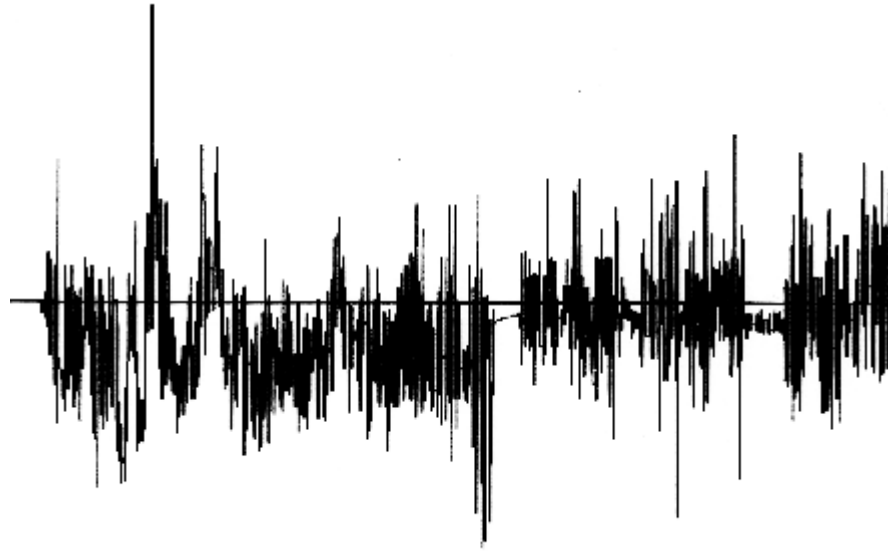
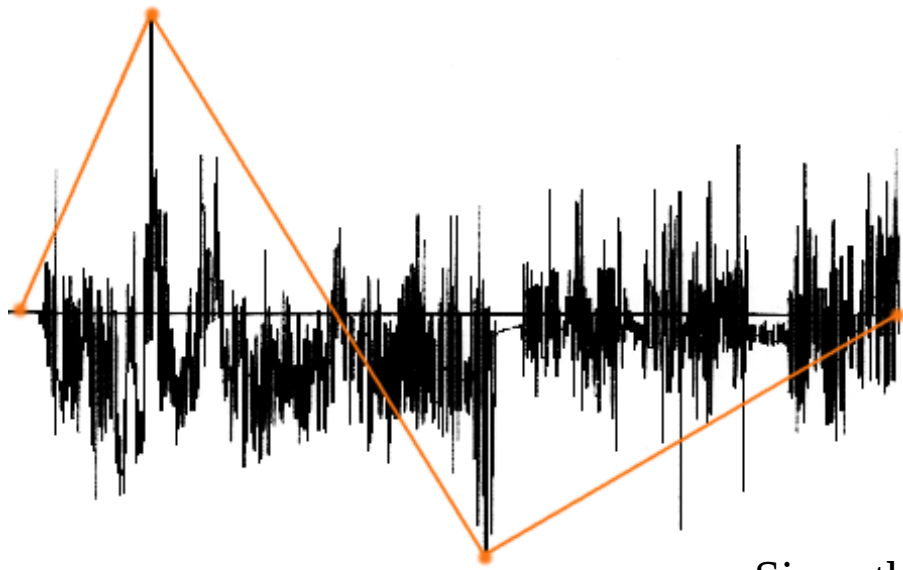
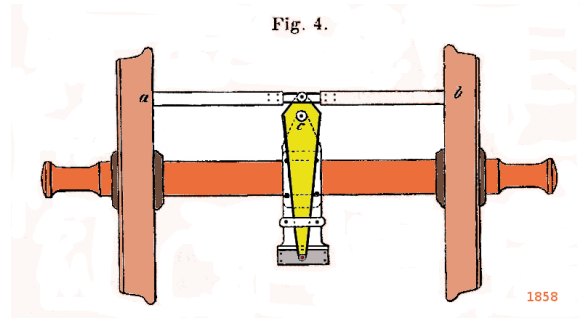


Cycle Counting



In Chapter 5 Pt.2 a memory modelling process was described that follows a stress or strain input service history and resolves individual hysteresis loops. Such a model is the best method for loop resolution, but many other methods have been developed and applied in the past. In this chapter we will describe some of the older methods, because you may run into their results, and we will look in more detail at presently used techniques.

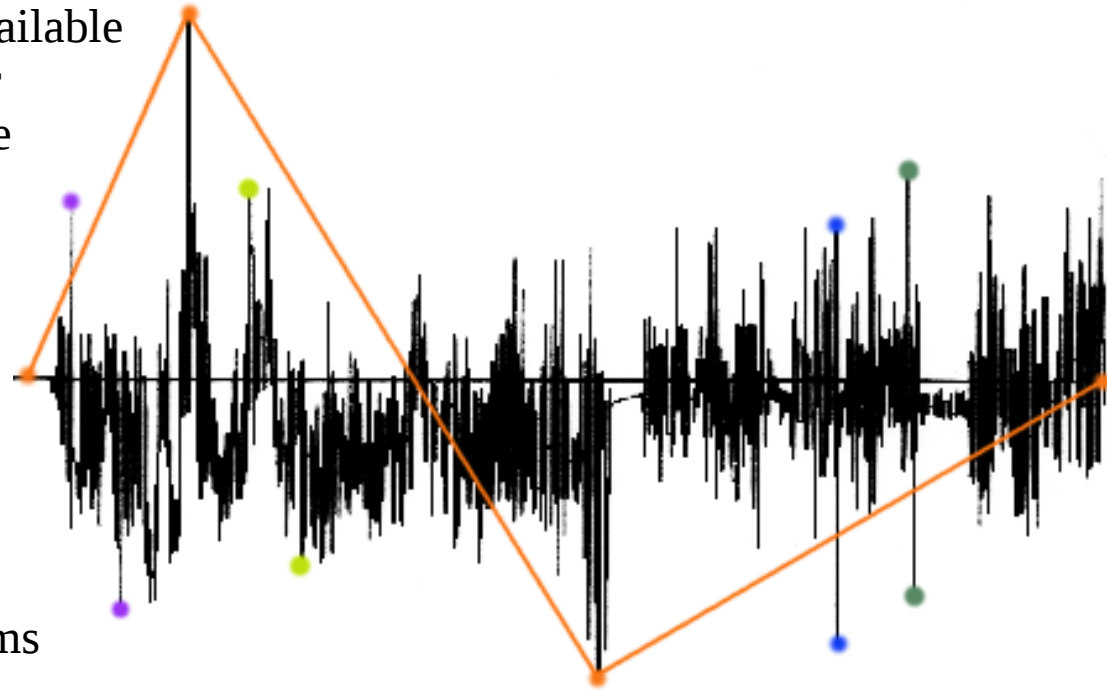
In Chapter 4 on deflection measurement Wöhler's scratch gage measured the bending deflections of a railway wagon axle.



