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Statistical methods in process management — Capability and performance —

Part 3: Machine performance studies for measured data on discrete parts

Méthodes statistiques dans la gestion de processus — Aptitude et performance —

Partie 3: Études de performance de machines pour des données mesurées sur des parties discrètes

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 22514-3 was prepared by Technical Committee ISO/TC 69, *Applications of statistical methods*, Subcommittee SC 4, *Applications of statistical methods in process management*.

ISO 22514 consists of the following parts, under the general title *Statistical methods in process management — Capability and performance*:

— *Part 1: General principles and concepts*

— *Part 3: Machine performance studies for measured data on discrete parts*

— *Part 4: Process capability estimates and performance measures* [Technical Report]

In the future, it is planned to revise ISO 21747:2006 (*Statistical methods — Process performance and capability statistics for measured quality characteristics*) as Part 2.

NOTE ISO 22514-3 was initially prepared as ISO/DIS 13700. It was renumbered before publication to include it in the ISO 22514 series.

Introduction

This part of ISO 22514 has been prepared to provide guidance in circumstances where a study is necessary to determine if the output from a machine, for example, is acceptable according to some criteria. Such circumstances are common in engineering when the purpose for the study is part of an acceptance trial. These studies may also be used when diagnosis is required concerning a machine's current level of performance or as part of a problem solving effort. The method is very versatile and has been applied to many situations.

Machine performance studies of this type provide information about the behaviour of a machine under very restricted conditions such as limiting, as far as possible, external sources of variation that are commonplace within a process, e.g. multi-factor and multi-level situations. The data gathered in a study might come from items made consecutively, although this may be altered according to the study requirements. The data are assumed to have been, generally, gathered manually.

The study procedure and reporting will be of interest to engineers, supervisors and management wishing to establish whether a machine should be purchased or put in for maintenance, to assist in problem solving or to understand the level of variation due to the machine itself.

Statistical methods in process management — Capability and performance —

Part 3: Machine performance studies for measured data on discrete parts

1 Scope

This part of ISO 22514 prescribes the steps to be taken in conducting short-term performance studies that are typically performed on machines where parts produced consecutively under repeatability conditions are considered. The number of observations to be analysed will vary according to the patterns the data produce, or if the runs (the rate at which items are produced) on the machine are low in quantity. The methods are not recommended where the sample size produced is less than 30 observations. Methods to be used for handling the data and carrying out the calculations are described. In addition, machine performance indices and the actions required at the conclusion of a machine performance study are described.

The document is not applicable when tool wear patterns are expected to be present during the duration of the study, nor if autocorrelation between observations is present. The situation where a machine has captured the data, sometimes thousands of data points collected in a minute, is not considered suitable for the application of this part of ISO 22514.

2 Symbols and abbreviations

P_{m} machine performance index

P_{mk} minimum machine performance index

$P_{\text{mk}L}$ lower machine performance index

$P_{\text{mk}U}$ upper machine performance index

f frequency

Σf cumulative frequency

i subscript used to identify values of a variable

L lower specification limit

N total sample size

$X_{\alpha\%}$ $\alpha\%$ distribution fractile

X_i ith value in a sample

σ standard deviation, population

S standard deviation, sample statistic, $S = \sqrt{\frac{\sum_{i=1}^{N}\left(X_i - \bar{X}\right)^2}{N-1}}$

U upper specification limit

z_α fractile of the standardized normal distribution from $-\infty$ to α

μ population mean value in relation to the machine location

$\bar{X}$ arithmetic mean value, sample, $\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N}$

GRR gauge repeatability and reproducibility

χ_α^2 fractile of the Chi-square distribution

3 Pre-conditions for application

3.1 General

The pre-conditions given below are the minimum and may be exceeded when needed. In this type of study, it is important to maintain constant all factors, other than the machine, which will influence the results, if the study is to properly represent the machine itself, e.g. the same operator, same batch of material, etc.

3.2 Number of parts to be used in the study

The number specified will usually be 100. However, if the pattern of variation is expected to form a non-normal distribution, the number of parts should be at least 100. The methods given within this part of ISO 22514 may also be used when conducting audits of a process, in which case the number of measurements taken might be less than the above number, e.g. 50.

NOTE 1 This is to ensure that a reasonably narrow confidence interval can be calculated for the machine performance indices when a normal distribution has been used. The interval will be approximately ± 12 % of the estimated index with a confidence of 90 % for samples of 100.

Some machines have very slow cycle times and a “run” cannot produce 100 parts. In such circumstances, it will be necessary to proceed with available data. The minimum number that this part of ISO 22514 recommends with the methods described herein is 30.

NOTE 2 Special techniques beyond the scope of this part of ISO 22514 exist for circumstances when there are fewer samples.

By contrast, a machine that produces parts at a very high rate, e.g. a rivet-making machine, the sampling strategy may require alteration since 100 parts will be produced in a few seconds. In circumstances such as these, several studies may be required each allowing a different sampling approach to examine the machine’s behaviour.

3.3 Materials to be used

Ensure all input materials to be used in the study have been checked, conform to specifications and belong to the same batches. It is not advised that a study be conducted with materials that are outside specification since this could lead to unrepresentative results.

Care should be exercised not to introduce any other sources of variation other than those to be studied. A typical example is where a machine run has to change to another batch of a particular material within a single process batch, and batch material variation is not included in the study. In this instance, only data taken while the first batch of that particular material was in use should be used in the analysis.

3.4 Measurement system

Ensure the measurement system to be used during the study has adequate properties, is calibrated and the measurement system variation has been quantified and minimized. Special studies on the measurement system should be undertaken to establish the amount of variation present due to measuring. The measurement system should ideally have a combined gauge repeatability and reproducibility (GRR) of less than 10 % of the process spread of the characteristic that the machine study is to investigate as determined through a properly conducted measurement system analysis. This analysis should address issues of bias, stability, linearity and discrimination, as well as GRR.

It may be appropriate to express the GRR as a percentage of a given specification tolerance. If the measurement system has between 10 % and 30 % GRR, it may still be regarded as acceptable dependant upon application. If it exceeds 30 %, the measurement system should be regarded as inappropriate. In addition, the measurement system should have a measurement uncertainty appreciably less than the tolerance or of the expected total variation of the characteristic, if known, as indicated above. Should a study be performed using a measurement system with a performance worse than these requirements, some erroneous conclusions to the study might be reached.

3.5 Running the study

Ensure an uninterrupted run takes place, under normal operating conditions. This will include any warm-up time for the machine necessary to bring it up to its usual operating condition and with the machine set at nominal for the characteristic to be studied. If the machine is stopped during the study for whatever reason, either re-run the study again or analyse the data collected, as long as sufficient data has been collected and as long as the repeatability conditions have not been violated. Under no circumstance should less than 30 results be used.

3.6 Special circumstances

In a multiple fixture set-up, multiple-cavity or multi-stream situation, each station, fixture, cavity or stream should be treated as a separate machine for machine performance purposes since those streams may violate the repeatability conditions.

In the case of a multiple-cavity tool, some extra studies may be performed to examine the between-cavity and within-cavity variation. Consecutive observations from all cavities may be used in the study so as to examine the total machine performance. Other statistical techniques may be employed, e.g. analysis of variance (ANOVA), to assist with the analysis of such circumstances.

4 Data collection

4.1 Traceability of data

It is important for all data to be traceable so that unexpected values can be investigated. The collection sequence should be preserved so that a time series can be plotted of the data that might indicate unexpected variations. Such occurrences should be explained and a decision taken about the admissibility of such data. A "log-book" would be suitable for recording all machine settings including any prior work on the machine, e.g. maintenance, and for recording all events during the study, such as adjustments.

4.2 Retention of specimens

Unless the tests performed are destructive in their nature, all specimens should be retained so that all necessary examinations can be made. They should only be disposed of once the study is complete and all conclusions determined.

4.3 Data recording

Data should be clearly recorded either electronically or on the appropriate analysis sheet in numerical form to the appropriate number of significant digits. This should be determined prior to the measuring process and will be dependent on the resolution of the measuring instrument.

5 Analysis

5.1 General

The analysis of the data generated in the study may be done manually, an example of which is given within this clause, or by means of computer programs an example of which is in given in Annex B.

