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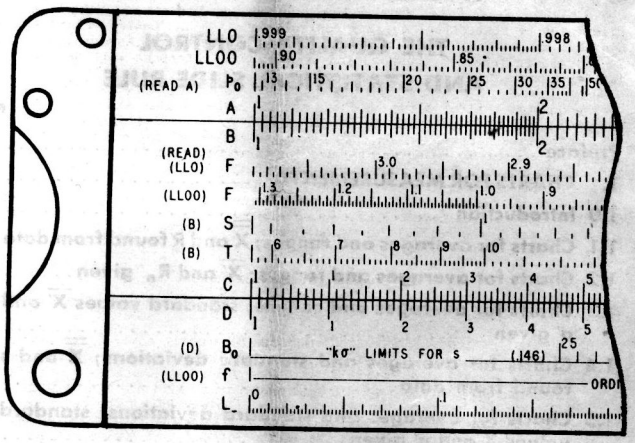
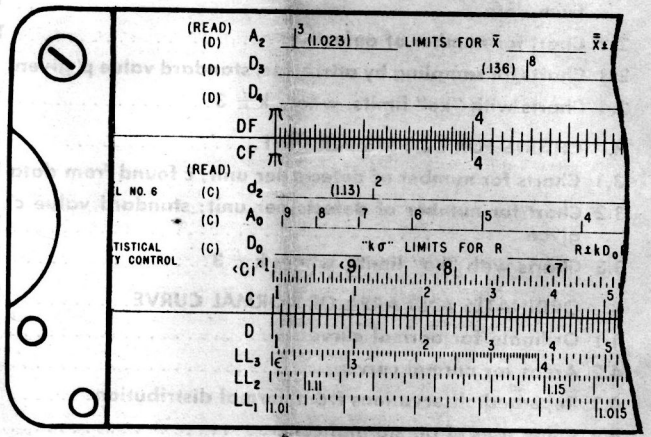
THE QUALITY CONTROL AND STATISTICAL SLIDE RULE





PREFACE

It is assumed that the reader is familiar with the use of a standard slide rule and with calculations used in statistical quality control. A knowledge of the use of a standard slide rule may be gained from the manual, *How to Use the Ortho-Phase Log Log Slide Rule*, Model # 500, published by **Pickett and Eckel, Inc.** Basic principles of statistical quality control are given in *"Control Chart Method of Controlling Quality During Production"*, American Standards Association Pamphlet Z1.3-1942. In general, the notation used in this reference will be used in the following pages.

The quality control slide rule has the following scales which are ordinarily found on a log-log slide rule: C, D, CI, CF, DF, A, B, S, T, L, LLOO, LLO, LL1, LL2, LL3. The scales A_0, A_2, B_0, D_0, D_3, D_4, c_2, d_2 are used for calculating control limits for charts for measurements, and for estimating standard deviation of population from samples drawn from normal distributions. The small numbers in parentheses on these scales show approximate values of these constants as an aid in location of the decimal point. The p_0 scale is used for control limits for fraction defective and related charts. The f and F scales are used in finding ordinates of, and areas under, the "normal" distribution curve, respectively.

1. Charts for Measurements.

1.0 Introduction.

In the application of statistical methods to quality control the number n of observations in a sample plays a fundamental role. Some formulas, such as $\bar{X}_{UL}=\bar{X}'+3\sigma'/\sqrt{n}$, involve n explicitly. Other formulas, such as $\bar{X}_{UL}=\bar{X}+A_2\bar{R}$ and $R_{UL}=d_2D_4\sigma'$ involve factors A_2, d_2, D_4, etc. which vary with n. The special scales for these factors found on the *Quality Control Slide Rule* make calculations of this sort relatively easy. If the scale for a particular factor is on the stock of the rule, the numerical value of the factor for any n on that scale may be read opposite it on the D scale. If the factor scale is on the slide, the numerical value of the factor for any n on the scale may be read opposite it on the C scale. However, it is not necessary to *read* these values in using the rule. They are automatically set in the rules which follow.

For convenience of discussion the various calculations will be classified into types.

TYPE I. Form ax, where a represents one of the factors A_0, A_2, B_0, D_0, D_3, D_4, c_2, d_2, and where x represents a value which may either be found from measurements in the samples (for example, the average range, $\bar{R}$), or be otherwise known.

EXAMPLES:

i) $A_2\bar{R}$, for n=5, R=8.54. See Sec. 1.11 below.

ii) $d_2\sigma'$, for n=5, σ'=4. See Sec. 1.34 below.

The general rule for calculations of this type follows:

RULE I (a) If the appropriate a scale is on the stock (A_2, D_4, D_3, B_0), set an index of the C scale opposite n on the a scale. Move hairline over x on the C scale. Read ax on the D scale under the hairline.

