9.1 Inadequate Measurement Units

The purpose of this section is to explain the problem of Inadequate Measurement Units. This will require the answers to two basic questions: What happens to the control chart when the measurement units used are too large? And, what is the effect on control charts of measurement "round-off." The answers to these two questions will lead to certain tell-tale signs for Inadequate Measurement Units. They will also show why this problem exists, and will suggest what can be done to remedy this problem when it is present.

The easiest way to see the effect of Inadequate Measurement Units is to manipulate a data set to create measurement units which are too large. One may then compare the control charts before and after the manipulation of the data to discover the effect of excessively large measurement units. The Rheostat Knob Data will be used to demonstrate this effect.

EXAMPLE 9.1: *The Rheostat Knob Data:*

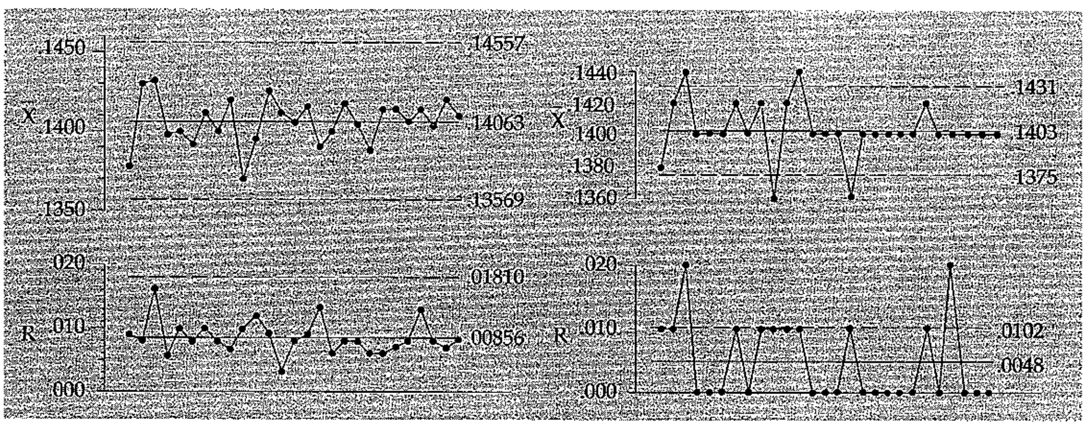
A particular rheostat knob had a pin hole on the shaft housing. The dimensions recorded in Table 9.1 are the distances from the back of the piece to the far side of the pin hole. These measurements were made to the nearest thousandth of an inch. The same measurements, rounded to the nearest hundredth of an inch, are shown in Table 9.2. These rounded measurements represent the values that would have been obtained if the parts had only been measured to the nearest hundredth of an inch. The control charts for the data in Tables 9.1 and 9.2 are shown in Figure 9.1.

Table 9.1: Rheostat Knob Data Recorded to 0.001 inch

Subgroup						$\bar{X}$	R
1	.140	.143	.137	.134	.135	*.1378*	*.009*
2	.138	.143	.143	.145	.146	*.1430*	*.008*
3	.139	.133	.147	.148	.149	*.1432*	*.016*
4	.143	.141	.137	.138	.140	*.1398*	*.006*
5	.142	.142	.145	.135	.136	*.1400*	*.010*
6	.136	.144	.143	.136	.137	*.1392*	*.008*
7	.142	.147	.137	.142	.138	*.1412*	*.010*
8	.143	.137	.145	.137	.138	*.1400*	*.008*
9	.141	.142	.147	.140	.140	*.1420*	*.007*
10	.142	.137	.134	.140	.132	*.1370*	*.010*
11	.137	.147	.142	.137	.135	*.1396*	*.012*
12	.137	.146	.142	.142	.146	*.1426*	*.009*
13	.142	.142	.139	.141	.142	*.1412*	*.003*
14	.137	.145	.144	.137	.140	*.1406*	*.008*
15	.144	.142	.143	.135	.144	*.1416*	*.009*
16	.133	.132	.144	.145	.141	*.1390*	*.013*
17	.137	.137	.142	.143	.141	*.1400*	*.006*
18	.137	.142	.142	.145	.143	*.1418*	*.008*
19	.142	.142	.143	.140	.135	*.1404*	*.008*
20	.136	.142	.140	.139	.137	*.1388*	*.006*
21	.142	.144	.140	.138	.143	*.1414*	*.006*
22	.139	.146	.143	.140	.139	*.1414*	*.007*
23	.140	.145	.142	.139	.137	*.1406*	*.008*
24	.134	.147	.143	.141	.142	*.1414*	*.013*
25	.138	.145	.141	.137	.141	*.1404*	*.008*
26	.140	.145	.143	.144	.138	*.1420*	*.007*
27	.145	.145	.137	.138	.140	*.1410*	*.008*

