LUBRICANT TEST MONITORING SYSTEM

Second Edition

Contents

Section Page Number

1. Lubricant Test Monitoring System Structure

A. Goals

B. Theory

C. Practical Considerations

D. Test Development

E. Update Analyses

F. Second Edition Control Charts

G. Surveillance Panel Guidelines for Implementing LTMS Version 2

H. Reference Oils

I. Engineering Judgment as Applied to the Interpretation of LTMS Control Charts

J. Guidelines for Numbering of New Test Stands

K. Surveillance Panel Guidelines for Revisions to the LTMS

L. Guidelines for Introduction of New Procedures, Hardware, Parts, and/or Fuel

M. Reference Test Validity Codes and Chartable Reference Tests

APPENDIX A History of LTMS Reference Oil Means and Standard Deviations A-1

APPENDIX B History of Industry Correction Factors Applicable to LTMS Data B-1

APPENDIX C History of Severity Adjustment (SA) Standard Deviations C-1

APPENDIX D Reference Oil Viscosity Grades D-1

APPENDIX E Applying Severity Adjustments E-1

APPENDIX F Templates for Version 2 Stand and Laboratory Based LTMS F-1

APPENDIX G Development of Variance Estimators and Chart Limits G-1

APPENDIX H Flow Charts H-1

APPENDIX I References I-1

F. SECOND EDITION CONTROL CHARTS

i. Reference Qualification

For the sake of brevity and simplicity, we will assume in this section that the severity adjustment entity is a laboratory. If, as described above, a compelling case for other severity adjustment entity (e.g., engine) has been accepted, details of this section are slightly modified (see Appendix F).

With the default system, the first stand within a laboratory requires three reference tests for initial non-reference testing qualification. These reference tests are run consecutively, before non-references, and may include precision study oils as well as reference oils. Calibration status is not judged until the final reference test in the consecutive string is complete.

In order to remain qualified for non-reference oil testing, a test stand shall begin a reference oil test after no more than 18 valid non-reference oil tests in the stand or no later than 15 months following the completion of the stand’s previous qualifying reference oil test, whichever comes first. If more than 15 valid non-reference oil tests or more than 12 months are allowed in the standard reference period, then the laboratory is required to run 1 acceptable reference per six month interval. The time limits could be decreased if appropriate by the Surveillance Panel. These intervals might be reduced or increased as a function of monitoring. If reference period extensions push intervals over the 15 tests or 12 months limits, the requirement to run 1 acceptable reference per six month interval is **not** invoked.

If two full length reference oil tests are declared operationally invalid during the attempt to calibrate an existing stand, increases to the reference interval that would otherwise apply, will not occur in this situation.

ii. Severity adjustment entity Charting and Actions

For each severity adjustment entity, let

Xi = ith test result in original units in end of test order,

Ti = ith test result in appropriate units in end of test order,

(Ti=Xi unless a transformation is used in which case Ti=transformed (Xi))

Yi = ith standardized test result = (Ti – target) / (standard deviation),

(Target and standard deviation are as currently defined for the reference oil used in the reference test)

Zi = EWMA = λ Yi + (1- λ) Zi-1,

(By default, λ=0.2. With sufficient data and appropriate analyses, λ could be optimized by Box procedure minimizing sum of squares for prediction, , see Reference 1, pages 87-88.)

(Fast start is used, i.e., Z0=average of Y1, Y2, and Y3.)

and,

ei = prediction error from EWMA = Yi – Zi-1.

For each severity adjustment entity, chart Yi, Zi, and ei versus i. Zi is used as an adjustment chart to promote similar severity across severity adjustment entities. Shewhart charts of the ei’s indicate whether we know the relative performance of the severity adjustment entity well enough to adequately severity adjust using the Zi.

Level 1, 2, and 3 limits and their implications for prediction error monitoring are described in Appendix F. Suggested limits for prediction error monitoring are shown in the following table. Derivation of these limits is explained in Appendix G. As discussed, in Section G, it is each surveillance panel’s responsibility to select an appropriate set of limits for each of the prediction error monitoring parameters.

