THE APPLICATION OF STATISTICAL QUALITY CONTROL
TO THE
CASTING OF TRACTOR TRANSMISSION CASES

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I. INTRODUCTION

Statistical quality control has been very successful in many industries; however, there are still many industries which have not fully accepted its use.

This thesis is written with the intention to help establish the fact that there are definite advantages to be claimed from the use of statistical quality control in the foundry industry. In this paper, the author would like to establish the fact that the Lynchburg Foundry Company could have saved a great deal of money in the past production of tractor transmission cases had they utilized statistical quality control. How could this have been accomplished? A quality control program would have enabled the foundry to bring the three component phases of their process, specifications, production, and inspection into an integrated whole. The desired result, of course, is to have a more realistic view of product specifications, accompanied by successful inspection results, realized by the economic control of the process variables.

The author made a thorough study of the portion of the Lynchburg Foundry process that pertained to the production of tractor transmission cases before the process data was analyzed. This was deemed necessary so that when statistical methods were applied to the past recorded data taken from the process, the results would be meaningful.
It should be noted that whenever process is referred to hereafter in this paper, the author is speaking of the three phases – specifications, production, and inspection.

It is hoped that the reader will absorb from this paper, the importance of statistical quality control to foundry work and at the same time project the readers' imagination towards other possibilities in industry.
II. BRIEF DESCRIPTION OF THE TRACTOR TRANSMISSION CASE PROCESS

The Radford Special Foundry began production on a large transmission case for a tractor company on September 3, 1942. Initially, the foundry had to make many changes in their existing facilities and also purchase new equipment in order to produce and inspect the number of transmission cases that were cast each day.

Foundry terminology, the equipment used, and other practices which are common knowledge only to an experienced foundryman will be deleted in this paper. The reason, of course, is that we are primarily interested in the product specifications and the end result or inspection results of the final product. It is believed that the inclusion of foundry terminology, etc., would distract the reader and lead him astray.

The physical inspection of the transmission cases included a brinell hardness test and a tensile strength test that was made on test-bar specimens that were poured from the same lot of molten metal used for that particular transmission case. Similarly, an impact test was performed on test-bar specimens by the buyer, the tractor company, since impact testing equipment was not available at the Lynchburg Foundry Company. Finally, each tractor transmission case was inspected at the foundry for correctness of physical dimensions. Fortunately, the foundry kept complete data of the results of the tensile strength and brinell hardness tests in order of production. It was this past data that was used in this thesis.
Similarly, I studied the various chemical constituents that are important to structural control. The constituents measured were carbon, silicon, sulphur, manganese, and phosphorous. The foundry kept complete data on each chemical constituent giving the per cent of each found in any given lot of molten metal. Very conveniently, this data was compared to the analysis of the physical test data and further compared to the accepted product specifications. Actually, the three should have compared favorably. Unfortunately, this was not true. The results of the testing in these three areas did not jibe.

There could have been many causes for the large amount of variation that was evidenced in the process and probably an experienced foundryman could have pointed out many of them. From my study, however, I do feel justified in concluding that the inadequate control of the chemical constituents did contribute to a large amount of the variation in the brinell hardness and tensile strength results.

In order that the reader may be able to interpret the control charts used in the analysis of the different variables, the subsequent section of this thesis is written to offer a background on statistical quality control charts.
III. TRACTOR TRANSMISSION CASE SPECIFICATIONS

The following specifications were accepted by the Lynchburg Foundry Company for the production of tractor transmission cases:

**Chemical Specifications**

- Carbon........max. 3.40 %  
- Phosphorous....max.  0.250 %
- Manganese.....max. 0.90 %  
  min. 0.60 %
- Silicon........max. 2.25 %
- Sulphur........max. 0.175 %

**Physical Specifications**

- Brinell Hardness........max. 4.6  
  min. 3.9
- Shock Resistance..........min. 25 ft.-#/min.
- Tensile Strength.........max. 40,000 p.s.i.  
  min. 30,000 p.s.i.
IV. THE THOUGHT BEHIND STATISTICAL QUALITY CONTROL CHARTS

Historical Review

The control chart was originated in 1924 by Dr. Walter A. Shewhart and has been used to some extent ever since for the control of repetitive processes. However, it was not until World War II, after the Army and Navy had worked together to expand methods of statistically organizing data, that the control chart really became popular. Today, many manufacturers use statistical quality control methods which have made possible the manufacture of controlled quality products. It should be noted at this time, that modern quality control is an aid to...not a substitute for...the good engineering designs, good manufacturing methods that have always been required for production of specified quality articles.

What is Statistical Quality Control?

Statistical quality control is well defined. Statistical means "arrangement and organization of numerical data from which useful conclusions can be drawn."(1) Quality, intuitively, might mean a degree of conformance or the fact that a product meets the desired specifications. Control simply means "to regulate". So, when statistical

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(1) "Basic Principles of Statistical Quality Control" by H. E. Robbins
quality control is applied in the form of control charts to a process, the process is actually portrayed and will reveal the state of control of the process. Further, control charts offer a means of attaining control of a process as well as a means for judging whether control has been attained in a process. What is meant by the expression "in control"? When control charts are applied to process data, sample averages are plotted with respect to an average line and control limits which are calculated from a substantial amount of past data recorded from the same process. Briefly, the average line ($\bar{X}$) is determined by the average of a minimum of 25 subgroups. Each subgroup will consist of a number of individual values and all subgroups should contain the same number of individual values for any one control chart. The control limits are calculated from the relationship, $\bar{X} \pm 3\bar{M}_2$, and the author makes reference to the Appendices for further explanation. The desired situation would be for all the plotted sample averages to fall within the control limits with no evidence of non-random variation. We would conclude this situation to be "in control" with respect to the level designated by the average line. Fortunately, a process can be in control without all the sample averages falling within the control limits. The mathematical model upon which the theory of control chart analysis rests, allows for a certain percentage of sample averages to fall outside of the control limits and yet portray a state of control. The mathematical model utilizing 3-sigma control limits allows for three out of one thousand sample averages to fall outside of the
control limits and yet be considered "in control". Chance variation has to be considered in any process. This does not mean that sample averages that fall outside of the control limits should not be investigated. Even though averages could fall outside of control limits by chance, they should be investigated because they cannot be differentiated from assignable causes. When a control chart reflects a sample average to be out of control with respect to the control limits and subsequent sample averages reflect control, there may or may not be an assignable cause. One never can tell. In this case, it may be concluded that the process is in a state of "economical control".