I (b) If the appropriate a scale is on the slide (A_0, c_2, d_2, D_0), set an index of the C scale opposite x on the D scale. Move hairline to n on the appropriate a scale. Read ax on the D scale under hairline.

This operation is ordinary multiplication on the slide rule using the C and D scales, except that the value of the factor a is automatically set by setting to n on the factor scale. Consequently, the results can also be read on the DF scale if this is more convenient. Moreover, if the factor scale is on the stock the rule can be altered to read:

I (a) set the indicator over n on the a scale, move slide until x on the CI scale is under the hairline, and read ax on the D scale opposite the index of C scale.

TYPE II. Form x/a.

EXAMPLES:
i) $\bar{R}/d_2$ — See Sec. **1.14** below.
ii) s/c_2 — See Sec. **1.44** below.

The scales for the factors d_2 and c_2 which occur in the denominator are on the slide. Hence the division in forms of Type II may be done in the usual manner.

RULE II. Set the hairline over x on the D scale, move the slide until n on d_2 (or on c_2) is under the hairline, and read the result x/a on the D scale at the C-index.

TYPE III. Form abx, where a and b are *both* special factors, and where one is set on the stock and the other on the slide.

EXAMPLES:
i) $d_2D_4\sigma'$ — See Sec. **1.32** below.
ii) $c_2B_0\sigma'$ — See Sec. **1.53** below.

Calculations of Type III are easily done in the usual manner for continued products by using the CI scale.

RULE III. Set the C-index opposite n on the appropriate factor scale, move hairline over n of the factor scale on the slide, then move the slide until x on the CI scale is under the hairline, and read the result on the D scale at the C-index.

In some cases the forms indicated above have additional factors. If so, the computation may be continued using any appropriate scale on the rule. For example, to compute $3\bar{s}/(c_2\sqrt{n})$ use the D, C, c_2 and B scales as follows. Place hairline over 3 on D scale, move n on c_2 scale under hairline, move hairline to $\bar{s}$ on C scale, move slide to bring n on B scale under hairline, read result on the D scale at the C-index.

TYPE IV. Some formulas require the use of no special scales, but are computed by using the regular scales on the rule.

EXAMPLES:
i) $3\sigma'/\sqrt{n}$ — See Sec. **1.31** below.
ii) $3\sigma'$ — See Sec. **1.33** below.

If a form of a type indicated above is to be added to and subtracted from another value, as in $\bar{\bar{X}}\pm A_2\bar{R}$, the addition and subtraction may be done by arithmetic after the form has been computed on the slide rule.

1.1 Charts for averages and ranges; $\bar{\bar{X}}$ and $\bar{R}$ found from data.

EXAMPLE: $\bar{\bar{X}}=51.34$, $\bar{R}=8.54$, $n=5$.

1.11 To find control limits for average chart.

FORMULAS: $\bar{X}_{UL}=\bar{\bar{X}}+A_2\bar{R}$, $\bar{X}_{LL}=\bar{\bar{X}}-A_2\bar{R}$. Type I (a).

Place index of C scale (right index for given example) opposite n=5 on A_2 scale. Place hairline over $\bar{R}$=8.54 on C scale. Read $A_2\bar{R}$=4.93 on D scale under hairline. Add this value to $\bar{\bar{X}}$ for upper limit; subtract it from $\bar{\bar{X}}$ for lower limit:

$\bar{X}_{UL}=51.34+4.93=56.27$, $\bar{X}_{LL}=51.34-4.93=46.41$.

1.12 To find control limits for range chart.

FORMULAS: $R_{UL}=D_4\bar{R}$, $R_{LL}=D_3\bar{R}$. Type I (a).

(*NOTE:* Lower limit for range chart is zero for sample sizes of 6 or less. These values do not appear on D_3 scale.) For upper limit, place index of C scale opposite n=5 on D_4 scale. Place hairline over $\bar{R}$=8.54 on C scale. Read $R_{UL}=D_4\bar{R}$=18.05 on D scale under hairline. Lower limit, R_{LL}=0.

1.13 To find limits for individual values.

FORMULAS: $X_{UL}=\bar{\bar{X}}+A_0\bar{R}$, $X_{LL}=\bar{\bar{X}}-A_0\bar{R}$. Type I (b).

(*NOTE:* Limits for individual values and estimate of standard deviation of population should only be calculated if all points are in control on both average and range charts.) Place index of C scale opposite $\bar{R}$=8.54 on D scale. Move hairline over n=5 on A_0 scale. Read $A_0\bar{R}$=11.02 on D scale under hairline. Add to $\bar{\bar{X}}$ for upper limit; subtract from $\bar{\bar{X}}$ for lower limit:

$X_{UL}=51.34+11.02=62.36$, $X_{LL}=51.34-11.02=40.32$.