5.2 Run chart

5.2.1 Purpose

When conducting a machine study, it is important to understand whether the data collected form a single and stable pattern or not. There will be occasions when the conditions within the machine under study will lead to a drift in its settings that will influence the pattern of data produced. There might be occasions when an unauthorized adjustment has been made to the machine or data have been mixed in some way. Such an event should stop the study and a new study should be begun. A run chart will be helpful to identify such circumstances. The pattern on the run chart in Figure 1 might have been caused by such an adjustment or something might have gone wrong with the machine itself or it is being used wrongly.

If a change such as that indicated in Figure 1 occurs, it will be necessary to take special measures according to the circumstances. These might range between repeating the whole study to analysing the data in its separate parts or eliminating certain results.

A manual graphical approach or a suitable software tool may be used to construct the run chart.

ISO 7873 contains guidance about the application of control charts and their associated statistical tests that should be applied to plots such as that shown in Figure 1 to assist with the interpretation of the plots.

5.2.2 Review the plot

Inspect the plot for evidence of instability. This may be apparent as in Figure 1 where there has been a step change in the data. Other patterns might appear such as a drift. It is possible to use control limits and control chart rules to assess, easily, for any other assignable causes in the data. The data might be put into an individuals and moving range chart to check for potential outliers in the data. (See ISO 8258 for further information about such limits and rules.)

There exist a number of software products that can replace the above manual methods. These have become popular because they produce the graphs mentioned above quickly and easily.

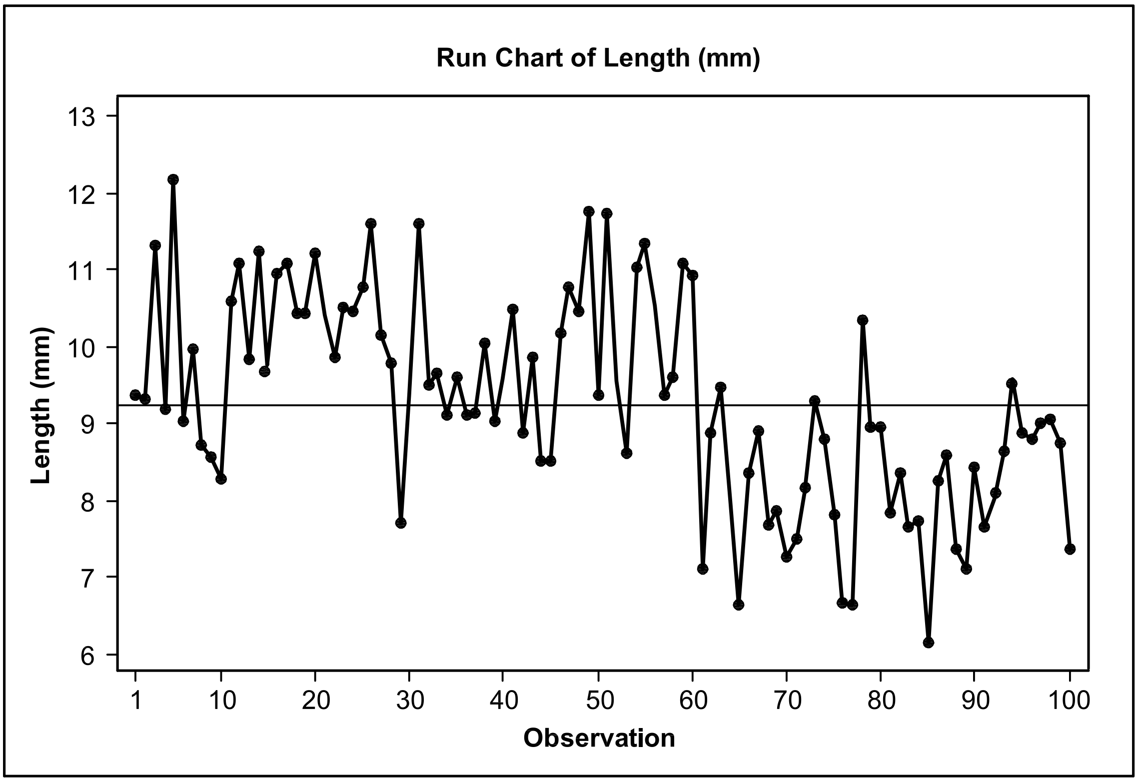

Figure 1 — Example of a run chart 1)

5.3 Analyze the pattern of the data

5.3.1 Manual approach

A simple manner to begin analyzing the pattern the data form is to construct a tally chart.

The data are arranged into "classes". The convention of counting the data into groups of five is often used and an example of this can be seen in Figure 2. In this example, the data have been recorded to the nearest 5 mm that is appropriate for the process from which the data are coming from.

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1) This run chart was generated using a software programme called MINITAB™. MINITAB™ is the trade name of a product supplied by Minitab Inc. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

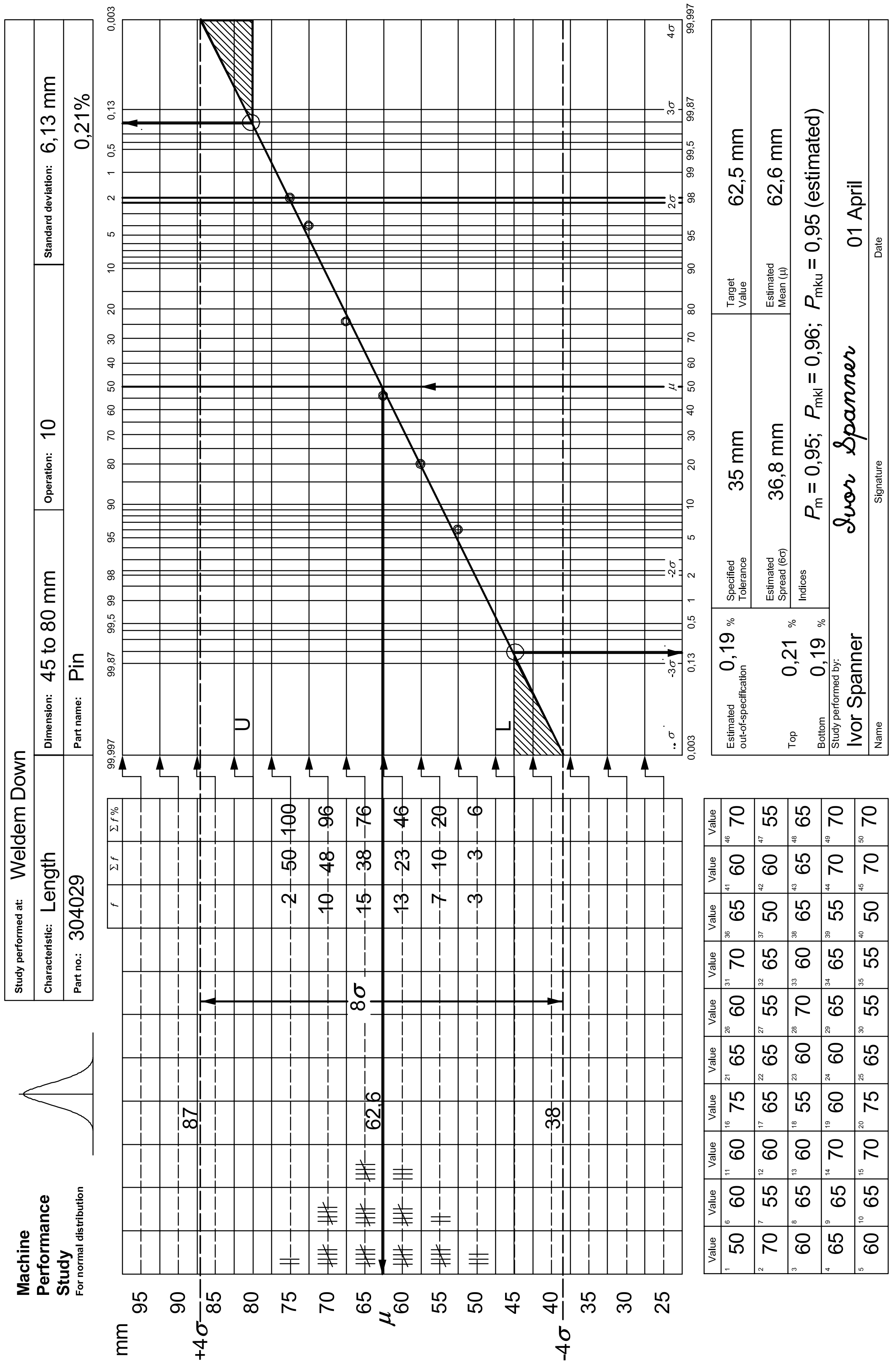

Figure 2 — Example of a worksheet for normally distributed data

5.3.2 Software approach

As an alternative to a manual approach, the data should be entered into a software tool and a histogram produced of the data. There exist a number of suitable software products that will carry out such analysis.

