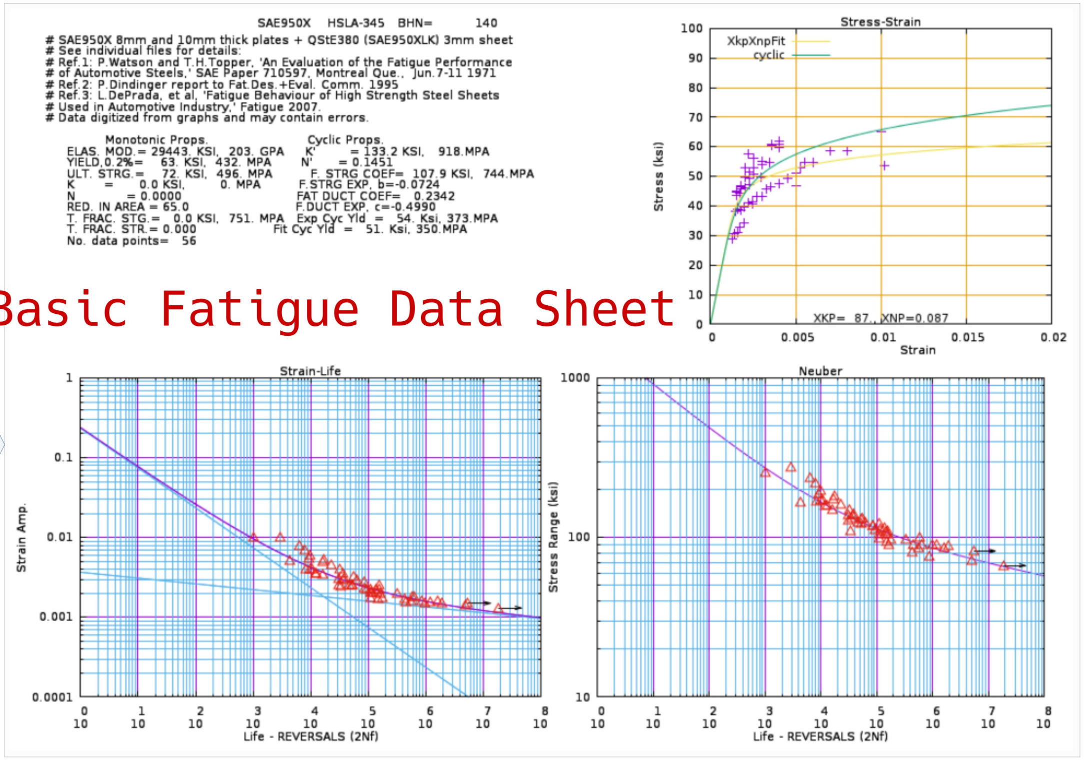
Small Specimen Testing for Basic Fatigue Properties

Philosophy:
Test small specimens for basic fatigue data.
Then design components & structures.