1.14 Estimate of standard deviation of population.

FORMULA: $\hat{\sigma}=\bar{R}/d_2$ Type II.

Place hairline over $\bar{R}$=8.54 on D scale. Move slide so that n=5 on d_2 scale is under hairline. Read $\hat{\sigma}=\bar{R}/d_2$=3.67 on D scale under C-index. (*NOTE:* an alternate formula for calculation of above is, $\hat{\sigma}=A_0\bar{R}/3$).

1.15 Problems.

GIVEN			*ANSWERS*						
$\bar{\bar{X}}$	$\bar{R}$	n	$\bar{X}_{UL}$	$\bar{X}_{LL}$	R_{UL}	R_{LL}	X_{UL}	X_{LL}	$\hat{\sigma}$
7.5	2.3	2	11.82	3.18	7.52	0	13.62	1.48	2.04
-0.1	1.5	8	0.460	-0.660	2.80	0.20	1.48	-1.68	0.527
48.2	3.7	5	50.33	46.07	7.82	0	52.97	43.43	1.59
5.7	1.3	10	9.70	1.70	2.31	0.29	6.97	4.43	0.423
41.32	5.71	5	44.61	38.03	12.07	0	48.69	33.95	2.46
51.34	8.54	5	56.27	46.41	18.05	0	62.36	40.32	3.67

1.2 Charts for averages and ranges; standard values X' and R_n' given.

If standard values are given instead of values found from data, limits for control charts and individual values are found by replacing $\bar{\bar{X}}$ and $\bar{R}$ by $\bar{X}'$ and R_n', respectively, in the formulas in sections **1.11** to **1.13** incl. Paralleling Sec. **1.14**, we have an equivalent standard σ' in place of an estimate.

1.21 Problems

GIVEN			*ANSWERS*						
$\bar{X}'$	R_n'	n	$\bar{X}_{UL}$	$\bar{X}_{LL}$	R_{UL}	R_{LL}	X_{UL}	X_{LL}	σ'
40	10	2	58.80	21.20	32.68	0	66.60	13.40	8.87
40	10	5	45.77	34.23	21.14	0	52.90	37.10	4.30
40	10	10	43.08	36.92	17.77	2.23	49.80	30.20	3.25
40	10	15	42.23	37.77	16.52	3.48	48.60	31.40	2.87
10	20	5	21.54	-1.54	42.28	0	35.80	-15.80	8.60
50	13	10	54.00	46.00	23.1	2.9	62.74	37.26	4.22

1.3 Charts for averages and ranges; standard values $\bar{X}'$ and σ' given.

EXAMPLE: $\bar{X}'=50$, $\sigma'=4$, $n=5$.

1.31 Control limits for average chart.

FORMULAS: $\bar{X}_{UL}=\bar{\bar{X}}'+3\sigma'/\sqrt{n}$, $\bar{X}_{UL}=\bar{\bar{X}}'-3\sigma'/\sqrt{n}$. Type IV

Place hairline over $\sigma'=4$ on D scale. Move slide so that n=5 on B scale is under hairline. Move hairline to 3 on C scale. Read $3\sigma'/\sqrt{n}=5.37$ on D scale under hairline. Add to $\bar{\bar{X}}'$ for upper limit; subtract from $\bar{\bar{X}}'$ for lower limit:

$$\bar{X}_{UL}=50+5.37=55.37, \quad \bar{X}_{LL}=50-5.37=44.63.$$

1.32 Control limits for range chart.

FORMULAS: $R_{UL}=d_2D_4\sigma'$, $R_{LL}=d_2D_3\sigma'$. Type III

Place index of C scale opposite n=5 on D_4 scale. Move hairline to n=5 on d_2 scale. Move slide so that $\sigma'=4$ on CI scale is under hairline. Read $R_{UL}=d_2D_4\sigma'=19.67$ on D scale at C-index. $R_{LL}=0$ (See note, Sec. 1.12).

1.33 Limits for individual values.

FORMULAS: $X_{UL}=\bar{\bar{X}}'+3\sigma'$, $X_{LL}=\bar{\bar{X}}'-3\sigma'$. Type IV

Place index of C scale opposite $\sigma'=4$ on D scale. Move hairline to 3 on C scale. Read $3\sigma'=12$ on D scale under hairline. Add to $\bar{\bar{X}}$ for upper limit; subtract from $\bar{\bar{X}}'$ for lower limit:

$$X_{UL}=50+12=62, \quad X_{LL}=50-12=38.$$

1.34 Central line for range chart, or equivalent standard R_n'.

FORMULA: $R_n'=d_2\sigma'$. Type I (b)

Place index of C scale opposite $\sigma'=4$ on D scale. Move hairline to n=5 on d_2 scale. Read $R_n'=d_2\sigma'=9.30$ on D scale under hairline.

