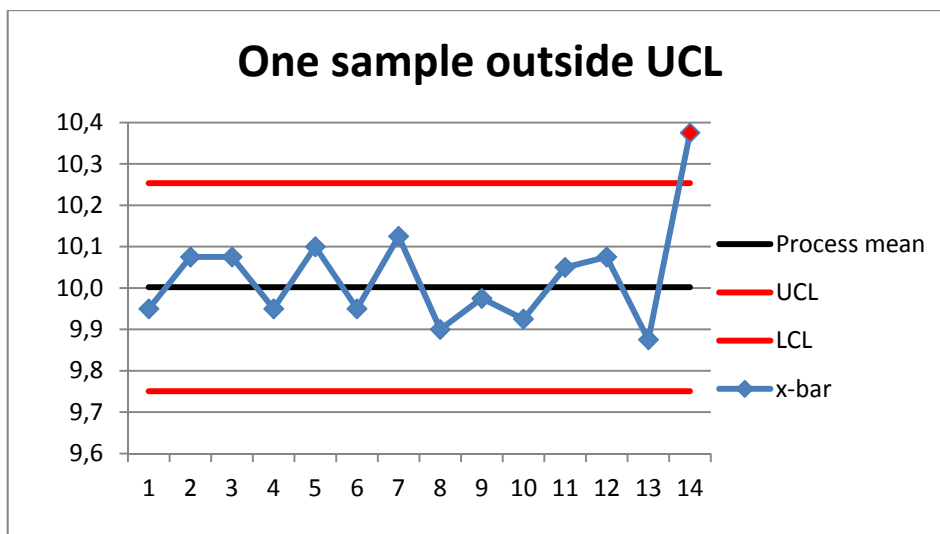
Chart 2-3: one sample outside the UCL.

2.   *If more than two out of three points in a row are outside the 2σ line on the same side of the centre line.* The probability of a point being outside the 2σ line on either side of the centre line is 1-0.9545=4.55% (can be read in a normal distribution table or calculated) but the probability of a point being outside the 2σ line on one side is 1-0.97725=2.275%. So there is a considerably smaller chance than 2.275% of two out of three points being on the same side of the 2σ line. The probability of two samples in a row being outside the 2σ line on the same side is:

$$P(2 \text{ } outside \text{ } the \text{ } 2σ \text{ line } on \text{ } the \text{ } same \text{ } side) = (1 - 0.97725)^2 = 0.052\%$$

3. *If more than four out of five points in a row are outside the 1σ line on the same side of the centre line.* The probability of being outside the 1σ line once on one side is 1-0.8413 (can be read in a normal distribution table or calculated). The probability of four samples in a row being outside the 1σ line on the same side is:

$$P(4\ points\ outside\ the\ 1\sigma\ line\ on\ the\ same\ side) = (1 - 0.8413)^4$$
$$= 0.063\%$$

4. *If more than m samples in a row are on the same side of the centre line.* In a centred normal distributed process there is a 50% chance to be on either side of the centre line therefore:

$$P(m\ samples\ in\ a\ row\ above\ the\ centre\ line) = 0.5^m$$

Equation 2-13

$$P(6\ samples\ above\ \bar{x}) = 0.5^6 = 0.015625 \approx 1.6\%$$
$$P(7\ samples\ above\ \bar{x}) = 0.5^7 = 0.0078 \approx 0.8\%$$
$$P(8\ samples\ above\ \bar{x}) = 0.5^8 = 0.0039 \approx 0.4\%$$
$$P(9\ samples\ above\ \bar{x}) = 0.5^9 = 0,001953 \approx 0.2\%$$
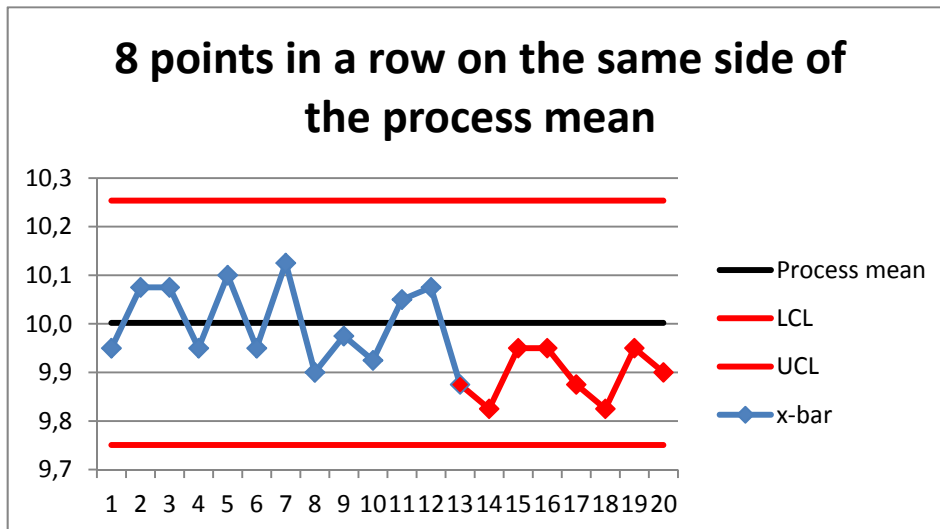
Chart 2-4: Example of 8 points in a row on the same side of the process mean in an X-Bar chart.

The literature has different recommendations on how many samples that should be used. In the end it is up to every user to decide which is more important, to risk not discovering a problem for a little while longer or to risk getting to many alarms.

5. *If more than m points in a row is larger or smaller than the last point.* See Chart 2-5.
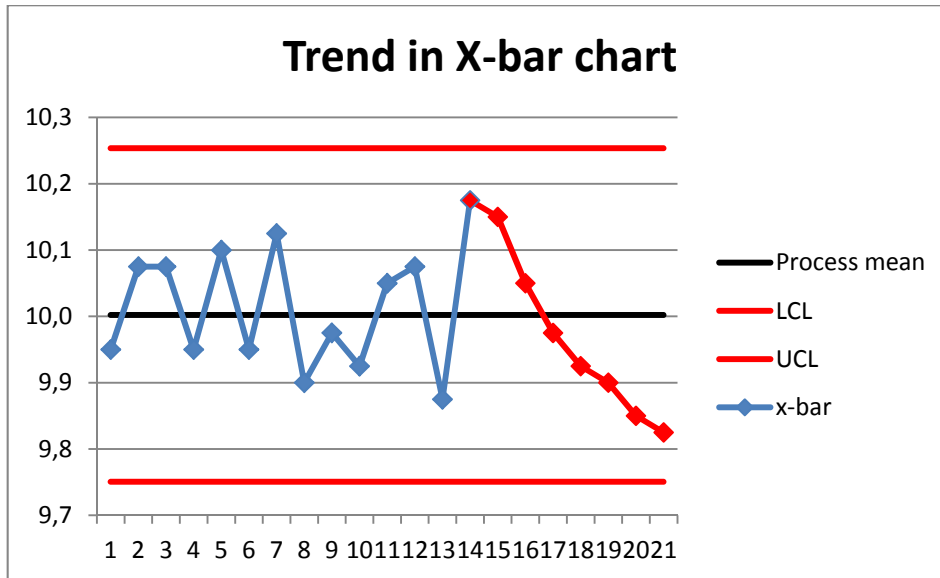
Chart 2-5: Example of a Trend in an X-Bar diagram, here every point is smaller than the last one.

This rule is to detect trends. A trend is when the points in the chart display a pattern as those in Chart 2-5. It is one of the more complicated rules since you can have a trend without all points being in a row. If you have points that go; larger, larger, larger, smaller, larger, larger, larger, larger, smaller, larger, you still probably have a trend. To be able to see these trends requires experience of the process.

2.2.6.2 Rules for the process spread beginning to increase

Then there are rules to see if the process spread is increasing. When the process spread is starting to increase this will always show in the R-charts. Commonly used rules for this:

1. *If one point is above R_{max}, see* Chart 2-6.
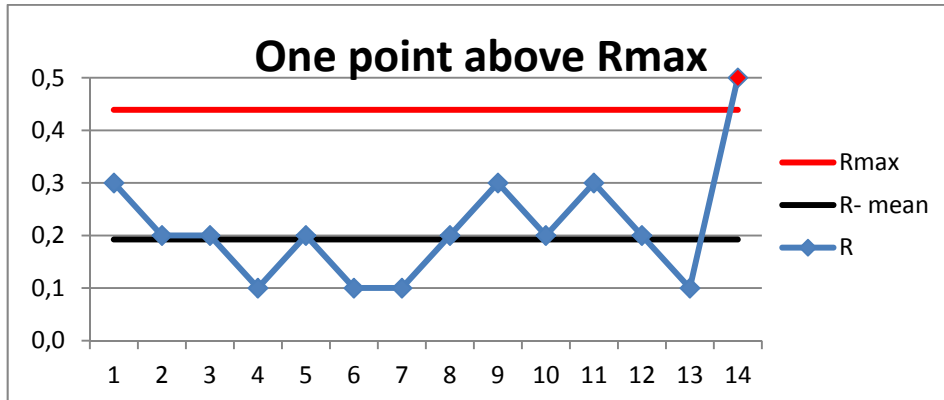
Chart 2-6: One point above R_{max}.

2. *If more than m points are above the average value of R.* Here goes the same as for rule four for the X-Bar chart except it is only if the points are above the mean that there is a problem. If there are more than m points below the R-mean you could look in to lower the R_{max} because it could mean that the process spread have become less. Equation 2-13 works here as well but as with the charts, it will only trigger an alarm if it's above the process mean. See Chart 2-7.
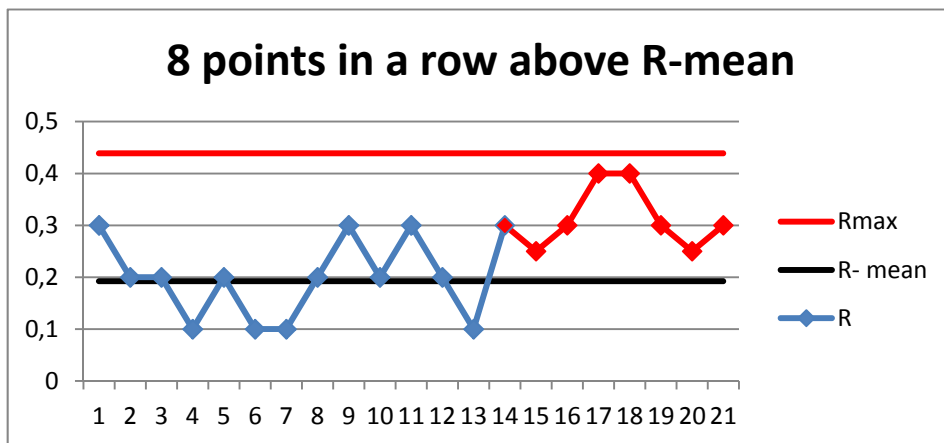
Chart 2-7: several points in a row above R- mean.

3. *If more than m points create a trend, see* Chart 2-8. Deciding the value m is as with the X-Bar charts up to every process. A trend in a R-chart also has to go upwards to show that the process spread is increasing. If there is a downward trend the process spread may have decreased and it should be evaluated if R_{max} should be lowered.
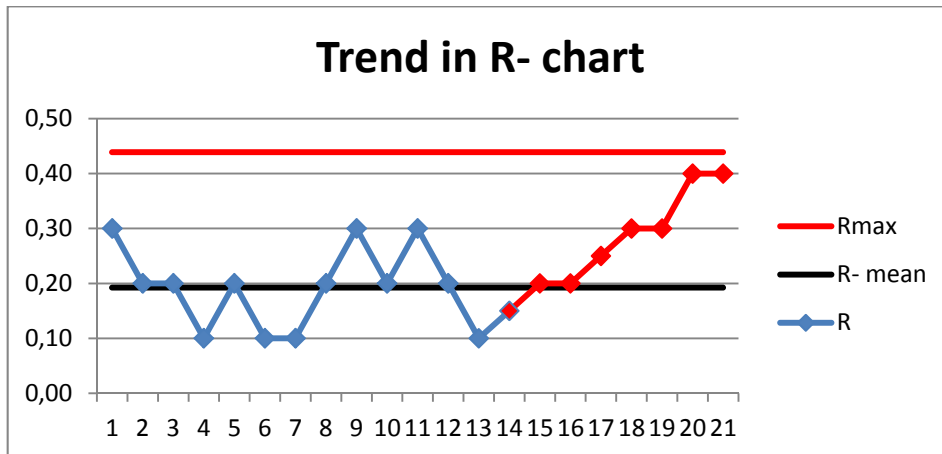
Chart 2-8: Trend in R- chart.

