



Block Cycle Test Data Analysis

1 Introduction

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

This procedure applies to the development of a block cycle test specification (load amplitudes and counts). It does not include details of applying the developed block cycle test to the specimen. Refer to procedure GMW16319 for an example of executing the developed block cycle test.

1.1 Purpose. This document provides a standard process for developing a block cycle test. The fatigue calculations used in this procedure are assumed to be performed following GMW15269. The block cycle test, if properly designed, brings out weaknesses in the structure in a very short time, compared to the time required for road tests or real-time type laboratory testing. Block cycle tests are especially useful when a single axis of test input provides sufficiently accurate testing. This procedure is based on uniaxial fatigue theory and may not be effective in duplicating failure modes due to multi-axial inputs and other mechanisms, such as wear, corrosion, or thermal cycling.

In block cycle testing, a set of time histories are replaced by a number of **cycles** arranged in repeating **blocks** of constant peak and valley load or strain. This approach is used to decrease fatigue testing time for components and structures and simplify creation of the test. A series of these **cycles** forms a block. The blocks may be further arranged into passes of multiple blocks. The block cycle loading test is developed by comparing the rainflow matrix of the original time history and the percent damage per bin associated with that time history. The combinations of most damaging cycles will produce the block test. It has been documented that for some cases the experimental fatigue lives for specimens and components subjected to variable amplitude loading can be well below or greater than the fatigue life predicted using constant amplitude test results. In other words, a constant amplitude test may give a different fatigue life than a variable amplitude block test. Some indication of this can be found by creating a constant amplitude variant in 4.9, then comparing with an upsized (full or subset of cycle counts) test order determination as shown in 4.10.

In general, high cycles of small amplitudes below a specified level (usually the endurance limit) are omitted. Six to ten series of load levels typically provide adequate approximations of variable amplitude fatigue inputs. The sequence of blocks is important. A random sequence will minimize undesirable sequence effects, but generally the most severe arrangement is used. However, a series of blocks may be grouped into a pass consisting of several blocks. The use of passes gives some **random** nature to the test to prevent **front-loading** all damage. Note that high amplitude ranges that occur only seldom are added once in every n^{th} pass. It has been found that a test should contain at least eight passes in order to represent the original history.

Multi-axis inputs should be used with caution as this process loses all phase relationships between channels. As block cycle testing usually is run only at a single frequency, specimens with a frequency-dependent nature and/or subject to high inertial loading, should be tested with caution.

As mentioned earlier, the small amplitude cycles are generally not included in the block cycle test. However, recent work has suggested that care should be taken in the elimination of smaller levels. A solution for this problem based on theoretical models and a few fundamental data, describing strength of material and/or components, is not available to date. To partially consider the small cycle effect for the preceding example, a range of 3 levels with the number of cycles equal to 120 000 cycles may be added to the block test. Note that a range of 3 levels was chosen as the average between 1 to 6 levels and the selected number of cycles is about 10% of the total rainflow cycles in the ranges 1 to 6 levels.

1.2 Applicability. This procedure is typically used for creating block cycle lab tests suitable for durability evaluations of a development or validation nature where uniaxial and constant frequency loading is acceptable.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

GMW15019 (ID)

GMW15269

GMW16319

(ID) = This document is limited to internal use within General Motors and shall not be accessed outside this company. Contact the GM Lead Engineer for further instructions.

2.3 Additional References.

- Dowling, N. E., & Khosrovaneh, A. K. (1989). *Simplified analysis of helicopter fatigue loading spectra*. In: ASTM STP 1006, American Society for Testing and Materials, Philadelphia, PA, pp. 150 to 171.
- Khosrovaneh, A. K. (1995 February). *Block Cycle Test Development Using NAO-Testware and CFS* (Report Number PG063337). Milford, MI: General Motors.
- Khosrovaneh, A. & Pattu, R. (2006). *Vehicle Component Fatigue Analysis Considering Largest Overall Loop for Multiple Surfaces*, SAE World Congress (2006: Detroit, Michigan, USA). Paper Number 2006-01-0979. Society of Automotive Engineers, Inc., Warrendale, PA, USA: SAE 2006.
- Stephens, R. I., Fatemi, A., Stephens, R. R., & Fuchs, H. O. (2000). *Metal Fatigue in Engineering*, 2nd Edition; New York: John Wiley & Sons.