1.35 Problems.

GIVEN			*ANSWERS*						
$\bar{\bar{X}}'$	σ'	n	$\bar{X}_{UL}$	$\bar{X}_{LL}$	R_{UL}	R_{LL}	X_{UL}	X_{LL}	R_n'
50	4	10	53.79	46.21	21.88	2.75	62	38	12.31
50	6	10	55.69	44.31	32.82	4.12	68	32	18.47
50	8	10	57.59	42.41	43.76	5.49	74	26	24.62
50	4	5	55.37	44.63	19.67	0	62	38	9.30
50	6	5	58.05	41.95	29.50	0	68	32	13.96
50	8	5	60.73	39.27	39.34	0	74	26	18.61

1.4 Charts for averages and standard deviations; $\bar{\bar{X}}$ and $\bar{s}$ found from data.

EXAMPLE: $\bar{\bar{X}}=51.34$, $\bar{s}=4.53$, n=5. (where $\bar{s}$ is average standard deviation)

1.41 Control limits for average chart.

FORMULAS: $\bar{X}_{UL}=\bar{\bar{X}}+3\bar{s}/(c_2\sqrt{n})$, $\bar{X}_{LL}=\bar{\bar{X}}-3\bar{s}/(c_2\sqrt{n})$. Type II

Place hairline over 3 on D scale. Bring n=5 on B scale under hairline. Move hairline to $\bar{s}=4.53$ on C scale. Bring n=5 on c_2 scale under hairline. Read $7.23=3\bar{s}/(c_2\sqrt{n})$ on D scale opposite C-index. Add to $\bar{\bar{X}}$ for upper limit; subtract from $\bar{\bar{X}}$ for lower limit:

$$\bar{X}_{UL}=51.34+7.23=58.57, \quad \bar{X}_{LL}=51.34-7.23=44.11.$$

1.42 Control limits for standard deviation chart.

FORMULAS: $s_{UL}=\bar{s}+3B_0\bar{s}$, $s_{LL}=\bar{s}-3B_0\bar{s}$. Type I (a)

Place hairline over n=5 on B_0 scale. Bring 3 on CI scale under hairline. Move hairline to $\bar{s}=4.53$ on C scale. Read $5.11=3B_0\bar{s}$ on D scale under hairline. Add to $\bar{s}$ for upper limit; subtract from $\bar{s}$ for lower limit:

$$s_{UL}=4.53+5.11=9.64, \quad s_{LL}=0.$$

(*NOTE:* If calculations show lower limit to be negative, use zero. Samples of size 5 or less have zero lower limit.)

1.43 Limits for individual values.

FORMULAS: $X_{UL}=\bar{\bar{X}}+3\bar{s}/c_2$, $X_{LL}=\bar{\bar{X}}-3\bar{s}/c_2$. Type II

Place hairline over $\bar{s}=4.53$ on D scale. Bring n=5 on c_2 scale under hairline. Move hairline to E on C scale. Read $16.16=3\bar{s}/c_2$ on D scale under hairline. Add to $\bar{\bar{X}}$ for upper limit; subtract from $\bar{\bar{X}}$ for lower limit:

$$X_{UL}=51.34+16.16=67.50, \quad X_{LL}=51.34-16.16=35.18.$$

1.44 Estimate of standard deviation of population.

FORMULA: $\hat{\sigma}=\bar{s}/c_2$ Type II

Place hairline over $\bar{s}=4.53$ on C scale. Bring n=5 on c_2 scale under hairline. Read $5.39=\bar{s}/c_2$ on D scale opposite C-index.

1.45 Problems.

GIVEN			*ANSWERS*						
$\bar{\bar{X}}$	$\bar{s}$	n	$\bar{X}_{UL}$	$\bar{X}_{LL}$	s_{UL}	s_{LL}	X_{UL}	X_{LL}	$\hat{\sigma}$
4.31	1.26	2	9.05	-0.43	4.61	0	11.00	-2.38	2.23
51.34	4.53	5	58.57	44.11	9.64	0	67.50	35.18	5.39
162.1	21.2	6	192.0	132.2	42.3	0.062	235.3	88.9	24.4
.675	0.0021	10	0.6772	0.6728	0.0036	0.0006	0.6818	0.6682	.00228
0.32	0.06	25	0.357	0.283	0.086	0.034	0.506	0.134	0.0619

1.5 Charts for averages and standard deviations; standard values $\bar{\bar{X}}'$ and σ' given.

EXAMPLE: $\bar{\bar{X}}'=50$, $\sigma'=6$, n=10.

