RATER CALIBRATION MONITORING SYSTEM

ASTM Test Monitoring Center
Requirements for Rater Calibration

ASTM Test Monitoring Center
203 Armstrong Drive
Freeport, PA 16229
Phone No. 412-365-1000

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Acknowledgment

The Rater Calibration Monitoring System (RCMS) described in this document is the result of efforts of the ASTM L-37 Surveillance Panel. The panel applied a logical and data based analytical approach to available ASTM rater calibration test data in the development of the RCMS. This system of managing rater calibration for severity (bias) and precision was presented to the ASTM L-37 Surveillance Panel in January, 2003 by the ASTM TMC.

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1. Rater Calibration Monitoring System Control Charts

Raters are calibrated by the ASTM Test Monitoring Center (TMC). Calibration is in terms of both test severity and precision and is checked by the application of the control charts in the Rater Calibration Monitoring System (RCMS). The purpose of the control charts is to monitor and track both large abrupt changes and smaller consistent trends in both rating severity and precision. The Shewhart charts check for the abrupt changes while the Exponentially Weighted Moving Average (EWMA) charts check for consistent changes and trends over time. The four control charts are listed below:

1. Shewhart Chart for Monitoring Severity
2. Shewhart Chart for Monitoring Precision
3. EWMA Chart for Monitoring Severity
4. EWMA Chart for Monitoring Precision

A. Control Chart Construction

This section outlines the construction of the four control charts that constitute this Rater Calibration Monitoring System. An example is provided in Exhibit I.

1. Shewhart Chart for Monitoring Severity

The vertical axis of this control chart represents the average (M) of four standardized rating results (Y). These results are plotted against count in completion date order on the horizontal axis. Y is calculated as follows:

$$Y_i = \frac{T_i - \text{Segment MEAN}}{\text{Segment STANDARD DEVIATION}}$$

T_i = Rating result at order i in appropriate units (see applicable test type in Section 2).

M_i = Average of the four standardized rating results at order i.

The following are the control chart limits for the Shewhart chart for monitoring severity (Y plotted against completion date order).

$$0 \pm \frac{K}{\sqrt{n}}$$

K is a constant that determines the chart's estimated false detection rate. The false detection rate is the percentage of time that a plotted result will fall outside the control limits when, in fact, no change in the process has occurred. As K increases, the false detection rate decreases. However, the false detection rate must be balanced with the chart's sensitivity to real changes in the process. This sensitivity is diminished as K increases. K is test type specific. n is a constant that is based on the number of parts rated. For the L-37 this n = 4.

2. Shewhart Chart for Monitoring Precision

The vertical axis of this control chart represents the standardized natural log of the standard deviation of the four results (R). These results are plotted against completion date order (integer) which is on the horizontal axis. R is calculated as follows:

$$Ri = \left[\frac{\ln(Ni) + 0.1838}{0.4855} \right]$$

R_i = Standardized natural log of the standard deviation of the four results at order i.
N_i = Is the standard deviation of the Δ/s values (Y) for the four rating results. If Ni equals zero set Ni equal to 0.005 so that the natural log can be evaluated.

The following is the control chart limit for the Shewhart chart for monitoring precision (R plotted against completion date order).

0 + K

K is a constant that determines the chart's estimated false detection rate. Deterioration in precision is signaled by control chart points exceeding the value of K. K is test type specific.

3. Exponentially Weighted Moving Average (EWMA) Chart for Monitoring Severity

The vertical axis of this control chart represents the EWMA of the average of four standardized rating results (Z). These results are plotted against completion date order (integer) which is on the horizontal axis. Z is calculated as follows:

Z_i = EWMA of the average of four standardized individual segment results at result order i.

Z_i = (LAMBDA) M_i + (1 - LAMBDA) Z_{i-1}

where: $0 \leq \text{LAMBDA} \leq 1$,
$Z_0 = 0$

LAMBDA (λ) is the smoothing constant and must be between 0 and 1. This value determines the amount of weight given to the current and past data points. As LAMBDA decreases, past data points are given more weight and the resulting plot gets smoother. When LAMBDA is set equal to 1, the EWMA chart is equivalent to the Shewhart chart. The value of Z at result order 0, Z_0, must be set equal to 0.

The following are the control chart limits for the EWMA chart for monitoring severity (Z

$$0 \pm \frac{K}{\sqrt{n}} \left(\sqrt{\frac{\lambda}{2-\lambda}} \right)$$

plotted against completion date order).

K is a constant that determines the chart's estimated false detection rate. K is test type specific. n is the number of parts rated. For the L-37, n=4.

4. EWMA Chart for Monitoring Precision

The vertical axis of this control chart represents the EWMA of standardized natural log of the standard deviation of the four results (Q).). These results are plotted against completion date order (integer). Q is calculated as follows:

Q_i = (LAMBDA) R_i + (1 - LAMBDA) Q_{i-1}

where: $0 \leq \text{LAMBDA} \leq 1$, $Q_0 = 0$

Q_i = EWMA of standardized natural log of the standard deviation of the four results at test order i.

LAMBDA (λ) is the smoothing constant and must be between 0 and 1. The value Q at result order 0, Q_0, must be set equal to 0.

The following is the control chart limit for the EWMA chart for monitoring precision (Q plotted against completion date order).

$$0 \pm K\sqrt{\frac{\lambda}{2-\lambda}}$$

K is a constant that determines the chart's estimated false detection rate. K is test type specific.