From the preceding discussion, the author has hoped to associate the expression "in control" and "economical control" to be interchangeable expressions. The two expressions will be used as such hereafter in this paper.

Discussion on Control Charts

It has been established that control charts can be used to control production provided the process is repetitive or continuous. By repetitive process, the author is referring to one that functions from day to day without significant changes being made in the operating conditions. With this in mind, control charts can be computed and plotted for a process and action can be taken to control the uniformity of production whenever the charts indicate the need for such action.
There are many benefits derived from the proper application of quality control charts. Proper application means to develop and adapt quality control charts to the process on which they are intended to be used. "Do away with the cook-book solution!" Benefits that often result from the proper use of quality control charts are reduction in operating cost and losses, improvement in employee morale, and reduction of production line bottlenecks. Also, management learns whether or not a process is capable of producing parts within the engineering specification limits or at a definite quality level. On a lower plant level, production operators learn when a process should be left alone and when corrections should be made.

Types of Control Charts Used in This Paper

In modern quality control there are many different kinds of control charts used to try and portray the state of control of a process. There are various types of control charts for variables and there are control charts for attributes. The author worked only with control charts for one variable. The three types of control charts for single variables used in this paper for analyzing purposes were the sample average control chart (X), range control chart (R), and the standard deviation (σ) control chart. The mechanics of construction of the control charts will not be discussed in this paper. The reader should refer to the book entitled, "Statistical Quality Control", by Eugene L. Grant. The meaning and uses of each chart, however, will be discussed.
Sample Average (X) Control Chart

The variable chosen for X control charts must be one that can be measured and expressed in numbers. The next important step is to divide the observations taken into what is known as rational sub-groups. In industrial practice, five observations per sample has proved to give very satisfactory results. Four observations per sample has also proved fairly reliable. To date, there is no absolute criteria by which to choose the size of the sub-group or sample. However, the primary reason for taking a relatively small number of observations in each sub-group is to give maximum opportunity for variation to occur between sub-groups and also give minimum opportunity for large variation to occur within sub-groups. It has been accepted that a minimum of 25 sub-groups taken in time order of production is sufficient for calculating the average line and the control limits. It is usual practice to take the 25 sub-groups from past data, make the necessary calculations, construct the chart, and then plot future production data on the same chart. The break-down of future production data should fall within the projected control lines if we are to say the process stayed "in control".

In order for this to occur, the operating conditions of the process must remain essentially the same. If these conditions are fulfilled, the X control chart will provide criteria for removing assignable causes of variation that are brought to attention by out-of-control points caused by abnormal variation between the sub-group averages.
In industrial practice, it is necessary to accompany the \( \bar{X} \) control chart with either a range (\( R \)) or a standard deviation (\( \sigma \)) control chart to indicate within sub-group variation.

**Range (\( R \)) and Standard Deviation (\( \sigma \)) Control Charts**

The author believes it is appropriate to discuss these two types of control charts in the same section since they both have similar uses. These control charts will reveal variation within the sub-group. The decision of choosing which one to use in conjunction with the \( \bar{X} \) control chart depends on the number of observations in a sub-group. For a sub-group consisting of ten or less observations, both control charts will reveal the same information. However, the simplicity of calculations for the range control chart (\( R \)) gives the nod over the standard deviation control chart (\( \sigma \)) for sub-groups of equal to or less than ten observations. For sub-groups of greater than ten observations, the standard deviation (\( \sigma \)) control chart is normally used because it is more sensitive to small variations in the process average. Thus, the range control chart is normally used in practice because the sub-group size of five has been established as being the most practical number of observations to make up a sub-group.

It should be noted that these control charts are derived from the same sub-groups as the \( \bar{X} \) control charts; they are made up from the same data used differently. The author makes reference to Appendix VI for all calculations concerning control charts.
How are Control Charts Related to Specifications

In a manufacturing process, the primary aim is to produce individual items to economical engineering specifications. \( \bar{X} \) control charts are constructed from sample averages. How, then, can they possibly be used to control the individual items of a manufacturing process? With evidence from control charts that a process is in control, it is possible to judge what is necessary to permit the manufacture of individual items that meet the specifications for the variable that was charted. The control chart gives us the following estimates: the centering of the process (\( \bar{X} \) is estimated from \( \bar{X} \)), and the dispersion of the process (\( \sigma \) which is estimated from \( \bar{X}/\sigma_2 \)). The symbols are defined in the Appendices.

Actions based on the relationship between the specifications, the centering, and dispersion of a process depend to some extent on whether there are two specification limits, upper and lower, or only one specification limit. It will be noted later that both situations have to be contended with in the tractor transmission case process.

Briefly, when a process has to meet two specification limits, one of three situations usually comes up. They are as follows:

1. The spread of the process (6\( \sigma \)) is appreciably less than the difference between the specification limits.

2. The spread of the process (6\( \sigma \)) is approximately equal to the difference between the specification limits.
3. The spread of the process is appreciably greater than the difference between the specification limits. It is easy to see that the key to the choice of action by management or a quality control engineer in any one of the three situations is the process dispersion.

Likewise, in the relationship of a process to a single specification limit, there are normally one of three situations that could come up. They are as follows:

1. The low value of the process data ($\bar{x} - 3\sigma'$) is appreciably above the specification minimum.

2. The low value of the process data is approximately at the specification limit.

3. The low value of the process data is appreciably below the specification minimum.

Again, the key to the most useful situation is the process dispersion.

The two general relationships may be better visualized in the next section of this thesis as it will be seen that brinell hardness and tensile strength both have upper and lower specifications. With respect to the chemical constituents, only manganese has upper and lower specifications. Carbon, sulphur, phosphorus, and silicon have only an upper specification to meet.
V. CONTROL CHARTS APPLIED TO THE LYNCHBURG FOUNDRY PROCESS

Actually, control charts for variables may influence specifications in two ways. The control charts may be used to determine the capabilities of a manufacturing process before the specification limits are set and also may be used to give evidence that, because of the inability of a manufacturing process to meet existing specification limits even when it is in control, a review of specification limits is called for. With these two facts in mind, let us analyze each variable separately to see if the use of statistical quality control might have been an aid to the Lynchburg Foundry Company.