5.3.3 Check the pattern of the data

Study the pattern of the data to see if it conforms to a known distribution. Investigate the cause if the data appear to form a quite different pattern. If the data do not form a normal distribution, it may become necessary to employ a different worksheet such as that shown in Figure 3. An analysis carried out on non-normal data using the worksheet designed for the normal distribution may produce inaccurate results. Non-normality can occur from circumstances where the data are limited in some way, such as the results of measurements of stress or of concentricity. There might be some anticipation of non-normal data if geometric tolerances have been specified for a dimension or characteristic, for example. Consult the Bibliography for assistance in determining if the data conform to a normal distribution (e.g. ISO 5479) as well as using other statistical procedures beyond the scope of this part of ISO 22514.

Special cases, such as skewed distributions and bimodal data, are discussed in 5.6.

If similar studies have been conducted prior to the current one, there will be a certain expectation of what the distribution might be. Scientific knowledge might also suggest what the pattern ought to be and this will be an important reference should the pattern appear unusual. It will be likely that something has happened to induce a non-random pattern and an investigation should be conducted.

Misleading results can occur if a computer program is used, that does not check for normality, as an alternative to the manual method.

5.3.4 Summarize the data

Calculate the sample mean $\left(\bar{X}\right)$ and the sample standard deviation (S) using the formulae shown in Clause 2. If the distribution is non-normal, calculate the sample statistics corresponding to the relevant parameters for the assumed distribution.

5.4 Construct a probability plot

5.4.1 General

A probability plot should be produced of the data. This may be achieved by using either a manual method or by using a software tool described in 5.3.2 to 5.3.3. An example of the output of one software package can be seen in Annex B.

5.4.2 Plot the cumulative frequency percentages

Using the bottom percentage scale on the probability paper, plot the cumulative frequency percentage for each value in the tally chart at the intersection of its upper class limit and its cumulative frequency percentage.

NOTE 1 It will not be possible to plot the last cumulative frequency percentage (which will be 100 %) onto the probability paper because the scale terminates at 99,997 %. Do not plot this percentage value at 99,997 % as it may mislead and cause false conclusions. Loss of data can be avoided by plotting the average of the last two cumulative frequency percentages at the mid-point of the last value rather than at its upper class limit.

NOTE 2 Some software products do not use grouped frequencies to generate the probability plot. Instead, the individual values are used.

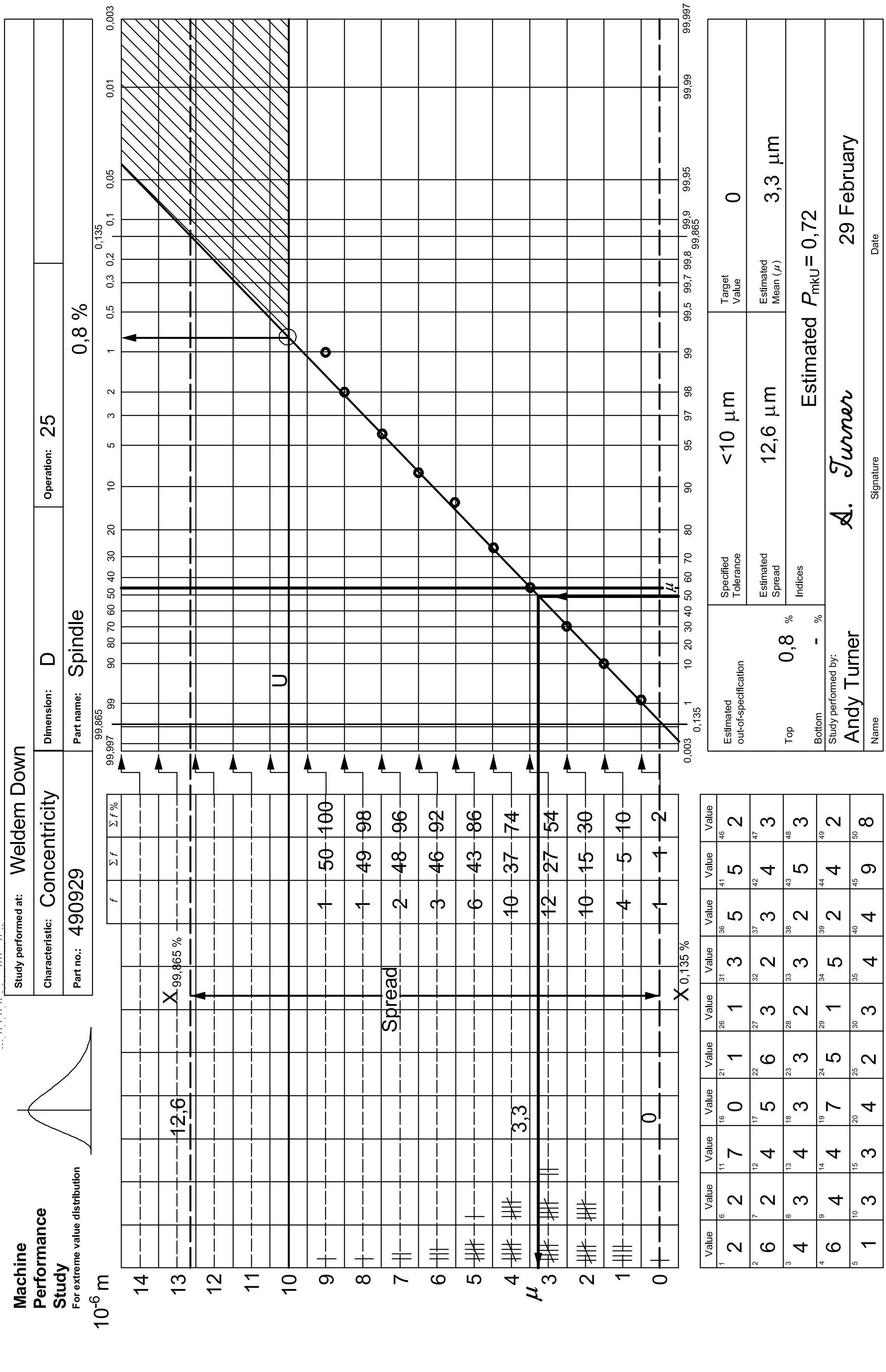

Figure 3 — Example of a worksheet for extreme value distributed data

5.4.3 Draw a fitted line through the plotted points

Examine the plotted points to see if they can be approximately described by a straight line. If so, draw a best-judged line through them. As a help to the judgment of where to draw the fitted line, the user should:

a) plot the sample mean, $\overline{X}$;

b) plot $\overline{X} \pm 3S$;

c) draw the line between these plotted points.

Extend the line so that it meets the vertical lines at the extremes of the percentage scales (i.e. the $\pm 4\sigma$ lines). If the drawn line does not fit the plotted data points very well, it indicates the data have not come from the normal distribution. Special cases such as this are discussed in 5.6.

The worksheet shown in Figure 2 is based on normal probability paper. It is constructed so that when the cumulative percentages are plotted onto it they will be represented by a straight-line plot if the data have come from a normal distribution. Otherwise, the plot will not be a straight line and will indicate to the analyst that other methods or other such papers should be used, such as the example in Figure 3. It is recommended that at least six cumulative percentages be available for plotting, to improve the position of the drawn line.

5.4.4 Superimpose specification limit lines

Draw the specification limit lines onto the tally chart and extend them across the full scale of the probability paper.

5.5 Interpretation of the worksheet

5.5.1 Assess conformance to specification

5.5.1.1 General

In the case of a two-sided specification, if the fitted line does not cross either of the specification limit lines, the machine is deemed to be performing with at least 99,994 % of its output within specification. The percentage performing deemed acceptable will vary according to the industry sector, the characteristic used in the study, its significance and the opinion of the customer. The minimum acceptable percentage should always be stated. It might be, for example, that a performance of 99,999 94 %, i.e. $\pm 5\sigma$, is required before a machine can be regarded as acceptable in certain circumstances. Machine performance indices (P_{m} and P_{mk}) can be reported using the method of calculation shown in 5.7. Because these studies are carried out with minimal data over a very short interval of time the user is advised to also compute the confidence intervals for the indices. The calculations are shown in 6.2.