Since the zinc scratch plate was not indexed with time or mileage, the measured result would have been an observation of the max and the min loads (when calibrated) on the axle during the service test.

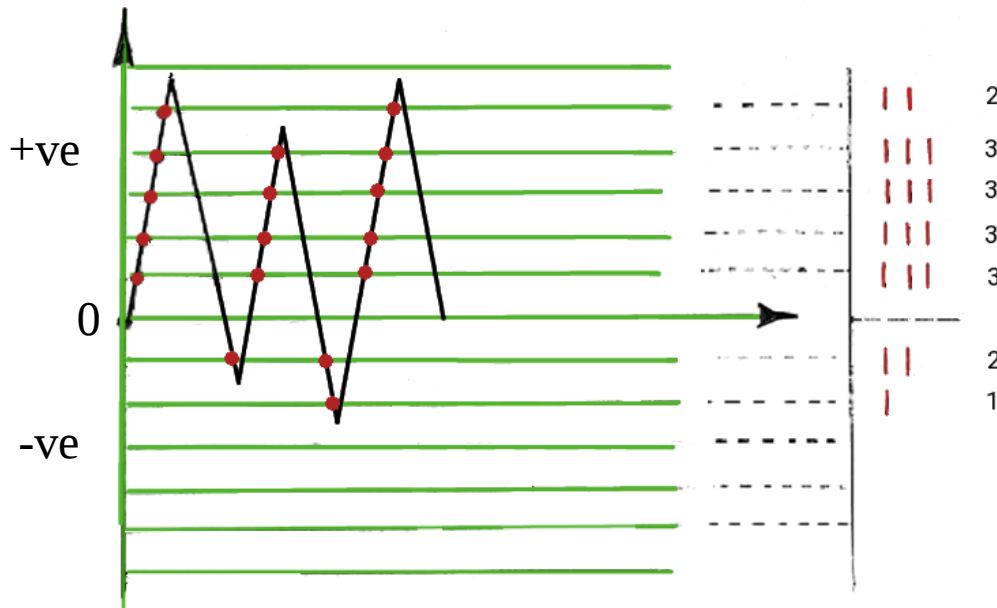
The measured result would have been as shown by the orange spots in the history plot above: Many loads experienced, only the max and min counted for evaluation.

If a time-indexed scratch gage had been available Wöhler could have counted more tensile or compressive peaks but, without knowledge of material memory rules, the question would remain as to which peaks to join together to form a "cycle" for counting damage.



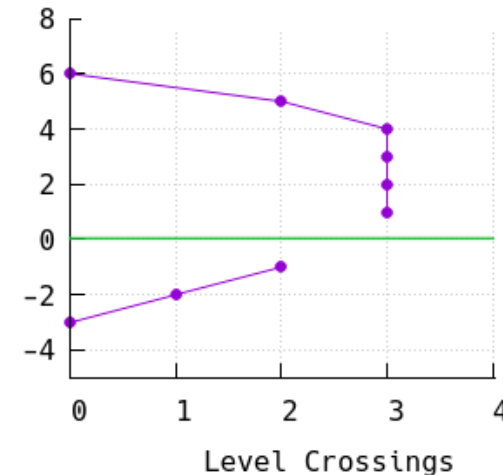
The advent of electrical resistance strain gages shifted the counting problem into terms of electrical circuits.

Level Crossing counting was adopted in the 1950s by the aircraft industry to count accelerations that exceeded certain levels. Although largely replaced by "Rainflow" counting (next section) it is still used today and its features should be understood by engineers.



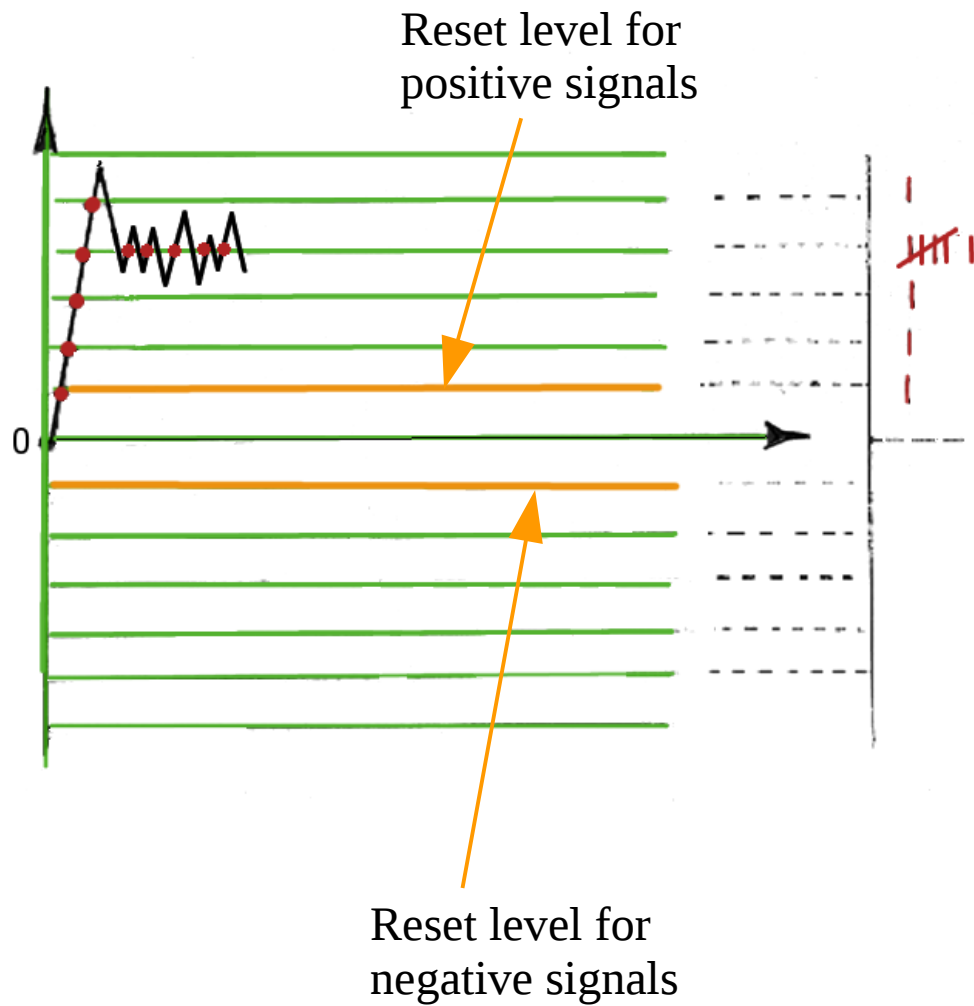
The original circuits sent a pulse to electro-mechanical counters as a signal crossed each positive voltage level.