1.51 Control limits for average chart.

FORMULAS: $\bar{X}_{UL}=\bar{\bar{X}}'+3\sigma'/\sqrt{n}$, $\bar{X}_{LL}=\bar{\bar{X}}'-3\sigma'/\sqrt{n}$. Type IV

Place hairline over $\sigma'=6$ on D scale. Bring n=10 on B scale under hairline. Move hairline to 3 on C scale. Read $5.69=3\sigma'/\sqrt{n}$ on D scale under hairline. Add to $\bar{\bar{X}}'$ for upper limit; subtract from $\bar{\bar{X}}'$ for lower limit:

$$\bar{X}_{UL}=50+5.69=55.69, \quad \bar{X}_{LL}=50-5.69=44.31.$$

1.52 Central line for standard deviation chart.

FORMULA: $s_n'=c_2\sigma'$ Type I (b)

Place index of C scale opposite $\sigma'=6$ on D scale. Move hairline to 10=n on c_2 scale. Read $s_n'=c_2\sigma'=5.54$ on D scale under hairline.

1.53 Control limits for standard deviation chart.

FORMULAS: $s_{UL}=c_2\sigma'+3c_2B_0\sigma'$, $s_{LL}=c_2\sigma'-3c_2B_0\sigma'$. Type II

Place hairline over n=10 on B_0 scale. Bring 3 on CI scale under hairline. Move hairline to n=10 on c_2 scale. Bring $\sigma'=6$ on CI scale under hairline. Read

$4.02=3c_2B_0\sigma'$ on D scale opposite C-index. Add to $c_2\sigma'$ (found in Sec. **1.52** above) for upper limit; subtract from $c_2\sigma'$ for lower limit:

$$s_{UL}=5.54+4.02=9.56, \quad s_{LL}=5.54-4.02=1.52.$$

(*NOTE:* If calculations show lower limit to be negative, use zero).

1.54 Limits for individual values.

FORMULAS: $X_{UL}=\bar{X}'+3\sigma'$, $X_{LL}=\bar{X}'-3\sigma'$. Type IV

Place index of C scale opposite $\sigma'=6$ on D scale. Move hairline to 3 on C scale. Read $18=3\sigma'$ on D scale under hairline. Add to $\bar{X}'$ for upper limit subtract from $\bar{X}'$ for lower limit:

$$X_{UL}=50+18=68, \quad X_{LL}=50-18=32.$$

1.55 Problems.

GIVEN			*ANSWERS*						
$\bar{X}'$	σ'	n	$\bar{X}_{UL}$	$\bar{X}_{LL}$	s_{UL}	s_n'	s_{LL}	X_{UL}	X_{LL}
50	6	2	62.73	37.27	12.38	3.39	0	68	32
50	6	5	58.05	41.95	10.73	5.04	0	68	32
50	6	6	57.35	42.65	10.41	5.21	0.018	68	32
50	6	10	55.69	44.31	9.56	5.54	1.52	68	32
50	6	15	54.65	45.35	8.96	5.59	2.41	68	32
50	6	20	54.02	45.98	8.62	5.77	2.93	68	32
50	6	25	53.60	46.40	8.36	5.82	3.27	68	32

1.6 Charts with "kσ" limits, where k≠3.

The central lines on charts and the estimate of σ of population are not affected by use of "kσ" limits in place of "3σ" limits. Hence if "kσ" limits are to be used, the term to be added to and subtracted from the central value may be computed as follows:

1. If this term does not contain the factor 3, find value for "3σ" limits first then divide by 3 and multiply by k. That is multiply by k/3.

2. If this term contains the factor 3, use same formulas with k substituted for 3.

3. For range charts use the formulas: $R_{UL}=\bar{R}+kD_0\bar{R}$, $R_{LL}=\bar{R}-kD_0\bar{R}$.

1.61 Problems.

GIVEN				*ANSWERS*						
$\bar{\bar{X}}$	$\bar{R}$	n	k	$\bar{X}_{UL}$	$\bar{X}_{LL}$	R_{UL}	R_{LL}	X_{UL}	X_{LL}	$\hat{\sigma}$
51.34	8.54	5	1.5	53.80	48.88	13.30	3.78	56.84	45.84	3.67
51.34	8.54	5	2	54.63	48.05	14.88	2.20	58.69	43.99	3.67
51.34	8.54	5	2.5	55.34	47.24	16.46	0.62	60.52	42.16	3.67
51.34	8.54	5	3	56.27	46.41	18.05	0	62.36	40.32	3.67
51.34	8.54	5	3.09	56.41	46.27	18.34	0	62.68	40.00	3.67
51.34	8.54	5	3.5	57.08	45.60	19.64	0	64.18	38.50	3.67

2. Charts for Sampling by Attributes.

The p_0 scale is used for charts for attributes. Numbers on the p_0 scale are in percent. If chart for fraction defective instead of percent defective is used, it is necessary to point off two decimal places. The factor 3 is incorporated in this scale so that when "3σ" limits are being used, it is not necessary to multiply by 3.