**Brinell Hardness**

An inspection of the control charts constructed for brinell hardness reveals the process to be out of control at the level designated by the average line. Actual production data shows the average brinell hardness number to be approximately 4.224 and the calculated control limits to be from 4.136 to 4.31. An estimate of the dispersion of the process ($\sigma^2$) and the calculation of $\pm 3\sigma^{-1}$ limits indicates that the brinell hardness specifications are being met easily. However, this is because brinell hardness specifications (4.6 - 3.9) allows for a large amount of variation and at the same time permits a comfortable margin of safety.
Actually, the average brinell hardness number is at the proper level, but the sample average ($\bar{X}$) control chart indicates the presence of assignable causes which are disclosed by the number of averages falling outside the control limits.

In summation, product specifications and production are not in line. In this case, the foundry is trying to hold brinell hardness to closer tolerances than is necessary which is an indication that specifications were not set in light of what the production process could presumably accomplish.
PART NAME: TRANSMISSION CASES for D-9 TRACTORS
PATTERN NO: 9E3X13

INSPECTED for: HARDNESS (DIA.

SAMPLE SIZE: 4

DATA: SEE TABLE IX.10

FIG. 2

<table>
<thead>
<tr>
<th>RANGE A (DAM)</th>
<th>0.40</th>
<th>0.35</th>
<th>0.30</th>
<th>0.25</th>
<th>0.20</th>
<th>0.15</th>
<th>0.10</th>
<th>0.05</th>
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<tbody>
<tr>
<td>UCLR = 269</td>
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<td>R = 118</td>
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<td>LCLR = 0</td>
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<table>
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<tr>
<th>RANGE B (DAM)</th>
<th>0.80</th>
<th>0.75</th>
<th>0.70</th>
<th>0.65</th>
<th>0.60</th>
<th>0.55</th>
<th>0.50</th>
<th>0.45</th>
<th>0.40</th>
<th>0.35</th>
<th>0.30</th>
<th>0.25</th>
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</tbody>
</table>
PART NAME: TRANSMISSION CASES
for D-8 TRACTORS
PATTERN NO: 9E3313

INSPECTED FOR: HARDNESS (BHN)
SAMPLE SIZE: 4
DATA: SEE TABLE I & II

SUB-GROUPS

SUB-GROUPS
Tensile Strength

An inspection of the control charts constructed for tensile strength reveals the process to be out of control at the level designated by the average line. The charts were constructed from actual test results which show the average tensile strength to be approximately 40,136 p.s.i. and the calculated control limits to run from 37,139 p.s.i. to 43,237 p.s.i. Production specifications that were accepted by the Lynchburg Foundry Company for tensile strength were a minimum of 30,000 p.s.i. and a maximum of 40,000 p.s.i. Here is a case of the upper specification limit, 40,000 p.s.i., being lower than the average tensile strength as calculated from actual test data. Since this is true, one could expect many of the individual tensile strength readings to be out of control. The tractor company specified an upper and lower specification limit to meet; however, the author was informed by foundry personnel that only the lower specification limit was critical to meet.

The fact still remains that product specifications are not in line with production. The Lynchburg Foundry has accepted specifications which the present process does not meet economically.

In summation, specifications were not set in light of what production could presumably accomplish.
Range Control Chart for Tensile Strength (psi)

Sample Size: 3

Specifications: 30,000 - 40,000 psi

- UCLR = 7684
- LCLR = 0

Range R (psi)

- R = 2990

SUB-GROUPS

Range R (psi)

- UCLR = 7684
- LCLR = 0

SUB-GROUPS
Silicon

An inspection of the control charts constructed for silicon content reveals the process to be in control with respect to the level designated by the average line. The average value of silicon was calculated to be 1.893% with the control limits ranging from 1.706% to 2.08%. An estimate of the dispersion (σ⁻¹) of the process and the calculation of the 3σ⁻¹ limit (2.217%) shows that silicon is being controlled with success. In addition, there is a comfortable margin of safety between the upper specification limit (2.35%) and the 3σ⁻¹ limit (2.217%).
Average Control Chart for Silicon (%)

Sample size: 3  Data: See Table  Specifications: Max: 2.25 %

Average X (%)  
2.50  2.40  2.30  2.20  2.10  2.00  1.90  1.80  1.70  1.60

UCL = 2.08  
LCL = 2.05

\bar{X} = 1.893

Sub-Groups

0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75 78 81 84 87

Average X (%)  
2.50  2.40  2.30  2.20  2.10  2.00  1.90  1.80  1.70  1.60

UCL = 2.08  
LCL = 2.05

\bar{X} = 1.893

LCL = 1.706

Sub-Groups

87 90 93 96 99 102 105 108 111 114 117 120 123 126 129 132 135 138 141 144 147 150 153 156 159 162 165 168 171 174
RANGE CONTROL CHART for SILICON (\%)

SAMPLE SIZE: 3  DATA: SEE TABLE  SPECIFICATIONS: MAX: 2.25 \%

\[ \bar{R} = 1.83 \]

\[ \bar{R} = 1.83 \]

SUB-GROUPS

SUB-GROUPS
Carbon

An inspection of the control charts constructed for carbon content reveals the process to be out of control at the level designated by the average line. The average value of carbon was calculated to be 3.23% with the control limits ranging from 3.25% to 3.40%. The accepted carbon upper specification limit was 3.40%. Here is a case of the upper specification limit being lower than the upper control limit as calculated from actual production data. Once again, many of the individual readings of carbon content could be found to be higher than the upper specification limit of 3.40%.

The precise extent of the effect of carbon content with respect to brinell hardness and tensile strength is unknown to the author. However, the fact remains that once again specifications and production are not in line, which is an indication that specifications were not set in light of what production could accomplish.
AVERAGE CONTROL CHART for TOTAL CARBON (%)

Sample Size: 3  Data: See Table  Specifications

Max: 3.40 %

UCL X = 3.605

\[ \bar{R} = 3.33 \]

LCL X = 3.255

SUB-GROUPS

87 90 98 96 99 102 105 108 111 114 117 120 126 129 132 135 138 141 144 147 150 153 156 159 162 165 168 171 174
Sulphur

An inspection of the control charts constructed for sulphur content reveals the process to be out of control at the level designated by the average line. The average value of sulphur was calculated to be .062% with the control limits ranging from .0563% to .0793%. The accepted sulphur upper specification limit was .175%. Even though the process is statistically out of control with respect to the level designated by the average line, sulphur content still meets the specification. An estimate of the dispersion ($\sigma^2$) of the process and the calculation of the $3\sigma^2$ limit shows a comfortable margin of safety between the $3\sigma^2$ limit (.0381) and the upper specification limit of .175%. The fact still remains that specifications and production are not in line. In this instance, production is being held to much closer tolerances than is necessary. To eliminate this situation, specifications should be reviewed and carefully examined in light of what is needed and what production can accomplish.
Average Control Chart for Sulphur (%)  