2.3 Start-up of SPC

If the capability test has showed that the process is capable, in statistical control, start up with SPC can begin.

2.3.1 Measurement

A decision on which measurement on a product that should be used in SPC is needed. The measurement or measurements used should tell as much as possible about the production process. To decide which measurement to use smaller test of different measurements can be made and evaluated.

2.3.2 History

Before start up with Statistical Process Control is made for a product in a production process the limits UCL, LCL and R_{max} for the charts needs to be calculated. To calculate these values to an adequate level a lot of history on the chosen measurement, on that specific product in that specific production line, is needed.

To collect all that history is a great deal of work and will take some time. It should cover as many of the potential scenarios, which can occur in the line, as possible. The data should be collected in the same way as SPC is performed except the fact that there will be no limits thus there will not be any alarms. This will give the operator training and the data will be in the correct form when the limits are calculated.

2.3.3 Education

To implement Statistical Process Control in a production process there need to be an understanding amongst operators and managers of what it mean. In literature that treats the subject of quality and Statistical Process Control there is almost always a chapter or part about the importance of top management support and proper education of every level in an organization.

To understand SPC you need to understand natural variation in a process, distribution of the outcome of the process and the charts used. To understand why it should be used in a specific process you also need understanding of that process. Without proper knowledge of what is done, there is risk that it´s not being utilized to its full potential. Lack of understanding may lead to tests not being done or not being done with enough meticulousness.

Some things that are particularly important to understand are[3]:

- That nothing should be done to the process unless there is evidence that change is needed
- Stability is key but there is always variation in a process
- SPC is used for prevention, not detection, of default products

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[3] *Statistical Process Control*, Oakland & Followell, p. 325-326

3. METHOD

In this master thesis the project plan started out from the sex sigma method. But since it early on was decided that the economical aspect should be kept out of the project the method used, have grown from there.

The thesis started off with reading a lot of theory about Statistical Process Control and general mathematical statistics. Parallel to this some old tests was studied and analysed with the new information. From the theory and the analysis of old tests decisions were made to do more tests and a plan for these was created. After conducting the tests a new plan was made. This has been a continuous process throughout the project, jumping back and forth between the different steps as the figure show.

- Books
- Internet

- Previuosly done tests
- New tests

- Going through data
- Calculations
- Summarize

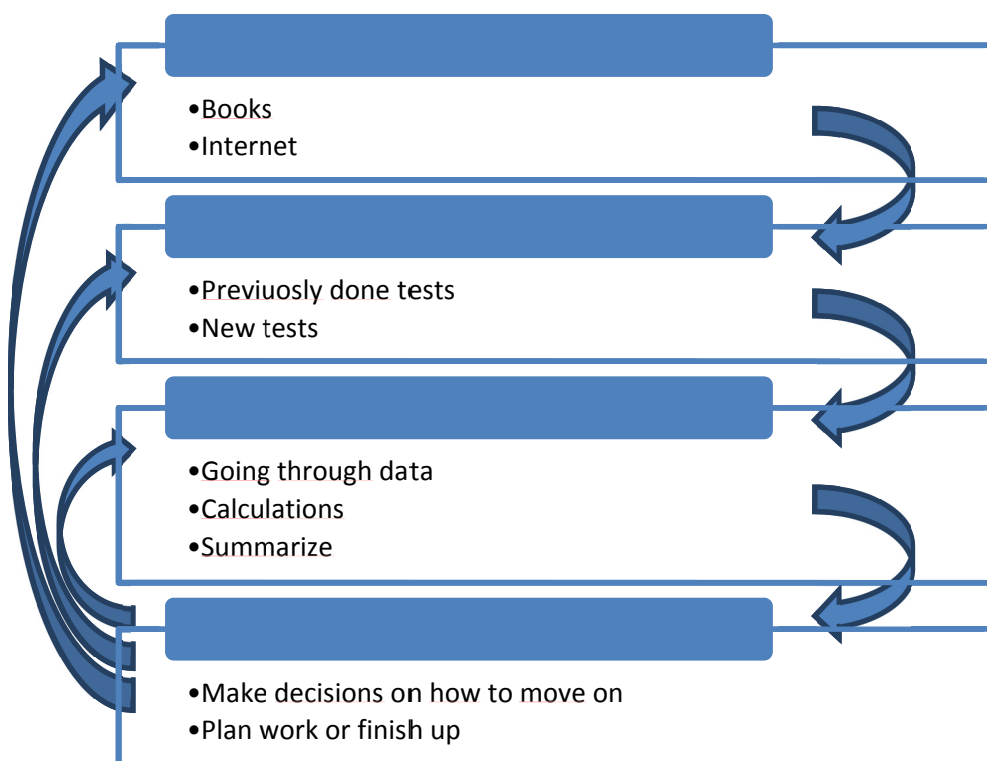- Make decisions on how to move on
- Plan work or finish up

Figure 3-1: visualization of the work process.

The principle came naturally in the working process. It can be said to build on the basic idea that quality improvement is a continuous process.

3.1 Tests

To evaluate if it is possible to introduce Statistical Process Control at the specific lines at Alfa Laval it needs to be evaluated if the machine (only one in this case) and the process is capable.

3.1.1 Machine capability test

3.1.1.1 Product information:

Material: Stainless steel
Thickness: 0.5 mm
Size: ~ 900x400 mm

3.1.1.2 Test pieces for C_m evaluation

To do a machine capability test 50 test pieces in form of a specific product was manufactured.

The products were manufactured with the machine set, as close as possible, to an optimum going at regular speed. Nothing was changed during the production of the 50 pieces. Some measurements on the material were made at the beginning, in the middle and at the, of the manufacturing.

The Team Leader for the production expressed that this was "*perfect production*"[4].

3.1.1.3 Measurements for C_m

There were 22 measurements taken on every product to be sure that the pattern is symmetric and the measurements are correct. There are additional measurements taken to be sure that the material is straight. These measurements were done by the company Excello AB in Malmö and had an accuracy of ±0.001 mm.

3.1.2 Process capability test

A process capability test was performed at the same production line as the machine capability test.

3.1.2.1 Product information:

Material: Stainless steel
Thickness: 0.5 mm
Size: ~ 900x400 mm

3.1.2.2 Test execution

Sample size: n=4
Interval: Every 100 products

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[4] 7/11 2011 Team Leader, production, Martin Backenheim

The test was performed by stopping the shearing machine and letting the finished products go through the rest of the process and then starting the shearing process again and producing four products. These four products was picked out of the machine and brought to a measurement station.

The reason why the samples were collected like this is due to how the process is built and the operator thought it was the best way.

Four measurements was taken on each product and logged in a table. The products were measured in the order they were produced for traceability reasons. The measurements were chosen to represent both width and length. The two measurements, measurements 9 and 10, in the length direction have the same profile and the same optimal value and so does the two, measurements 16 and 18, in the width direction.

The two measurements in the length direction were taken with a digital dial indicator fixed in a special designed fixture Appendix C. The dial indicator was set to zero at the drawing value so that if the value was exactly as in the drawing the displayed value would be zero. The two measurements in the width direction were taken with a digital vernier caliper.

After the products were measured they were put back into the process for normal production so that no scrap was produced. The products was but back at the same time as the next four products was picked out. This way time was saved as the machine only had to stop once for each sample.

In the table where the measurements were logged, the average and the range were calculated for each sample group and individual measurement. These calculations were done in a excel chart that was produced in advance. These calculated values were then plotted in x-bar and R-charts.

After sample group 17 was taken in the process capability test, a longer stop occurred due to wear on one of the punching tools in the process. That tool was brought out of the machine and grinded. When it was put back the operator adjusted the process and started the machine again and the last three tests were made just as the others.

3.1.2.3 Three samples

The measurement of the first product was removed from measurement 9 and the measurement of the second product was removed from measurement 10 and a new table was made. Measurement 10 of the second product and measurement 9 of the first product, in a sample group, is punched with the same tool at the same time and later sheared through. This shear is the first one made after the machine was started again to produce the samples. New charts were made with these smaller sample groups.

4. DATA

4.1 Old data

Some old data was received and analysed in the beginning of the project. This data included:

- Measurement of the length of specially sheared test pieces
- Measurements of some samples of one larger product for both "good" and "bad" material
- Measurements of some samples of one smaller product

The test pieces for length measurements were made with the machine set to produce pieces with the length 450 mm. There were 30 pieces made. Measurements were taken with a veriner caliper at three positions on each piece. These points were one on the left side, one in the middle and one on the right. The outcome of the test was as in Table 4-1.

	Left	Middle	Right
Mean value	450.01	449.98	449.97
Standard deviation	0.054	0.025	0.073

Table 4-1: test results from length measurements of test pieces.

The smaller products are the same type of product as the ones in the new tests performed during the project. The measurements logged on the smaller products are in both length and width direction, 16 different measurements were logged. The products are produced from different materials and different thicknesses. Most of the samples were taken two at the time.

Also on the bigger products measurements in both length and width directions were taken. The biggest different between this test and the one on the smaller products is that this were deliberately taken on material known to be good and material known to be bad. The material was measured before manufacturing. This was to evaluate how the measurements were affected by unsatisfying material.

4.2 Collected data

The data was collected as described in method. All of the data will not be published here because without all the background it is just a big table with measurements. The data that was analysed closer will be described under the headline Analysis.

5. ANALYSIS

5.1 Sample size, interval and charts

Which sample size and interval that shall be used is commonly decided by cost factors and optimization to the process. In this case, at Alfa Laval, where the process is so complex and it takes a comparably long time to stop the production to take samples, deciding the size and interval needs to consider time issues and complexity.

An even number should be used as sample size simply because of the fact that after the processing in the first machine in the line two or four products fit on the handling equipment before they are sent on to the next stage.

If SPC is implemented only a few measurements can be taken on each product due to the fact that measuring takes time.

The decision was made to use x-bar and R charts in the report and at Alfa Laval. The reason for this is that it is easy to set the machine to a specific value. So in this case it is better to have fixed control limits, that way the process can be brought back on target, instead of moving control limits. The control limits are moving in some other charts used for SPC.

All the rules for alarms can be difficult to follow manually but a computer program can easily track all of them and give alarms. The alarm can come with an explanation on what has happened. E.g. alarm goes, textbox with information say "two points out of three have been outside the 2σ line". After a while the operator learns what alarms usually are connected to specific events. These connections should be written down over time so that instructions on what to do in case of alarms can be made.

5.2 What to measure and why

To determine if the process is capable tests needs to be done, *"process capability must be assessed and not assumed"*[5]. One of the difficult parts is to determine what to measure since the process is so complex. There are many steps in the shearing/punching machine that affect the final product. For practical and economical reasons not all of them can be measured. The punching of the pattern in the product and the shearing off the product is two of the elements which may be affected.

One measurement that, for several reasons, affects the symmetry within the pattern of the product is the length of the product. The length is also a direct measurement of the accuracy of the timing of the machine in that direction. It seems fairly easy to measure but since the products are quite long and the tolerances are very tight it might cause a problem.

After considering how the machine works and how different parts of the shearing/punching process works it was decided to make tests on actual products. This will take all parts of the process into account. As described in the Method part a lot of measurements were taken during the C_m test. This was to evaluate both machine capability and appropriate measurements for SPC. From these tests the measurements for the C_p test was decided.

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[5] *Statistical Process Control*, Oakland & Followell, p. 332

5.3 Old data

5.3.1 Length measurement on test pieces

From the data in Table 4-1 C_m values were calculated to see the machine capability of the length shearing. Calculations were made for both the tolerance ±0.2 and ±0.3 because the different products have different tolerances. The result is shown in Table 6-1.

5.3.2 Measurements on smaller products

Since most of the measurements were taken in sample groups of two, calculations on them can be made with sample size n=2. Even if this normally is not an adequate sample size it is better to calculate with two than to treat them as individual samples, otherwise systematic errors can occur. There are 15 sample groups of two products.