Axial loaded specimen



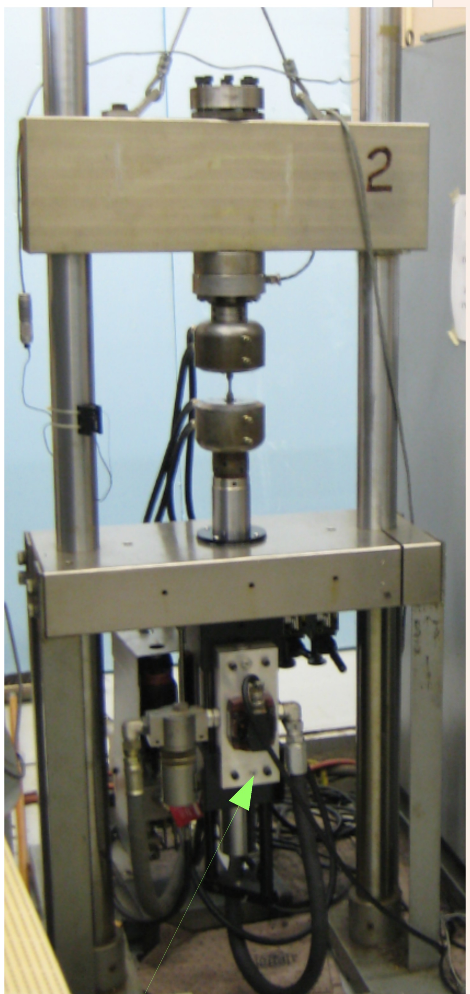
Basic Fatigue Data Sheet

Component

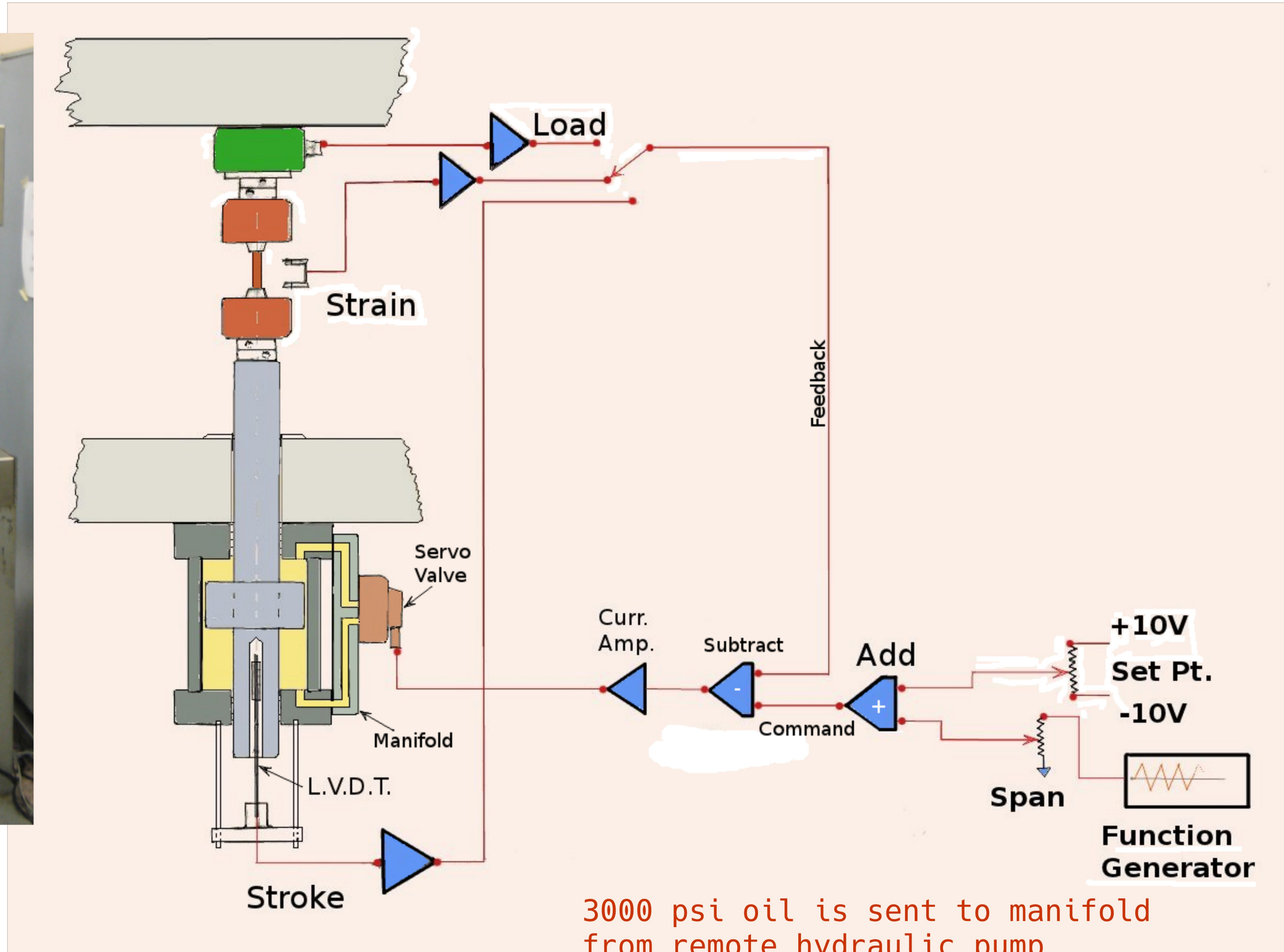
Objective
With good design: Only 1 final component test is needed