Table 9.2: Rheostat Knob Data Recorded to 0.01 inch

Subgroup						$\bar{X}$	R	Subgroup						$\bar{X}$	R
1	.14	.14	.14	.13	.14	.138	.01	15	.14	.14	.14	.14	.14	.140	.00
2	.14	.14	.14	.14	.15	.142	.01	16	.13	.13	.14	.14	.14	.136	.01
3	.14	.13	.15	.15	.15	.144	.02	17	.14	.14	.14	.14	.14	.140	.00
4	.14	.14	.14	.14	.14	.140	.00	18	.14	.14	.14	.14	.14	.140	.00
5	.14	.14	.14	.14	.14	.140	.00	19	.14	.14	.14	.14	.14	.140	.00
6	.14	.14	.14	.14	.14	.140	.00	20	.14	.14	.14	.14	.14	.140	.00
7	.14	.15	.14	.14	.14	.142	.01	21	.14	.14	.14	.14	.14	.140	.00
8	.14	.14	.14	.14	.14	.140	.00	22	.14	.15	.14	.14	.14	.142	.01
9	.14	.14	.15	.14	.14	.142	.01	23	.14	.14	.14	.14	.14	.140	.00
10	.14	.14	.13	.14	.13	.136	.01	24	.13	.15	.14	.14	.14	.140	.02
11	.14	.15	.14	.14	.14	.142	.01	25	.14	.14	.14	.14	.14	.140	.00
12	.14	.15	.14	.14	.15	.144	.01	26	.14	.14	.14	.14	.14	.140	.00
13	.14	.14	.14	.14	.14	.140	.00	27	.14	.14	.14	.14	.14	.140	.00
14	.14	.14	.14	.14	.14	.140	.00								



(a) Data from Table 9.1 **(b) Data from Table 9.2**

Figure 9.1: Two Control Charts for the Rheostat Knob Data

It is immediately apparent that the two charts do not look alike. One would hardly guess that they represented the same dimension on the same parts. The running records in Figure 9.1(b) have fewer levels. This is due to the fact that the smallest unit of measurement is ten times larger than its counterpart in Figure 9.1(a). Secondly, the control limits in Figure 9.1(b) are narrower than those in Figure 9.1 (a).

The out-of-control points in Figure 9.1(b) have nothing to do with the underlying physical process. Instead, they were created by the excessive round-off in Table 9.2.

Excessive round-off in the measurements can make a control chart appear to be out-of-control even when the underlying process is in a state of statistical control.

Fortunately, when this problem exists, it is easy to identify. Ordinary control charts signal the presence of inadequate discrimination due to measurement units which are too large: they do this by showing too few possible values within the control limits on the range chart.

If there are only 1, 2, or 3 possible values for the range within the control limits, then the measurement units are too large for the purposes of the control chart. Moreover, if the subgroup size is three or larger ($n \geq 3$), and there are only 4 possible values for the range within the control limits, then the measurement units are too large for the purposes of the control chart.