Sample size: 3  Data: See Table  Specifications: Max. 0.175 %

- UCL = 0.0798
- LCL = 0.0268

Sub-Groups:

- 0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75 78 81 84 87

- 87 90 93 96 99 102 105 108 111 114 117 120 123 126 129 132 135 138 141 144 147 150 153 156 159 162 165 168 171 174
RANGE CONTROL CHART for SULPHUR (%)

SAMPLE SIZE: 3  DATA: SEE TABLE  SPECIFICATIONS: MAX. 0.175 %

UCL R = 0.029
LCL R = 0

R = 0.013

SUB-GROUPS

SUB-GROUPS
Phosphorous

An inspection of the control charts constructed for phosphorous content reveals the process to be out of control at the level designated by the average line. The average phosphorous content was calculated to be .114% and the control limits to be from .114% to .173%. An estimate of the dispersion ($\sigma'$) of the process and the calculation of the $3\sigma'$ limit (.195%) shows that even though the process is out of statistical control, the specifications for phosphorous content is being met with relative ease. The reason, of course, is the comfortable margin of safety between the upper specification limit (.250%) and the $3\sigma'$ limit (.195%). Once again, there is evidence that production and specifications are not in line. In this instance, production is being held to closer tolerances than is necessary, which can be caused when specifications are not set in light of what production can accomplish.
Average Control Chart for Phosphorous (%)

Sample size: 3  Data: See Table  Specifications: Max: 2.50 %

Average R (%)
RANGE CONTROL CHART for PHOSPHOROUS (%) 

SAMPLE SIZE: 3  DATA: SEE TABLE  SPECIFICATIONS: MAX. 250 %

SUBL-GROUPS


SUB-GROUPS

Manganese

An inspection of the control charts constructed for manganese content reveals the process to be out of control at the level designated by the average line. The average manganese content was calculated to be .816% and the control limits to be from .708% to .924%. Manganese specifications were accepted at a minimum of .60% and a maximum of .90%. In this case, the upper specification limit of .90% is lower than the upper control limit that was calculated from actual production data. An estimate of the dispersion ($\sigma'$) of the process and the calculation of the $\sigma'3$ limit (1.602%) indicates that many of the individual manganese readings could be expected to be higher than the .90% upper specification limit. Here again, production and specifications are not in line which indicates that specifications were not set in light of what production could accomplish.
Range Control Chart for Manganese (%)

Sample Size: 3  Data: See Table  Specifications: Max. 90% - Min. 60%

R LCL = 0
R UCL = 272

R = 106

5 Sub-Groups

5 Sub-Groups
AVERAGE CONTROL CHART for MANGANESE (%)

SAMPLE SIZE: 3  DATA: SEE TABLE  SPECIFICATIONS: MAX..:90%-MIN..:60%

\[ \overline{x} = 816 \]
\[ UCL = 924 \]
\[ LCL = 708 \]
Final Summary

In industrial practice in general, as at the Lynchburg Foundry Company, Radford, Virginia, it is impossible to produce identical parts. It is possible to produce uniform parts. In this case, it is possible to produce uniform transmission cases. The production of a process is considered to be uniform when the product meets all engineering specifications. To establish this situation, engineering specifications must be set in light of the control measures available for controlling the variables that enter into the production process. If this is done, engineering specifications will be in line with production possibilities.

The author recommends a complete study of the process from the viewpoint of process control and a review of the engineering specifications. The end result could be the re-setting of engineering specifications so that they will be in line with process capabilities. If this can be done, the economic production of a uniform product should be reasonably assured.

Of equal importance, is the necessity of having a thorough understanding of the fact that engineering specifications must also be set in light of the ultimate use that the transmission cases will be put to. This viewpoint should be clear to both the producer and the customer. It is possible in this case that the tractor designer may have set the most desirable specifications for transmission cases; it is also possible that more economical specifications on transmission
cases could have been set. Economical specifications, in this instance, would mean specifications which the Lynchburg Foundry Company could fulfill and at the same time produce a transmission case that would serve the purpose of the tractor company. This happy medium was not in existence during the course of this study; however, it is believed that a joint study of the design specifications, on the part of the Lynchburg Foundry and the tractor company, would provide a workable solution.

This paper has pointed out the usefulness of the application of statistical quality control to a particular problem. It is hoped that this concept will be used more extensively in the future by foundry personnel.
APPENDIX I

BIBLIOGRAPHY


Robbins, H. E., "Some Basic Principles of Statistical Quality Control."
### APPENDIX II

**KING PORTABLE BRINELL HARDNESS TABLE**

(Puts an actual load of 3000 kg. on a 10 mm. ball)

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### APPENDIX III

**FACTORS FOR DETERMINING THE CENTRAL LINES AND CONTROL LIMITS FOR \( \bar{X}, R, \) AND \( \sigma \) CHARTS**

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<th>No. of Observations in a Sub-Group</th>
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Reference - "Statistical Quality Control" by Eugene L. Grant,
GLOSSARY OF SYMBOLS

\( \bar{X} \) The estimated value of universe standard deviation.

\( \bar{X} \) The average of a set of values.

\( \bar{X} \) The standard deviation of a sub-group of numbers; the root mean square deviation about the average.

\( X \) A value representing some variable. It is usually the value of some quality characteristic.

\( \bar{X} \) The average of two or more \( X \) values.

\( \bar{X} \) The average of \( \bar{X} \) values; an estimate of \( \bar{X} \).

\( \bar{X} \) The true universe average.

\( A_1 \) A multiplier of \( \overline{X} \) to determine the distance from the central line to 3-sigma control limits on an \( X \) chart.

\( A_2 \) A multiplier of \( \bar{X} \) to determine the distance from the central line to 3-sigma control limits on an \( X \) chart.

\( D_3 \) A multiplier of \( \bar{X} \) to determine the 3-sigma lower control limit on a chart for \( X \).

\( D_4 \) A multiplier of \( \bar{X} \) to determine the 3-sigma upper control limit on a chart for \( X \).

LCL Lower control limit on a control chart.

\( n \) Number of values in any sample or sub-group.