EXHIBIT I: Example of Control Charts
Sequence L-37 Wear Data

Calibration Cycle	Segment	Pinion ID	Rating Result	Transformed Rating Result (Ti)	Target		Yi	Average Yi (Mi)	EWMA Severity (Zi)	Std of Yi's (Ni)	Ri	Qi
					Pinion Mean	Pinion Std						
1	A	8	7	7	7.6	1.09	-0.5505	-0.6881	-0.1376	0.4270	-1.3742	-0.2749
	B	10	5	5	5.9	1.09	-0.8257					
	C	24	8	8	8.2	1.09	-0.1835					
	D	26	8	8	9.3	1.09	-1.1927					
2	A	6	8	8	7.1	1.09	0.8257	0.4358	-0.0229	0.3463	-1.8058	-0.5810
	B	12	7	7	7	1.09	0.0000					
	C	25	8	8	7.6	1.09	0.3670					
	D	27	9	9	8.4	1.09	0.5505					
3	A	2	7	7	8.1	1.09	-1.0092	-0.1376	-0.0459	1.1761	0.7126	-0.3223
	B	3	5	5	6.4	1.09	-1.2844					
	C	13	10	10	9.2	1.09	0.7339					
	D	30	5	5	3.9	1.09	1.0092					

Shewhart Chart for Monitoring Severity: K=1.8
Shewhart Chart for Monitoring Precision: K=2.1
EWMA Chart for Monitoring Severity: K=1.96 LAMBDA=0.2
EWMA Chart for Monitoring Precision: K=2.1 LAMBDA=0.2

B. Engineering Judgment as Applied to the Interpretation of RCMS Control Charts

The Rater Calibration Monitoring System (RCMS) Shewhart and EWMA control charts, by design, will infrequently produce false indications of the severity and/or precision of a rating result. One type of false indication is an alarm that is not the result of a real problem but is, rather, an anomaly. A second type of false indication occurs when a real problem exists, yet the control charts remain within acceptable limits. On occasion, when sufficient technical information is available, either type of false indication can be identified as such. In these cases, the ASTM Test Monitoring Center (TMC), through the application of engineering judgment, may determine that a deviation from normal RCMS actions is warranted. The following points describe the process by which engineering judgment is applied by the TMC:

1. The TMC determines if the potential exists for the application of engineering judgment in the interpretation of control charts.

2. When it is determined that the potential exists for the application of engineering judgment, all subsequent investigation proceeds under the assumption that the current control chart indications are correct.

3. When an engineering investigation is commenced, it is incumbent on the affected rater to prepare necessary technical information in concert with the TMC.

4. The TMC may solicit relevant input from outside sources, such as the Test Developer, Surveillance Panel Chairman, O&H Subpanel Leader and ASTM rating workshop chairman. In all cases, the confidentiality of the affected rater will be appropriately maintained.

5. If, in the judgment of the TMC, a deviation from normal RCMS actions is warranted, this judgment will be documented in writing along with a summary of the relevant technical information considered in making the judgment. The affected rater will receive copies of this document.

6. If, in the judgment of the TMC, normal RCMS action should be followed by the affected rater, no special documentation is required.

7. The application of engineering judgment in the interpretation of RCMS control charts is handled on a case-by-case basis. The TMC does not consider any prior judgment rendered to be precedent setting.

C. TMC Notification Requirement

In order to allow time for shipment of parts, it is the responsibility of the test lab to schedule a rater calibration with the TMC at least 14 working days prior to expiration of the rater's calibration period. The TMC will transmit an analysis confirmation to the lab contact(s) after reviewing the results.

D. Hardware Monitoring & New Hardware Introduction

The TMC is responsible for monitoring hardware to track possible severity changes over-time. This monitoring will occur each time a part is rated. Upon request the TMC will provide a severity plot of individual hardware to assess possible changes with time. Hardware may be removed from the system when sufficient cause is documented.

New hardware that is intended for introduction into the system must be rated by experienced in-control industry raters so that consensus targets are obtained. The TMC will facilitate this process with direction from the L-37 Surveillance Panel. In order, to ease the burden of raters participating in this function every attempt will be made to minimize the frequency of the activity.

E. New Rater Introduction

The process of an individual becoming a calibrated rater starts with attending the gear rating workshop. For a potential new rater to attend a workshop the lab must first submit a brief resume to the Test Monitoring Center. The resume is to highlight the individual's experience and training related to rating. Once approved for attendance, an individual must then attend two consecutive rating workshops.

At the conclusion of attending the second consecutive workshop the rater is calibrated to rate L-33-1, and L-60-1 parts as long as the individual participated in these rating activities at both workshops. To calibrate as a rater for L-37 and L-42, an individual must pass the RC parts requirements. If the new rater is successful when rating their first set of RC parts then the rater is calibrated for a period of three months. If the rater is not successful with the first set, then the rater must pass two additional sets. If the rater is able to pass two out of three sets then the rater is calibrated for a period of three months. If not able to pass two out of three, then the rater must attend an additional gear rating workshop before requesting additional RC parts. Newly established raters are calibrated for a 3-month period at a time, and are eligible for a 6-month calibration period one year after their first successful RC parts rating.

F. Workshop Attendance Requirements

The Test Monitoring Center will conduct two workshops throughout a calendar year. One workshop to be held in January and the other in July. Established raters are required to attend at least one workshop in a 12-month period to maintain calibration.

A rater calibration expiration date will be assigned post workshop to all participating attendees for L-60-1 and L-33-1. The calibration expiration date will be the last day of the 13th month following the workshop.

- Ex: If workshop is held on Jul 12, 2020, the calibration expiration date is Aug 30th, 2021

Calibration expiration dates for L-37 and L-42 are not based on workshop dates and are instead based on the rating of RCMS parts. A rater that only participates in L-42 and L-37 activities is still required to attend a workshop once a year as part of the calibration requirements.

In the instance of unforeseen circumstances preventing a rater from attendance of a workshop needed for calibration, the TMC will use engineering judgement to determine the best course of action. In these instances, the rater is responsible for notifying the TMC of the circumstances.

G. Rater Training/Review

A rater may seek training to understand problem areas and determine corrective action. The matter of training is an internal laboratory issue that various labs may choose to handle differently. For example, in-house raters may be used for consultation, a rater may attend an upcoming rater workshop or other laboratory raters may be brought in-house or visited. Documentation of the training event is to be provided to the TMC with any calibration request after an alarm. After a training event, engineering judgment may be used to ensure that control charting accurately reflects the rater's performance.