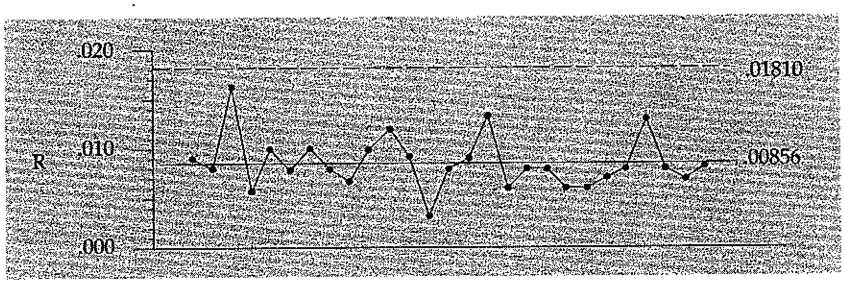


Figure 9.2: Range Chart for Data Recorded to 0.001 inch

In Figure 9.2, the tick marks on the vertical axis define the possible values for the Subgroup Ranges. There are 19 possible values for the range within the control limits. This is evidence that there is no problem with Inadequate Measurement Units.

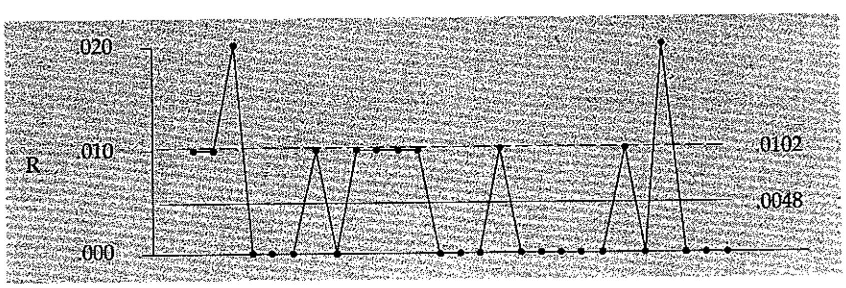


Figure 9.3: Range Chart for Data Recorded to 0.01 inch

$$UCL_R = D_4 \; d_2 \text{ measurement units}$$
$$LCL_R = D_3 \; d_2 \text{ measurement units.}$$

These values are tabled for subgroup sizes of $n = 2$ to $n = 10$ in Table 9.3.

Table 9.3: Control Limits for Range Chart When SD(X) = Measurement Unit

Subgroup Size	*LCL*	*UCL*	*Possible Values for Range Within Limits*	*Number of Possible Values for Range Within Limits*
2	none	3.69	0, 1, 2, 3	4
3	none	4.36	0, 1, 2, 3, 4	5
4	none	4.70	0, 1, 2, 3, 4	5
5	none	4.92	0, 1, 2, 3, 4	5
6	none	5.08	0, 1, 2, 3, 4, 5	6
7	0.21	5.20	1, 2, 3, 4, 5	5
8	0.39	5.31	1, 2, 3, 4, 5	5
9	0.55	5.39	1, 2, 3, 4, 5	5
10	0.69	5.47	1, 2, 3, 4, 5	5

Since the values in Table 9.3 define the borderline condition, the following guidelines for detecting Inadequate Measurement Units can be established.

The measurement unit borders on being too large when there are only 5 possible values within the control limits on the Range Chart. Four values within the limits will be indicative of Inadequate Measurement Units, and fewer than four values will result in appreciable distortion of the control limits.

The only exception to this occurs when the Subgroup Size for the Range Chart is $n = 2$; here 4 possible values within the control limits on the Range Chart will represent the borderline condition. Three possible values within the limits will be indicative of Inadequate Measurement Units, and fewer than three values will result in appreciable distortion of the control limits.

Thus, there need be no confusion about whether or not the measurement unit being used is sufficiently small for the application at hand. The control chart clearly shows when it is not. Fortunately, when this problem exists, the solutions are straightforward. But one must implement one of these solutions before the control charts will be of any real use.

One other note is needed. Occasionally the measurement unit will be too large simply because the data are truncated to a certain level in order to avoid reporting "noise." When such truncation creates inadequate discrimination, it is also cutting off part of the signal! Recording one extra digit will usually be sufficient to eliminate this source of inadequate discrimination.