Out of all the 16 different measurements on the smaller products, four were chosen for calculations. The reasons for choosing these four are because they are affected both of the shearing and the punching parts of the process and two of them are of critical value to the final product. The measurements chosen were the two measurements of the length, measurement 1 and 2 see Figure 5-1, both of them were chosen to see if there were any difference between them. Then two smaller measurements, measurements 9 and 10 see Figure 5-1, were chosen. These are two of the most critical ones and have in previous test shown a connection to other measurements both in the length and width directions. These two measurements are identical to each other, one in the front of the product and one in the back. They are the same as measurement 9 and 10 in the tests performed in the master thesis, see Figure 5-1.

The C_p and C_{pk} were calculated for all four measurements, Table 6-2 and Table 6-3, x-bar and R-charts were produced as a test to see how it would look. In these charts both the control limits and the specification limits are shown to get a picture of how the outcome of the process performs, see Chart 6-1 to Chart 6-8.

5.3.3 Measurements on bigger products

There have already been analysis done on the tests of the bigger products and the conclusions from those tests were that the spread of the measurement increases when the material turns bad and that all the measurements follow this pattern though the ones in length direction shows it more, especially measurement 9 and 10. No extra calculations or charts were considered to be necessary.

5.4 Machine capability test

The tests were decided to include 50 products that were considered to be a sufficient amount for statistical reasons. Costs for measuring the products were taken into consideration. 100 products do not give that much more than 50 since the increase in statistical certainty does not increase linearly. It was decided to take as many measurements as possible on each product so that everything could be analysed and patterns between the measurements, if there were any, could be found.

5.4.1 Normal distribution test

All the 22 measurements that were taken on each product in the test were analysed to see if they were normally distributed. This was made in MatLab by creating Histograms and Normal probability plots. Some other distributions were tested as well but they did not fit as well as normal distribution so the result of them will not be accounted for in this thesis.

The result of a couple of the histograms and plots are shown under result in Chart 6-9, Chart 6-10, Chart 6-11 and Chart 6-12. These are for measurement 1 and 2, the length measurements.

5.4.2 Measurement analysis

There are a lot affecting the different measurements in width and length direction. Here comes some explaining on what affects the different measurements and how they were analysed.

Table 6-4 shows the C_m and C_{mk} values that were calculated for a lot of the measurements. In the process the length of the product (measurement 1 and 2) is affected by; the timing between the feeding and the shearing and the shearing itself (the condition of the plate shear). To some extent the length is also affected by the punching of the holes since this is made between the shears.

Measurement 9 and 10, see Figure 5-1, is affected by the timing between feeding and punching of the holes and feeding and shearing of the length together with the tool punching the holes. Measurement nine and ten has a lower tolerance than one and two. They also are directly affected by each other; measurement 9 is in the back of the product in the feeding direction and measurement 10 in the front. These holes are made with one tool and then sheared straight through. So if measurement 9 is bigger on one plate measurement 10 will be smaller on the next and if measurement 9 is smaller on one plate measurement 10 will be bigger on the next. This can be seen in Chart 6-13.

Measurements 11 and 12 (not shown in any figure) are measurements for how well centred punched holes in the product are in the width direction of the product. The C_m and C_{mk} values are calculated with the x-bar value in Equation 2-4 and Equation 2-5 set to half the average width of the products and the UCL and LCL are also calculated from this new value. This because the important thing is that the measurement is as centred as possible, not that the measurement from the edge to the centre is as accurate as possible. The width also has a wider tolerance width than the centre measurement and depends entirely on the material.
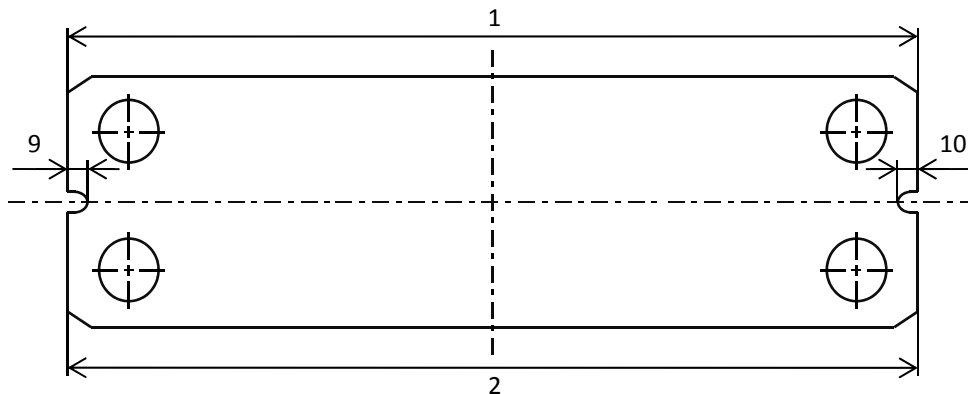
Figure 5-1: shows approximately how the product looks and measurements 1, 2, 9 and 10.

Measurement 13 and 14 (not shown in any figure) are measurements in width direction between two holes in the product. They are entirely dependent on the fixture in the machine.

Measurement 22 (not shown in any figure) is the width and is only a measurement of the original material after it has gone through the machine. It is included to show how the material width varies.

To see if it is possible to measure exactly from an edge of a hole to an edge of the plate or to an edge of another hole, instead of measuring from the middle of a hole this is hard to do by hand. The standard deviation of two holes were calculated, see *Table 6-6* the measurement from which the calculations were done is the diameter of two round holes. The tolerance was unknown, consequently C_m was not calculated.

To see if some of the length measurements followed each other they were plotted in Chart 6-13. Measurements 5 to 8 are smaller measurements and are all identical two in each end of the plate. Measurements number five and six are in the same end as measurement 9 and number seven and eight are in the same end as measurement 10.

Measurement 15 to 18 are smaller width measurements, they are identical, two on each side of the product. Measurement 15 and 17 are on the same side and measurement 16 and 18 are on the same side. To see if any connection could be showed to measurement 9 and 10 Chart 6-14 was created.

The measurement between the holes in the pattern, measurement 19-22x and 19-21x is affected by the feeding and the timing for the punching of the holes. Depending on which product is in the machine it can be sheared off in one end before all the holes in that product is punched, then the shearing also affect measurement 19-22x and 19-21x. All four length measurements have the same tolerance and are shown in Figure 5-2.
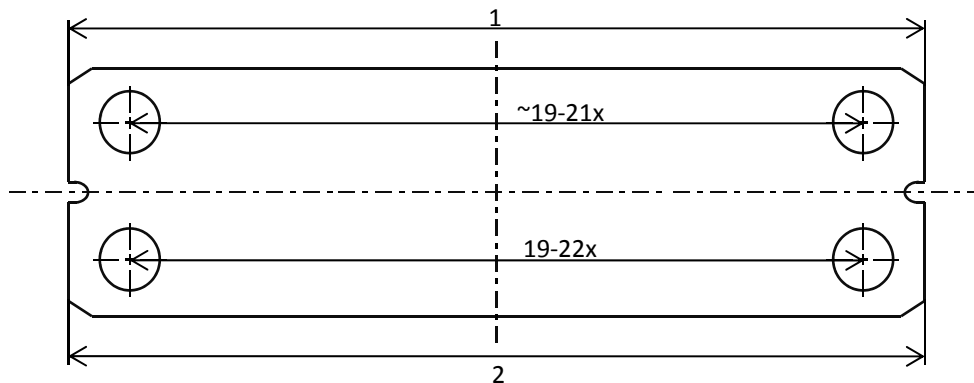
Figure 5-2: shows measurements 1, 2, 19-22x and 19-21x.

A comparison between C_m values for measurements 1, 2, 19-22x and 19-21x is showed in Table 6-8.

5.5 Process capability test

Measurements 9 and 10 were considered most suitable to continue with after the machine capability test, even though the C_m values were a bit unsatisfactory. From the old test and the machine capability test they still seemed to have connections to the other measurements. They are critical values to make good end products and they are comparably easy to measure exactly with the specially constructed fixture. To have a value in the width direction as well measurements 16 and 18 were included in the test.

In the C_p test fewer measurements were taken and x-bar and R-charts was created for all of them, Chart 6-16 to Chart 6-27. The C_p and C_{pk} values were calculated for measurements 9 and 10. They were not calculated for measurement 16 and 18 since these two are not directly connected to a tolerance on the drawing.

After looking at the measurement result of measurement 9 and 10 some of the values stood out being much higher than the others. It seemed to be systematically the same values as well, see Table 6-10 the red values. Consequently these values were removed and new x-bar and R-charts were created, Chart 6-20 to Chart 6-23. New C_p values were also calculated, Table 6-11.

5.6 Vision

A discussion has been held about a vision system. This vision system would be used to measure the plates directly in the process without stopping the machine and without extra labour for the operator.

It would consist of some sort of camera photographing or video filming the products when they travel on the handling equipment. The computer would then measure the desired values and feed them in to a computer program used for SPC.

6. RESULTS

6.1 Old tests, calculations

6.1.1 Test pieces for test measurements

	Left	Middle	Right
C_m ±0.2	1.23	2.65	0.91
C_m ±0.3	1.84	3.97	1.36

Table 6-1: C_m values for Length measurements of test pieces with tolerance widths ±0.2 and ±0.3.

This show varying values for C_m on the different sides of the product, which means that the process spread, varies over the width of the product.

6.1.2 Smaller products

	Right side	Left side
C_p ±0.2	1.08	0.89
C_{pk} ±0.2	0.47	0.55

Table 6-2: C_p and C_{pk} values for the old tests of the length measurements on the left and right side of the products.
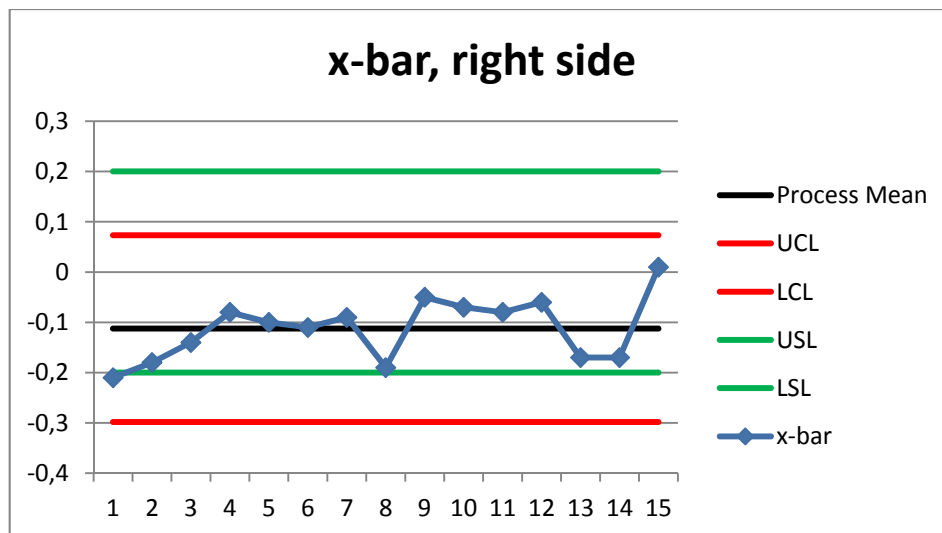
Chart 6-1: x-bar chart for the right side of the products.