If the fitted line crosses one or both of the specification limit lines, the machine performance may be considered *not* acceptable, i.e. it crosses at a point that corresponds to less than $\pm 4\sigma$. If it is required that, as indicated above, at least 99,999 9 % of output to be within specification, then the point will correspond to less than $\pm 5\sigma$. This may be the result of one or both of the conditions described in 5.5.1.2 and 5.5.1.3.

5.5.1.2 The spread of the data is too large

This condition may be caused by a problem with the machine itself, e.g. excessive wear on internal parts such as bearings or slides. In order to satisfy the specification, it will be necessary to reduce the variation by identifying the sources of the excessive variation and removing them. If a reduction in the variation is achieved, a further study will show the drawn line $\left(\overline{X} \pm 4\sigma\right)$ to have a smaller gradient, and if small enough, this line will lie between the specification limit lines indicating an acceptable machine. See Figure 4.

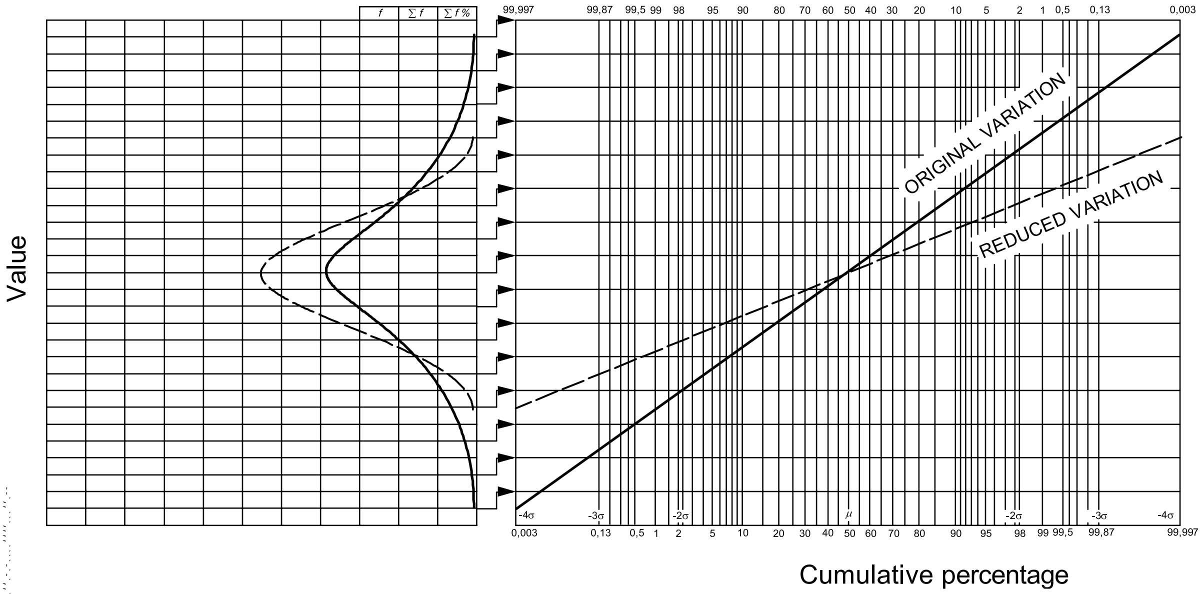

Figure 4 — Variation too large — Machine after improvement

5.5.1.3 Location (setting) is too high or too low

If the mean of the distribution could be shifted, e.g. by adjusting the machine setting, the fitted line might then lie within the specification limit lines and the machine performance might be considered acceptable.

A prediction about any adjustment and if it would achieve the required result can be made by shifting the line on the probability paper keeping it parallel to its original position. If the fitted line then lies within the specification limit lines, a machine adjustment could correct the condition. See Figure 5.

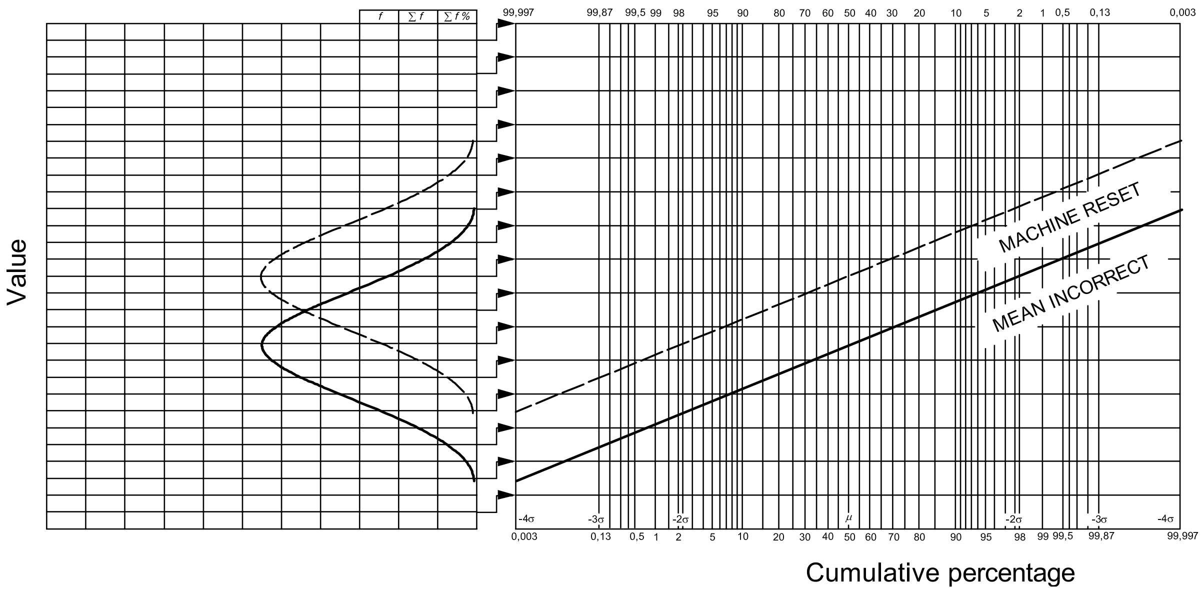

Figure 5 — Mean incorrect — Reset machine

5.5.2 Estimate the percentage out of specification

If the fitted line cuts through a specification limit line, an estimate can be made of the proportion out of specification that would be found if the machine were to continue running. At the intersection of the fitted line with the specification limit line, read off the nearest percentage scale the estimated percentage. For example, in Figure 2, to estimate the percentage occurring beyond the upper specification limit (U), read off the percentage scale on the top of the worksheet probability plot. To estimate the percentage below the lower specification limit (L), use the percentage scale on the bottom of the worksheet. The total estimated out of specification is the sum of these two percentages.

When a software tool is used for this work, the proportion of out of specification estimation is usually a standard output. This is shown in the example in Annex B.

5.6 Special cases

5.6.1 Data indicate a skewed distribution

There are occasions when machine studies produce data that indicate a skewed distribution. These often arise when a natural limit exists beyond which data cannot occur. An example of this is the measurement of concentricity where it is impossible to obtain readings less than zero.

If skewed data are plotted onto normal probability paper, the progression of the points on the probability paper will deviate away from a straight line and indicate some curvature. To analyse the skewed distribution, it is necessary to select a different probability paper that is based on the same skew distribution as that from which the data has come. This should result in a straight-line plot. An example of the method is given in Figure 3 for the extreme value distribution. Other papers that are generally available include the log-normal, exponential and Weibull distributions.

The average value can be read from the plot. Estimate the value on the value axis where the drawn line passes through the line at μ on the cumulative percentage axis. Alternatively, the mean value can be calculated using a calculator.

5.6.2 Bimodal data

If the machine is adjusted during the study, the adjustment is likely to affect the results and often produces a distribution with more than one mode. For example, the distribution possesses two modes (sometimes more), each mode representing the different settings of the machine. It can be caused if the machine has multiple tools or cavities and the samples from each are mixed together. It may also be symptomatic of something wrong with the machine.

Bimodal (or multi-modal) data, when plotted onto normal probability paper, will not produce a straight-line plot. Instead the plot will show a different shape, as shown in Figure 6.

When the data have come from different tools or cavities, if at all possible, the data should be segregated into their respective separate sets and the analysis carried out as described above.