2. L-37 RCMS Requirements

Following are the specific L-37 rater calibration requirements.

A. Parameters

The critical parameters are Pinion Wear, Rippling, Ridging, and Spalling/Pitting ("Spitting"). The means and standard deviations for the parts for each critical parameter are presented below.

PINION WEAR

Pinion Id	Severity Targets Unit of Measure: WEAR MERITS	
	Mean	Standard Deviation
1	5.8	0.42
2	5.9	0.28
3	6.0	0.17
4	Removed from system	
5	Removed from system	
6	5.8	0.36
7	6.4	0.60
8	6.9	0.35
9	Removed from system	
10	5.6	0.50
11	6.2	0.44
12	Removed from system	
13	7.5	0.64
14	6.0	0.29
15	5.6	0.50
16	Removed from system	
17	5.9	0.52
18	5.6	0.49
19	6.1	0.34
20	Removed from system	
21	5.6	0.50
22	6.4	0.50
23	Removed from system	
24	Removed from system	
25	6.0	0.28
26	8.3	0.50
27	5.6	0.55
28	Removed from system	
29	6.5	0.67
30	6.0	0.24

PINION WEAR

Pinion Id	Severity Targets Unit of Measure: WEAR MERITS	
	Mean	Standard Deviation
31	7.2	0.62
32	7.4	0.55
33	6.0	0.42
34	6.4	0.50
35	6.6	0.55
36	6.2	0.45
37	7.7	0.58
38	6.4	0.50
39	6.4	0.50
40	6.2	0.43
41	7.2	0.58
42	6.0	0.15
43	6.8	0.60
44	6.2	0.43
45	6.4	0.50
46	6.5	0.51
47	6.1	0.32
48	6.5	0.61
49	Removed from system	
50	6.5	0.51
51	7.1	0.35
52	6.2	0.37
53	6.9	0.61
54	6.7	0.68
55	6.9	0.47
56	7.3	0.67
57	5.9	0.30
59	5.7	0.45
60	7.8	0.42

PINION RIPPLING

Pinion Id	Severity Targets Unit of Measure: RIPPLING MERITS	
	Mean	Standard Deviation
1	7.5	0.80
2	7.9	0.72
3	6.9	0.60
4	Removed from system	
5	Removed from system	
6	7.2	0.57
7	8.8	0.62
8	7.8	0.71
9	Removed from system	
10	6.4	0.65
11	6.5	0.61
12	Removed from system	
13	9.7	0.46
14	8.5	0.56
15	8.6	0.68
16	Removed from system	
17	8.9	0.50
18	9.1	0.65
19	9.2	0.43
20	Removed from system	
21	8.8	0.41
22	9.2	0.59
23	Removed from system	
24	Removed from system	
25	7.1	0.61
26	9.4	0.54
27	8.7	0.66
28	Removed from system	
29	9.7	0.48
30	4.5	0.61
31	9.3	0.44
32	8.9	0.34
33	9.1	0.39
34	6.8	0.66
35	4.8	0.69
36	9.4	0.49
37	9.1	0.43

PINION RIPPLING

Pinion Id	Severity Targets Unit of Measure: RIPPLING MERITS	
	Mean	Standard Deviation
38	9.1	0.42
39	9.0	0.37
40	8.9	0.42
41	9.3	0.53
42	7.4	0.71
43	9.4	0.50
44	8.8	0.66
45	8.3	0.66
46	4.8	0.73
47	8.8	0.51
48	9.1	0.45
49	Removed from system	
50	9.5	0.51
51	8.6	0.50
52	8.7	0.46
53	8.8	0.46
54	9.2	0.46
55	9.1	0.47
56	9.0	0.58
57	8.6	0.62
59	5.7	0.75
60	8.9	0.52

PINION RIDGING

Pinion Id	Severity Targets Unit of Measure: RIDGING MERITS	
	Mean	Standard Deviation
1	5.8	0.67
2	8.5	0.51
3	8.3	0.59
4	Removed from system	
5	Removed from system	
6	6.4	0.49
7	9.0	0.24
8	7.7	0.63
9	Removed from system	
10	8.4	0.60
11	8.6	0.49
12	Removed from system	
13	9.5	0.50
14	6.4	0.87
15	5.6	0.70
16	Removed from system	
17	8.0	0.61
18	4.9	0.64
19	7.4	0.50
20	Removed from system	
21	8.3	0.53
22	9.1	0.42
23	Removed from system	
24	Removed from system	
25	7.6	0.55
26	9.6	0.50
27	5.6	0.65
28	Removed from system	
29	9.6	0.50
30	9.2	0.38
31	9.2	0.49
32	9.5	0.51
33	9.1	0.39
34	7.5	0.76
35	7.6	0.73
36	9.1	0.28
37	9.2	0.53

PINION RIDGING

Pinion Id	Severity Targets Unit of Measure: RIDGING MERITS	
	Mean	Standard Deviation
38	7.2	0.62
39	8.7	0.46
40	5.7	0.68
41	9.2	0.45
42	8.6	0.50
43	9.0	0.17
44	5.3	0.70
45	5.9	0.87
46	9.1	0.42
47	5.1	0.73
48	9.3	0.52
49	Removed from system	
50	8.2	0.83
51	9.7	0.48
52	5.3	0.75
53	9.2	0.48
54	8.7	0.59
55	8.8	0.54
56	8.5	0.56
57	8.9	0.34
59	8.2	0.61
60	9.1	0.35

PINION SPALLING/PITTING ("SPITTING")