As seen in Chart 6-1 the UCL falls inside the USL but the LCL doesn't fall inside the LSL. From Table 6-2 you can see that the C_{pk} value is less than one but the C_p value is larger than one so the process is not centred on target.
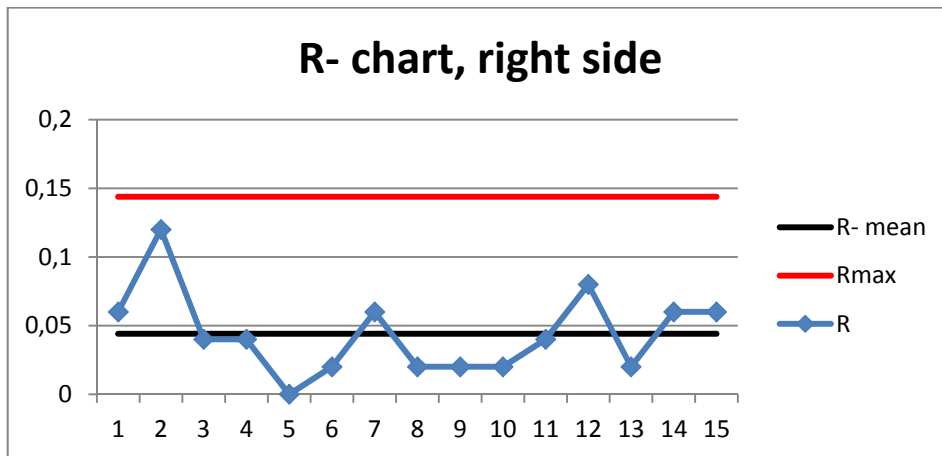
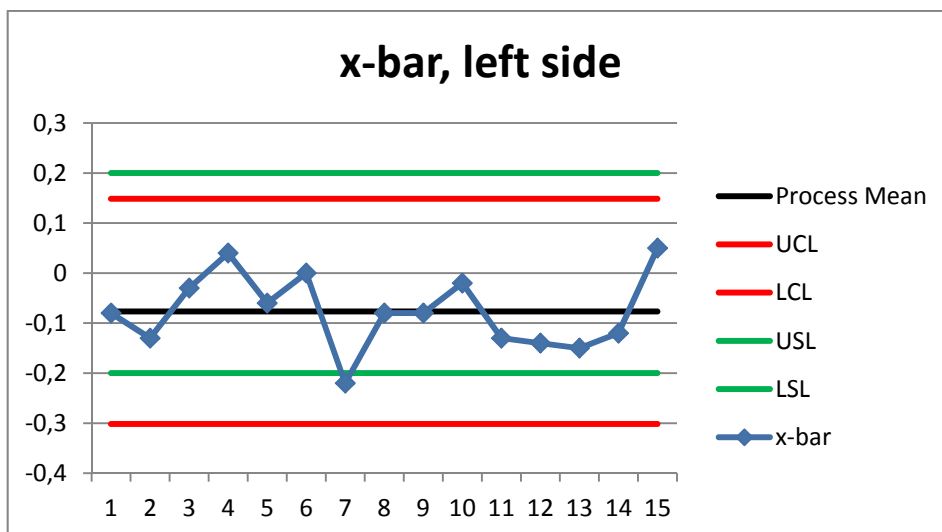*Chart 6-2: R- chart for the length measurement on the right side of the products.*

Chart 6-3: x-bar chart for the left side of the products.

For the left side the length measurements have a lower C_p but a higher C_{pk} than for the right side. This means that the process spread is higher but the process is closer to target. That the left side is closer to target shows a little bit in Chart 6-3.
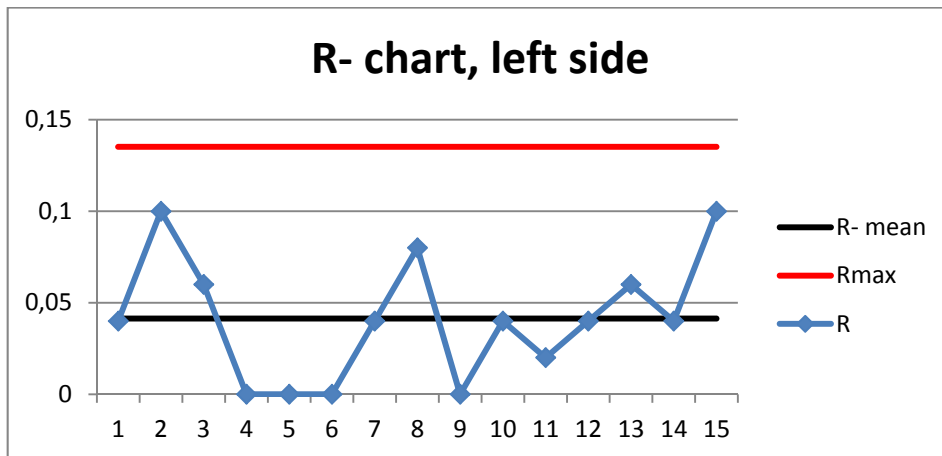
Chart 6-4: R- chart for the measurement on the left side of the products.

The range between the samples is within R$_{max}$ on the left side of the product and a little bit lower than on the right side.

The smaller measurements in the front and back of the products have a lot lower values for C$_p$ and C$_{pk}$, see Table 6-3 but they also have a lower tolerance.

	Front measurement	Back measurement
C$_p$	0.28	0.19
C$_{pk}$	0.19	0.16

Table 6-3: C$_p$ and C$_{pk}$ values for the old tests of front and back measurements for the smaller products.
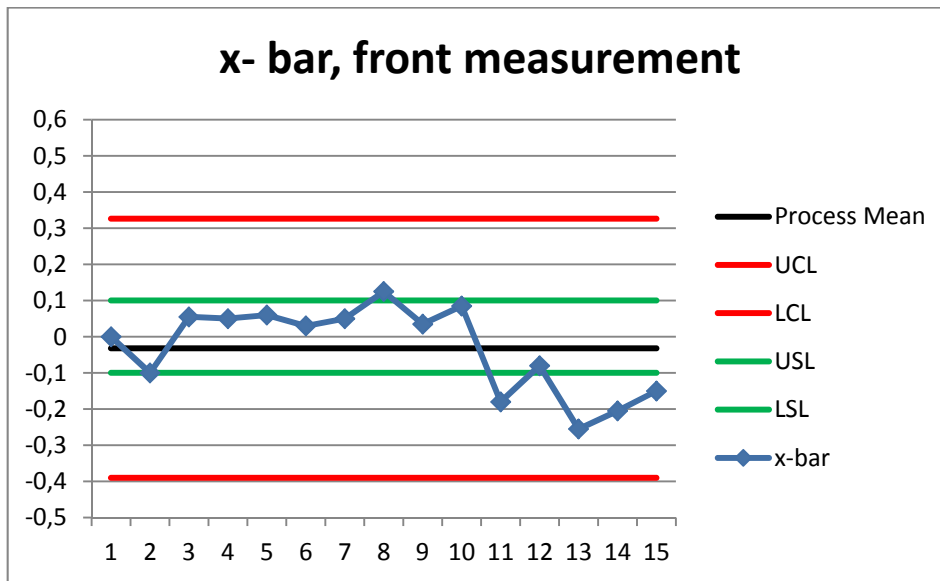
Chart 6-5: x-bar chart for the smaller measurement in the front of the products.

In the x-bar chart for the smaller measurement in the front it gets really obvious that the spread is to high, look at where the UCL and LCL are compared to the specification limits.
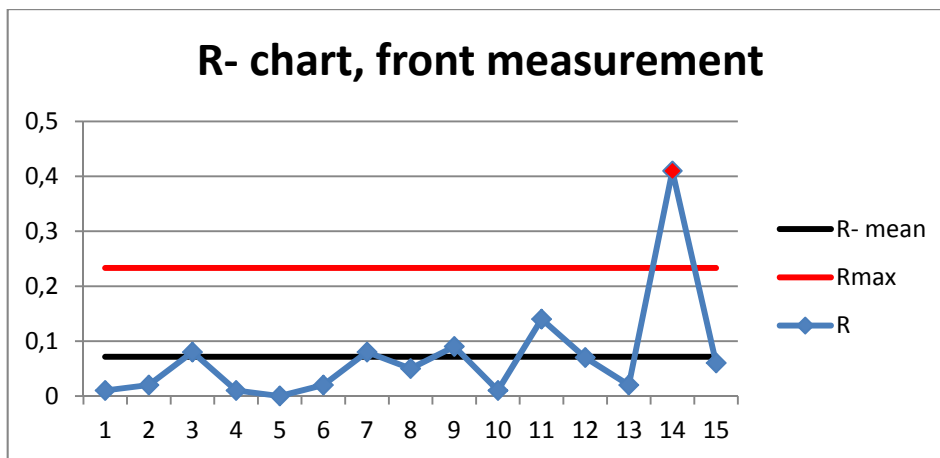

Chart 6-6: R-chart for the smaller measurement in the front of the products.

In the R-chart for the smaller measurement in the front there is one point above R_{max}. If this had not been a test, an alarm would have gone off because the process spread had probably increased.
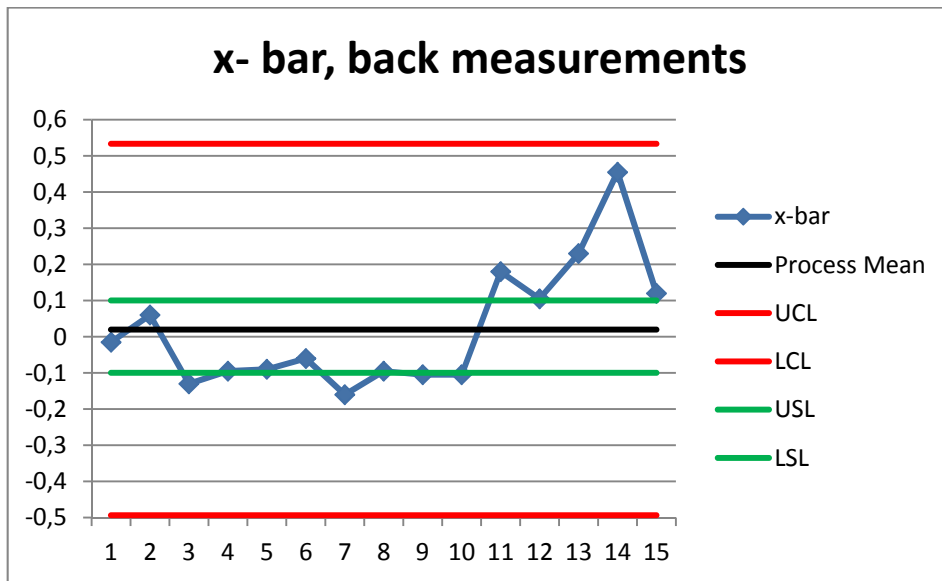
Chart 6-7: x-bar chart for the smaller measurement in the back of the products.

For the smaller measurement in the back goes the same as for the front measurement. The control limits are way outside the specifications and also in the R-chart below one point is outside the R_{max} and the points are from the same two samples.
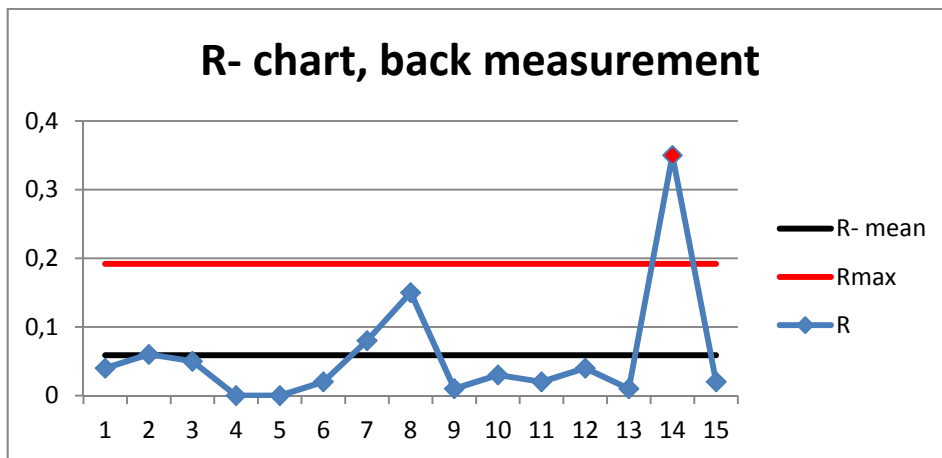

Chart 6-8: R-chart for the smaller measurement in the back of the products.