Shewhart Limits for Prediction Error Monitoring Parameters



Level 1 and 2 limits and their implications for severity monitoring and adjustment are described in Appendix F. The default recommendation for the level 1 limit for each severity adjustment parameter is zero. That is, continuous or no threshold severity adjustment is recommended. Selection of EWMA level 2 limits should be made by the surveillance panel in original engineering units as discussed in Section G.

iii. Industry Charting and Actions

For the entire testing industry, let

Xi = ith test result in original units in end of test order,

Ti = ith test result in appropriate units in end of test order,

(Ti=Xi unless a transformation is used in which case Ti=transformed (Xi))

Yi = ith standardized test result = Yi = (Ti – target) / (standard deviation),

(Target and standard deviation are as currently defined for the reference oil used in the reference test)

and,

Zi = EWMA = λ Yi + (1- λ) Zi-1.

(By default, λ=0.2. With sufficient data and appropriate analyses, λ could be optimized by Box procedure minimizing sum of squares for prediction, , see Reference 1, pages 87-88.)

(Fast start is used, i.e., Z0=average of Y1, Y2, and Y3.)

Industry Zi charts without application of severity adjustment can indicate when a change in testing has caused the entire industry to drift. Such drift would be captured by severity adjustments. However, the industry chart might alert faster than individual testing entities. It might also indicate when the entire industry has shifted to the extent that the originally intended engine oil performance characteristics can no longer be reliably measured.

TMC will maintain industry Zi charts and include them in semiannual reports. To enhance understanding of trends, individual reference entities will be indicated on the charts through color or symbols in coded form. Further, when the following limits are exceeded in absolute value, the TMC will take actions as indicated in Appendix F.

As described in Section G, the surveillance panel should determine level 2 limits based on mechanistic understanding of the test and discussed in engineering units. Suggested level 1 limits are shown in the following table.

Industry EWMA Limits for Severity Adjustment Parameters

|  |  |  |  |
| --- | --- | --- | --- |
|  | | | |
|  |  |  |  |
|  |  |  |  |



G. SURVEILLANCE PANEL GUIDELINES FOR IMPLEMENTING LTMS VERSION 2

Surveillance panels have the ultimate responsibility and authority for test development, target creation, and implementation of LTMS. However, given the importance of LTMS to test definition, it is advisable to include industry statisticians early and throughout the test development process. LTMS implementation for a test typically includes an engagement of industry statisticians with the surveillance panel or test development task force. From analyses of precision study data and/or historical data, the statisticians will present a recommendation to the surveillance panel for most of the LTMS parameters. It is the responsibility of the surveillance panel to review and endorse or modify the proposed system parameters. Other system parameters should originate at the surveillance panel. Selection of these other parameters by the surveillance panel might be informed by data analyses; but, the criteria for selection should primarily be determined by subject matter experts.

i. Existing Tests

Using historical data from an existing test, potential parameters can be explored. The goal is not to determine exactly where each severity adjustment entity would start but to explore in a limited way whether various parameter settings might have more accurately compensated for past situations.

Each severity adjustment entity would begin its application of Version 2 LTMS with its first reference run in the new regime. It would be the decision of the surveillance panel whether all entities would start simultaneously with a reference test or with each entity’s next reference test. For example, if new hardware were being introduced, the surveillance panel might specify that each entity run a reference with new hardware before starting another non-reference test.

ii. Lab and industry level 2 Zi limits

Level 2 limits for severity adjustment entity Zi charts are intended to identify when a severity adjustment entity is so far from target that it cannot discriminate oil performance in the same manner as when testing is on target. This choice of limits is based on subject matter expertise related to the mechanism being evaluated. For example, when using a 0 to 10 cleanliness rating scale, if the target is 5 and a severity adjustment entity is obtaining results close to 10, then the entity will not likely be able to discriminate oil performance because all oils would be producing very clean results due to the severity of the entity. These limits must be determined for each parameter in original units. Limits need not be symmetric, i.e., severe and mild limits might not be the same distance from the target in any metric. Surveillance panels should consider that two labs could be farther apart than the difference between mild and severe limits; but, the non-reference tests would not be severity adjusted farther than those limits. The panel should consider Zi lag in setting limits.

One form of help in making these determinations could come from plotting original unit results (xi) versus deviation from target in standardized units (yi) for reference oil(s) and theoretical pass limit oil. It would also be very helpful for additive companies to bring input from formulators to the surveillance panel.