Pinion Id	Severity Targets Unit of Measure: SPITTING MERITS	
	Mean	Standard Deviation
1	9.90	0.024
2	9.59	0.185
3	9.88	0.041
4	Removed from system	
5	Removed from system	
6	9.91	0.024
7	9.89	0.023
8	9.90	0.017
9	Removed from system	
10	9.87	0.670
11	9.59	0.172
12	Removed from system	
13	9.91	0.033
14	9.88	0.042
15	7.63	0.490
16	Removed from system	
17	6.10	0.394
18	9.87	0.046
19	9.90	0.017
20	Removed from system	
21	8.10	0.280
22	9.88	0.039
23	Removed from system	
24	Removed from system	
25	9.88	0.047
26	9.92	0.039
27	9.76	0.141
28	Removed from system	
29	9.91	0.042
30	9.89	0.028
31	9.90	0.045
32	9.90	0.017
33	2.30	0.550
34	9.90	0.016
35	9.90	0.017
36	9.91	0.032
37	9.91	0.023

PINION SPALLING/PITTING (“SPITTING”)

Pinion Id	Severity Targets Unit of Measure: SPITTING MERITS	
	Mean	Standard Deviation
38	9.91	0.024
39	9.90	0.010
40	9.89	0.028
41	9.91	0.033
42	9.81	0.106
43	9.90	0.010
44	9.89	0.047
45	9.88	0.079
46	9.92	0.044
47	9.89	0.036
48	9.89	0.024
49	Removed from system	
50	9.91	0.024
51	9.90	0.018
52	9.90	0.010
53	9.90	0.018
54	9.90	0.170
55	9.90	0.031
56	9.89	0.069
57	9.60	0.106
59	8.66	0.525
60	9.90	0.017

B. Acceptance Criteria

1. New Rater

- A minimum of 2 groups of four (4) pinion ratings with no Shewhart severity or precision alarms after the last rating

- All ratings results must be charted to determine if the rater is currently "in control" as defined by the control charts from the Rater Calibration Monitoring System. Note, that non-lubrited and lubrited hardware rating results are charted together.

2. Existing Rater

- The rater must have previously been accepted into the system by meeting RCMS calibration requirements.

- All ratings results must be charted to determine if the rater is currently "in control" as defined by the control charts from the Rater Calibration Monitoring System. Note, that non-lubrited and lubrited hardware rating results are charted together.

3. Rating Calibration Frequency

Once raters have been accepted into the system, the TMC will conduct rating calibration cycles for continuing calibration using approved hardware.

A calibration cycle consists of a rater rating four pinions. Only the tooth marked with a dot by the TMC is rated. If a gear has an X and a dot, then the X tooth is rated for WEAR and the dot tooth is rated for all other parameters. The results are to be returned to the TMC for analysis.

4. Control Charts

In Section 1, the construction of the control charts that constitute the Rating Calibration Monitoring System is outlined. The constants used for the construction of the control charts for the L-37 and the response necessary in the case of control chart limit alarms are depicted below. Note that control charting all parameters is required.

RATER CALIBRATION MONITORING SYSTEM CONSTANTS

		EWMA Chart				Shewhart Chart	
		LAMBDA		K		K	
Chart Level	Limit Type	Precision	Severity	Precision	Severity	Precision	Severity
Rater	Action	0.2	0.2	2.1	1.96	2.1	1.80

The following are the steps that must be taken in the case of exceeding control chart limits.

- Exceed EWMA limit for precision
  - Rater is not calibrated. Request additional pinions from TMC.
- Exceed Shewhart limit for precision
  - Rater is not calibrated. Request additional pinions from TMC.
- Exceed Shewhart limit for severity
  - Rater is not calibrated. Request additional pinions from TMC.
- Exceed *only* EWMA limit for severity
  - Rater is calibrated for a period of 3 months. Upon the fourth consecutive alarm, the rater is no longer calibrated. The rater is to complete a documented training exercise before re-testing is allowed.
- No alarms
  - Rater is calibrated for a period of 6 months.

3. L-42 RCMS Requirements

The following are the specific L-42 rater calibration requirements.

A. Parameters

The critical parameters are Pinion Scoring and Ring Scoring. The means and standard deviations for the parts for each critical parameter are presented below.

PINION SCORING

Part Set	Severity Targets Unit of Measure: %	
	Mean	Standard Deviation
1	17.9	1.87
2	27.2	2.41
3	8.4	1.52
4	22.2	1.82
5	32.3	2.40
7	15.0	1.18
8	25.2	2.24
9	21.7	4.22
10	14.1	1.01
11	23.1	3.31
12	21.6	2.38
13	35.8	2.60
14	63.1	2.33
15	10.7	3.90
17	14.5	1.53
18	12.3	1.39
19	12.2	1.17
20	45.2	4.05
21	21.5	1.76
22	24.6	1.97
23	20.3	2.20
24	15.2	1.06
25	14.7	1.50
27	34.9	4.12
28	21.5	1.80
29	19.1	2.02
30	25.5	3.06
31	26.0	2.67
32	31.5	2.24
33	22.9	1.60
34	46.2	4.65

RING SCORING

Part Set	Severity Targets Unit of Measure: %	
	Mean	Standard Deviation
1	10.0	1.47
2	18.4	2.79
3	4.8	1.19
4	13.8	1.07
5	18.1	2.05
7	9.4	1.41
8	17.4	2.31
9	15.0	3.51
10	7.8	1.21
11	17.4	2.24
12	13.4	1.01
13	27.1	1.96
14	52.7	3.36
15	5.9	1.54
17	8.1	1.01
18	7.5	0.88
19	6.6	1.37
20	36.3	2.88
21	14.2	1.36
22	14.9	1.20
23	14.0	1.75
24	8.3	0.89
25	10.2	1.27
27	25.7	2.95
28	13.3	1.60
29	13.7	1.70
30	16.1	1.96
31	18.3	2.65
32	21.7	2.60
33	15.2	1.38
34	34.3	2.72

B. Acceptance Criteria

1. New Rater

- A minimum of 2 groups of four (4) part set ratings with no Shewhart severity or precision alarms after the last rating. A part set consists of one pinion and one matching ring segment.