A second set of counters were pulsed by the signal crossing negative voltage levels.
(separate counters for each level)



The counts are often presented in a histogram form, joined by lines to the points.

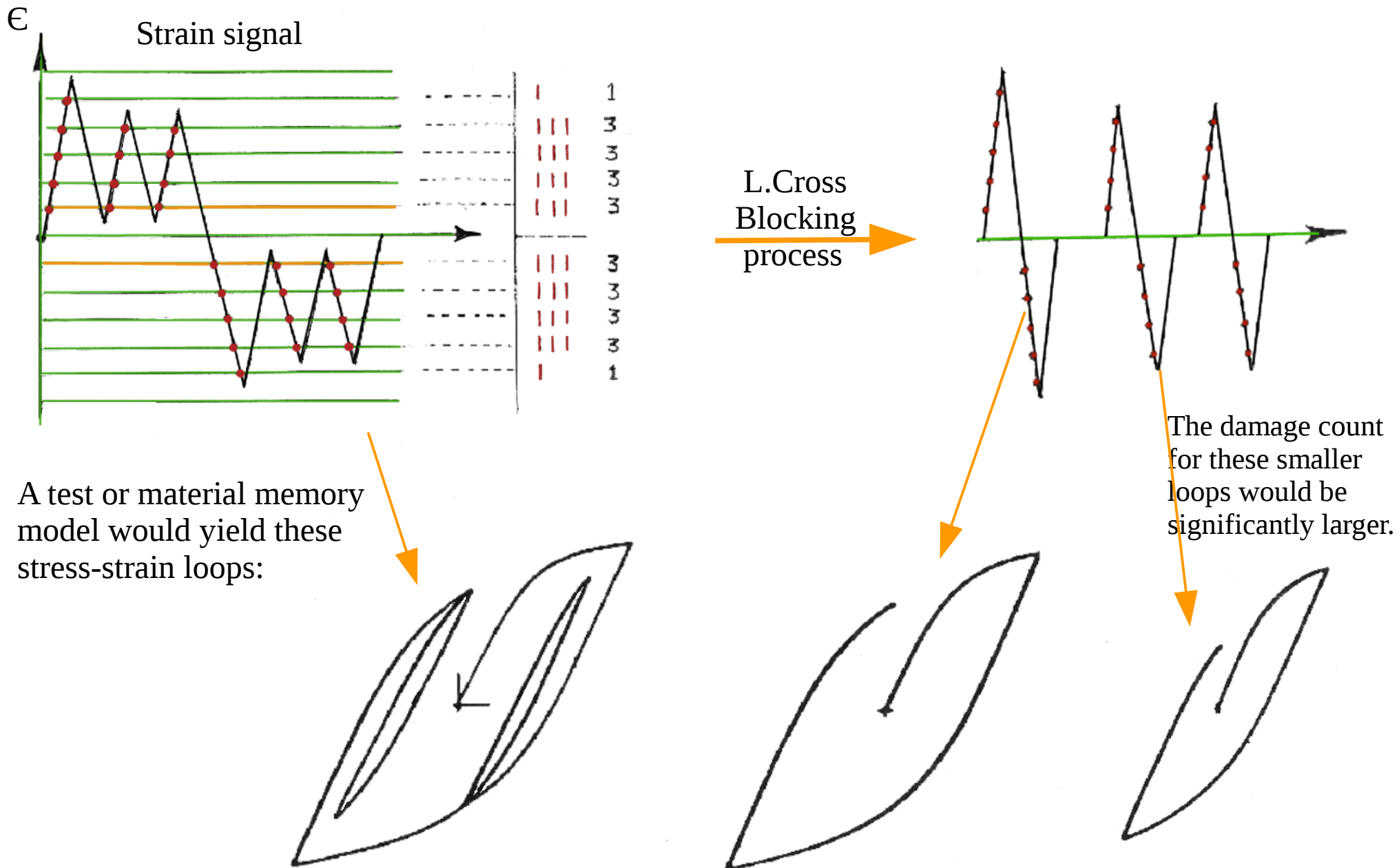
A log scale is used for the X axis when counts become large in number.

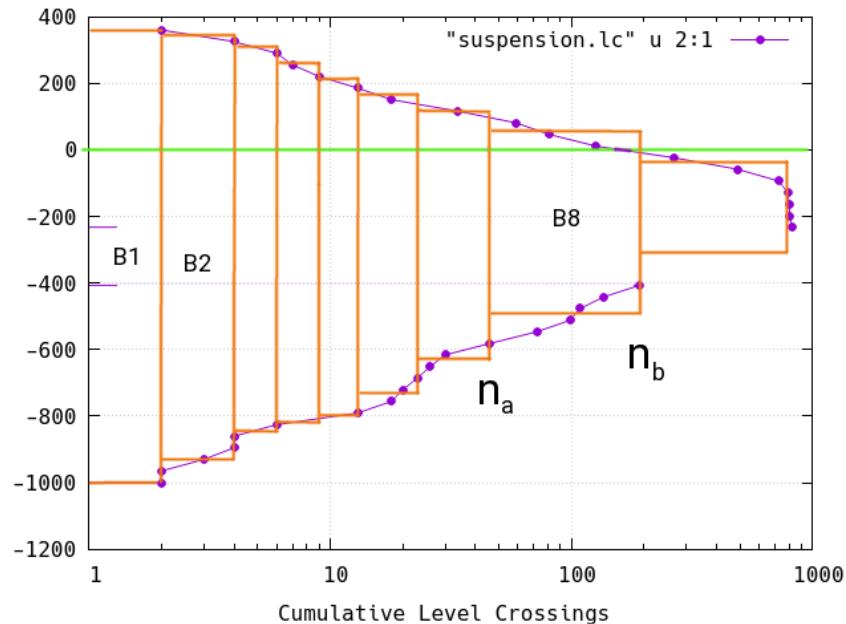


The problem of signal noise causing unexpected counts was somewhat mitigated by setting a reset level to which the signal had to return to before any further counts were allowed.