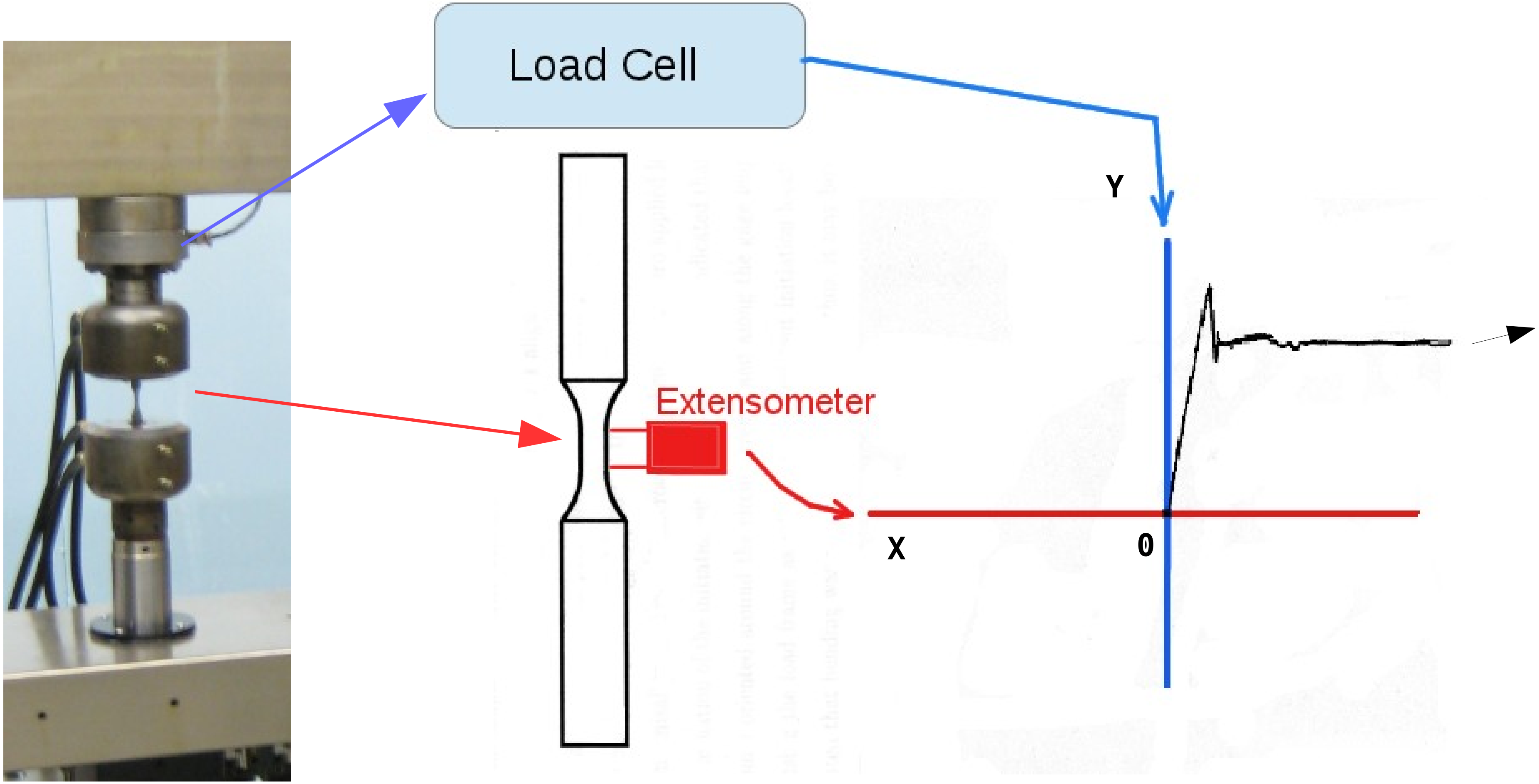
Servo-hydraulic test machines are used for small specimen testing.