- All ratings results must be charted to determine if the rater is currently "in control" as defined by the control charts from the Rater Calibration Monitoring System.

2. Existing Rater

- The rater must have previously been accepted into the system by meeting RCMS calibration requirements.

- All ratings results must be charted to determine if the rater is currently "in control" as defined by the control charts from the Rater Calibration Monitoring System.

3. Rating Calibration Frequency

Once raters have been accepted into the system, the TMC will conduct rating calibration cycles for continuing calibration using approved RCMS hardware:

A calibration cycle consists of a rater rating four part sets. A part set consists of one pinion and one matching ring segment. Only the tooth marked by the TMC is rated. The results are to be returned to the TMC for analysis.

4. Control Charts

In Section 1, the construction of the control charts that constitute the Rating Calibration Monitoring System is outlined. The constants used for the construction of the control charts for the L-42, and the response necessary in the case of control chart limit alarms, are depicted below. Both pinion scoring and ring scoring are control charted.

RATER CALIBRATION MONITORING SYSTEM CONSTANTS

		EWMA Chart				Shewhart Chart	
		LAMBDA		K		K	
Chart Level	Limit Type	Precision	Severity	Precision	Severity	Precision	Severity
Rater	Action	0.2	0.2	2.1	2.1	2.1	2.6

The following are the steps that must be taken in the case of exceeding control chart limits.

- Exceed EWMA limit for precision
  - Rater is not calibrated. Request additional pinions from TMC.
- Exceed Shewhart limit for precision
  - Rater is not calibrated. Request additional pinions from TMC.
- Exceed Shewhart limit for severity
  - Rater is not calibrated. Request additional pinions from TMC.
- Exceed *only* EWMA limit for severity
  - Rater is calibrated for a period of 3 months. Upon the fourth consecutive alarm, the rater is no longer calibrated. The rater is to complete a documented training exercise before re-testing is allowed.
- No alarms
  - Rater is calibrated for a period of 6 months.

APPENDIX A

HISTORY OF RCMS PARTS MEANS
AND STANDARD DEVIATIONS

L-37 Rating Calibration Targets[1]											
		Effective Dates		Wear		Rippling		Ridging		Spitting	
Pinion	n	From	To	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s
1	9	19010101	20110228	5.9	1.00	7.8	0.89	5.4	0.67	9.91	0.100
1	33	20110301	99999999	5.8	0.42	7.5	0.80	5.8	0.67	9.90	0.024
2	9	19010101	20060620	6.6	0.67	8.1	1.22	8.4	0.67	9.54	0.289
2	19	20060621	20110228	5.9	1.01	8.0	1.12	8.6	0.67	9.60	0.224
2	36	20110301	99999999	5.9	0.28	7.9	0.72	8.5	0.51	9.59	0.185
3	9	19010101	20060620	6.6	0.67	6.4	0.67	7.6	1.56	9.86	0.067
3	23	20060621	20110228	5.9	1.01	6.8	0.89	8.4	0.67	9.88	0.089
3	34	20110301	99999999	6.0	0.17	6.9	0.60	8.3	0.59	9.88	0.041
4	9	19010101	20021016	7.2	0.89	9.1	1.00	9.2	0.89	9.87	0.078
5	9	19010101	20050915	6.6	0.67	9.1	1.22	8.2	0.89	6.89	0.989
6	9	19010101	20060620	6.2	0.89	7.1	1.00	6.1	1.00	9.91	0.100
6	18	20060621	20110228	5.8	0.89	7.2	0.89	6.3	0.78	9.91	0.101
6	33	20110301	99999999	5.8	0.36	7.2	0.57	6.4	0.49	9.91	0.024
7	9	19010101	20110228	7.8	0.89	8.6	0.67	9.2	0.89	9.87	0.078
7	36	20110301	99999999	6.4	0.60	8.8	0.62	9.0	0.24	9.89	0.023
8	9	19010101	20071119	7.7	0.78	7.6	0.67	7.9	1.00	9.91	0.100
8	27	20071120	20110228	7.0	0.60	7.8	0.89	7.7	0.78	9.90	0.090
8	33	20110301	99999999	6.9	0.35	7.8	0.71	7.7	0.63	9.90	0.017
9	9	19010101	20020911	6.1	1.00	8.7	0.78	7.8	0.89	9.67	0.189
10	9	19010101	20060620	5.7	0.78	5.9	1.00	8.3	0.78	9.86	0.067
10	18	20060621	20110228	5.6	0.67	6.2	0.89	8.4	0.67	9.86	0.067
10	34	20110301	99999999	5.6	0.50	6.4	0.65	8.4	0.60	9.87	0.670
11	9	19010101	20060620	6.9	1.00	6.9	1.00	8.4	0.67	9.58	0.133
11	15	20060621	20110228	6.1	1.01	6.4	0.67	8.5	0.56	9.60	0.112
11	37	20110301	99999999	6.2	0.44	6.5	0.61	8.6	0.49	9.59	0.172
12	9	19010101	20030515	3.4	0.67	7.0	1.11	4.6	0.67	5.44	0.622
13	9	19010101	20071119	8.2	0.89	9.2	0.89	9.9	1.00	9.97	0.078
13	20	20071120	20110228	7.5	0.60	9.6	0.67	9.5	0.56	9.92	0.089
13	40	20110301	99999999	7.5	0.64	9.7	0.46	9.5	0.50	9.91	0.033
14	9	19010101	20060620	6.7	0.78	9.0	1.11	6.7	1.44	9.86	0.067
14	28	20060621	20110228	5.9	1.01	8.5	0.56	6.5	0.56	9.88	0.089
14	37	20110301	99999999	6.0	0.29	8.5	0.56	6.4	0.87	9.88	0.042
15	9	19010101	20110228	5.4	0.67	8.6	0.67	5.6	0.67	7.56	0.622
15	40	20110301	99999999	5.6	0.50	8.6	0.68	5.6	0.70	7.63	0.490

[1] Targets are derived through rater consensus. In some cases, standard deviations were back-calculated to ensure acceptable limits.