6.2 Machine capability test
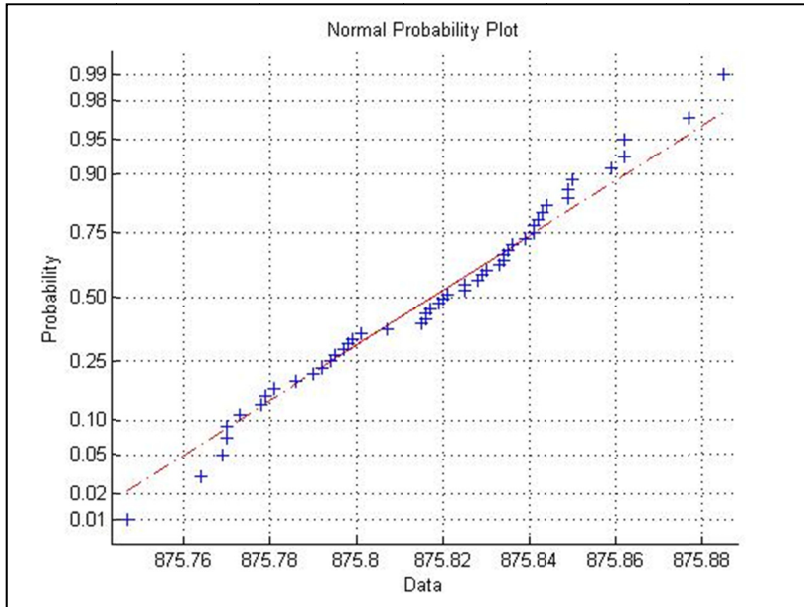
6.2.1 Tests for normal distribution

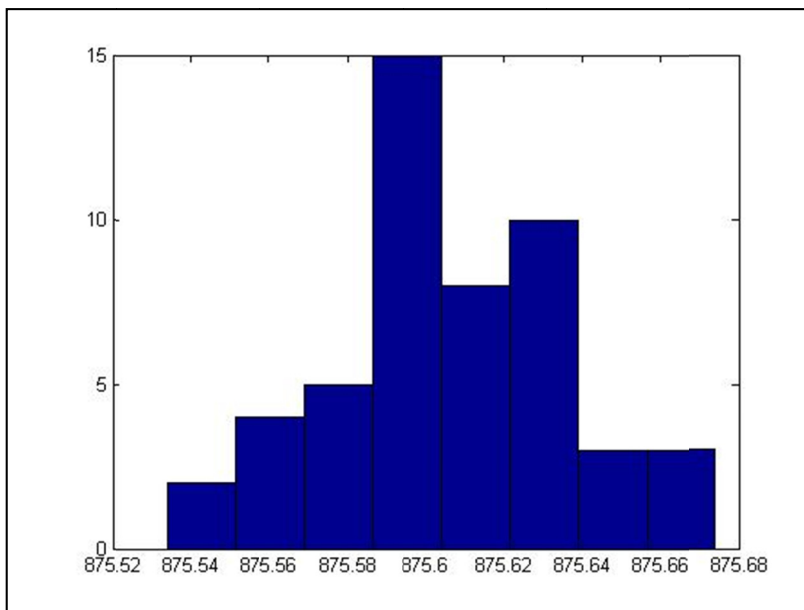*Chart 6-9: normal probability plot for measurement 1.*
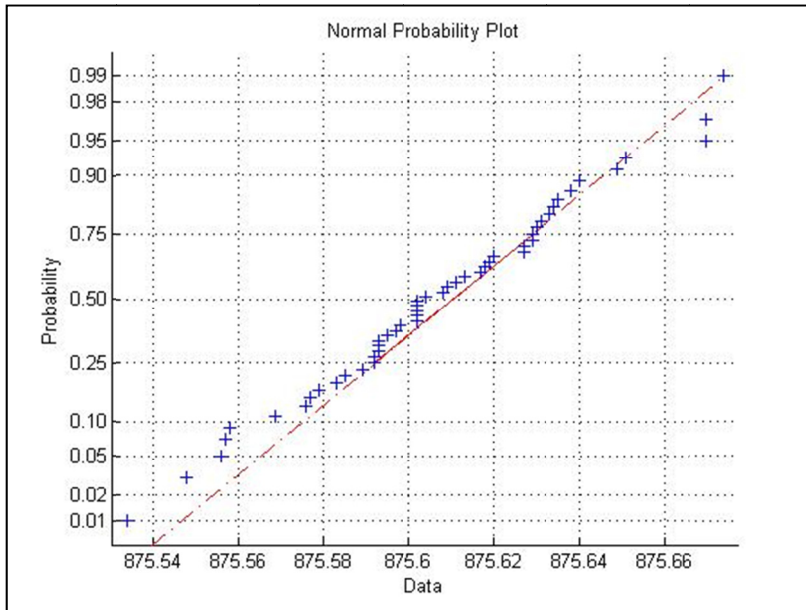

Chart 6-10: histogram for measurement 1.

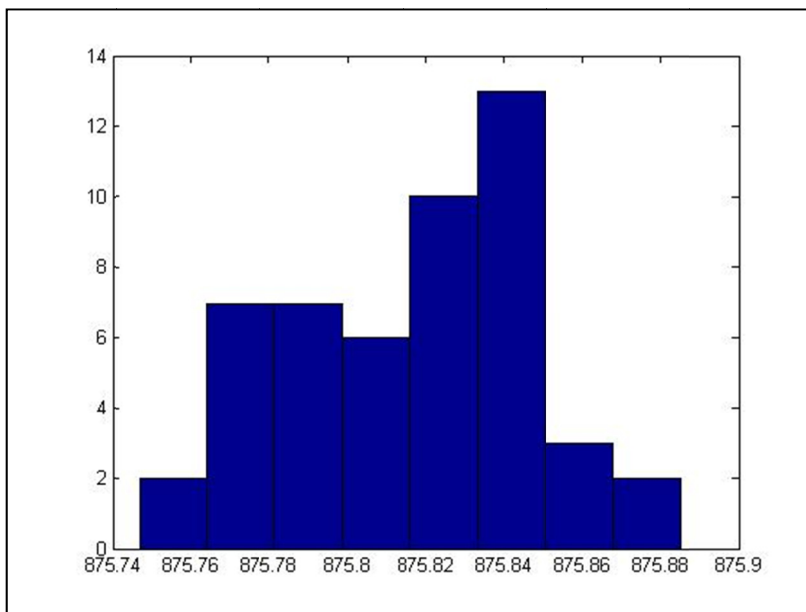*Chart 6-11: normal probability plot for measurement 2.*

Chart 6-12: histogram for measurement 2.

6.2.2 C_m analysis result

Measurement	1	2	3	4	9	10	11	12	13	14	22
C_m	2.17	2.14	3.48	2.86	0.67	0.65	2.22	2.63	16.69	18.48	8.12
C_{mk}	0.08	1.96	1.02	1.35	-0.29	-0.52	1.53	1.82	11.21	12.47	4.22

Table 6-4: C_m values for different measurements taken in the machine capability test.

Measurement 1 and 2 are still length measurements and as can be seen in Table 6-4 the C_m>1.4 which mean the machine is capable to produce the right length, the adjusted values differ a bit, one is very good and the other is almost zero.

Measurement 3 and 4 are length measurements between two punched holes, they are the same length. Both of them have C_m>1.4 and C_{mk}<1.4. But the C_{mk} values are fairly close.

Measurements 9 and 10 have tighter tolerance widths than all the other measurements taken. They have really low C_m values. The C_{mk} values are negative which mean of the outcome are outside the USL or LSL. In this case the average value for measurement 9 was 0.044mm outside the LCL and measurement 10 was 0.08mm outside the UCL.

Width	Measurement 13	Measurement 14	Measurement 22
Standard deviation	0.0040	0.0036	0.0123

Table 6-5: table with standard deviations for a couple of width measurements with high C_m and C_{mk} values.

Hole punch	Right	Left
Standard deviation	0.0036	0.0044

Table 6-6: standard deviation for two identical holes punched with two different tools.
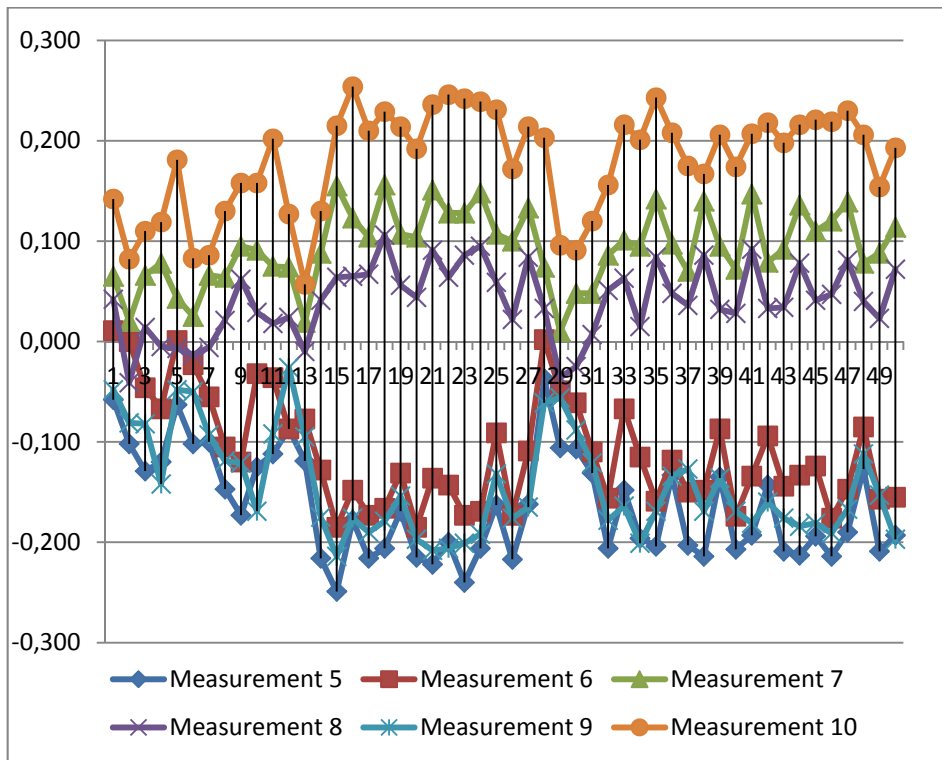
Chart 6-13: here measurements 5 to 10 are plotted with their difference from target value.

So measurement 5 and 6 do follow the same pattern as measurement 9 and measurement 7 and 8 follow the same pattern as measurement 10.

Measurement	5	6	7	8
Stand. Dev.	0.05125	0.05461	0.03676	0.03524

Table 6-7: Standard deviation for measurement 5 to 8.

Here is no direct connection to a tolerance therefore the standard deviation is considered instead. As shown in Table 6-7 the standard deviation is considerably larger for measurement 5 and 6 than for 7 and 8.
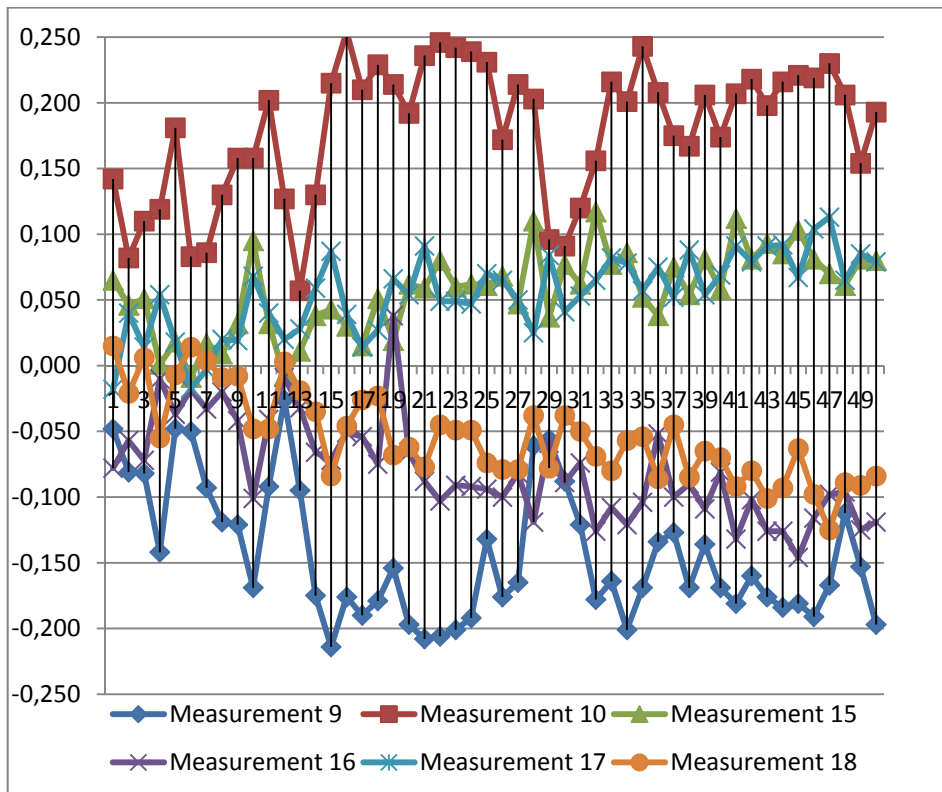
Chart 6-14: here measurements 9, 10 and 15 to 18 are plotted with their difference from target value.
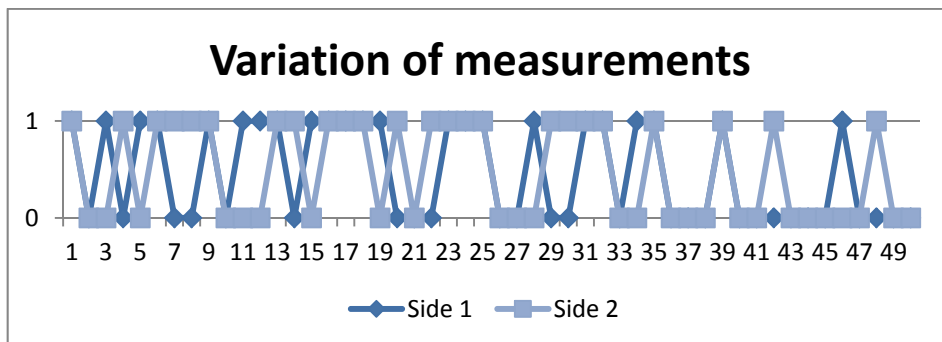
Chart 6-15: value one represent the measurements on the same side going in the same direction. E.g. the length increase and the measurement between the holes in the pattern on the same side also increase gives a one. A zero is when they vary in opposite ways.