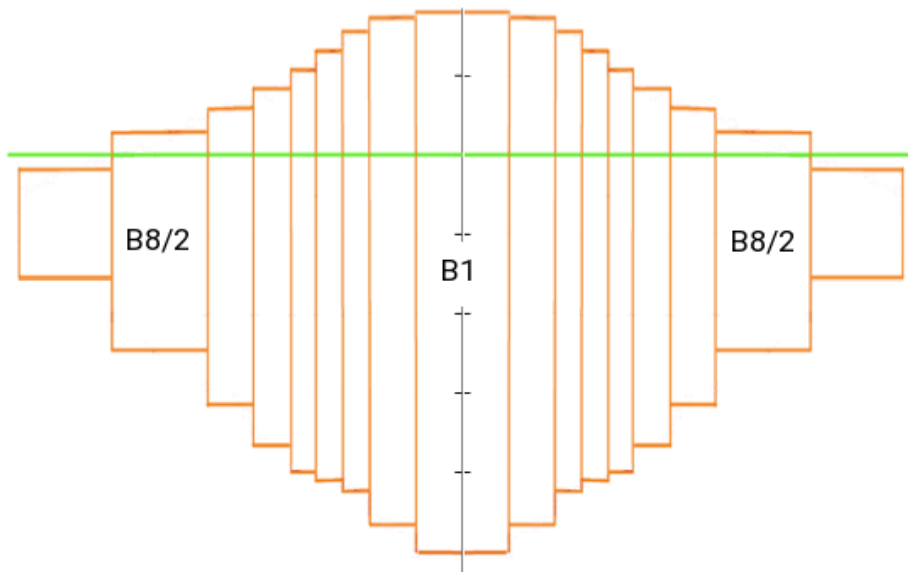
This feature is probably ok for aircraft acceleration signals, where a return to mean occurs often, but many other service signals do not have this characteristic.

Even with the adoption of reset levels the Level Cross Counting method can yield inaccurate counts given some histories





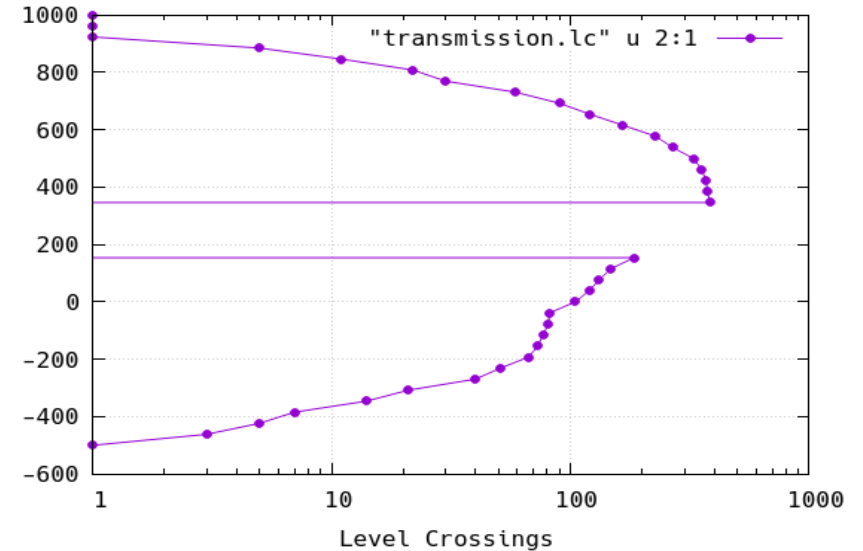
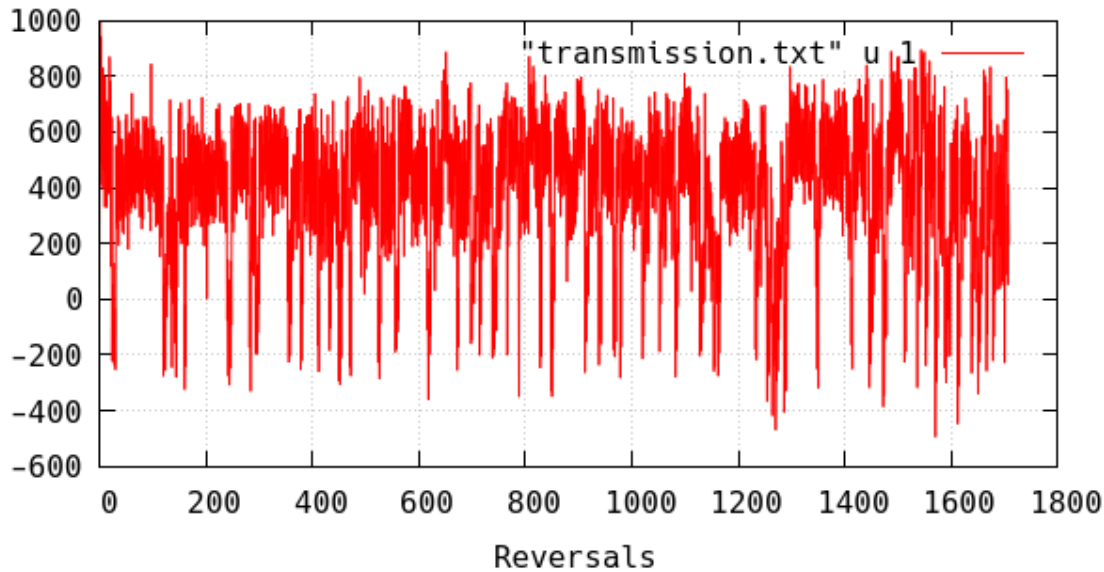
When we are given a Level count data set or plot, we can re-constitute the cycles that created it by sectioning or "blocking" the counts: Block B8 for example would have $(n_b - n_a)$ cycles



In the years before computer control of test machines, the blocks were often played back in the sequence shown; called a Block Program; with B1 in the center and the others placed half on each side of B1.