APPENDIX A
HISTORY OF RCMS PARTS MEANS
AND STANDARD DEVIATIONS

L-37 Rating Calibration Targets[1]											
		Effective Dates		Wear		Rippling		Ridging		Spitting	
Pinion	n	From	To	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
16	9	19010101	20021018	8.2	0.89	9.6	0.67	9.6	0.67	9.97	0.078
17	9	19010101	20071119	6.0	1.11	8.6	0.67	7.4	0.67	5.78	0.867
17	23	20071120	20110228	5.7	0.78	9.0	1.11	8.1	1.00	6.10	1.000
17	39	20110301	99999999	5.9	0.52	8.9	0.50	8.0	0.61	6.10	0.394
18	9	19010101	20071119	5.7	0.78	9.0	1.11	4.8	0.89	9.88	0.089
18	28	20071120	20110228	5.6	0.67	9.1	1.00	4.9	1.00	9.87	0.078
18	34	20110301	99999999	5.6	0.49	9.1	0.65	4.9	0.64	9.87	0.046
19	9	19010101	20071119	7.0	1.11	9.6	0.67	7.6	0.67	9.92	0.089
19	20	20071120	20110228	6.1	0.56	9.3	0.78	7.5	0.56	9.90	0.056
19	34	20110301	99999999	6.1	0.34	9.2	0.43	7.4	0.50	9.90	0.017
20	9	19010101	20020110	6.2	1.12	8.6	1.09	5.7	1.33	9.87	0.880
21	9	19010101	20060620	6.0	1.11	9.2	0.89	8.2	0.89	8.00	1.000
21	22	20060621	20110228	5.6	0.67	8.8	0.89	8.4	0.67	8.10	1.010
21	35	20110301	99999999	5.6	0.50	8.8	0.41	8.3	0.53	8.10	0.280
22	9	19010101	20060620	7.3	0.78	9.0	1.00	8.9	1.11	9.90	0.100
22	17	20060621	20110228	6.4	0.67	8.9	1.01	9.1	1.01	9.88	0.089
22	34	20110301	99999999	6.4	0.50	9.2	0.59	9.1	0.42	9.88	0.039
23	9	19010101	20020110	6.2	1.12	7.7	1.09	8.0	1.33	9.81	0.880
24	9	19010101	20060123	5.6	0.67	8.2	0.89	7.4	0.67	2.50	0.556
25	9	19010101	20110228	6.7	0.78	7.6	0.67	8.1	1.00	9.90	0.111
25	38	20110301	99999999	6.0	0.28	7.1	0.61	7.6	0.55	9.88	0.047
26	9	19010101	20110228	8.8	0.89	9.3	0.78	9.8	0.89	9.98	0.089
26	38	20110301	99999999	8.3	0.50	9.4	0.54	9.6	0.50	9.92	0.039
27	9	19010101	20071119	5.7	0.78	8.4	0.67	5.6	0.67	9.80	0.111
27	21	20071120	20110228	5.6	0.67	8.4	0.67	5.3	0.78	9.66	0.200
27	38	20110301	99999999	5.6	0.55	8.7	0.66	5.6	0.65	9.76	0.141
28	9	19010101	20020911	6.2	0.89	8.3	0.78	7.4	0.67	9.58	0.133
29	9	19010101	20060620	7.0	1.11	9.6	0.67	9.7	0.78	9.93	0.078
29	22	20060621	20110228	6.5	0.56	9.5	0.56	9.6	0.67	9.91	0.101
29	33	20110301	99999999	6.5	0.67	9.7	0.48	9.6	0.50	9.91	0.042
30	9	19010101	20060620	6.1	1.01	3.9	1.00	8.9	1.00	9.87	0.144
30	22	20060621	20110228	6.1	1.01	4.6	0.67	9.1	1.01	9.89	0.101
30	35	20110301	99999999	6.0	0.24	4.5	0.61	9.2	0.38	9.89	0.028

[1] Targets are derived through rater consensus. In some cases, standard deviations were back-calculated to ensure acceptable limits.