Level 2 limits for industry Zi charts are intended to mandate alert to the industry that something in the test appears to be causing a severity shift. At that point the industry must evaluate whether normal severity adjustments are adequate and also investigate whether the cause of the shift can be determined. Level 1 limits for industry Zi charts can trigger a TMC investigation with possible involvement by the surveillance panel. Level 2 triggers, however, require the immediate involvement by the surveillance panel.

iii. Prediction error monitoring parameters, severity adjustment parameters, and reference period adjustment parameters

When multiple pass / fail criteria are defined for a test, statisticians’ preparation for engagement would include evaluation of correlation among the criteria. It is generally detrimental to include redundant measures of oil performance. For purposes of LTMS, redundant measures bias ability of the system to detect appropriate signals. While all passing criteria should have severity adjustments in the system, it might reduce the effect of redundant criteria if test parameters of lesser importance or meaning are not included as prediction error monitoring parameters. These parameters would not be subject to the prediction error (ei) judgments of reference test acceptability. As part of the statisticians’ engagement, the surveillance panel should consider whether a subset of criteria should be designated as severity adjustment only parameters. Generally, this parameter bifurcation could be accomplished by declaring whether each parameter is ei only, Zi only, or both. However, if special circumstances justify it, designation of parameters for reference period adjustment might be different from designation of parameters for prediction error monitoring.

One of the severity adjustment parameters is the industry approved severity adjustment standard deviation. As part of the implementation engagement, statisticians will propose standard deviations appropriate at the pass limit for the criterion. The statistician will suggest transformations, if appropriate. It is hoped that transformations homogenize variability. If adequate transformations are not determined, statisticians and the surveillance panel need to consider how to deal with multiple pass limits such as when a test is used in multiple categories and whether the severity adjustment standard deviation remains appropriate when the test experiences large severity shifts.

After designating whether each pass / fail criterion is a prediction error monitoring parameter, severity adjustment parameter, and / or a reference period adjustment parameter, appropriate limits should be addressed. Unless there is justification for a difference, default limits should be used as shown in Section F. If a specific pass / fail criterion requires more severe or more lenient limits, suggestions for these limits are included in Section F.

The surveillance panel should decide whether time extensions should be included with test count extensions and, if they are to be included, whether the extensions should be sufficient time to allow extended test count or if the extensions should be percentage time extensions similar to test count extensions.

For tests with merit systems used in passing criteria, the potential impact of LTMS should also be considered. Unless there is clear evidence for the specific test that another approach is better, all of the parameters should be monitored and adjusted individually. Reference test disposition decisions should be made based on individual parameter monitoring. Total merits should also be monitored.

The surveillance panel should consider whether the system would allow reference acceptance based on test results that are not meaningful. The surveillance panel should determine whether ei limits stacked on top of Zi limits could mean a result outside a reasonable range could be acceptable.

iv. Annual review

The Technical Guidance Committee (TGC) will organize and conduct annual reviews of the LTMS system in its entirety. Surveillance Panel chairmen are ex officio members of the TGC. The chairmen should prepare with their surveillance panel for these reviews. As part of this preparation, the surveillance panel together with the TMC will review data to determine if any laboratory or laboratories exhibit(s) unusual performance. Such unusual performance might include but not be limited to severity differences from other laboratories, poor relative precision, high invalid rates, and etcetera. Concerns identified in LTMS data and in the LTMS process should be brought forward to the TGC annual review meetings.

v. LTMS documentation

It is very desirable that we have consistent documentation of LTMS for individual test types. Someone needing this information should be able to find it in an analogous place regardless of test type.

Some aspects of LTMS are more permanent and more logically contained in the test method. As part of the test method, they are subject to revision by information letter. This includes definitions of new laboratories and new stands, specification of basic reference intervals, reference oil targets, and implications of exceeding LTMS limits.

Other parts of LTMS definition are more transient. They might be subject to periodic update or tunable during the annual review. Changes are suggested by data and analyses. They are subject to the consensus and timing guidelines as specified in section K, below. These latter aspects should be documented in a compendium of test type specific LTMS parameters maintained by the Test Monitoring Center. They include reference oil standard deviations, limits for ei and Zi monitoring, and lambdas for Zi calculations.