The variation, for an individual value, in length of the product and the measurement between the holes in the pattern along the length does not follow each other, see Chart 6-15. Side one and two does not follow the same pattern either.

Measurement	1	2	19-21x	19-22x
C_m	2.17	2.14	3.90	2.95

Table 6-8: C_m values for length measurements outer and inner.

As shown in Table 6-8 machine capability is higher for measurements 19-21x and 19-22x than for one and two. This indicates that the shears is a source of variation.

6.3 Process capability test

	Measurement 9	Measurement 10
C_p	0.70	0.88
C_{pk}	-0.68	-0.38

Table 6-9: C_p values with all four samples included from each sample group.

Chart 6-16: The average values, X-bar chart, of measurement 9 for the twenty sample groups in the C_p test.

Chart 6-17: Range chart of measurement 9 for the twenty sample groups in the C_p test.
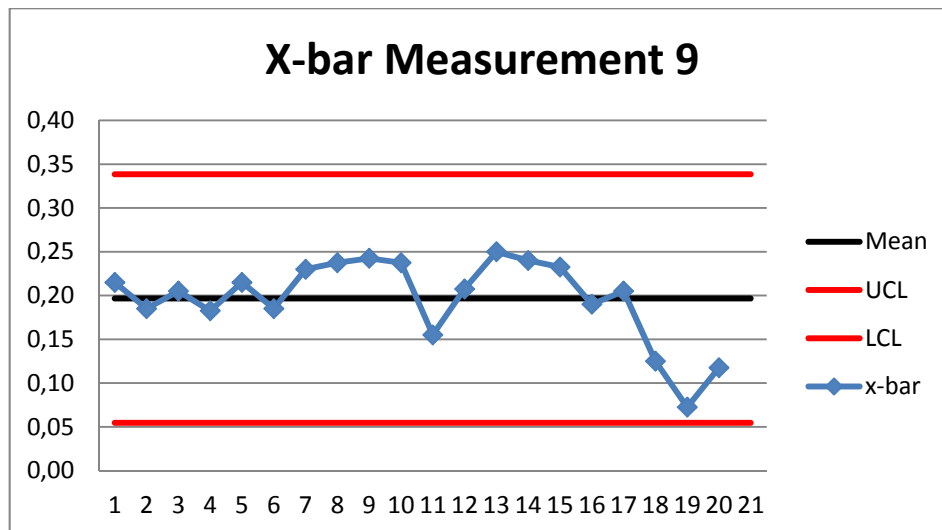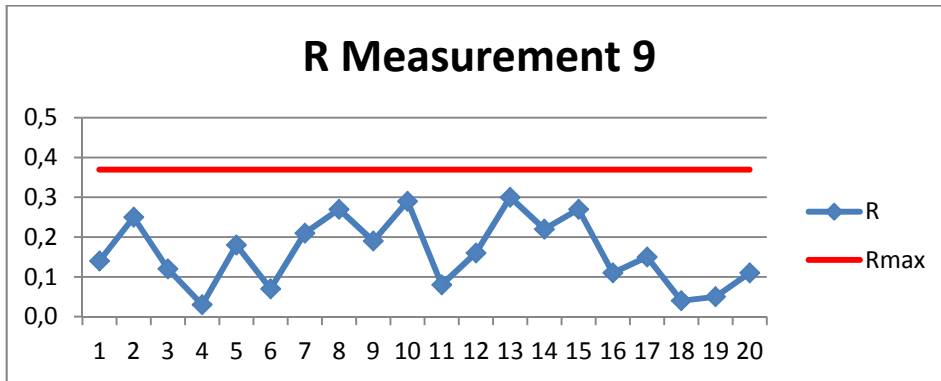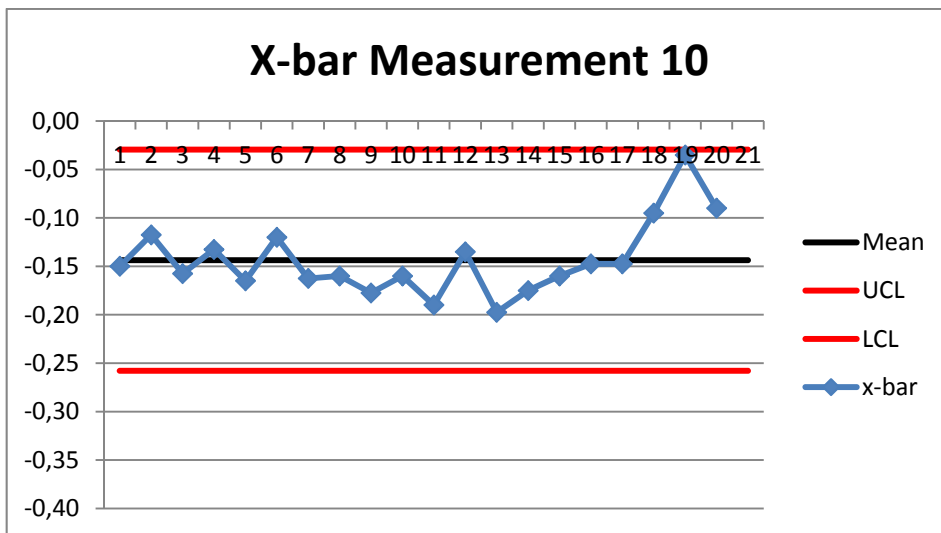

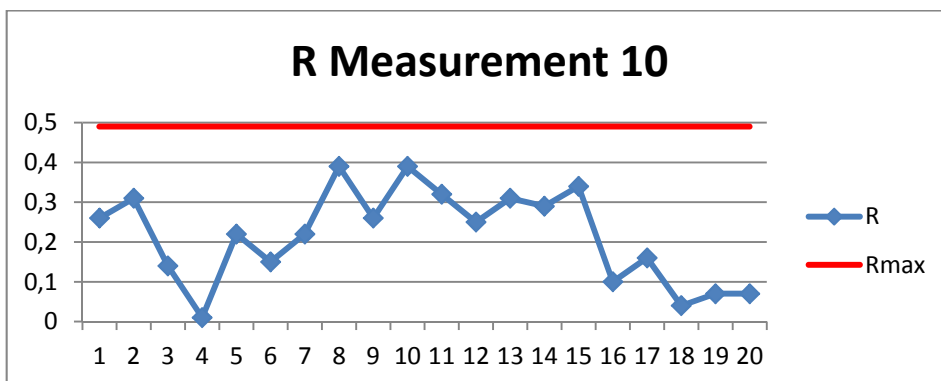*Chart 6-18: The average values, X-bar chart, of measurement 9 for the twenty sample groups in the C_p test.*

Chart 6-19: Range chart of measurement 10 for the twenty sample groups in the C_p test.

Measurement	Plate	Sample 7	Sample 8	Sample 9	Sample 10
9	1	0.37	0.42	0.38	0.44
9	2	0.16	0.2	0.19	0.15
9	3	0.19	0.15	0.21	0.16
9	4	0.2	0.18	0.19	0.2
9	Mean	0.23	0.2375	0.2425	0.2375
9	Range	0.21	0.27	0.19	0.29
10	1	-0.09	0	-0.06	-0.01
10	2	-0.31	-0.39	-0.32	-0.4
10	3	-0.11	-0.14	-0.15	-0.1
10	4	-0.14	-0.11	-0.18	-0.13
10	Mean	-0.1625	-0.16	-0.1775	-0.16
10	Range	0.22	0.39	0.26	0.39

Table 6-10: a cut out from the table created during the C_p test. It shows sample groups 7 to 10 for measurement 9 and 10.

	Measurement 9	Measurement 10
C_p	1.45	1.18
C_{pk}	-0.33	0.23

Table 6-11: C_p values with plate 1 in the sample group excluded for measurement 9 and plate 2 excluded for measurement 10.

Chart 6-20: The average values, X-bar chart, of measurement 9 for the twenty sample groups in the C_p test, without taking product one in each sample group in to consideration.