3 Resources

3.1 Facilities.

3.1.1 Calibration. The test facilities and equipment shall be in good working order and shall have a valid calibration label.

3.1.2 Alternatives. Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

3.2 Equipment. Not applicable.

3.3 Test Vehicle/Test Piece. Not applicable.

3.4 Test Time. Varies based on test being developed and skill level of personnel creating the test.

3.5 Test Required Information. Not applicable.

3.6 Personnel/Skills. Test technician familiar with test facilities and equipment.

4 Procedure

4.1 Preparation. Not applicable.

4.2 Conditions.

4.2.1 Environmental Conditions. Not applicable.

4.2.2 Test Conditions. Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

4.3 Instructions. The overall process for this procedure is shown in Appendix A, Figure A1. This procedure is intended to be usable with any acceptable fatigue analysis software with all required functionality. It has been verified with nCode's Glyphworks and MTS' RPC Pro. Appendices B and C show a method to perform this procedure with these software packages.

This procedure assumes a series of time histories, such as recorded during a Road Load Data Acquisition (RLDA) (See GMW15019). Although a native format for the data processing tool may be preferred, a common format for data transfer is RPCIII format. (See following note.) Multiple channels may be processed simultaneously; however the assumption is that each channel is an independent dataset. If the data are already processed, and the desired composite rainflow-with-mean (RWM) matrix exists in a PC or workstation, then skip to step 4.5. **Note:** If the processed data already exists in rainflow format and consists of individual rainflow files for each road surface, then a duty cycle or test sequence must be applied to create a composite rainflow matrix. **If the input rainflow files do not have closed residuals**, see following note.

Note: RPCIII is a registered trademark and software package formerly produced by MTS Corporation. The software package specified a binary file format still used by MTS and readable by other applications. Details of this file format are available on the MTS web site, www.mts.com.

Note: Residual is the term used during rainflow counting for a partial cycle that occurs during rainflow counting a time-history to produce a rainflow matrix. It occurs when a peak and/or valley are not **paired** during the counting process. They can be **forced** closed when the matrix is finalized, but this will prevent properly combining matrices at a later date.

4.4 Rainflow Count Time Histories. Rainflow counting is a method to calculate the fatigue cycles within a time-history. Typically, a rainflow histogram is created in range-mean, or rainflow-with-mean, histograms. Other types also exist, but this procedure will only deal with range-mean histograms.

4.4.1 Summarize the Maxima And Minima Of All Time-Histories. Typically, to rainflow count time-histories, the user must determine bin sizes. Typically, a rainflow histogram will be approximately 64 bins. (See GMW15269, Appendix C.) However, for block cycle calculations, the fidelity of 64 bins is not needed and 32 bins will suffice. The preferred process (See Appendix B) automatically selects 32 bins. Prior to, or during, the rainflow counting process, noisy signals may require a gate level be applied. This gate level is typically 1% of the maximum peak or one bin size.

4.4.2 Create the Rainflow Matrix. Once the bin sizes are determined, the rainflow counting can be performed. The units/level, or bin size, for each channel should be equal to the value found in Step 4.4.1 for all road surfaces. These individual rainflow matrices are combined with the corresponding number of repetitions in the next operation.

During the rainflow counting, the rainflow residuals must remain open for the next operation.

4.5 Create the Composite Rainflow Matrix. The individual rainflow histograms for each channel are combined into a composite using a duty cycle (sometimes known as a test sequence). During this operation, the open residuals are closed through appropriately **matching** peaks and valleys left open in the residuals. For each channel, the resultant composite rainflow histograms are used in the next processing steps. Some software packages can perform 4.4 and 4.5 in one step.