Figure 6 gives an example of such a plot of data forming a bimodal distribution. If such a pattern emerges following a study, the assignable cause should be established and, if possible, eliminated. There might be several reasons for a bimodal pattern, one of which could be an adjustment to the machine was made during the study that resulted in two modes in the data. A simple run chart of the data can illustrate such a shift. Figure 1 is an example of a run chart. Once the assignable cause has been identified, it might be necessary to repeat the study again. A run chart is an excellent tool to show problems during data collection. As an alternative to a run chart, a control chart can be used. A control chart has a number of advantages over a run chart as it has the ability to provide statistical signals about changes within the data. However, just as with a run chart, the sequence with which the data were created is required.

5.6.3 Truncated data

Some studies may be made with data that have been truncated in some way. This may be due to some display of the data. Such an example would be if a test or a control instrument measures, for example resistance (ohms) of an insulator, but only displays values over 5 Ω. Specialist advice should be sought, if this situation exists, on how to analyse the data to avoid potentially misleading results.

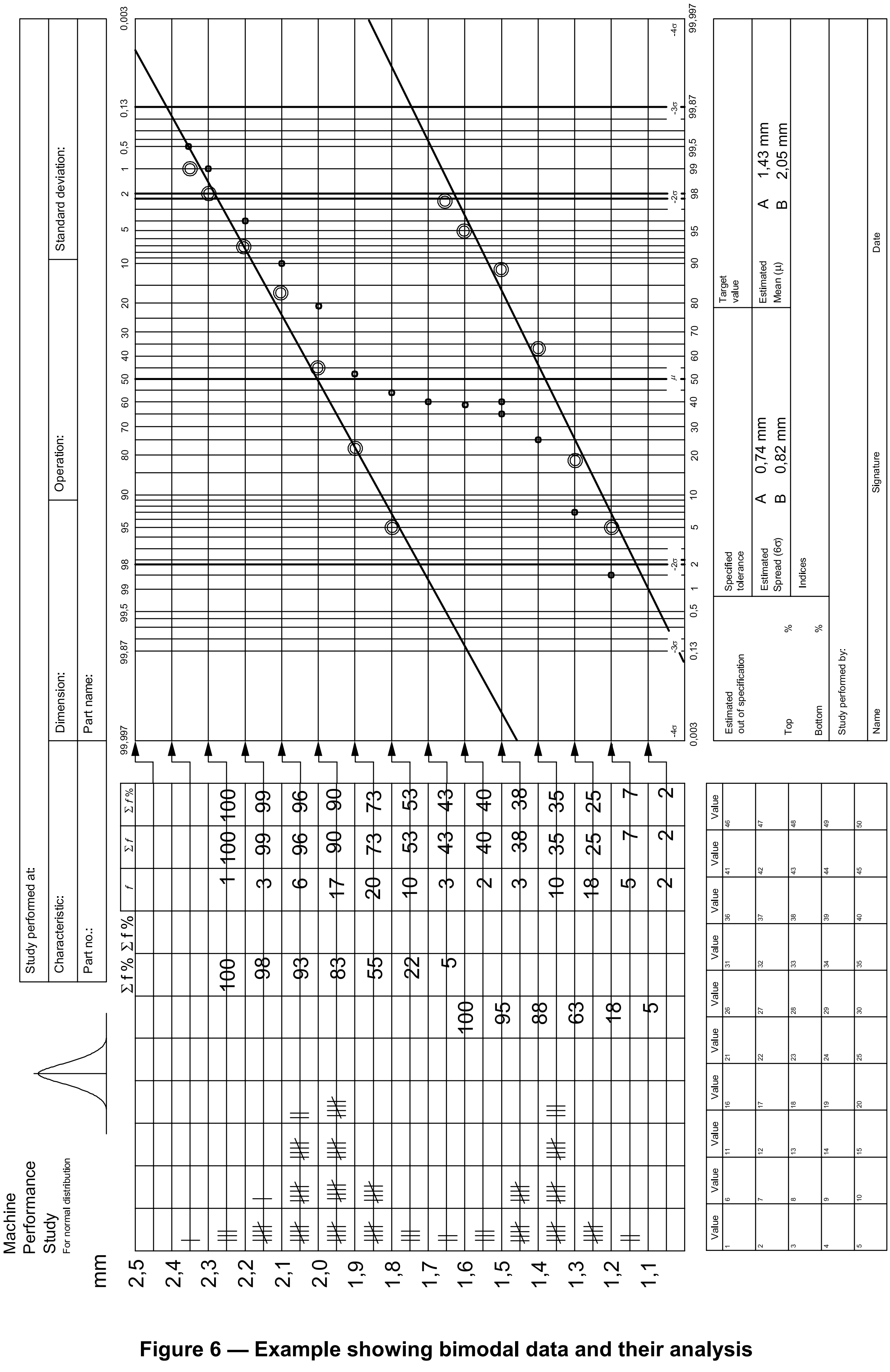

Figure 6 — Example showing bimodal data and their analysis

5.6.4 Censored data

Censored data will occur if certain values are ignored. This can be introduced by some sampling strategy, such as taking results only from the first two cavities of a four-cavity tool. Values from cavities three and four are excluded from the analysis. This could be brought about by some machine control device and not necessarily known to the experimenter or analyst. Another example occurs if the parts have been sorted prior to analysis and any oversize or undersize parts have been eliminated from the data set.

The consequence of using censored data may be an erroneous conclusion about the performance of the machine. Such data will produce an unexpected plot on the worksheet and the analyst should seek specialist advice.

5.7 Machine performance indices for normal and skew distributions

5.7.1 Data following a normal distribution

5.7.1.1 P_{m} index

$$\hat{P}_{\text{m}} = \frac{U - L}{6S}$$

NOTE Historically, these indices have been recorded as C_{m} and $C_{\text{mk}L}$ and $C_{\text{mk}U}$. Because no attempt is made to establish statistical control, it is preferred to use the symbols $\hat{P}_{\text{m}}$ and $\hat{P}_{\text{mK}L}$ and $\hat{P}_{\text{mK}U}$ to be compatible with process performance indices.

5.7.1.2 P_{mk} index

$$\hat{P}_{\text{mk}U} = \frac{U - \overline{X}}{3S}$$

or

$$\hat{P}_{\text{mk}L} = \frac{\overline{X} - L}{3S}$$

The index is given as the minimum of the following:

$$\hat{P}_{\text{mk}} = \min\left\{\hat{P}_{\text{mk}U}, \hat{P}_{\text{mk}L}\right\}$$

NOTE The “hats” above the indices indicate these are estimated values.

5.7.1.3 Estimation of proportion out of specification

Having calculated the $\hat{P}_{\text{mk}}$ values, the proportion out of specification can be read from Table A.1. For example, if $\hat{P}_{\text{mk}U}$ is 0,85, the estimated proportion is 0,005 4.

5.7.2 Data following a non-normal distribution

5.7.2.1 General

For skewed data, the actual distribution function should be identified and the percentile values $X_{0,135\ \%}$ and $X_{99,865\ \%}$ estimated from it. They can be substituted into equations to give numerical values for the indices. Additionally, they may be estimated from the probability paper plot that although simple and quick, is subject to error.

5.7.2.2 P_{m} index

The following expression is used to estimate the index.

$$\hat{P}_{\mathrm{m}} = \frac{U - \overline{X}}{\hat{X}_{99,865\ \%} - \hat{X}_{0,135\ \%}}$$

5.7.2.3 P_{mk} index

The following expressions are used to estimate the indices.

$$\hat{P}_{\mathrm{mk}U} = \frac{U - \hat{X}_{50\ \%}}{\hat{X}_{99,865\ \%} - \hat{X}_{50\ \%}}$$

or

$$\hat{P}_{\mathrm{mk}L} = \frac{\hat{X}_{50\ \%} - L}{\hat{X}_{50\ \%} - \hat{X}_{0,135\ \%}}$$

6 Reporting

6.1 Test report

The study report shall contain the following information:

a) the place where the study was performed and the type of process the machine is part of;

b) the persons who performed the study and who took the measurements;

c) when the study was performed including the date, times of start and finish, log of any interruptions;

d) the machine reference number;

e) the component's name and reference number;

f) the component characteristic(s) measured;

g) the specification for the characteristic(s) and what factors were held constant;

h) ambient conditions;

i) the raw data;

j) non-standard conditions.

For each characteristic measured, the following should be reported (or provided):

— a run chart of the data;

— a tally chart or histogram of the data;

— a probability plot of the data;

— the mean value from the data;

— the standard deviation from the data;

— the estimated percentage out of specification;

— the machine performance indices;

— the machine performance indices' confidence intervals;

— the measurement uncertainty.