Chart 6-21: Range chart of measurement 9 for the twenty sample groups in the C_p test, without taking product one in each sample group in to consideration.
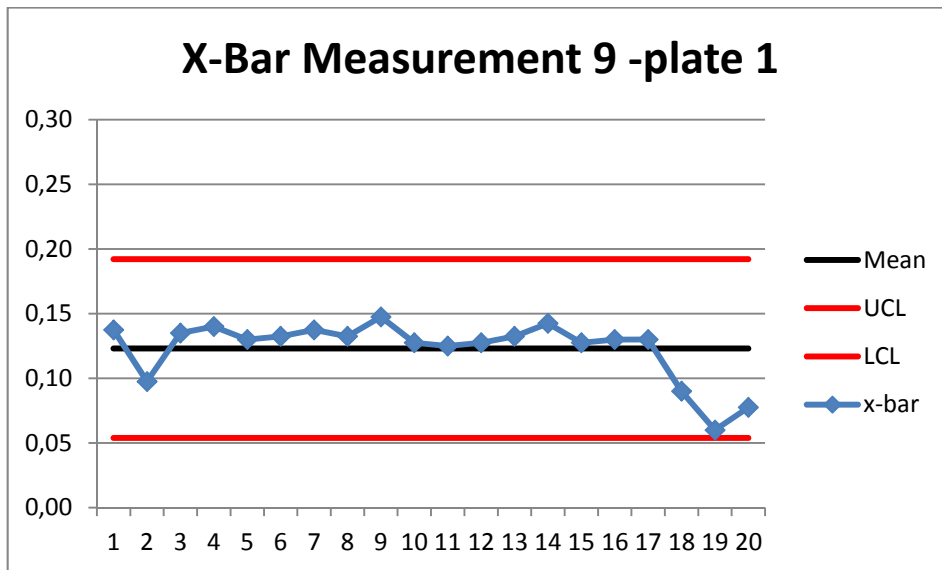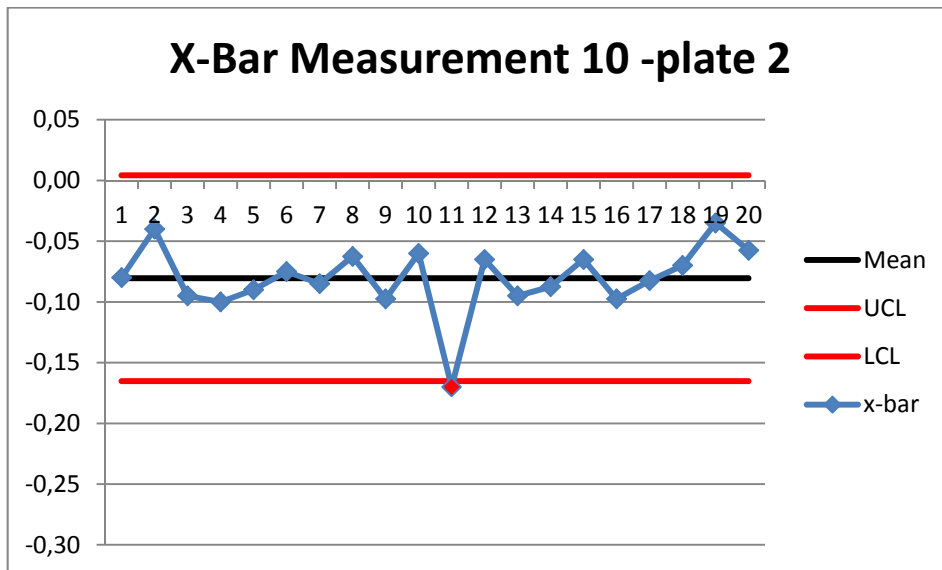
Chart 6-22: The average values, X-bar chart, of measurement 10 for the twenty sample groups in the C_p test, without taking product one in each sample group in to consideration.
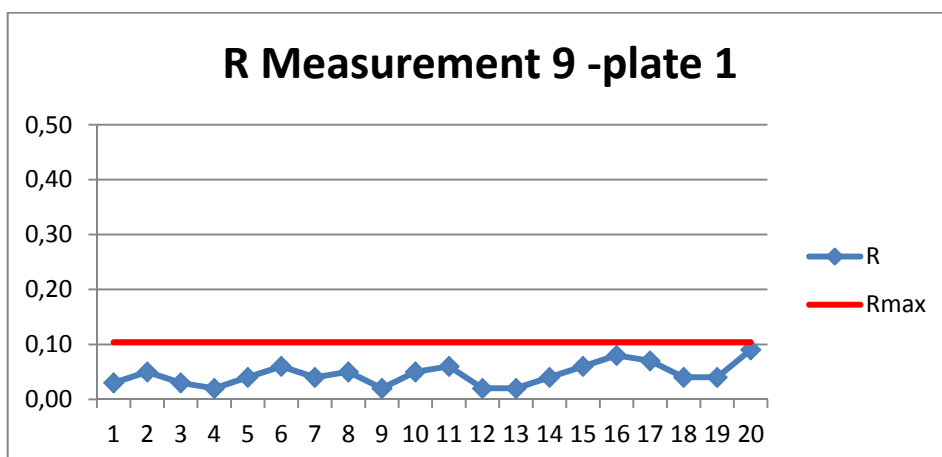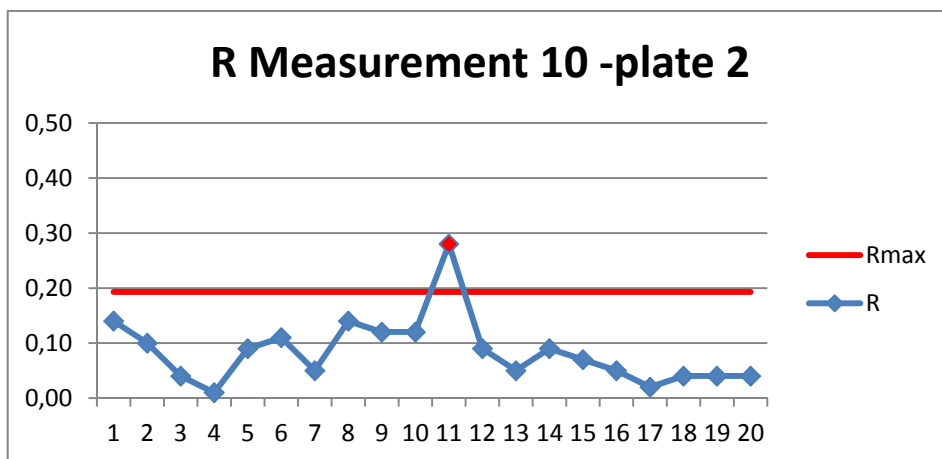

Chart 6-23: Range chart of measurement 10 for the twenty sample groups in the C_p test, without taking product two in each sample group in to consideration.

Measurement	Plate	Sample 7	Sample 8	Sample 9	Sample 10
9	2	0.16	0.20	0.19	0.15
9	3	0.19	0.15	0.21	0.16
9	4	0.20	0.18	0.19	0.20
9	Mean	0.14	0.13	0.15	0.13
9	Range	0.04	0.05	0.02	0.05
10	1	-0.09	0.00	-0.06	-0.01
10	3	-0.11	-0.14	-0.15	-0.10
10	4	-0.14	-0.11	-0.18	-0.13
10	Mean	-0.09	-0.06	-0.10	-0.06
10	Range	0.05	0.14	0.12	0.12

Table 6-12: Samples 7 to 10 for measurement 9 and 10, from the C_p test without product 1 respectively product 2.

Chart 6-24: The average values, x-bar chart, of measurement 16 for the twenty sample groups in the C_p test.

Chart 6-25: Range chart of measurement 16 for the twenty sample groups in the C_p test.

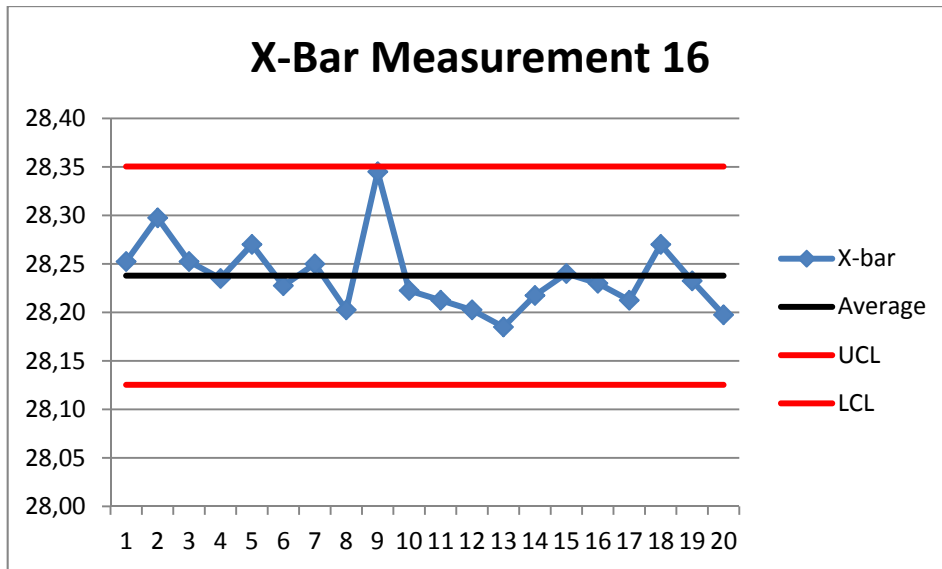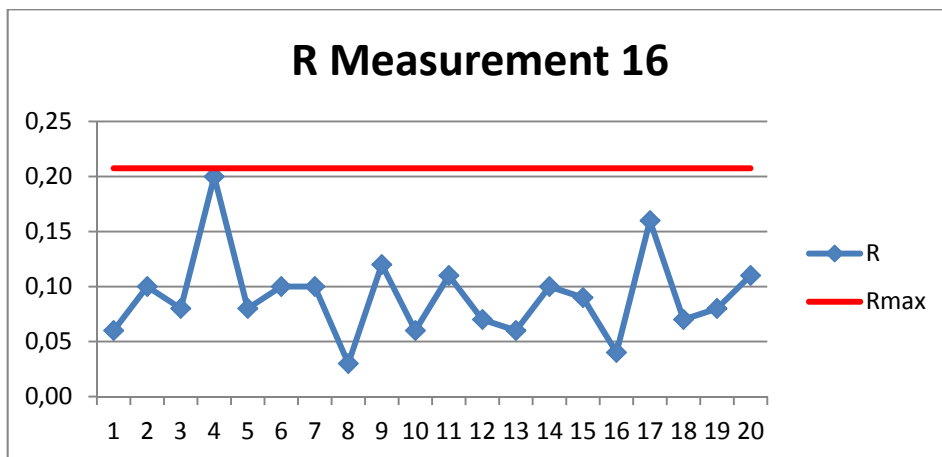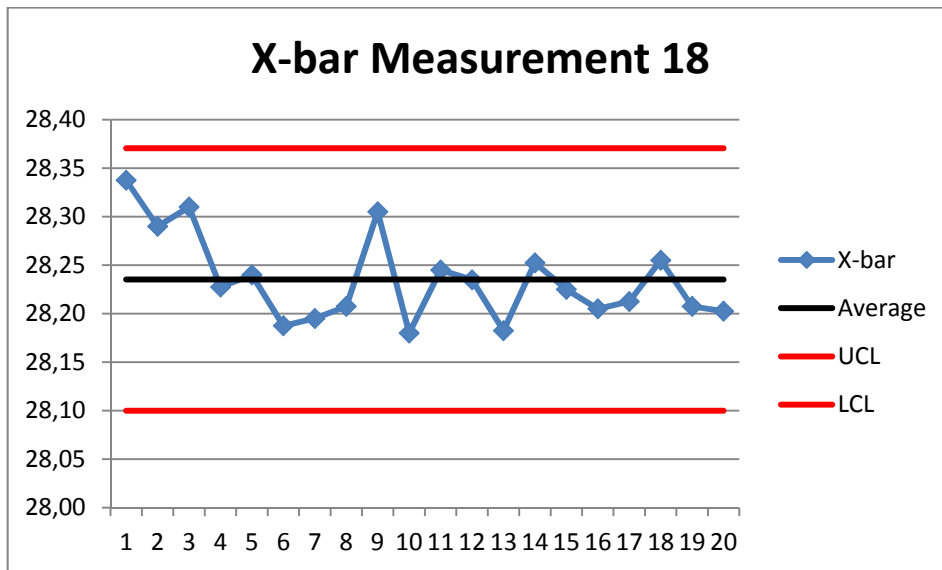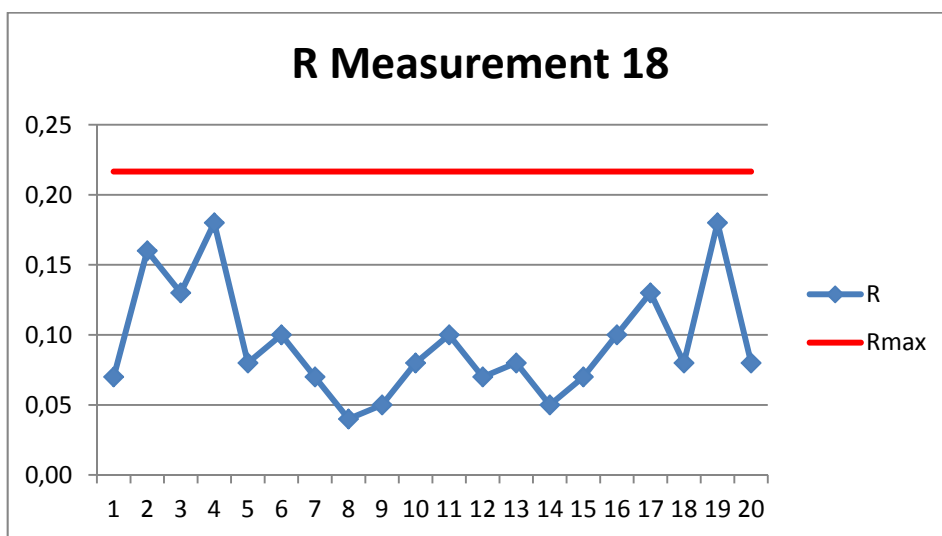*Chart 6-26: The average values, X-bar chart, of measurement 18 for the twenty sample groups in the C_p test.*

Chart 6-27: Range chart of measurement 18 for the twenty sample groups in the C_p test.

7. CONCLUSIONS

7.1 Old tests

The result of the C_m values in Table 6-1 shows varying values at different positions of the pieces. Some of them are satisfying for both the tolerance widths and some are not. Table 4-1 also show that the pieces are smaller on one side than on the other. These two factors indicate that there is not a feeding problem but more probably something wrong with the plate shear. The plate shear has been replaced since this test was done. These tests are also somewhat inadequate because they just test a part of the machine that is never used on its own. There is always punching done on real products and no products, in this line, are as small as 450mm.