\( N \) Number of sub-groups in a lot.

\( R \) The range, the difference between the largest value and the smallest value.

\( \overline{R} \) The average of a set of ranges.

UCL Upper control limit on a control chart.

Reference: "Statistical Quality Control" by Eugene L. Grant.
# APPENDIX V

**TABLE V - EXAMINATIONS OF IMPRESSIONS MADE BY BRINELL HARDNESS TESTS ON TRACTOR TRANSMISSION CASES**

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# APPENDIX V

## TABLE III - FOUNDRY DATA OF TENSILE STRENGTH
FOR TRACTOR TRANSMISSION CASES

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APPENDIX V

TABLE IV - FOUNDRY DATA OF EACH CHEMICAL CONSTITUENT COMPRISING THE MOLTEN METAL (%)

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**TABLE IV - Cont'd**

**TOTAL CARBON**
APPENDIX V

TABLE V - Foundry data of each chemical constituent comprising the molten metal (%)

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APPENDIX V

TABLE VI - FOUNDRY DATA OF EACH CHEMICAL CONSTITUENT
COMPRISING THE MOLTEN METAL (%)

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APPENDIX V

TABLE VII - FOURIERY DATA OF EACH CHEMICAL CONSTITUENT COMPRISING THE MOLTEN METAL (%)

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### APPENDIX V

**TABLE VIII - FOUNDRY DATA OF EACH CHEMICAL CONSTITUENT COMPRISING THE MOLTEN METAL (%)**

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<td>1.99 2.03 1.99</td>
<td>2.00</td>
<td>.04</td>
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<td>1.96</td>
<td>.20</td>
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<td>2.05</td>
<td>.09</td>
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<td>139</td>
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<td>1.86</td>
<td>.10</td>
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<td>1.78</td>
<td>.06</td>
<td></td>
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<tr>
<td>141</td>
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<td>1.93</td>
<td>.03</td>
<td></td>
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<td>.07</td>
<td></td>
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<tr>
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<td>1.79</td>
<td>.06</td>
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<td>2.03</td>
<td>.17</td>
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<td>1.93</td>
<td>.11</td>
<td></td>
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<td>1.81</td>
<td>.02</td>
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<td>147</td>
<td>1.81 1.74 1.85</td>
<td>1.80</td>
<td>.11</td>
<td></td>
</tr>
<tr>
<td>148</td>
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<td>1.69</td>
<td>.18</td>
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APPENDIX VI

CALCULATIONS FOR CONTROL CHARTS
CONTROL CHARTS FOR BRITWELL HARDNESS

The data that was collected from the foundry is tabulated in Table I and Table II of the Appendices and is recorded in sub-groups of four with each sub-group representing one day. The formulas used in calculating the columns of $\bar{X}$, $R$, and $\sigma$ are as listed below:

$$\bar{X} = \frac{X_1 + X_2 + \ldots + X_n}{n}$$

Where $X$ equals the individual readings

$n$ equals the size of the sub-group,

$$R = X_{\text{max.}} - X_{\text{min.}}$$

Where $R$ is the range for each sub-group.

$$\sigma = \sqrt{\frac{\frac{X_1^2}{n} + \frac{X_2^2}{n} + \ldots + \frac{X_n^2}{n} - \bar{X}^2}{n}}$$

Where $\sigma$ is the standard deviation for each sub-group.

Trial control limits were calculated based on the first 50 sub-groups. Before final control limits are projected into future production, they must be such to represent the process in a condition of control. For this reason three sets of control limits had to be calculated as follows:

Calculation of Control Limits:

Set No. 1

$$\bar{X} = \frac{\sum X}{N}$$

Where $N$ is the number of sub-groups making up the data used for calculating the first control limits or 50.
\[ \bar{x} = \frac{211.91}{50} \]
\[ \bar{x} = 4.238 \]
\[ \bar{R} = \frac{\sum R}{N} \]
\[ \bar{R} = 5.95 \]
\[ c = \frac{\sum c}{N} \]
\[ c = 0.119 \]
\[ \bar{\sigma} = \frac{\sum \sigma}{N} \]
\[ \bar{\sigma} = 2.7173 \]
\[ \bar{\sigma} = 0.0543 \]

Limits for \( \bar{x} \) control chart:

Upper Control Limit, \( UCL_{\bar{x}} = \bar{x} + A_2 \bar{R} \)
\[ UCL_{\bar{x}} = 4.238 + 0.47 \times 0.119 \]
\[ UCL_{\bar{x}} = 4.238 + 0.0563 \]
\[ UCL_{\bar{x}} = 4.325 \]

Lower Control Limit, \( LCL_{\bar{x}} = \bar{x} - A_2 \bar{R} \)
\[ LCL_{\bar{x}} = 4.238 - 0.47 \times 0.119 \]
\[ LCL_{\bar{x}} = 4.238 - 0.0563 \]
\[ LCL_{\bar{x}} = 4.151 \]

For the \( A_2 \) factor see Appendix III.
Limits for the $R$ control chart:

$\text{UCL}_R = D_4 \bar{R}$

$\text{UCL}_R = 2.28 \times .119$

$\text{UCL}_R = .271$

$LCL_R = D_3 \bar{R}$

$LCL_R = 0 \times .119$

$LCL_R = 0$

For the factors $D_3$ and $D_4$ see Appendix III.

Limits for the $\sigma$ control chart:

$\text{UCL}_\sigma = \bar{X}$

$\text{UCL}_\sigma = 2.27 \times .0543$

$\text{UCL}_\sigma = .123$

$LCL_\sigma = \bar{X}$

$LCL_\sigma = 0 \times .0543$

$LCL_\sigma = 0$

For the $D_3$ and $D_4$ factors see Appendix III.