If you are going to be involved in tests, make sure you understand this schematic.

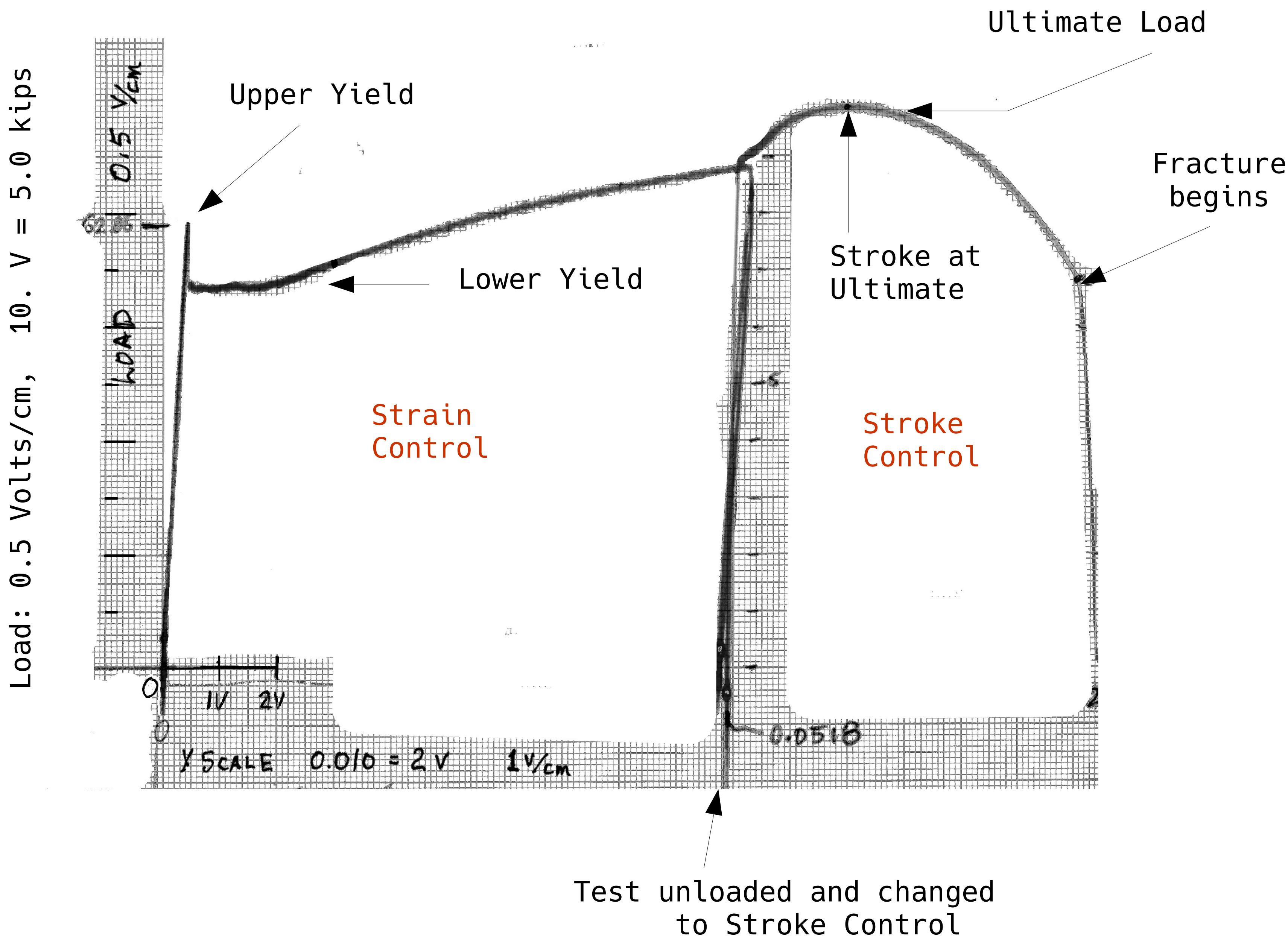