APPENDIX F

TEMPLATES FOR VERSION 2 LABORATORY AND STAND BASED LTMS

# *<Test Name>* LTMS Requirements(A Laboratory Based Severity Adjustment System)

**TEST METHOD PORTION**

The following are the specific *<Test Name>* calibration test requirements.

A. Reference Oils and Parameters

The prediction error monitoring parameter is Parameter 1 and the severity adjustment only parameter is Parameter 2. The reference oils required for test stand and test laboratory calibration are reference oils accepted by the ASTM *<Test Name>* Surveillance Panel. The targets for the current reference oils for each parameter are presented below.

PARAMETER 1

Unit of Measure: *units(including transform if any)*

PREDICTION ERROR MONITORING PARAMETER

|  |  |
| --- | --- |
| Reference Oil | Target |
|  |  |
|  |  |
|  |  |

PARAMETER 2

Unit of Measure: *units(including transform if any)*

SEVERITY ADJUSTMENT ONLY PARAMETER

|  |  |
| --- | --- |
| Reference Oil | Target |
|  |  |
|  |  |
|  |  |

B. Acceptance Criteria

1. New test labs [It is preferred that the definition of a new laboratory appears in the test method. But if it doesn’t or requires clarification, it should be done here.]

a. A minimum of three (3) operationally valid reference and/or matrix tests must be run on the first test stand in a new laboratory.

* Note that industry matrix runs may be included, as well as reference runs, at the discretion of the surveillance panel.

b. Following the necessary tests, check the status of the control charts and follow the prescribed actions.

c. If two full length reference oil tests are declared operationally invalid during the attempt to calibrate a stand, then an increase in the reference interval per section 5.d may not be granted.

2. Existing Test Lab

a. New test stands in an existing lab, and test stands in an existing test lab that have not run an acceptable reference in the past two years, may calibrate with one test provided Level 1 limit requirement is met. Otherwise a second test is required for calibration.

b. For an existing test stand in an existing lab run one test

c. Following an operationally valid reference oil calibration test, check the status of the control charts and follow the prescribed actions.

d. If two full length reference oil tests are declared operationally invalid during the attempt to calibrate a stand, then an increase in the reference interval per section 5.d may not be granted.

3. Reference Oil Assignment

Once a test stand has been accepted into the system, the TMC will assign reference oils for continuing calibration according to the following reference oil mix:

* 100% of the scheduled calibration tests should be conducted on reference oils <*Oil XXX*>, <*Oil YYY*>, and <*Oil ZZZ*> or subsequent approved reblends.

5. Chart Status

The following are the steps that must be taken in the case of exceeding chart limits. The steps are listed in order of priority, although charts should be studied simultaneously to determine the cause(s) of a problem. In the case of multiple alarms, contact the TMC for guidance. The laboratory always has the option of removing any stand from the system.

a. Shewhart Chart of Prediction Error (ei) for **prediction error monitoring parameters only**

• Level 3

– Immediately conduct one additional reference test in the stand that triggered the alarm. Do not update the control charts for the lab until the follow up reference test is completed and the ExI analysis, per Section 5.c (below), has been performed.

• Level 2

– Reduce the number of tests allowed in the calibration period in the stand that triggered the alarm to [enter number of tests representing 80% of the standard calibration period].

• Level 1

* + The level 1 limit applies in situations that have been pre-determined by the surveillance panel to have a potential impact on test results. These situations may include the introduction of new critical parts, fuel batches, reference oil reblends, or other test components. When these conditions have been met and a level 1 alarm is triggered, immediately conduct one additional reference test in the stand that triggered the alarm.
  + The level 1 limit also applies to a stand in an existing test lab that has not run an acceptable reference in the past two years. The stand can calibrate with one test if the level 1 limits are not exceeded. Otherwise, immediately conduct another reference test in the stand.

b. Reference entity EWMA of Standardized Test Result (Zi) for **all parameters**

• Level 2

* Immediately conduct one additional reference test either
  + in the stand that triggered the alarm, or
  + in the stand that is next due for calibration.
    - The stand that triggered the alarm is not calibrated for non-reference testing without further reference testing.