It is readily seen by comparing the $\bar{X}$ values of Table I, that all values of the following sub-groups were out of control: 4, 5, 13, 15, 16, 30, 34, 36, 39, 41, 44, and 45. The possible causes of variation was located and corrected and the sub-groups out of control were discarded. If control limits are to be meaningful, they necessarily have to be discarded. Sub-groups 51 to 62 were then added and a second set of control limits were calculated as follows:
Calculation of the Second Set of Control Limits:

\[ \bar{X} = \frac{\sum X}{n} \]

\[ \bar{X} = \frac{211.64}{50} \]

\[ \bar{X} = 4.232 \]

\[ \bar{R} = \frac{\sum R}{n} \]

\[ \bar{R} = \frac{5.80}{50} \]

\[ \bar{R} = .116 \]

\[ \bar{\sigma} = \frac{\bar{R}}{d_2} \]

\[ \bar{\sigma} = \frac{2.518}{20} \]

\[ \bar{\sigma} = .0503 \]

Limits for the \( \bar{X} \) control chart:

\[ \text{UCL}_{\bar{X}} = \bar{X} + A_2 \bar{R} \]

\[ \text{UCL}_{\bar{X}} = 4.232 + 0.73 \times .112 \]

\[ \text{UCL}_{\bar{X}} = 4.314 \]

\[ \text{LCL}_{\bar{X}} = \bar{X} - A_2 \bar{R} \]

\[ \text{LCL}_{\bar{X}} = 4.232 - 0.73 \times .112 \]

\[ \text{LCL}_{\bar{X}} = 4.150 \]
Limits for the $R$ control chart:

$\text{Ucl}_R = D_4 \bar{R}$

$\text{Ucl}_R = 2.28 \times \bar{R}$

$\text{Ucl}_R = .255$

$\text{Lcl}_R = D_3 \bar{R}$

$\text{Lcl}_R = 0 \times \bar{R}$

$\text{Lcl}_R = 0$

Limits for the $\sigma$ control chart:

$\text{Ucl}_\sigma = B_4$

$\text{Ucl}_\sigma = 2.27 \times \bar{R}$

$\text{Lcl}_\sigma = .114$

$\text{Lcl}_\sigma = B_3$

$\text{Lcl}_\sigma = 0 \times \bar{R}$

$\text{Lcl}_\sigma = 0$

By comparing the $\bar{X}$ values of the sub-groups listed in Table I for the second calculation of control limits, it is seen that sub-groups 20, 23, and 32 are out of control. They were similarly discarded as the sub-groups were that fell outside of the control limits in the first calculation of control limits and sub-groups 65 to 67 were added. Sub-group 64 was not considered because it was obviously out of control. A third set of control limits were calculated as follows:
Third Set of Control Chart Limits:

\[ \overline{X} = \frac{\sum X}{n} \]

\[ \overline{X} = \frac{211.22}{50} \]

\[ \overline{X} = 4.224 \]

\[ \overline{R} = \frac{\sum R}{N} \]

\[ \overline{R} = \frac{5.30}{50} \]

\[ \overline{R} = 0.116 \]

\[ \bar{\sigma} = \frac{\sum \sigma}{N} \]

\[ \bar{\sigma} = \frac{2.647}{50} \]

\[ \bar{\sigma} = 0.0539 \]

Limits for \( \overline{X} \):

\[ \text{UCL} \overline{X} = \overline{X} + A_2 \overline{R} \]

\[ \text{UCL} \overline{X} = 4.224 + 0.73 \times 0.116 \]

\[ \text{UCL} \overline{X} = 4.31 \]

\[ \text{LCL} \overline{X} = \overline{X} - A_2 \overline{R} \]

\[ \text{LCL} \overline{X} = 4.224 - 0.73 \times 0.116 \]

\[ \text{LCL} \overline{X} = 4.133 \]
Limits for the $R$ control chart:

$UCL_R = D_4 \bar{R}$
$UCL_R = 2.28 \times 0.118$
$UCL_R = 0.269$
$LCL_R = D_3 \bar{R}$
$LCL_R = 0 \times 0.118$
$LCL_R = 0$

Limits for the $\sigma$ control chart:

$UCL_\sigma = D_4 \bar{X}$
$UCL_\sigma = 2.27 \times 0.0529$
$UCL_\sigma = 0.120$
$LCL_\sigma = D_3 \bar{X}$
$LCL_\sigma = 0 \times 0.0529$
$LCL_\sigma = 0$
CONTROL CHARTS FOR TENSILE STRENGTH

All calculations are made from the same equations used in constructing the control charts on brinell hardness. It should be noted that a sample size of 3 (n=3) was used and also that control limits were calculated only once on the first 50 sub-groups (n=50) as follows:

\[ \bar{x} = \frac{\sum x}{n} \]

\[ \bar{x} = \frac{2,000,421}{50} \]

\[ \bar{x} = 40,183 \]

\[ R = \frac{\sum R}{n} \]

\[ R = \frac{149,500}{50} \]

\[ R = 2,990 \]

Control Limits for Average Chart:

\[ UCL = \bar{x} + A_2 R \]

\[ UCL = 40,183 + 1.02 \times 2,990 \]

\[ UCL = 40,183 + 3,049 \]

\[ UCL = 43,232 \]

\[ LCL = \bar{x} - A_2 R \]

\[ LCL = 40,183 - 1.02 \times 2,990 \]

\[ LCL = 40,183 - 3,049 \]

\[ LCL = 37,139 \]
Control Limits for Range Chart:

\[ UCL_R = D_4 \bar{R} \]
\[ UCL_R = 2.57 \times 2.930 \]
\[ UCL_R = 7.634 \]

\[ LCL_R = D_3 \bar{R} \]
\[ LCL_R = 0 \times 2.930 \]
\[ LCL_R = 0 \]
CONTROL CHARTS FOR SILICON

All calculations are made from the same equations used in constructing the control charts on tensile strength. $n = 3$ and $N = 50$ remains the same and for control charts on sulphur, phosphorus, manganese, and total carbon only the actual calculations will be shown as the above information is also true in each case. Control limits were calculated only once on the first 50 sub-groups as follows:

$$
\overline{X} = \frac{\sum X}{N}
$$

$$
\overline{X} = \frac{94.65}{50}
$$

$$
\overline{X} = 1.893
$$

$$
\overline{R} = \frac{\sum R}{N}
$$

$$
\overline{R} = \frac{9.14}{50}
$$

$$
\overline{R} = 0.183
$$

Control limits for average chart:

$$
\text{UCL} \overline{X} = \overline{X} + A_2 \overline{R}
$$

$$
\text{UCL} \overline{X} = 1.893 + 1.02 \times 0.183
$$

$$
\text{UCL} \overline{X} = 1.893 + 0.187
$$

$$
\text{UCL} \overline{X} = 2.08
$$

$$
\text{LCL} \overline{X} = \overline{X} - A_2 \overline{R}
$$

$$
\text{LCL} \overline{X} = 1.893 - 0.183
$$

$$
\text{LCL} \overline{X} = 1.706
$$
Control Limits for Range Chart:

\[ UCL_R = \bar{R} \sqrt{\frac{1}{n}} \]

\[ UCL_R = 2.57 \times 0.163 \]

\[ UCL_R = 0.470 \]

\[ LCL_R = \bar{R} \sqrt{\frac{1}{n}} \]

\[ LCL_R = 0 \times 0.163 \]

\[ LCL_R = 0 \]