2.1 Chart for fraction defective or percent defective; $\bar{p}$ found from data.

FORMULAS: $p_{UL}=\bar{p}+3\sigma_p$, $p_{LL}=\bar{p}-3\sigma_p$, $\sigma_p=\sqrt{\bar{p}(1-\bar{p})/n}$

EXAMPLE: $\bar{p}=0.07=7\%$ $n=185$.

Place hairline over $7=100\bar{p}$ on p_0 scale. Bring 185=n on B scale (left side of B scale for given example) under hairline. Read $0.056=3\sigma_p$ on D scale opposite C-index. Add to $\bar{p}$ for upper limit; subtract from $\bar{p}$ for lower limit:

$$p_{UL}=0.07+0.056=0.126=12.6\%. \quad p_{LL}=0.07-0.056=0.014=1.4\%.$$

2.2 Chart for number of defectives.

A chart for number of defectives may be used when the sample size is constant or nearly constant. The central line is at $n\bar{p}$ and limits are n times those for fraction defective chart. Since number of defectives must be an integer, limits may be rounded off to one decimal place.

2.3 Charts for sampling by attributes; standard value p' given.

Formulas and calculations are as above with p' replacing $\bar{p}$.

2.4 Charts with "kσ" limits, where k≠3.

Formulas are as above with k replacing 3.

Calculations are made as above, first finding $3\sigma_p$, then multiplying by k and dividing by 3 before adding to and subtracting from the central value.

(*NOTE:* If calculations show lower limit to be negative, use zero.)

2.5 Problems

GIVEN			*ANSWERS*				
$\bar{p}$ or p'	n	k	p_{UL}	p_{LL}	np_{UL}	$n\bar{p}$	np_{LL}
.07=7%	185	3	.1263=12.63%	.0137=1.37%	23.4	12.95	2.5
.05=5%	5000	3	.0592= 5.92%	.0408=4.08%	296.0	250	204.0
.05=5%	1000	3	.0707= 7.07%	.0293=2.93%	70.7	50	29.3
.05=5%	500	3	.0792= 7.92%	.0208=2.08%	39.6	25	10.4
.05=5%	100	3	.1154=11.54%	0 =0 %	11.5	5	0
.05=5%	50	3	.1425=14.25%	0 =0 %	7.1	2.5	0
.05=5%	1000	2	.0638= 6.38%	.0362=3.62%	63.8	50	36.2
.05=5%	1000	2.5	.0672= 6.72%	.0328=3.28%	67.2	50	32.8
.05=5%	1000	3.5	.0742= 7.42%	.0258=2.58%	74.2	50	25.8
.05=5%	100	2	.0936= 9.36%	.0064=0.64%	9.4	5	0.6
.05=5%	100	2.5	.1045=10.45%	0 =0%	10.4	5	0
.05=5%	100	3.5	.1263=12.63%	0 =0 %	12.6	5	0
.03=3%	275	3	.0609= 6.09%	0 =0 %	16.7	8.25	0
.03=3%	300	3	.0596= 5.96%	.0004=0.04%	17.9	9	0.1

3. Chart for Defects per Unit.

3.1 Chart for number of defects per unit; $\bar{c}$ found from data.

FORMULAS: $c_{UL}=\bar{c}+3\sqrt{\bar{c}}$, $c_{LL}=\bar{c}-3\sqrt{\bar{c}}$

EXAMPLE: $\bar{c}=12.3$

Place index of B scale opposite $\bar{c}=12.3$ on A scale (right hand side of A scale for given example). Move hairline to 3 on C scale. Read $10.52=3\sqrt{\bar{c}}$ on D scale under hairline. Add to $\bar{c}$ for upper limit, subtract from $\bar{c}$ for lower limit:

$c_{UL}=12.3+10.5=22.8$. $c_{LL}=12.3-10.5=1.8$.

(*NOTE:* If calculations show lower limit to be negative, use zero.)

3.2 Chart for number of defects per unit; standard value c' given.

Formulas and calculations as above with c' replacing $\bar{c}$.

3.3 Charts with "kσ" limits, where k≠3.

Formulas as above with k replacing 3.

Calculations are made by multiplying by k instead of by 3 before adding to and subtracting from central value.