APPENDIX A
HISTORY OF RCMS PARTS MEANS
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L-37 Rating Calibration Targets[1]											
		Effective Dates		Wear		Rippling		Ridging		Spitting	
Pinion	n	From	To	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s
31	6	20030319	20110228	6.8	0.89	9.2	0.89	9.5	0.56	9.91	0.100
31	35	20110301	99999999	7.2	0.62	9.3	0.44	9.2	0.49	9.90	0.045
32	6	20030319	20060620	7.0	1.10	8.7	0.78	9.7	0.78	9.91	0.100
32	22	20060621	20110228	7.4	0.67	8.9	1.01	9.5	0.56	9.89	0.101
32	35	20110301	99999999	7.4	0.55	8.9	0.34	9.5	0.51	9.90	0.017
33	6	20030319	20110228	6.3	0.78	9.2	0.89	9.0	1.10	2.33	0.744
33	40	20110301	99999999	6.0	0.42	9.1	0.39	9.1	0.39	2.30	0.550
34	6	20030319	20071129	6.3	0.78	6.7	1.44	8.0	1.11	9.93	0.078
34	22	20071120	20110228	6.4	0.67	6.7	0.78	7.5	0.56	9.90	0.056
34	39	20110301	99999999	6.4	0.50	6.8	0.66	7.5	0.76	9.90	0.016
35	6	20030319	20071119	6.5	0.56	4.5	1.21	7.5	0.56	9.88	0.089
35	23	20071120	20110228	6.7	0.78	4.8	0.89	7.7	0.78	9.90	0.056
35	36	20110301	99999999	6.6	0.55	4.8	0.69	7.6	0.73	9.90	0.017
36	6	20030319	20060620	6.2	0.89	9.3	0.78	9.3	0.78	9.92	0.089
36	6	20060621	20110228	6.1	1.01	9.4	0.67	9.1	1.01	9.91	0.101
36	35	20110301	99999999	6.2	0.45	9.4	0.49	9.1	0.28	9.91	0.032
37	6	20030319	20071119	6.7	0.78	9.3	0.78	9.8	0.89	9.92	0.089
37	20	20071120	20110228	7.7	0.78	9.2	0.89	9.4	0.67	9.91	0.056
37	37	20110301	99999999	7.7	0.58	9.1	0.43	9.2	0.53	9.91	0.023
38	6	20030319	20060620	6.7	0.78	9.2	0.89	7.3	0.78	9.92	0.089
38	15	20060621	20110228	6.4	0.67	9.1	1.01	7.1	1.01	9.91	0.101
38	35	20110301	99999999	6.4	0.50	9.1	0.42	7.2	0.62	9.91	0.024
39	6	20030319	20110228	6.8	0.89	8.5	0.82	8.7	0.78	9.92	0.089
39	38	20110301	99999999	6.4	0.50	9.0	0.37	8.7	0.46	9.90	0.010
40	6	20030319	20060620	6.3	0.78	9.2	0.89	5.8	0.89	9.90	0.110
40	28	20060621	20110228	6.2	0.89	8.9	1.01	5.8	0.89	9.89	0.101
40	35	20110301	99999999	6.2	0.43	8.9	0.42	5.7	0.68	9.89	0.028
41	6	20030319	20110228	6.8	0.89	9.3	0.78	9.3	0.78	9.92	0.089
41	36	20110301	99999999	7.2	0.58	9.3	0.53	9.2	0.45	9.91	0.033
42	6	20030319	20110228	6.0	1.10	6.8	0.89	8.8	0.89	9.80	0.222
42	45	20110301	99999999	6.0	0.15	7.4	0.71	8.6	0.50	9.81	0.106
43	6	20030319	20071119	6.5	0.56	9.5	0.56	9.2	0.89	9.92	0.089
43	22	20071120	20110228	6.8	0.89	9.3	0.78	9.0	0.56	9.90	0.056
43	35	20110301	99999999	6.8	0.60	9.4	0.50	9.0	0.17	9.90	0.010

[1] Targets are derived through rater consensus. In some cases, standard deviations were back-calculated to ensure acceptable limits.

APPENDIX A
HISTORY OF RCMS PARTS MEANS
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L-37 Rating Calibration Targets[1]											
		Effective Dates		Wear		Rippling		Ridging		Spitting	
Pinion	n	From	To	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
44	6	20030319	20110228	5.8	0.89	9.3	0.78	4.8	0.89	9.90	0.111
44	35	20110301	99999999	6.2	0.43	8.8	0.66	5.3	0.70	9.89	0.047
45	6	20030319	20110228	6.3	0.78	8.5	0.56	5.5	0.56	9.92	0.137
45	30	20110301	99999999	6.4	0.50	8.3	0.66	5.9	0.87	9.88	0.079
46	6	20030319	20060620	6.8	0.89	3.8	0.89	9.2	0.89	9.95	0.056
46	27	20060621	20110228	6.4	0.67	4.8	0.89	9.1	1.01	9.92	0.089
46	37	20110301	99999999	6.5	0.51	4.8	0.73	9.1	0.42	9.92	0.044
47	6	20030319	20071119	6.0	1.10	8.7	0.78	4.8	0.89	9.92	0.089
47	20	20071120	20110228	6.2	0.89	8.7	0.78	5.0	1.12	9.88	0.089
47	35	20110301	99999999	6.1	0.32	8.8	0.51	5.1	0.73	9.89	0.036
48	6	20030319	20110228	6.5	0.56	9.2	0.89	9.7	0.78	9.88	0.089
48	35	20110301	99999999	6.5	0.61	9.1	0.45	9.3	0.52	9.89	0.024
50	6	20030714	20060620	6.8	0.92	9.2	0.92	7.7	0.74	9.90	0.111
50	21	20060621	20110228	6.6	0.67	9.6	0.67	8.4	0.67	9.91	0.101
50	33	20110301	99999999	6.5	0.51	9.5	0.51	8.2	0.83	9.91	0.024
51	6	20030714	20060620	7.2	0.92	8.2	1.33	9.3	0.74	9.90	0.111
51	22	20060621	20110228	7.1	1.01	8.7	0.78	9.7	0.78	9.90	0.110
51	32	20110301	99999999	7.1	0.35	8.6	0.50	9.7	0.48	9.90	0.018
52	6	20030714	20060620	5.7	0.74	8.5	0.82	5.0	1.11	9.88	0.111
52	20	20060621	20110228	6.1	1.01	8.8	0.89	5.4	0.67	9.90	0.110
52	32	20110301	99999999	6.2	0.37	8.7	0.46	5.3	0.75	9.90	0.010
53	6	20030714	20110228	6.8	0.92	8.3	1.05	9.2	0.92	9.90	0.111
53	30	20110301	99999999	6.9	0.61	8.8	0.46	9.2	0.48	9.90	0.018
54	6	20030714	20071119	6.5	0.56	9.3	0.75	8.8	0.92	9.90	0.111
54	24	20071120	20110228	6.8	0.89	9.2	0.89	8.8	0.89	9.90	0.056
54	33	20110301	99999999	6.7	0.68	9.2	0.46	8.7	0.59	9.90	0.170
55	6	20030714	20110228	7.0	1.00	9.2	0.92	8.7	0.74	9.90	0.111
55	32	20110301	99999999	6.9	0.47	9.1	0.47	8.8	0.54	9.90	0.031
56	6	20030714	20071119	7.3	0.74	8.2	1.30	8.2	1.30	9.90	0.111
56	20	20071120	20110228	7.2	0.89	8.9	1.00	8.6	0.67	9.88	0.056
56	34	20110301	99999999	7.3	0.67	9.0	0.58	8.5	0.56	9.89	0.069
57	10	20070214	20110228	5.9	0.32	8.2	0.89	8.8	0.89	9.61	0.100
57	32	20110301	99999999	5.9	0.30	8.6	0.62	8.9	0.34	9.60	0.106

[1] Targets are derived through rater consensus. In some cases, standard deviations were back-calculated to ensure acceptable limits.