The sequences could also be arranged randomly, but one had to be aware of extra transition half-cycles introduced when switching from one sub-block to another.

Today the histories are usually just played back as originally recorded.

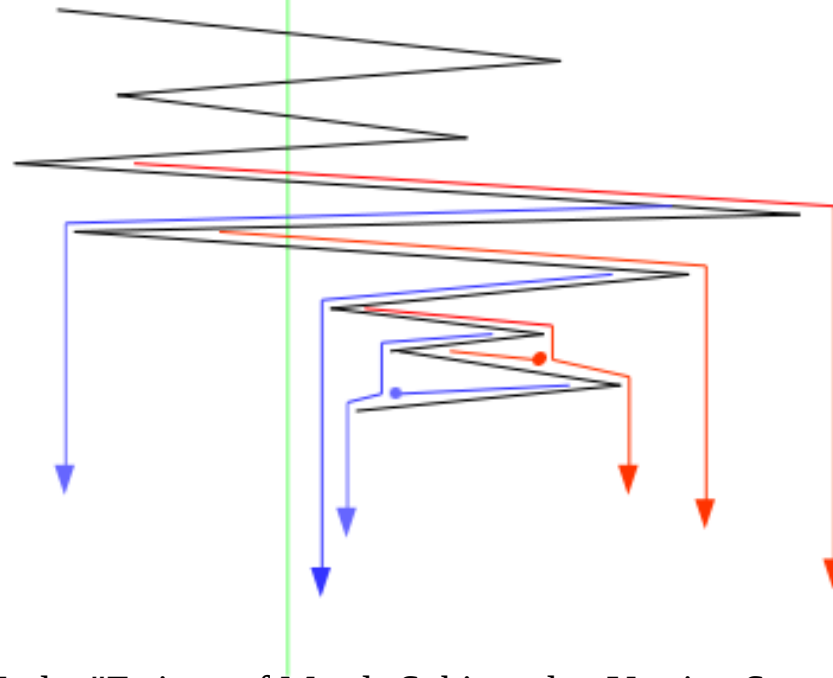


Many engineers have used the shape of the level crossing count as a form of signature as to the aspects of a service history. It shows size and mean and numbers.

The Level Crossing count method however, has deficiencies the user should be aware of.

Level Crossing cycle counting, and a number of other older methods described in more detail, are in the "SAE Fatigue Design Handbook," 3rd edition, edited by Richard C. Rice, SAE Fat. Des.& Eval. Comm., SAE AE-22, ISBN 1-56091-917-5 1997.

Rainflow Cycle Counting



Ref.: M.Matsuishi and T.Endo, "Fatigue of Metals Subjected to Varying Stress," presented at Japan Soc. Mech. Engr., Fukuoka, Japan, Mar. 1968, see also T.Endo et al, "Damage Evaluation of Metals for Random or Varying Load," Proc. of 1974 Symp. on Mech. Behav. of Mtls., Soc. of Materials Sci., Japan, 1974 pp.371-380

The method is explained by Matsuishi et al through an analog of rain drops flowing off the roofs of a pagoda structure. The main rules state:

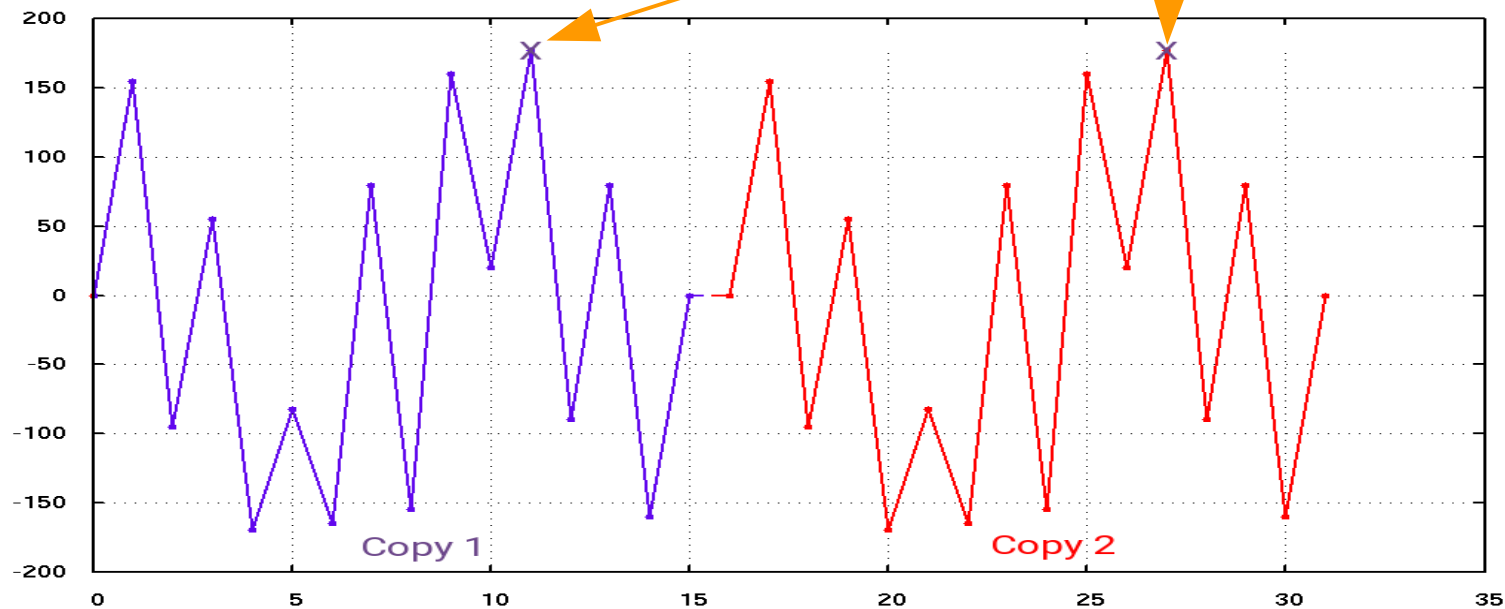
1. The rain-flow started from a maximum (minimum) peak stops when a following maximum (minimum) peak larger (smaller) than the peak appears.
2. If a rain-flow meets the rain-drop falling from an upper roof the rain-flow stops at that place.