• Level 1

* The level 1 limit applies to all reference tests that are control charted, even when other alarms have been triggered. Level 1 uses Zi to determine the laboratory severity adjustment (SA). Calculate the laboratory SA for each parameter as follows and confirm the calculation with the TMC:

SA = -Zi x sSA

where sSA =industry approved severity adjustment standard deviation

c. Excessive influence (ExI) Analysis for **prediction error monitoring parameters only**

* The ExI analysis is performed anytime that a lab ei level 3 alarm is triggered. As prescribed in Section 5.a, Level 3, a follow up reference test is run. The following comparisons then determine whether the value of Yi is modified to limit its influence on LTMS. Yi+1 is the next completed reference in the laboratory after the level 3 alarm

1. If |Yi – Yi+1| ≤ ei level 3 limit, then Yi is equal to the value originally determined.
2. If Yi > Zi-1 and Yi-Yi+1 > ei level 3 limit, then let

Yi = ei level 3 limit + Zi-1.

1. If Yi ≤ Zi-1 and Yi-Yi+1 < -ei level 3 limit, then let

Yi = -ei level 3 limit + Zi-1.

1. If none of i), ii), or iii) is true, then Yi is equal to the value originally determined.

Where: i = test that originally triggered level 3 alarm,

i-1 = test prior to alarm trigger, and

i+1 = test immediately following alarm trigger.

Once the proper Yi value has been determined, update the charts. Confirm calculations with the TMC. The laboratory and the TMC maintain a record of the modification.

d. Increase in the Number of Tests for the Stand Calibration Period

• The number of tests allowed in a stand calibration period, for existing stands only, may be increased if the previous test was an acceptable reference based upon the chart results for all prediction error monitoring parameters as follows:

* + If |ei| ≤ Ee, then the number of tests allowed for that calibration period may be increased by [insert number of tests representing 20% of the standard calibration period], [if surveillance panel opts to include “, and the time between references may be increased by” insert time extension required to extend number of tests or time period representing 20% of the standard period ], or
  + If |ei| ≤ Ee and |Zi|≤ Ze, then the number of tests allowed for that calibration period may be increased by [insert number of tests representing 40% of the standard calibration period] [if surveillance panel opts to include “,and the time between references may be increased by” insert time extension required to extend number of tests or time period representing 40% of the standard period “.

Confirm calculations with the TMC.

• If two full length reference oil tests are declared operationally invalid during the calibration sequence in the same stand, then the increase in calibration period will not be granted

e. Industry EWMA of Standardized Test Result (Zi) for **all parameters**

• Level 2

* + TMC informs the surveillance panel that the limit has been exceeded. The surveillance panel then investigates and pursues resolution of the alarm.

• Level 1

* + The TMC investigates whether severity adjustments are adequately addressing the trend, investigates the possible causes, and communicates as appropriate with industry.

**TMC COMPENDIUM PORTION**

The following are the specific *<Test Name>* calibration test requirements.

A. Reference Oils and Parameters

The prediction error monitoring parameter is Parameter 1 and the severity adjustment only parameter is Parameter 2. The reference oils required for test stand and test laboratory calibration are reference oils accepted by the ASTM *<Test Name>* Surveillance Panel. The standard deviations for the current reference oils for each parameter are presented below.

PARAMETER 1

Unit of Measure: *units(including transform if any)*

PREDICTION ERROR MONITORING PARAMETER

|  |  |
| --- | --- |
| Reference Oil | Standard Deviation |
|  |  |
|  |  |
|  |  |

PARAMETER 2

Unit of Measure: *units(including transform if any)*

SEVERITY ADJUSTMENT ONLY PARAMETER

|  |  |
| --- | --- |
| Reference Oil | Standard Deviation |
|  |  |
|  |  |
|  |  |

B. Acceptance Criteria

4. Adjustment (Zi) and Monitoring (ei) Charts

In Section 1, the construction of the adjustment and monitoring charts used in the Lubricant Test Monitoring System are outlined. The constants used for the construction of the control charts for the <*Test Name*>, and the adjustment and monitoring chart limits, are shown below.