3.4 Problems.

GIVEN		*ANSWERS*		*GIVEN*		*ANSWERS*	
$\bar{c}$ or c'	k	c_{UL}	c_{LL}	$\bar{c}$ or c'	k	c_{UL}	c_{LL}
12.3	3	22.8	1.8	26.5	3	41.9	11.1
8.6	3	17.4	0	8.6	2	14.4	1.8
90	3	118.5	61.5	0.9	3	3.8	0
2.6	3	7.4	0	9.0	2	15.0	3.0
22.5	3	36.7	8.3	9.0	2.5	16.5	1.5
1.7	3	5.6	0	9.0	3	18.0	0
450	3	512.6	387.4	9.0	3.5	19.5	0

4. Ordinates and Areas of Normal Curve.

4.1 Ordinate for normal curve.

The ordinate for the normal curve with zero mean and unit standard deviation: $f(t)=\frac{1}{\sqrt{2\pi}}e^{-t^2/2}$ where $t=(x-a)/\sigma$, is found by placing the hairline over t on the f scale and reading f(t) on the LL00 scale.

For negative values of t: $f(-t)=f(t)$.

4.2 Areas for normal curve.

The area under the normal curve from minus infinity to t: $F(t)=\int_{-\infty}^{t} f(t)dt$ is found by placing the index of the C scale opposite the index of the D scale. Then place the hairline over the value of t on the F scale. Read area F(t) on the LL0 or LL00 scale. The following relations hold:

$F(-\infty)=0$, $F(+\infty)=1$, $F(-t)=1-F(t)$.

Other areas related to that above.

Area from t to $+\infty$: $1-F(t)$. Area from -t to +t: $F(t)-F(-t)=2F(t)-1$.

Area "outside" of ±t (that is, from $-\infty$ to -t and from +t to $+\infty$): $2[1-F(t)]=2F(-t)$.

Area from 0 to t: $F(t)-0.5$.

4.21 Problems.

GIVEN	*ORDINATE*	*AREAS*				
t	f(t)	$-\infty$ to t	t to $+\infty$	-t to +t	"outside" ±t	0 to t
2.63	.013	.9957	.0043	.9914	.0086	.4957
-2.63	.013	.0043	.9957			
1.57	.116	.942	.058	.884	.116	.442
0.05	.398	.520	.480	.040	.960	.020
3.50	.00088	.99977	.00023	.99954	.00046	.49977
3.90	.00020	.99995	.00005	.99990	.00010	.49995

4.3 Repeated observations from normal distribution.

If a sample of one is drawn from a normal distribution, the probability that the value in sigma units is below t is F(t). If a sample of size n is drawn from a normal distribution, the probability that all values are below t is $[F(t)]^n$.

EXAMPLE: What is the probability that all four values of a sample of four are below t=2?

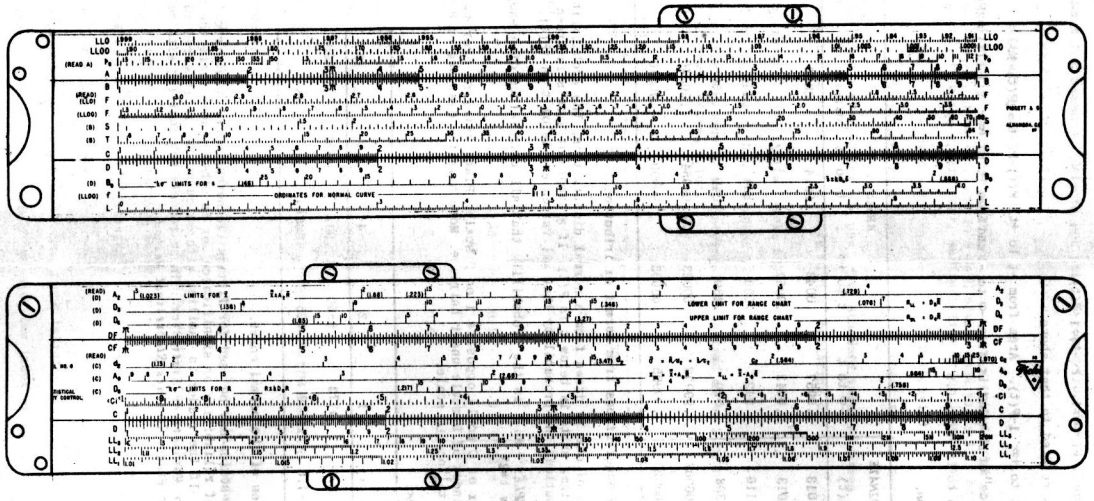
Place index of C scale opposite 1 on D scale. Place hairline over t=2 on F scale. Bring index of B scale under hairline. Move hairline over n=4 on B scale. Read $0.912=[F(t)]^n$ on LL0 scale.