APPENDIX A
HISTORY OF RCMS PARTS MEANS
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L-37 Rating Calibration Targets[1]											
		Effective Dates		Wear		Rippling		Ridging		Spitting	
Pinion	n	From	To	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s
59	40	20110301	99999999	5.7	0.45	5.7	0.75	8.2	0.61	8.66	0.525
60	10	20070214	20110228	7.9	0.32	8.7	0.78	9.1	0.32	9.90	0.056
60	33	20110301	99999999	7.8	0.42	8.9	0.52	9.1	0.35	9.90	0.017

[1] Targets are derived through rater consensus. In some cases, standard deviations were back-calculated to ensure acceptable limits.

APPENDIX A

HISTORY OF RCMS PARTS MEANS
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L-42 Rating Calibration Targets							
		Effective Dates		Pinion		Ring	
Part Set	n	From	To	$\overline{X}$	s	$\overline{X}$	s
1	10	20080101	20111024	17.5	1.72	9.8	1.75
2	15	20080101	20111024	27.3	1.72	19.3	1.77
3	15	20080101	20111024	8.3	1.31	4.6	1.18
4	14	20080101	20111024	22.4	1.98	13.9	0.85
5	14	20080101	20111024	32.6	2	17.8	2.26
6	6	20080101	20090102	.	.	.	.
7	10	20080101	20111024	14.8	0.93	10.6	1.26
8	11	20080101	20111024	25.5	1.21	18.5	2.11
9	11	20080101	20111024	21.5	2.07	14.9	1.76
10	13	20080101	20111024	14.4	1.1	8.2	1.52
11	18	20080101	20111024	21.8	1.77	17.2	1.93
12	16	20080101	20111024	21.3	1.77	13.4	1.08
13	20	20080101	20111024	36	2.31	27.6	2
14	15	20080101	20111024	63.5	2.7	53.5	3
15	10	20080101	20111024	9.8	1.23	5.4	1.24
16	18	20080101	20090010	13.4	1.58	7.5	1.98
17	11	20080101	20111024	14.8	1.72	8.8	1.39
18	11	20080101	20111024	12.7	1.49	7.5	1.16
19	11	20080101	20111024	12.3	1.01	6.8	1.39
20	18	20080101	20111024	44.8	4.5	35.9	3.22
21	18	20080101	20111024	21.6	1.97	14.3	1.41
22	25	20080101	20111024	24.6	1.93	14.9	1.26
23	11	20080101	20111024	20.7	2.45	14.5	2.25
24	11	20080101	20111024	15.2	1.47	8.5	1.16
25	11	20080101	20111024	14.6	1.36	10.8	1.54
26	.	20080101	20090102	.	.	.	.
27	18	20080101	20111024	34.4	4.36	25.9	2.27
28	13	20080101	20111024	21.6	1.33	13.5	1.39
29	25	20080101	20111024	19.2	2.08	13.8	1.7
30	11	20080101	20111024	24.4	2.2	17.6	1.85
31	11	20080101	20111024	27.9	2.27	19.7	2.15

APPENDIX A

HISTORY OF RCMS PARTS MEANS
AND STANDARD DEVIATIONS

L-42 Rating Calibration Targets							
		Effective Dates		Pinion		Ring	
Part Set	n	From	To	$\overline{X}$	s	$\overline{X}$	s
1	31	20111025	99999999	17.9	1.87	10	1.47
2	32	20111025	99999999	27.2	2.41	18.4	2.79
3	33	20111025	99999999	8.4	1.52	4.8	1.19
4	30	20111025	99999999	22.2	1.82	13.8	1.07
5	30	20111025	99999999	32.3	2.4	18.1	2.05
7	32	20111025	99999999	15	1.18	9.4	1.41
8	38	20111025	99999999	25.2	2.24	17.4	2.31
9	27	20111025	99999999	21.7	4.22	15	3.51
10	30	20111025	99999999	14.1	1.01	7.8	1.21
11	35	20111025	99999999	23.1	3.31	17.4	2.24
12	27	20111025	99999999	21.6	2.38	13.4	1.01
13	28	20111025	99999999	35.8	2.6	27.1	1.96
14	29	20111025	99999999	63.1	2.33	52.7	3.36
15	32	20111025	99999999	10.7	3.9	5.9	1.54
17	30	20111025	99999999	14.5	1.53	8.1	1.01
18	28	20111025	99999999	12.3	1.39	7.5	0.88
19	34	20111025	99999999	12.2	1.17	6.6	1.37
20	29	20111025	99999999	45.2	4.05	36.3	2.88
21	25	20111025	99999999	21.5	1.76	14.2	1.36
22	32	20111025	99999999	24.6	1.97	14.9	1.2
23	34	20111025	99999999	20.3	2.2	14	1.75
24	35	20111025	99999999	15.2	1.06	8.3	0.89
25	39	20111025	99999999	14.7	1.5	10.2	1.27
27	35	20111025	99999999	34.9	4.12	25.7	2.95
28	34	20111025	99999999	21.5	1.8	13.3	1.6
29	37	20111025	99999999	19.1	2.02	13.7	1.7
30	33	20111025	99999999	25.5	3.06	16.1	1.96
31	27	20111025	99999999	26	2.67	18.3	2.65
32	22	20111025	99999999	31.5	2.24	21.7	2.6
33	22	20111025	99999999	22.9	1.6	15.2	1.38
34	28	20111025	99999999	46.2	4.65	34.3	2.72