From the test of the smaller products it is clear that with these C_p values a start up with SPC is not possible before bringing the process into control. Though there is the fact that these measurements were taken on different materials and different thicknesses of materials, which also means different program settings in the machine. Also some changes to the process have been made since these tests were done. This is why new and more thoroughly thought out tests were done.

7.2 Machine capability test

The normal probability plots shows that the process might not be exactly normally distributed this is probably because there were 50 samples if there had been more samples the normal probability plot would probably be better.
The measurements 1 and 2 have different values off C_{mk}, Table 6-4, when the values that were put into the formula was evaluated it shows that the measurement on the left side is shorter than the other side. The material probably wasn´t exactly straight and therefore one side became a bit shorter than the other. If the material has a straightness error of 0.1mm the length will differ approximately 0,15mm/m which seems to be the case here. So as Alfa Laval already discussed before the study the material put in to the machine is of uttermost importance to the outcome.

Measurement 3 and 4 are easy to adjust in the computer, therefore these $C_{mk}<1.4$, Table 6-4, are not problem it´s just to adjust the machine. Their high values of $C_m>2.8$ shows that the internal process of punching the holes and material feeding is very stable.

Measurements 9 and 10 have the lowest C_m values, this is partly because they have a lower tolerance width but even with the same tolerance width the C_m values would be lower. They are the measurements that are affected by the most steps in the process. The problem is that measurement 9 and 10 are also two of the most critical values. One good thing though is that there will be easier to track a difference in these numbers because the offset values are a bit higher and therefore easier to measure. From the historic test on the bigger products it can also be seen that these measurements are the ones that varies the most when the material starts to become bad.

The measurement for measuring how well centred a hole is, measurement 11 and 12 both have C_m and $C_{mk}>1.4$ so the process is capable without any improvements in the width. They should not be used in SPC, for this type of production, even if the capability values are good, because it is not a critical value and if something is wrong with the feeding this

won´t show in the width direction. It is also a measurement that´s not very sensitive in general.

Measurement 13 and 14 has extremely high values of C_m and C_{mk} but as for measurement 11 and 12 they are not suitable for SPC. They won´t show anything useful and will be very hard to track since the normal variation is so very small.

The width of the material, measurement 22, has very high values of C_m and C_{mk}. This just shows that the material received is according to specification from the supplier.

Even if you wanted to use some of the width measurements for SPC it would be hard. As shown in *Table* 6-5 some of the width measurements vary especially little. This makes them harder to measure exactly in a practical way. Remember that all the measurements in the machine capability test were done in a specific laboratory by a company specialised on measuring objects.

The standard deviations of the holes punched, *Table 6-6*, are extremely small. This means that any additional variation they may cause on a measurement from the edge to the bottom off a hole is very small. If the tool starts to wear out it will have an effect on the other measurements but that is good because tool wear should be detected in SPC.

The smaller measurements 5 to 8 in length direction follow measurements 9 and 10. This means that all of them will not be necessary to measure in SPC.

In Chart 6-14 it is hard to see if measurement 15 to 18 really follows measurement 9 and 10. It is easy to see that measurement 15 and 17 follow each other quite well and that measurement 16 and 18 do the same. It also show that if measurements on one side increase when those on the other decreases which means that the material is not varying much. The variation is due to the fact that the material can move a little bit sideways in the machine. Some old test indicate that even though the actual measurements doesn´t follow each other the variation does, so if measurement 9 and 10 starts to vary more so does measurement 15 to 18. They vary a lot less but still they vary more.

Looking closer at the standard deviation of measurement 5 to 8, Table 6-7, it is shown that measurement 5 and 6 have considerably larger standard deviation than 7 and 8. The only difference that seems relevant is that they are on either side of the shears. It is not a very important measurement but it might still be good to try and figure out why this occurs.

7.3 Process capability test

Because the dial indicator have a much tighter tolerance than the vernier caliper and is fixed in a specially designed fixture measurements 9 and 10 will be more precise.

The C_p and C_{pk} values for measurement 9 and 10, Table 6-9, are not satisfactory. The same values after removing measurements for the products that seemed to come from a systematic source were a lot better, Table 6-11. The C_{pk} values are still unsatisfactory so the process still needs to be brought to target. In this case that should be easily done by changing the time for the shearing.

It´s easy to see that the C_{pk} values are bad just by looking at the x-bar charts, Chart 6-16 and Chart 6-17. Both should have their mean value equal to zero to be on target. The same happens for the x-bar charts with the removed values.

To see the improvement of C_p is easily done if you compare the R-charts for measurement 9 and 10 before and after removal of the faulty values. The R_{max} values have decreased enormously.

The last three measurements (sample 18-20), which were made after the adjustment of the machine, seem to be closer to optimal value for measurement 9 and 10. The operator must have set better values for this material. This shows that it isn´t that difficult to centre the process on target as long as you know how far from target you are, this is crucial if you are going to introduce Statistical Process Control. Because what´s the use in measuring your process and knowing how much off target it is if you can´t do anything about it.

In Chart 6-22 and Chart 6-23 sample group 11, the red points, is outside the warning limits. This is because the first product weren't picked out of the machine for some reason instead product two to five were picked. Thus when removing plate two from the data it wasn´t really plate two that were removed but plate three. The value for plate two was logged as plate one which created these points outside the limits. This does not show for measurement 9 seeing as it´s the first product that is usually removed.

The average values for measurement 16 and 18 are about the same and the LCLs and UCLs as well, compare Chart 6-24 and Chart 6-26. The R_{max} values are also about the same for both measurements. This means that they vary with the almost the same standard deviation. The conclusion is that the material went straight through the machine without wriggling.

7.4 Summary and errors

The C_p value for measurements 9 and 10 are lower than those for the length measurements, in all the tests were it is calculated, this is partly because the tolerance width is smaller. But the measurements are directly linked. If one product is sheared off a bit too late and therefore becomes a bit longer measurement 9 will become a little bit bigger on that product. Thus measurement 10 on the next product will become a little bit smaller. The tolerances on the length and measurements 9 and 10 therefore should be the same.

The material has quite a large width tolerance compared to other tolerances in the machine. Today the steering in width direction is always set to a little bit above the larger tolerance value so that the material is guaranteed to go through. This means that if the material is on the lower end of the tolerance width, we have already showed that it doesn´t vary much, it can wriggle a bit in the machine. This causes variations in both length and width measurements. Maybe the material should be measured before it goes in to the machine so that the machine can be set after each metal coil and not after a mean value from the supplier.

It seems the plate shear is one of the larger sources of variation. This shows partly from the fact that length measurements within the plates, e.g. 19-22x, have better C_m values than the length measurements that somehow is measured from either end of the plate, which would be measurement 1, 2, 9 and 10. The plate shear should hence be looked over if

measurement 1, 2, 9 and 10 shall be kept in statistical control. Since the length measurements affect the symmetry a lot it is very important that these are kept good.

The systematic error in measurement 9 and 10 in the C_p seems to occur when the machine is stopped. Thus the way of stopping the machine should be changed when more tests ought to be done.

7.5 How should Alfa Laval use SPC

First of all it is possible for Alfa Laval to use SPC in the shearing and punching process tested in the thesis. The thing to decide is how to do it and where to start.

The recommendation is to use either measurement 9 or 10 in SPC. It is not necessary to use both since they follow each other.

The first thing to do is to gather history of the measurements. This is a lot of work and a recommendation is to start with some of the products. In time more products can be added. When producing the products with the smallest batches SPC might not be necessary.

When choosing the products to start with size should be a factor. If the measurements are going to be made by hand it is easier to start with the smaller products that can be handled easily by hand.

A machine can be used to measure the products instead of measuring by hand. This will make the result less dependent of the operator they just rig the product in the machine and the machine takes the appropriate measurements and feed it to the control charts. The machine can have specific programs for specific products.

7.5.1 Program for value logging

The tests in the project were logged in an excel chart that was produced in advance but to create x-bar and R-charts in excel s not optimal. The table with values soon become big and difficult to manage. Excel can be used to store history but when SPC is in use a specific computer program should be used were it is simple to have a program for every product and that includes all the rules. The operator should never have to check the rules manually. The computer should tell what rule is broken so that the operator know what to look for.

When the history is collected, information on what happens in the machine and in the process when different problem occurs should be logged. If this is done it is easier to create procedures for different alarms later on.

7.5.2 Vision

A vision system that excludes the necessity to stop the machine isn´t essential to start up using SPC at Alfa Laval but it would be a good investment in the long run. A vision system would be good for several reasons, some main ones are listed here:

1. It would save time in the machine if you don´t have to stop the machine to take samples.
2. It would decrease the labour for the operator.
3. It would decrease the risk of errors and differences between operators in measuring and eliminate the risk of writing down the wrong value.
4. The machine wouldn´t have to stop which is good as we know it produces products outside the specification limit when it is stopped.

7.6 General recommendations to Alfa Laval

The new fixture for measuring measurement 9 and 10 should be used at every start-up to see that the process is on target and at least three products shall be measured. The products measured should not be the first two products produced after a stop, since those are the one that show a systematic error in the tests done.

Obviously it is always a good thing to have as little stops as possible in a machine. However in this case it is even more important since every time the shearing and punching machine stops two products with measurements outside the tolerance width is produced.

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8.2.2 Dissertations

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Appendix A

List of terms that appear Statistical Process Control

USL – Upper Specification Limit

LSL – Lower Specification Limit

USL-LSL – Tolerance width

μ – The mean value of a population

$\bar{x}$ – The mean value of a sample

σ – Standard deviation (calculated from entire population)

s – Estimated standard deviation (calculated from samples of the population)

n – Sample size

N – Size of population

6σ – Process spread

6s – Calculated process spread

UCL – Upper control limit

LCL – Lower control limit

C_m – Machine capability

C_{mk} – Adjusted machine capability, in literature often machine capability index

C_p – Process capability

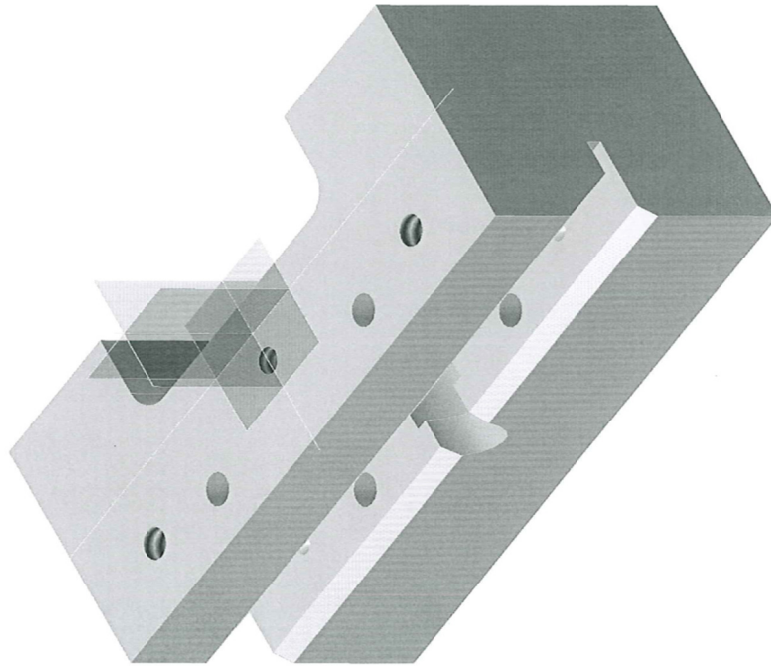C_{pk} – Adjusted Process capability, in literature often process capability index

Appendix B

Tabell med värden för konstanter för att räkna ut R_{max} [6]

n	D_3	D_4
2	0	3,269
3	0	2,574
4	0	2,282
5	0	2,114
6	0	2,004
7	0,076	1,924
8	0,136	1,864

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[6] *Modern methods for quality control and improvement*, Wadsworth, Stephens and Godfrey, p. 673

Appendix C

Fixture for the dial indicator, the "clock" sits in the slot on the top side of the fixture with the "peg" going through a hole. The product is placed in the long slot on the bottom of the fixture and the peg will go in.