4.31 Problems.

	n				
t	1	2	4	7	10
2.0	.9773	.9550	.912	.852	.795
-1.0	.159	.025	.00064		

4.4 Other uses of the normal curve.

The f and F scales may be used for fitting the normal curve to empirical data, or for tests of reliability or significance, or in other places where the normal curve is used. If the reader is familiar with calculus, he is referred to Hoel, *Introduction to Mathmetical Statistics.* Those readers not familiar with calculus are referred to Waugh, *Elements Statistical Method.*


LLO
LLOO
(READ A)
A
B
(READ D)
(LLO)
F
(LLOO)
S
(B)
T
C
D
(D)
"H" LIMITS FOR x
ORDINATES FOR NORMAL CURVE
(LLOO)
L
(READ)
(D)
LIMITS FOR x
LOWER LIMIT FOR RANGE CHART
UPPER LIMIT FOR RANGE CHART
DF
CF
(C)
"G" LIMITS FOR x
PHYSICAL "H" CONTROL
LL3
LL2
LL1

HOW TO ADJUST YOUR SLIDE RULE

A perfect slide rule, when out of adjustment, often appears defective. Each rule is accurately adjusted before it leaves the factory. However, handling during shipment, dropping the rule, or even a series of slight jars while laying the rule down during use, may loosen the adjusting screws and throw the rule out of alignment. Follow these simple directions for slide rule adjustment.

CURSOR-HAIRLINE ADJUSTMENT • Loosen the bottom two screws on both Cursor windows on spacer opposite tension spring. Press with left thumb to maintain constant contact with edge of rule; align hairline with left hand indices and tighten screws on that side. Turn rule over and check alignment of hairline on other Cursor window. If necessary, loosen all screws on this side and align with left hand indices as needed, and tighten screws carefully.

SLIDER TENSION ADJUSTMENT • Loosen adjustment screws on end brackets; regulate tension of slider, tighten the screws using care not to misalign the scales. The adjustment needed may be a fraction of a thousandth of an inch, and several tries may be necessary to get perfect slider action.

SCALE LINE-UP ADJUSTMENTS • (1) Move slider until indices of C and D scales coincide. (2) Move cursor to one end. (3) Place rule on flat surface with face uppermost. (4) Loosen end plate adjusting screws slightly. (5) Adjust upper portion of rule until graduations on DF scale coincide with corresponding graduations on CF scale. (6) Tighten screws in end plates.

REPLACEABLE ADJUSTING SCREWS • All Pickett All-Metal rules are equipped with Telescopic Adjusting Screws. In adjusting your rule, if you should strip the threads on one of the Adjusting Screws, simply "push out" the female portion of the screw and replace with a new screw obtainable from your dealer, or from the factory at a cost of $.06 each in stamps.

HOW TO KEEP YOUR SLIDE RULE IN CONDITION

Always hold your rule between thumb and forefinger at the ENDS of the rule. This will insure free, smooth movement of the slider. Holding rule at center tends to bind the slider.

LUBRICATION • *Do not use ordinary lubricating oil on your slide rule. It turns black and dirties your hands and work.* Your slide rule is treated with a light "silicone" lubricant at the factory. This oil, which works into the surface of the metal, is designed to lubricate your rule indefinitely.

If your rule should run dry, or if the slider begins to move hard or with a dry, rasping sound:

1. Lubricate with a light "Silicone" lubricant. Work in well by moving slider back and forth, then wipe off. OR –
2. If a light silicone is unobtainable, simply rub tongues and grooves with a very soft lead pencil. Move slider back and forth to work the graphite well into the metal, then wipe excess graphite off.

MAINTENANCE • The body of your rule is made of magnesium. The edges, not covered with plastic, may gradually darken (or oxidize) with age. This ageing, or darkening, is a common characteristic of metals like magnesium, German silver, silver, brass, copper, pewter, etc.

This normal ageing or darkening of the rule affects neither the accuracy of the scales nor ease of operation.

Extreme atmospheric exposure tends to warp and distort wood, and to rust steel, which is common knowledge. This is not true of magnesium. Such exposure may tend to deposit an oxidation film on the surface, causing the slider to stick or move hard.

If this happens to your rule, take out the Telescopic Adjusting Screws and remove both Top Rule Member and Slider without disassembling the Cursor. Clean the oxidized edges of the rule with a silver polish, Bon Ami, rubber ink eraser or other cleaning agent. Slide Top Rule Member and Slider back into position. Relubricate. Then make Scale Line-Up and Slider-Tension Adjustments.

WHY YOUR RULE OPERATES BETTER WITH CONSTANT USE • Being made of metal, the moving parts of your slide rule "lap in" with use. This process of wearing smooth means your slide rule will operate with increasing smoothness year after year.

CLEANING • Wash surface of the rule with non-abrasive soap and water when cleaning the scales. If Cursor window becomes dulled from long use, simply polish and brighten the window surfaces with a small rag and tooth powder.

Pickett

ALL-METAL SLIDE RULES

PICKETT & ECKEL, INC.

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