A version of the rainflow counting method was created by S.Downing and D.Socie and is listed in the aforementioned SAE Fatigue Design Handbook on page 149.

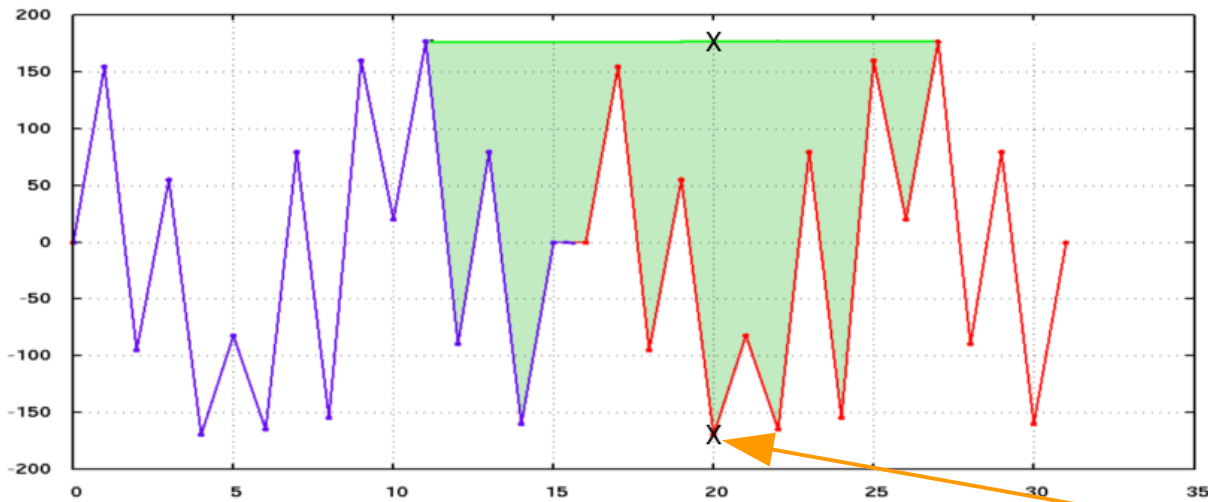
British standard BS 5400 Pt. 10 1980 introduced a visual interpretation of the rainflow cycle counting method. As a graphical method it is useful for short histories, such as for connecting rod loads in engines.

Step 1: Place 2 copies of your history side by side.

Step 2: Note the largest peaks. These will bound the region of interest.

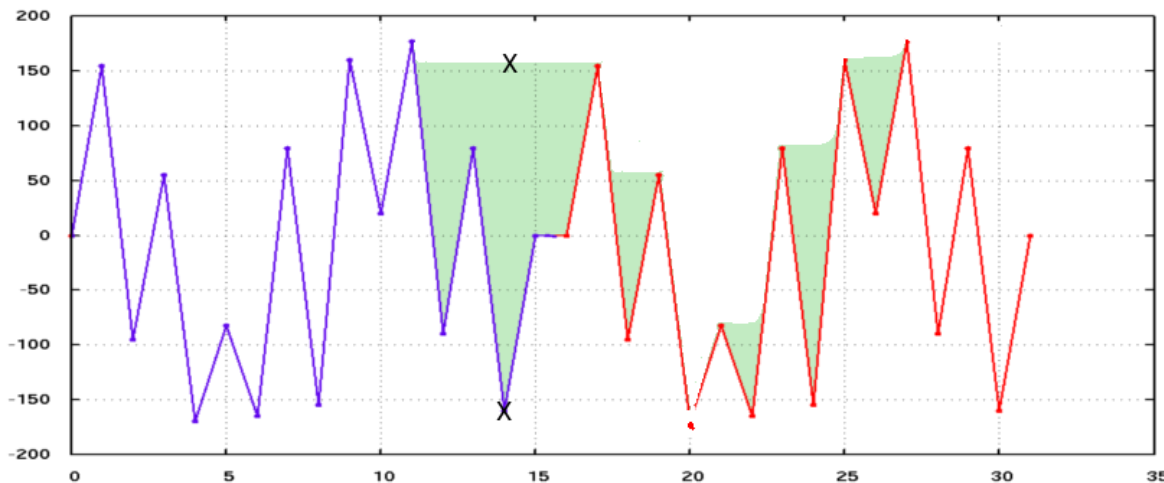


Step 3: Assume that this is the cross-section of a water reservoir.
"Fill" the region between the two peaks with water.



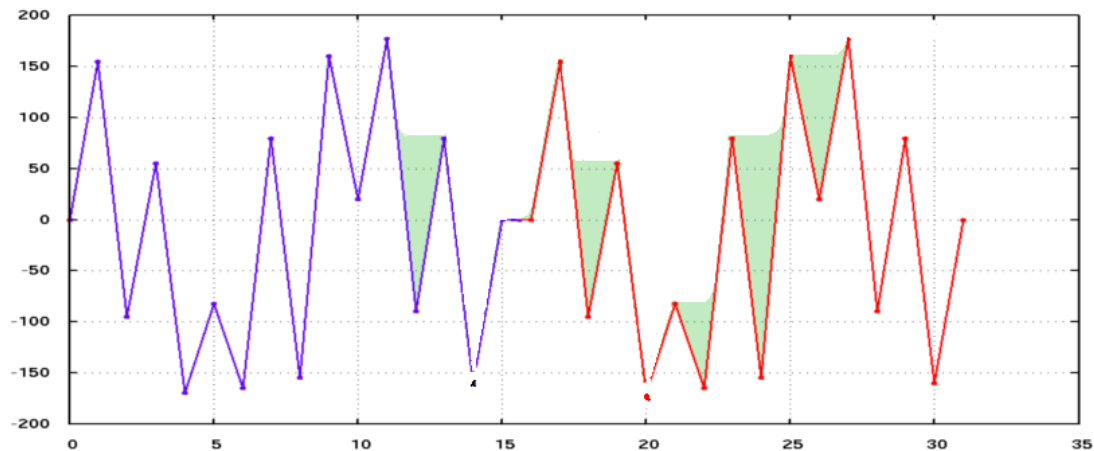
The "X" at the top of the water and the lowest point (also an X) in the reservoir will define the largest cycle. Record Xmax and Xmin.

Step 4: Drain out the water at the lowest point.