6.2 Confidence intervals

6.2.1 General

Studies mentioned in this part of ISO 22514 do not usually generate a large quantity of data. It is necessary to calculate both the performance indices and their confidence intervals. These will advise any user of the generated information about the level of uncertainty existing with a point estimate of a machine performance index based on a small sample of data.

6.2.2 Indices calculated with the data following a normal distribution

Assuming normally distributed data, the machine performance index $\hat{P}_{\mathrm{m}}$ follows a Chi-square distribution. The other indices $\left(\hat{P}_{\mathrm{mk}L}, \hat{P}_{\mathrm{mk}U} \text{ and } \hat{P}_{\mathrm{mk}}\right)$ have more complex distributions but approximate confidence limits related to the normal distribution may be adopted for $N > 30$. The following expressions give the approximate $100(1-\alpha)$ % confidence intervals.

$$\hat{P}_{\mathrm{m}}\sqrt{\frac{\chi^2_{\alpha/2}}{N-1}},\ \hat{P}_{\mathrm{m}}\sqrt{\frac{\chi^2_{1-\alpha/2}}{N-1}}$$

$$\hat{P}_{\mathrm{mk}L} \pm z_{1-\alpha/2}\sqrt{\frac{1}{9N}+\frac{\hat{P}^2_{\mathrm{mk}L}}{2N-2}}$$

$$\hat{P}_{\mathrm{mk}U} \pm z_{1-\alpha/2}\sqrt{\frac{1}{9N}+\frac{\hat{P}^2_{\mathrm{mk}U}}{2N-2}}$$

$$\hat{P}_{\mathrm{mk}} \pm z_{1-\alpha/2}\sqrt{\frac{1}{9N}+\frac{\hat{P}^2_{\mathrm{mk}}}{2N-2}}$$

z is the standardized deviate for the normal distribution.

NOTE The “hats” above the indices indicate these are estimated values.

6.2.3 Indices calculated with data following a non-normal distribution

Confidence intervals can be calculated for indices when the data are from a non-normal distribution, wherein it will be necessary to establish the particular distribution from which the data have been taken. Refer to ISO/TR 22514-4 and ISO 21747.

7 Actions following a machine performance study

At the conclusion of a study, the information detailed earlier in Clause 6 should be documented and attached to the completed study report.

Any subsequent actions required will depend on the purpose of the study. If the purpose was to approve a machine, then the outcome of a performance index less than a predetermined value will indicate the machine unacceptable and that remedial action will be required to improve it. Interpretation of acceptable or unacceptable should be made using the width of the confidence intervals of the indices and not using the point estimates alone. When such work has been completed, a further study should be conducted to verify whether the machine has been successfully improved.

A common application of a machine study is for the acceptance or purchase of a machine or a piece of equipment. In this circumstance, the minimum acceptance values of the performance indices shall be determined and agreed by both supplier and customer ahead of any such study. In some cases, it will be the responsibility of the customer to specify the values of the indices to the supplier.

If the purpose of the study is to aid some problem solving effort, the person or persons responsible for that effort should study the outcome. The variations in the data might explain the symptoms of the problem and indicate a possible solution.

Annex A
(informative)

Tables and worksheets

See Table A.1.

Table A.1 — Values of estimated proportion beyond a specification limit assuming a normal distribution

P_{mk}	0,0	0,01	0,02	0,03	0,04	0,05	0,06	0,07	0,08	0,09
1,6	7,9E-07	6,8E-07	5,9E-07	5,0E-07	4,3E-07	3,7E-07	3,2E-07	2,7E-07	2,3E-07	2,0E-07
1,5	3,4E-06	3,0E-06	2,6E-06	2,2E-06	1,9E-06	1,7E-06	1,4E-06	1,2E-06	1,1E-06	9,2E-07
1,4	1,3E-05	1,2E-05	1,0E-05	8,9E-06	7,8E-06	6,8E-06	5,9E-06	5,2E-06	4,5E-06	3,9E-06
1,3	4,8E-05	4,2E-05	3,7E-05	3,3E-05	2,9E-05	2,6E-05	2,3E-05	2,0E-05	1,7E-05	1,5E-05
1,2	0,000 2	0,000 1	0,000 1	0,000 1	0,000 1	0,000 1	0,000 1	0,000 1	0,000 1	0,000 1
1,1	0,000 5	0,000 4	0,000 4	0,000 3	0,000 3	0,000 3	0,000 3	0,000 2	0,000 2	0,000 2
1,0	0,001 3	0,001 2	0,001 1	0,001 0	0,000 9	0,000 8	0,000 7	0,000 7	0,000 6	0,000 5
0,9	0,003 5	0,003 2	0,002 9	0,002 6	0,002 4	0,002 2	0,002 0	0,001 8	0,001 6	0,001 5
0,8	0,008 2	0,007 5	0,006 9	0,006 4	0,005 9	0,005 4	0,004 9	0,004 5	0,004 1	0,003 8
0,7	0,017 9	0,016 6	0,015 4	0,014 3	0,013 2	0,012 2	0,011 3	0,010 4	0,009 6	0,008 9
0,6	0,035 9	0,033 6	0,031 4	0,029 4	0,027 4	0,025 6	0,023 9	0,022 2	0,020 7	0,019 2
0,5	0,066 8	0,063 0	0,059 4	0,055 9	0,052 6	0,049 5	0,046 5	0,043 6	0,040 9	0,038 4
0,4	0,115 1	0,109 3	0,103 8	0,098 5	0,093 4	0,088 5	0,083 8	0,079 3	0,074 9	0,070 8
0,3	0,184 1	0,176 2	0,168 5	0,161 1	0,153 9	0,146 9	0,140 1	0,133 5	0,127 1	0,121 0
0,2	0,274 3	0,264 3	0,254 6	0,245 1	0,235 8	0,226 6	0,217 7	0,209 0	0,200 5	0,192 2
0,1	0,382 1	0,370 7	0,359 4	0,348 3	0,337 2	0,326 4	0,315 6	0,305 0	0,294 6	0,284 3
0,0	0,500 0	0,488 0	0,476 1	0,464 1	0,452 2	0,440 4	0,428 6	0,416 8	0,405 2	0,393 6

NOTE 1 The values of P_{mk} in the table are for one tail of the distribution only. To estimate the total out of specification, the reader has to look up the proportions for both P_{mkU} and P_{mkL} and then add the two proportions added together.

NOTE 2 The notation E-a is to be read as $\times 10^{-a}$, e.g. 2,6E-06, is $2{,}6 \times 10^{-6}$.

NOTE 3 For negative values of P_{mk}, the proportion is $1 - p$, where p is the tabulated value.

The examples of probability paper that follow are for the normal distribution and the extreme value distribution. It is found in practice that these will be suitable for many situations. In addition, suppliers of stationery publish probability papers for other well known distributions.

Software products are also available to produce the same plots should the practitioner prefer to use them.