Laboratory Shewhart Limits for Prediction Error Monitoring Parameters

|  |  |
| --- | --- |
| Shewhart Chart of Prediction Error ei = Yi – Zi-1 | |
| Limit Type | Limit\* |
| Level 3 | TBD |
| Level 2 | TBD |
| Level 1 | TBD |

Laboratory EWMA Limits for Each Severity Adjustment Parameter

|  |  |  |
| --- | --- | --- |
| EWMA of Standardized Test Result Zi = λ(Yi) + (1 – λ)Zi-1 | | |
| Limit Type | λ | Limit |
| Level 2  Upper Limit | 0.2 | TBD by SP Input |
| Level 2  Lower Limit | 0.2 | TBD by SP Input |
| Level 1 | 0.2 | 0 |

Laboratory Prediction Error and EWMA Reference Period Extension Limits for Each Reference Period Adjustment Parameter

|  |  |
| --- | --- |
| Limit Type | Limit |
| Ee | 1.05 |
| EZ | 0.66 |

Industry EWMA Limits for Each Severity Adjustment Parameter

|  |  |  |
| --- | --- | --- |
| EWMA of Standardized Test Result Zi = λ(Yi) + (1 – λ)Zi-1 | | |
| Limit Type | λ | Limit |
| Level 2  Upper Limit | 0.2 | TBD by SP Input |
| Level 2  Lower Limit | 0.2 | TBD by SP Input |
| Level 1 | 0.2 | TBD |

APPENDIX G

DEVELOPMENT OF VARIANCE ESTIMATORS AND CHART LIMITS

If we assume (as we assumed for creation of the original LTMS in accord with traditional Statistical Process Control) the Yi to be independent and identically distributed, the variance for the EWMA can be estimated by

 for i=0,1,2,3, …

As i increases, the first bracketed factor decreases and we might approximate the variance of the EWMA as



Then, if we assume normalization makes Yi ~N(0,1), we might further simplify to



And limits for the EWMA chart for monitoring severity (Zi plotted against completion date order) might be expressed as

Similarly, the variance of ei might then be approximately estimated by



And limits for Shewhart charts of the ei’s might be expressed as



In traditional SPC, the constants, c, are typically selected with false alarm error rates and average run lengths in mind. Under the assumptions for traditional SPC, these false alarm error rates and run lengths have been well studied and documented through application of probability theory or simulation. In fact, we believe the Yi to be non-stationary (i.e., there is not a constant mean) and to frequently exhibit autocorrelation. Limits in version 2 of LTMS (which is a system for monitoring and adjustment rather than traditional SPC) do not have the same meaning and the probability theory and simulations are not applicable.

IF the EWMA or, equivalently ARIMA(0,1,1), adequately models the data such that the residuals from the model are approximately independent and identically distributed as N(0,) and  could be estimated as the mean squared error from the EWMA prediction, then we would use  to estimate . However, we suggest the following approach to start LTMS for a test unless adequate data and analyses have been done to implement the more rigorous approach. Residuals from the EWMA and alternate models should be reviewed along with regular review of reference oil variances.

The default approach is then to use the above along with the following table of constants to determine limits for a test. The resulting limits are shown in Section F. Surveillance panels should judge whether each pass criterion should be judged as for ei, Zi, or both and, if judged for that chart, whether the default, tightened, or loosened limits should be used.

Laboratory Shewhart Constants for Prediction Error Monitoring Parameters



Industry EWMA Constants for Severity Adjustment Parameters



APPENDIX H

FLOW CHARTS

**High-Level LTMS 2nd Edition Flowchart**

Report a valid reference to TMC

Does the difference (ei) between current test severity (Yi) and the historical severity of the adjusted entity (Zi-1) indicate this test may not be representative of the entity?

No

Does the current severity of the adjusted entity (Zi) indicate the entity continues to measure the selected parameter in a manner that is representative of the physical mechanisms the test is intended to measure and does the LTMS continue to interpret results in the manner originally intended?

Reference is acceptable

Yes

No

Conduct another reference immediately and perform excessive influence analysis.

Yes

Evaluate appropriate interval for next reference

Conduct another reference immediately.

*Note operation at this severity level indicates a sustained trend of producing results that significantly deviate from target and a thorough investigation of the reference entity should be conducted before resuming referencing.*