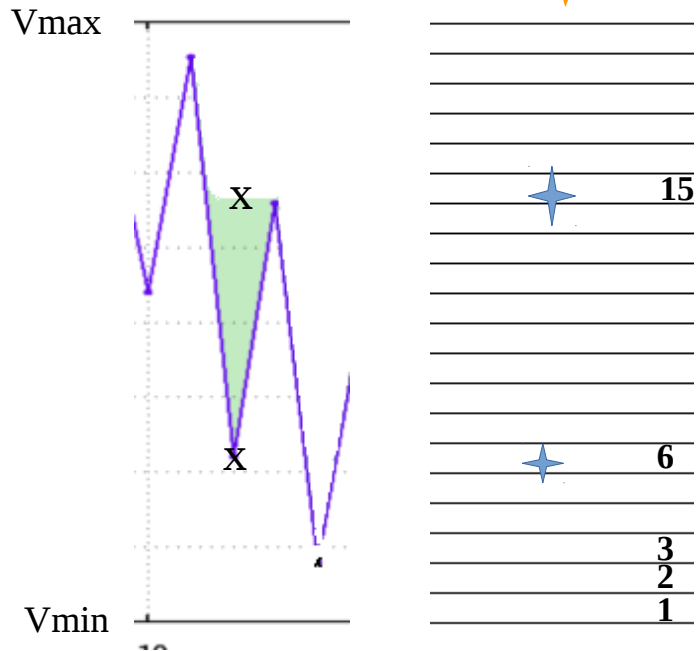
Some regions will not drain out.

Step 5...etc : Select another region of waters lowest bottom and highest water level (X to X) record this as a cycle, and drain the water from the lowest point.

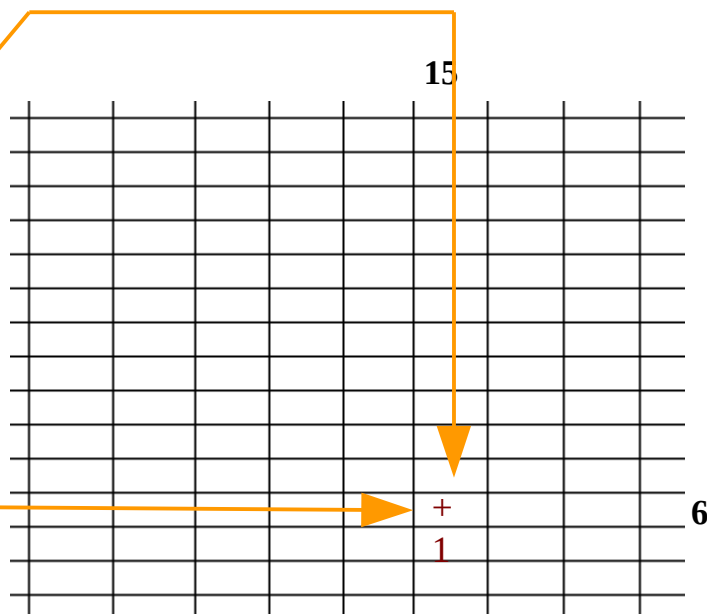


Repeat the process until all the "potholes" have been drained and their cycle max and min values recorded.

The signal range is divided into "bins"



Cycle Storage



For each resolved cycle a "1" is added to a matrix where

Column No. = X_{max}

Row No. = X_{min}

Typically the matrix is a 64x64

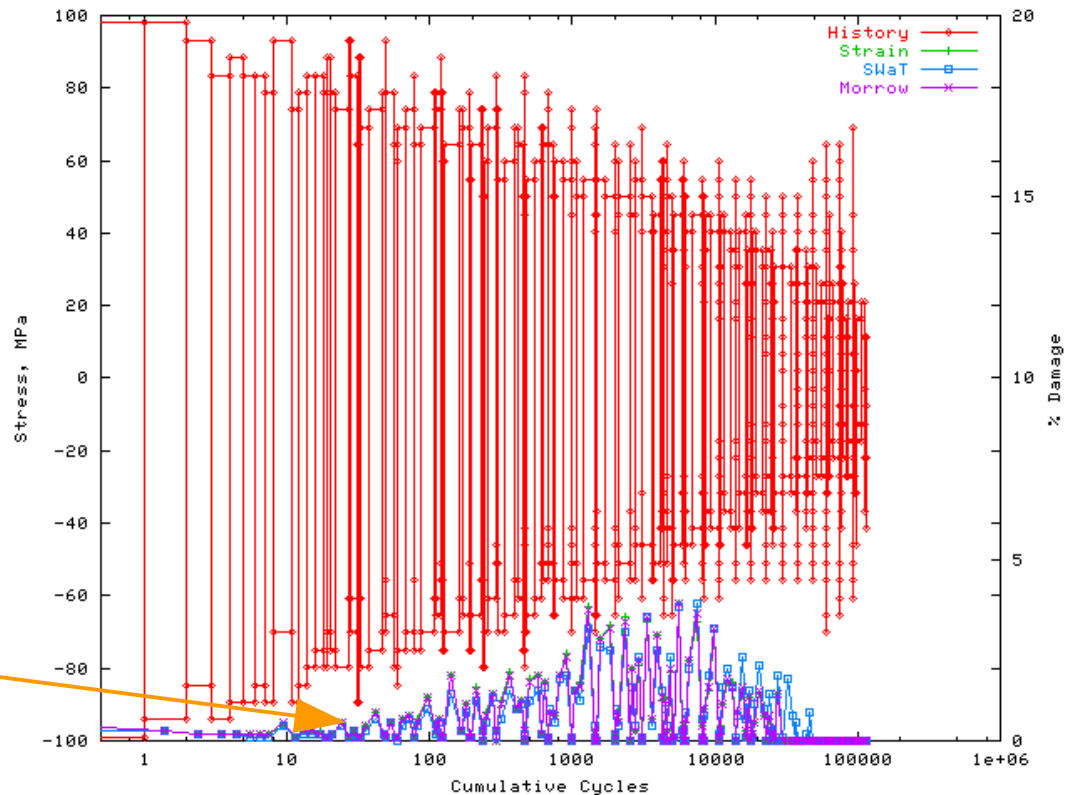
After the history has been processed the contents of the matrix are scaled back to signal value and printed to a text file with format such as:

```
#Data column code shown below:
#   Range      Mean      No.Cycles  Max.      Min.
#BEGIN DATA
  1032.      232.        1      748.     -284.
   826.      232.        1      645.     -181.
   877.      258.        1      697.     -181.
   51.6      -103.       17     -77.4     -129.
```

For subsequent calculations it is best, because of round-off effects, to use the max and min data columns, rather than the range and mean values.