The composite rainflow histogram should represent one life of the test being represented. If multiple lives are needed for reliability purposes, this should be handled by running the one life block that results to the number of lives required for reliability.

4.6 Calculate the Baseline Damage. Determine the baseline damage and scale factor (SF) as in GMW15269, shown here in brief form. Some of the parameters are set slightly differently depending on the type of input data. Often, this data is force, torque or displacement. **Note: Do not** use acceleration as input data for this procedure.

- Input data type is fully elastic (linear): The strain type is **measured** (elasto-plastic).
- Scale Factor (SF): Back calculated for non-strain data. Be careful with the SF units – the nCode method mentioned in Appendix B is set to use MPa/unit load, RPC Pro method in Appendix C works in microstrain per unit load. SF is 1 for strain (microstrain) data.
- Notch Factor(K_f): 1 (back-calculated for strain data).
- Offset: Dependent on whether static offsets were included in the data as processed for rainflow. Any removed offsets must be entered here. The block cycle test should be developed considering this effect.
- Cycle gate (where applicable): Default is to set gate equal to bin size.
- Number of repeats: 1.
- Model Parameters: Morrow mean stress correction for steels, Smith-Watson-Topper for aluminum and cast materials.
- Material Data: Select a material that represents the character of the material at the critical section. **Note:** The block test is only applicable to the material used to develop that test. This is very important to note relative to some statements in GMW15269 where a **close** material is adequate for A-B comparisons.
- Target life/damage: For the back-calculation, a target or known life or damage must be entered. Remember that damage is the inverse of life.

4.6.1 Calculate Baseline and Tower Plots. Apply the SF (non-strain data) and K_f (strain data) and perform a damage calculation to obtain a baseline tower plot. Some software packages require a separate **forward** calculation to generate the baseline tower plots.

4.7 Edit the Composite Rainflow Histogram.

4.7.1 Determine Range-Mean Pairs to Keep. Compare the rainflow matrix with percent damage per bin to identify the damaging rainflow ranges. Six to ten range-mean pairs are typically sufficient to provide an adequate approximation of the baseline data. Typically, a first approximation can be made by selecting a representative range-mean pair as the target **bin**, determining the damage per target cycle ratio by dividing the damage in that bin by the counts in that bin, summing the damage in a **region** (range of range-mean bins) of the baseline damage matrix, then dividing the region damage sum by the target bin damage per cycle ratio to get estimated counts:

$$EstCount_{R,M} = \frac{(\sum Dam_{Clump})}{\left[\frac{Damage_{R,M}}{Counts_{R,M}} \right]}$$

Where:

- $Counts_{R,M}$ is the original counts in the target bin.
- $Damage_{R,M}$ is the original damage in the target bin.
- $\sum Dam_{Clump}$ is the sum of the damage in the region or clump of the tower plot that the target bin will represent.
- $EstCount_{R,M}$ is the estimated number of counts (cycles) for that bin.

The estimated counts may need to be adjusted slightly to be evenly divisible by the number of passes.

Note that the largest-range bins in the edited Rainflow file represent **extreme** events and adjusting these bins should not be done. (See 4.3.10 of GMW15269.) If the largest-range bins are not divisible by the number of passes, they should be **scattered** as evenly as possible among the passes. For example, if there are 4 maximum-range events but 8 passes are planned, the 4 max-range events could be arranged, for example, before the 1st pass, 3rd pass, 5th pass, and 7th pass.

In some cases, the extreme values may be so much larger than the remainder of the load distribution (rainflow histogram), and an acceptable distribution (4 or 5 load levels at least) is not obtained. In this case, although interaction with other cycles is lost, these large events can be removed from the duty cycle and processed separately. Similarly, there may be cases where extreme events are removed from the duty cycle to process in a multiaxial manner instead of the embedded uniaxial manner of a traditional (uniaxial) block cycle.