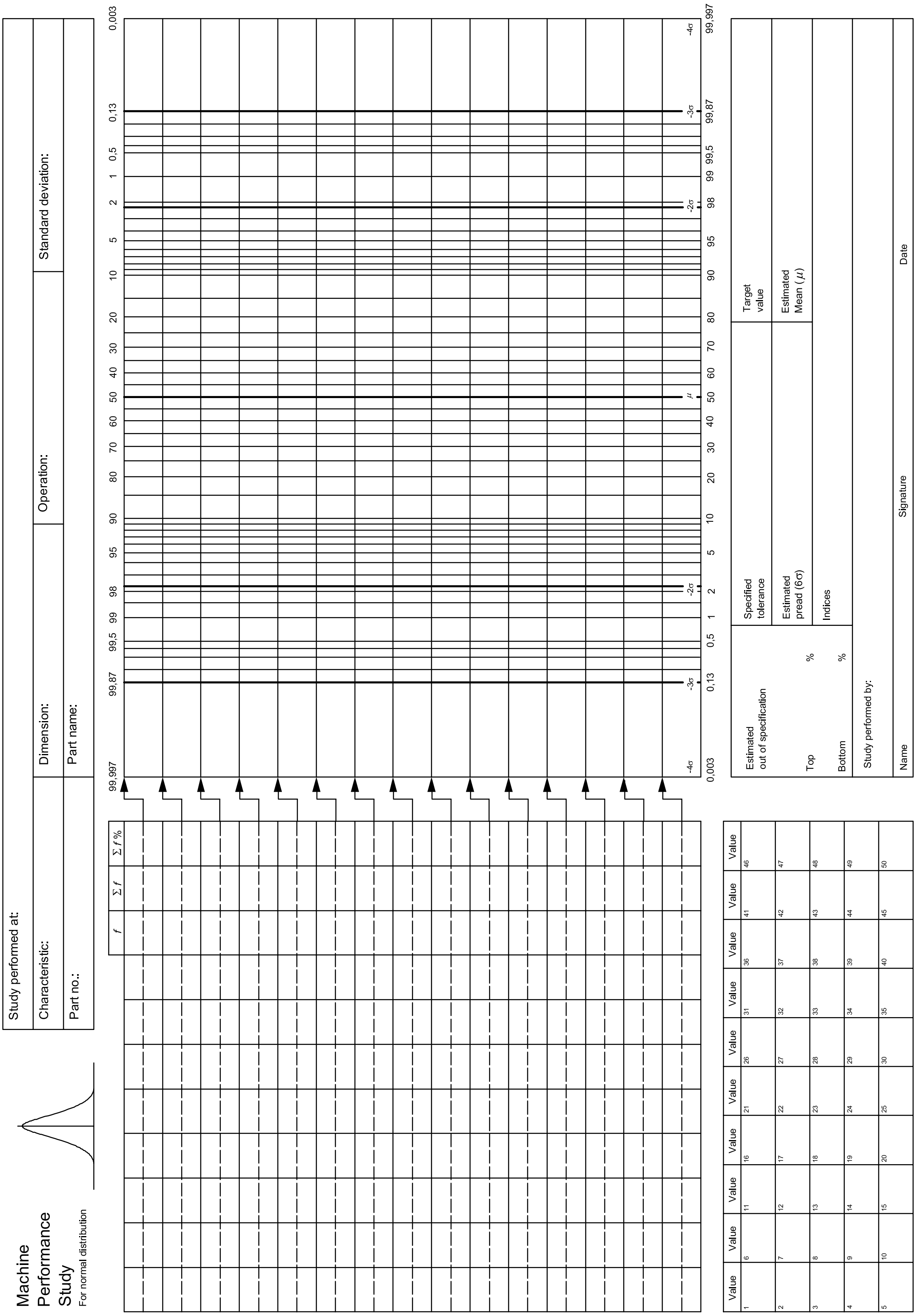

Figure A.1 — Worksheet for normal distribution data

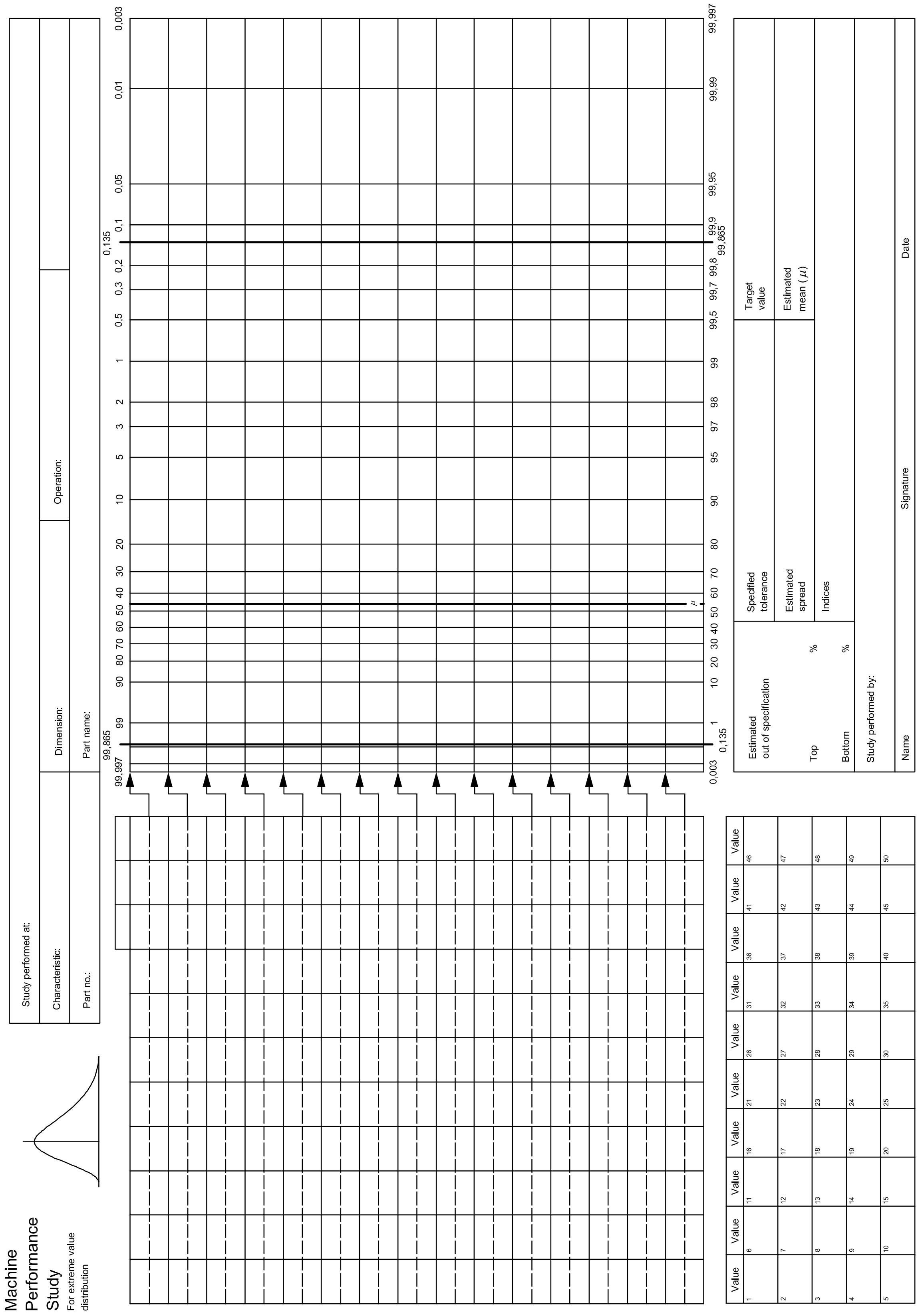

Figure A.2 — Worksheet for extreme value distributed data

Annex B
(informative)

Computer analysis of data

The plots given in Figures B.1 to B.3 are based on the data analysed manually in Clause 5 and shown in Figure 2. They were generated using a software program called MINITAB™.[2)]

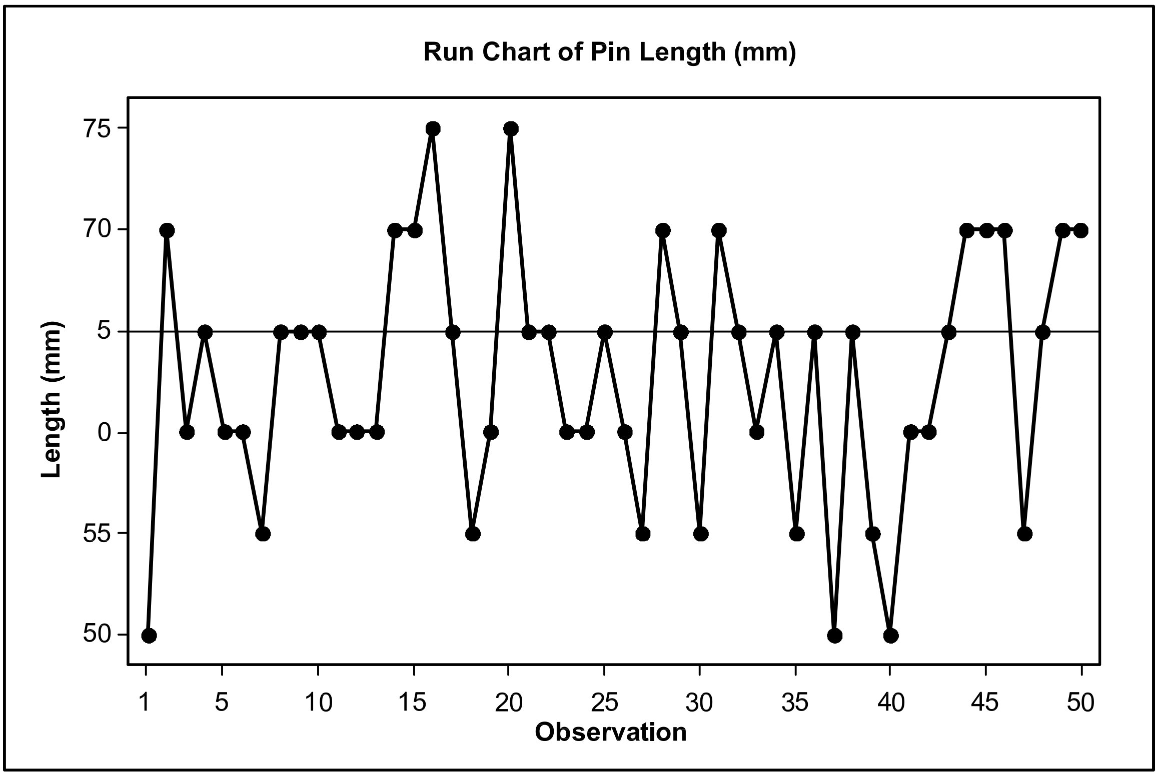

Figure B.1 — Example of the output of a run chart for a machine study

2) MINITAB™ is the trade name of a product supplied by Minitab Inc. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