Estimation of \( \bar{R} \) for Silicon:

\[ \bar{R} = \frac{\sum R}{n} \]

\[ \bar{R} = \frac{1.693}{10} \]

\[ \bar{R} = 0.169 \]

\[ \bar{\bar{R}} = \bar{R} \cdot \sqrt{n} \]

\[ \bar{\bar{R}} = 0.324 \]

\[ UCL_{\bar{R}} = 1.893 \times 0.324 \]

\[ UCL_{\bar{R}} = 2.327 \]

\[ LCL_{\bar{R}} = 1.893 - 0.324 \]

\[ LCL_{\bar{R}} = 1.569 \]

\[ \bar{\bar{R}} = \bar{R} \cdot \sqrt{n} \]

\[ \bar{\bar{R}} = 0.432 \]

\[ UCL_{\bar{R}} = \frac{\bar{R}}{d_2} \times \bar{R} \cdot \sqrt{n} \]

\[ UCL_{\bar{R}} = 2.323 \]
\[ L_{\xi_{\text{II}}} = \bar{X} - 4 \sigma' \]
\[ L_{\xi_{\text{II}}} = 1.393 - .432 \]
\[ L_{\xi_{\text{II}}} = 1.461 \]

\[ 5.6 \sigma' = 6.540 \]
\[ U_{\xi_{\text{II}}} = 1.893 + .540 \]
\[ U_{\xi_{\text{II}}} = 2.433 \]

\[ L_{\xi_{\text{II}}} = 1.893 - .540 \]
\[ L_{\xi_{\text{II}}} = 1.353 \]
CALCULATIONS FOR AVERAGE (\( \bar{x} \)) AND RANGE (R) 
CONTROL CHARTS FOR 2 CARBON

\[ \bar{x} = \frac{\sum x}{N} \]

\[ \bar{x} = \frac{166.63}{50} \]

\[ \bar{x} = 3.33 \]

\[ R = \frac{\sum R}{N} \]

\[ R = \frac{2.66}{50} \]

\[ R = .0732 \]

**Control Limits for Average Chart:**

Ucl\( \bar{x} \) = \( \bar{x} \) + \( A_2 \bar{R} \)

Ucl\( \bar{x} \) = 3.33 + 1.02 \times .0732

Ucl\( \bar{x} \) = 3.405

Lcl\( \bar{x} \) = 3.33 - \( A_2 \bar{R} \)

Lcl\( \bar{x} \) = 3.33 - .075

Lcl\( \bar{x} \) = 3.255

**Control Limits for Range Chart:**

Ucl\( R \) = \( D_4 \bar{R} \)

Ucl\( R \) = 2.57 \times .0732

Ucl\( R \) = .188

Lcl\( R \) = \( D_3 \bar{R} \)

Lcl\( R \) = 0 \times .0732

Lcl\( R \) = 0
Estimation of $\sigma'$ for Carbon:

\[ \sigma' = \frac{R}{d_2} \]

\[ \sigma' = \frac{0.732}{1.693} \]

\[ \sigma' = 0.43 \]

$6\sigma' = 0.129$

$U_{ul ki} = \bar{x} \pm 3\sigma'$

$U_{ul ki} = 3.33 \pm 0.129$

$U_{ul ki} = 3.459$

$L_{ll ki} = \bar{x} \pm 3\sigma'$

$L_{ll ki} = 3.33 - 0.129$

$L_{ll ki} = 3.201$

$4\sigma' = 0.172$

$U_{ul ki} = \bar{x} \pm 4\sigma'$

$U_{ul ki} = 3.33 \pm 0.172$

$U_{ul ki} = 3.502$

$L_{ll ki} = \bar{x} \pm 4\sigma'$

$L_{ll ki} = 3.33 - 0.172$

$L_{ll ki} = 3.159$

$5\sigma' = 0.215$

$U_{ul ki} = 3.33 \pm 0.215$

$U_{ul ki} = 3.545$

$L_{ll ki} = 3.33 - 0.215$

$L_{ll ki} = 3.115$
CALCULATIONS FOR AVERAGE (x) AND RANGE (R) CONTROL CHARTS FOR % MANGANESE

\[
\bar{x} = \frac{\sum x}{N}
\]

\[
\bar{R} = 4.076
\]

\[
\bar{x} = .816
\]

\[
\bar{R} = \frac{\sum R}{N}
\]

\[
\bar{R} = .106
\]

Control Limits for Average Chart:

UCL \( \bar{x} \) = \( \bar{x} \) + \( A_2 \bar{R} \)

UCL \( \bar{x} \) = \( .816 + 1.02 \times .106 \)

UCL \( \bar{x} \) = \( .816 + .108 \)

UCL \( \bar{x} \) = \( .924 \)

LCL \( \bar{x} \) = \( \bar{x} - A_2 \bar{R} \)

LCL \( \bar{x} \) = \( .816 - .108 \)

LCL \( \bar{x} \) = \( .708 \)

UCL \( R \) = \( D_4 \bar{R} \)

UCL \( R \) = \( 2.57 \times .106 \)

UCL \( R \) = \( .272 \)

LCL \( R \) = \( D_3 \bar{R} \)

LCL \( R \) = \( 0 \times .106 \)

LCL \( R \) = \( 0 \)
Estimation of $\sigma'$ for Manganese:

$$\sigma' = \frac{1}{a_2}$$

$$\sigma' = \frac{1}{1.893}$$

$$\sigma' = 0.542$$

$$\sigma'^3 = \pm 0.186$$

$Ue_{xi} = \bar{x} \pm 3 \sigma'$

$Ue_{xi} = 0.816 \pm 0.186$

$Ue_{xi} = 1.002$

$Le_{xi} = \bar{x} - 3 \sigma'$

$Le_{xi} = 0.816 - 0.186$

$Le_{xi} = 0.630$

$$\sigma'^2 = \pm 0.248$$

$Ue_{xi} = \bar{x} \pm 4 \sigma'$

$Ue_{xi} = 0.816 \pm 0.248$

$Ue_{xi} = 1.064$

$Le_{xi} = \bar{x} - 4 \sigma'$

$Le_{xi} = 0.816 - 0.248$

$Le_{xi} = 0.568$

$$\sigma' = \pm 0.310$$

$Ue_{xi} = 0.816 \pm 0.310$

$Ue_{xi} = 1.126$

$Le_{xi} = 0.816 - 0.310$

$Le_{xi} = 0.506$
CALCULATIONS FOR AVERAGE (X) AND RANGE (R)
CONTROL CHARTS FOR % SULPHUR

\[ \bar{X} = \frac{\sum X}{N} \]
\[ \bar{X} = \frac{2.415}{50} \]
\[ \bar{X} = .0483 \]

\[ \bar{R} = \frac{\sum R}{N} \]
\[ \bar{R} = \frac{.565}{50} \]
\[ \bar{R} = .0113 \]