4.7.2 Create the Block Cycle File. Copy the composite baseline rainflow and edit the histogram to retain only those identified in the previous step. The proposed block cycle test is based on the cycles that cause most of the damage. As mentioned before, the effect of small amplitude cycles will not be included in the block cycle test. The nCode flow referenced in Appendix B has a GM-developed algorithm that will semi-automatically select the most appropriate bins to realistically retain the damage in a manner that will be fairly representative of the road data.

4.8 Calculate Block Cycle Damage. Calculate the damage for the matrix from step 4.7.2 and obtain the percent damage per bin file. This is identical to the operation in Step 4.6.1 but with the edited file as input.

4.9 Verify Results. Review the results and compare to the results from 4.6.1. The objective is to match the original damage within about 10%, that is, 90% to 110%, while at the same time meeting any requirements for the total number of cycles. The total number of cycles will typically be somewhere between 100 000 and 200 000 total cycles. Results that are significantly outside this may be legitimate but should be reviewed by an expert.

If these results do not match adequately, repeat Steps 4.7 and 4.8 until damage for the proposed block cycle test is similar to the assumed damage for the road and the character of the tower plots is acceptable.

Steps 4.4 to 4.9 can be accomplished using an nCode Glyphworks flow that includes a patent applied-for algorithm to automatically select bin sizes and counts to meet the requirements.

4.10 Test Order Determination. The test order sequence can be checked by the following method.

For each range-mean pair selected in the Block Cycle Test, use the range and mean to create a pseudo time-history that starts and ends at 0. Each cycle in the time-history is determined by calculating the peak as:

$$Peak = \frac{1}{2}(Range + 2 * Mean)$$

And the valley as:

$$Valley = Peak - Range$$

Two time-histories must be created: One starting at the smallest range (small first) and ending with the largest, and one starting at the largest range and ending with the smallest. Using these two time-histories, calculate two damage numbers directly from the time-history (not on a rainflow matrix), using the same Fatigue parameters as in the preceding. The result with the largest damage (shortest life) is the proper ordering of the loads.

This ordering of cycles is the order of cycles within a pass.

4.11 Document the Block Cycle Test. Document the block cycle test for use as needed. This documentation must include all specifics of the fatigue calculations and both baseline and block cycle rainflow matrices and tower plots.

5 Data

5.1 Calculations. Not applicable.

5.2 Interpretation of Results. Not applicable.

5.3 Test Documentation. If using the preferred tool of nCode, the default reports can be used to document the resultant test. If using another tool, the resultant test should be documented in a similar fashion.

6 Safety

This Engineering Standard may involve safety requirements for hazardous materials, the method of operations and equipment. This standard does not propose to address all the safety issues associated with its use. It is the responsibility of the user of this standard to ensure compliance with all appropriate safety and health practices. This would include any specific training that may be required. The safety and health standards include site specific rules and procedures, company rules and procedures, and Government Standards. Contact shall be made with the appropriate site Safety and Health personnel for further direction and guidance in these matters.

7 Notes

7.1 Glossary.

Duty Cycle: Also known as a test sequence.

Pass: Also sometimes known as a phase. Essentially, a pass is a repeating subset of the total test.

Rainflow Matrix: Method to summarize fatigue cycles for further analysis.

7.2 Acronyms, Abbreviations, and Symbols.

CSV Comma Separated Variable

Kf Notch factor

RLDA Road Load Data Acquisition

RWM Rainflow-With-Mean

SF Scale Factor

8 Coding System

This standard shall be referenced in other documents, drawings, etc., as follows:

Test to GMW16285

9 Release and Revisions

This standard was originated in August 2009. It was first approved by the Global Structural Durability Laboratory Expert Team in November 2009. It was first published in January 2010.

Issue	Publication Date	Description (Organization)
1	JAN 2010	Initial publication.
2	JUL 2015	Updated template, references and technical content for 5 year refresh. (Body – Global Structural Durability Laboratory Expert Team)
3	AUG 2020	5 year refresh. (Body – Global Structural Durability Laboratory Expert Team)