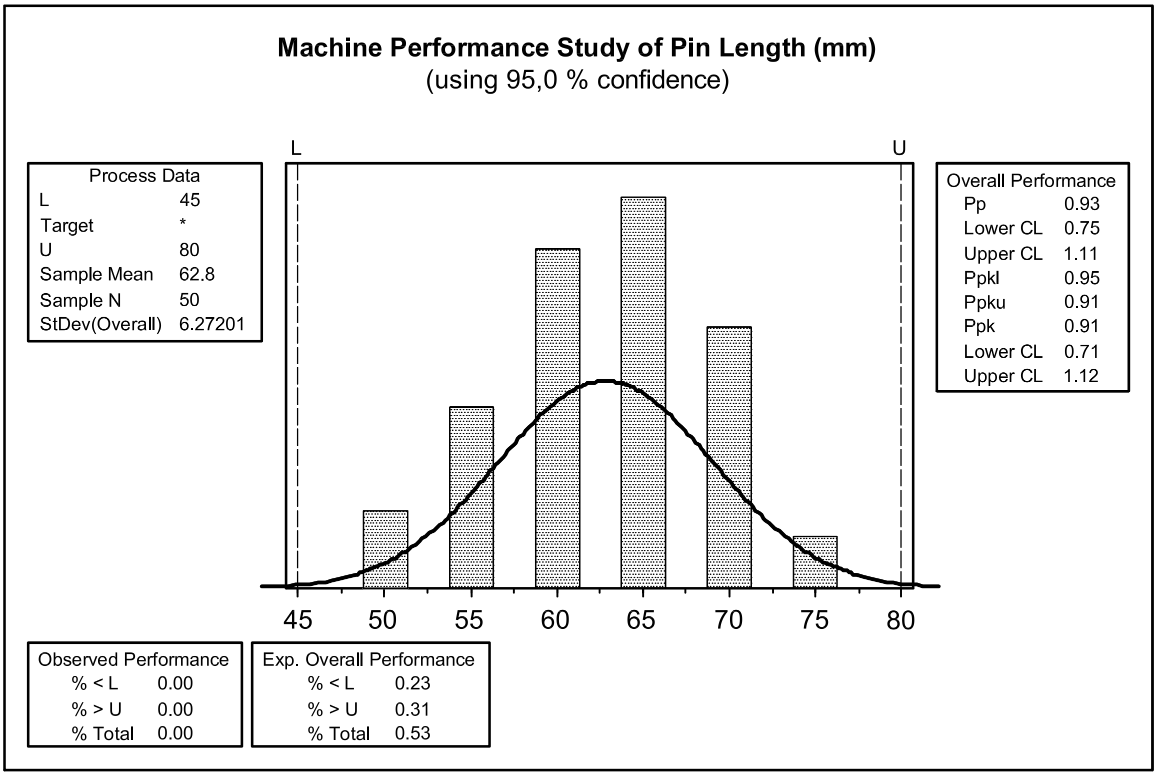

Figure B.2 — Example of the output of a machine performance study

NOTE 1 In these examples of the output from the software (Figures B.2 and B.3), the decimal point is used instead of the decimal comma.

NOTE 2 The mean value, standard deviation and the percentages given for out of specification shown in Figure 2 do not precisely agree with those given in Figure B.2 because of the small inaccuracies associated with estimating values graphically.

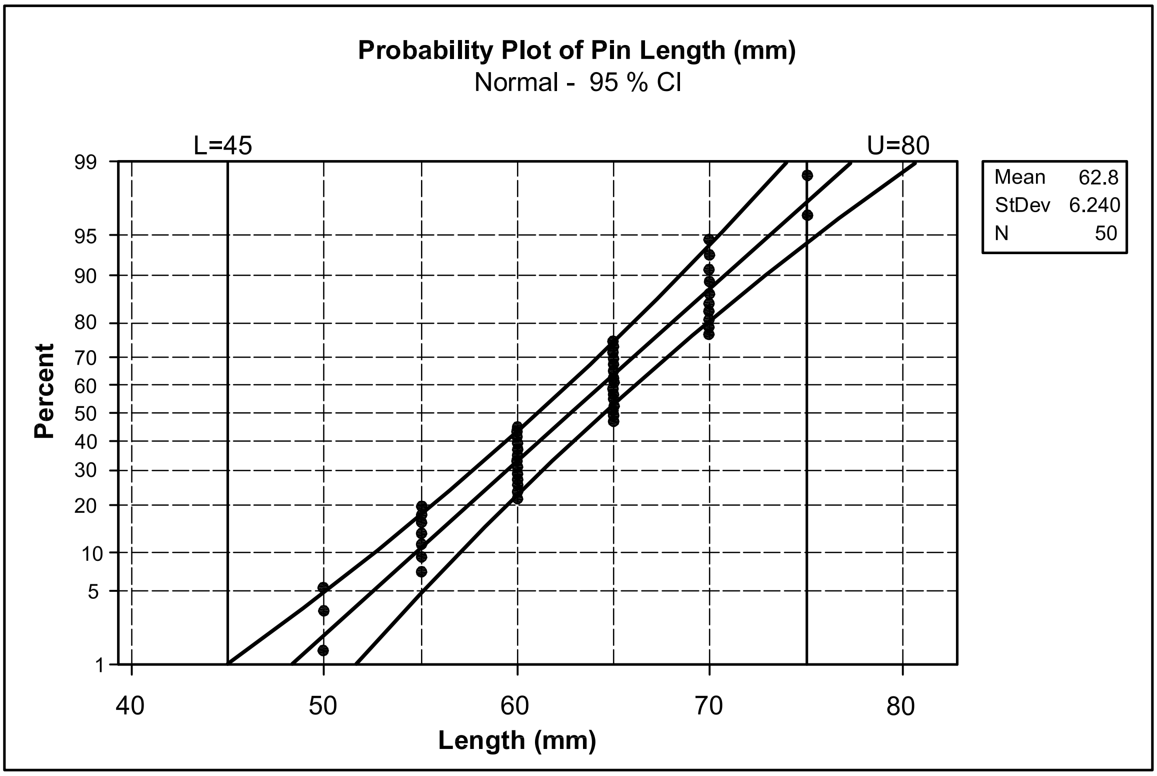

Figure B.3 — Example of the output of a probability plot

NOTE 3 The above probability plot (Figure B.3) appears different to Figure 2 because that plot is constructed using “class” frequencies, whereas the software generated plot uses each data point.

Bibliography

[1] ISO 3534-1, *Statistics — Vocabulary and symbols — Part 1: General statistical terms and terms used in probability*

[2] ISO 3534-2, *Statistics — Vocabulary and symbols — Part 2: Applied statistics*

[3] ISO 5479, *Statistical interpretation of data — Tests for the departure from the normal distribution*

[4] ISO 7870-1, *Control charts — Part 1: General guidelines*

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[8] ISO 21747, *Statistical methods — Process performance and capability statistics for measured quality characteristics*

[9] ISO/TR 22514-4, *Statistical methods in process management — Capability and performance — Part 4: Process capability estimates and performance measures*

[10] Automotive Industry Action Group (AIAG). *Measurement Systems Analysis Reference Manual*, 3rd edn. Chrysler, Ford, General Motors Supplier Quality Requirements Task Force, 2002

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