Control Limits for Average Chart:

\[ Ucl\bar{X} = \bar{X} + A_2\bar{R} \]
\[ Ucl\bar{X} = .0683 + 1.02 \times .0113 \]
\[ Ucl\bar{X} = .0683 + .0115 \]
\[ Ucl\bar{X} = .0798 \]

\[ Lcl\bar{X} = \bar{X} - A_2\bar{R} \]
\[ Lcl\bar{X} = .0683 - .0115 \]
\[ Lcl\bar{X} = .0568 \]

Control Limits for Range Chart:

\[ UclR = D_4\bar{R} \]
\[ UclR = 2.57 \times .0113 \]
\[ UclR = .029 \]

\[ LclR = D_3\bar{R} \]
\[ LclR = 0 \times .0113 \]
\[ LclR = 0 \]
Estimation of $\sigma'$ for Sulphur:

$\sigma' = \frac{K}{N_2}$

$\sigma' = \frac{.0113}{1.693}$

$\sigma' = .0066$

$3 \sigma' = .0198$

$\text{Ucl}_\text{XI} = \bar{x} + 3 \sigma'$

$\text{Ucl}_\text{XI} = .0683 + .0198$

$\text{Ucl}_\text{XI} = .0881$

$\text{Lcl}_\text{XI} = \bar{x} - 3 \sigma'$

$\text{Lcl}_\text{XI} = .0485$

$4 \sigma' = \frac{4}{1.964}$

$\text{Ucl}_\text{XI} = \bar{x} + 4 \sigma'$

$\text{Ucl}_\text{XI} = .0683 + .0264$

$\text{Ucl}_\text{XI} = .0947$

$\text{Lcl}_\text{XI} = \bar{x} - 4 \sigma'$

$\text{Lcl}_\text{XI} = .0683 - .0264$

$\text{Lcl}_\text{XI} = .0419$

$5 \sigma' = \frac{5}{1.963}$

$\text{Ucl}_\text{XI} = \bar{x} + 5 \sigma'$

$\text{Ucl}_\text{XI} = .0683 + .033$

$\text{Ucl}_\text{XI} = .1013$

$\text{Lcl}_\text{XI} = .0683 - .033$

$\text{Lcl}_\text{XI} = .0353$
CALCULATIONS FOR AVERAGE ($\bar{X}$) AND RANGE ($R$) CONTROL CHARTS FOR % PHOSPHOROUS

\[ \bar{X} = \frac{\sum X}{n} \]
\[ \bar{X} = \frac{7.18}{20} \]
\[ \bar{X} = .359 \]
\[ \bar{R} = \frac{\sum R}{n} \]
\[ \bar{R} = .0293 \]

Control Limits for Average Chart:

\[ UCL\bar{X} = \bar{X} + A_2 \bar{R} \]
\[ UCL\bar{X} = .359 + 1.02 \times .0293 \]
\[ UCL\bar{X} = .397 \]
\[ UCL\bar{X} = .473 \]

\[ LCL\bar{X} = \bar{X} - A_2 \bar{R} \]
\[ LCL\bar{X} = .359 - .0293 \]
\[ LCL\bar{X} = .330 \]
\[ LCL\bar{X} = .310 \]

Control Limits for Range Chart:

\[ UCLR = D_4 \bar{R} \]
\[ UCLR = 2.57 \times .0293 \]
\[ UCLR = .0753 \]
\[ LCLR = D_3 \bar{R} \]
\[ LCLR = 0 \times .0293 \]
\[ LCLR = 0 \]
Estimation of $\sigma'$ for Phosphorus:

$$\sigma' = \frac{\bar{X}}{\sigma}$$

$$\sigma' = \frac{0.0203}{1.693}$$

$$\sigma' = 0.017$$

$$\xi 3 \sigma' = \xi 0.051$$

Ue LXI = $\bar{X} + 3 \sigma'$

Ue LXI = 0.144 + 0.051

Ue LXI = 0.195

Le LXI = $\bar{X} - 3 \sigma'$

Le LXI = 0.144 - 0.051

Le LXI = 0.093

$$\xi 4 \sigma' = \xi 0.068$$

Ue LXI = $\bar{X} + 4 \sigma'$

Ue LXI = 0.144 + 0.068

Ue LXI = 0.212

Le LXI = $\bar{X} - 4 \sigma'$

Le LXI = 0.144 - 0.068

Le LXI = 0.076

$$\xi 5 \sigma' = \xi 0.085$$

Ue LXI = 0.144 + 0.085

Ue LXI = 0.229

Le LXI = 0.144 - 0.085

Le LXI = 0.059
VII. Vita

The author was born April 9, 1930 in Charleston, West Virginia. He now resides at Hopewell, Virginia. Elementary education was taken at the Woodlawn Grammar School in Hopewell, and high school training was taken at Hopewell High School. The high school education consisted of the successful completion of the scientific course on June 6, 1947.

On September 17, 1947, the author enrolled in Virginia Polytechnic Institute to major in Industrial Engineering. Upon the completion of the requirements, the author received the Bachelor of Science Degree in Industrial Engineering in June, 1951.

In July, 1951, the writer began working for the Atomic Energy Division and continued this work until being called into the Armed Forces, November 19, 1951. He entered the service as a Second Lieutenant in the Army Corps of Engineers and was discharged as a First Lieutenant on October 23, 1953.

The author entered Virginia Polytechnic Institute in January, 1954 to begin work on the Master of Science Degree in Industrial Engineering. He will receive the degree on June 5, 1955.

The author is single and is now employed by the National Aniline Division of the Allied Chemical and Dye Corporation located in Hopewell, Virginia.

E. Darwood Barco