A graphical "signature" of the history similar to a level count plot can be created by sorting the Rainflow file rows by Range value, and then plotting the max, min and cumulative cycles on a semi-log graph.

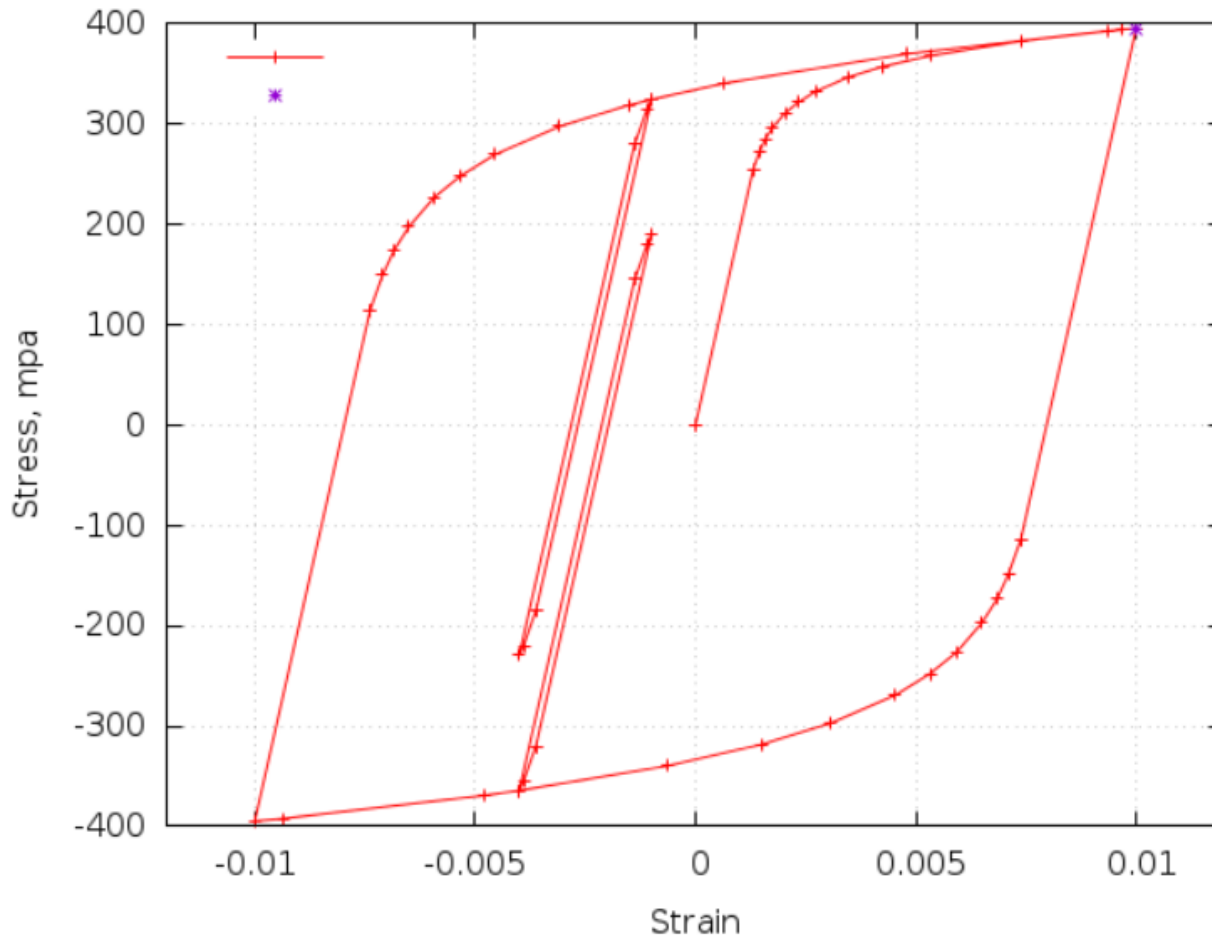
After damage processing is completed the % damage of each cycle set can be added to the plot to indicate which cycles of the history are responsible for the most fatigue damage.



Although better than Level Crossing Counting, Rainflow Counting also has some problems that under special history conditions could lead to significant damage evaluation errors. If one imposes the strain history shown below on an axial sample the stress-strain response will show one large loop and two small ones:

#MagFactor=1.0

0.01 -0.004 -0.001 -0.01 -0.001 -0.004 0.01



If one Rainflow cycle counts the Strain history the two small loops will have the same max and min values.

They have a different mean stress however, due to plastic deformation, and their mean stress values will lead to differences in computed fatigue damage, particularly if there are large numbers of the small cycles.

Most software that processes Rainflow data assumes the worst case by tying both small loops to the upper half-cycle of the largest hysteresis loop.

Summary of Cycle Counting Chapter

Level Crossing cycle counting is still in use in several industries. It has several serious deficiencies and, if you are given the choice, do not use it.

Rainflow cycle counting is the best available for creating a summary matrix of counts but it also has a deficiency due to its inability to track some material memory effects.

Both counting methods are suitable for creating short signature files for display and damage counting, but would be difficult to use for re-generation of a variable amplitude test history; too much sequence information is lost.

If sequence of cycles is of utmost importance it is probably best to use a material memory simulation model such as the LIFO technique.

For all the methods a question can be raised as to the validity of using closed hysteresis loops as the fatigue damaging event, however at present, no other technique has proven reliable.

Exercise for Cycle Counting

Download the following:

1. Level Crossing Count Program

<http://fde.uwaterloo.ca/FatigueClass/Notes/lcross.f.txt>
(mv or rename the lcross.f.txt file to lcross.f)

2. Rainflow Count Program

<https://github.com/pdprop/pdprop/blob/master/CleanPdprop/pdrain.f>
(at the Github site click on "Raw" to download)

3. A history file

http://fde.uwaterloo.ca/Fde/Loads/TotalLife/S32_1_Blz_Tx3_Bx1_Sx2.txt

Compile the programs (see top of each file for a howto) and run them with the history file as input.

Extra effort: use gnuplot to plot some of the output files