Manifold



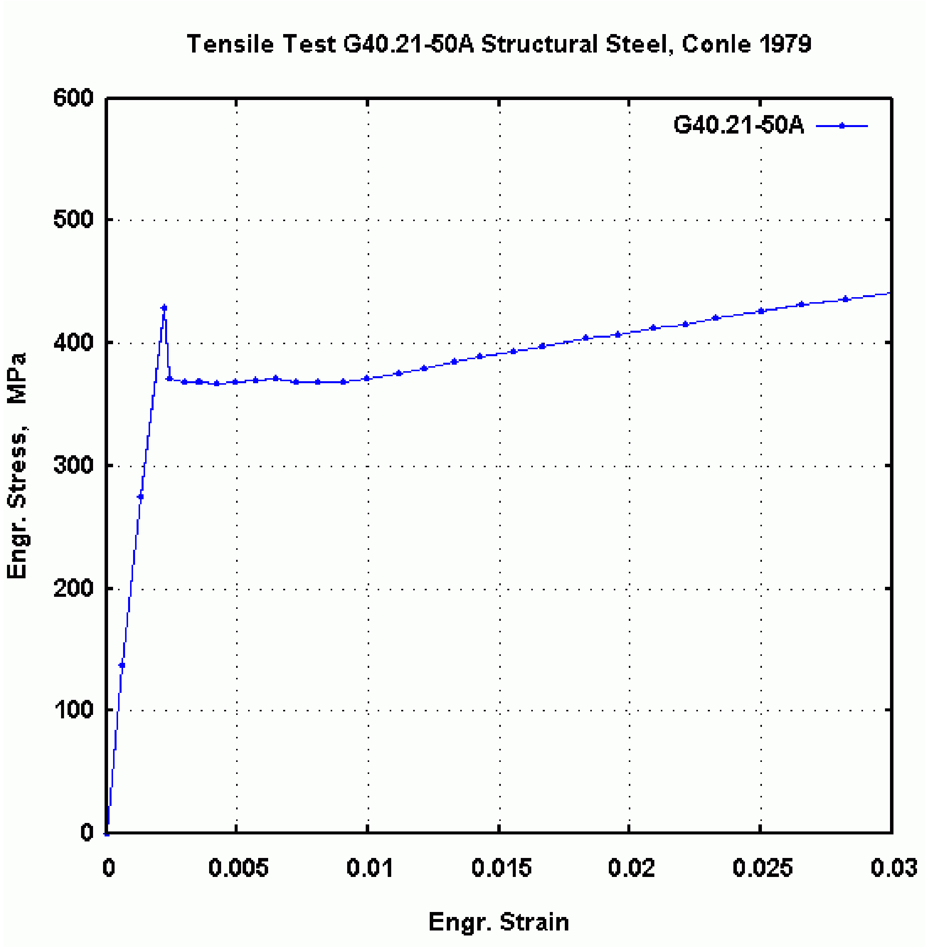

Load Cell
Extensometer
Y
X
0

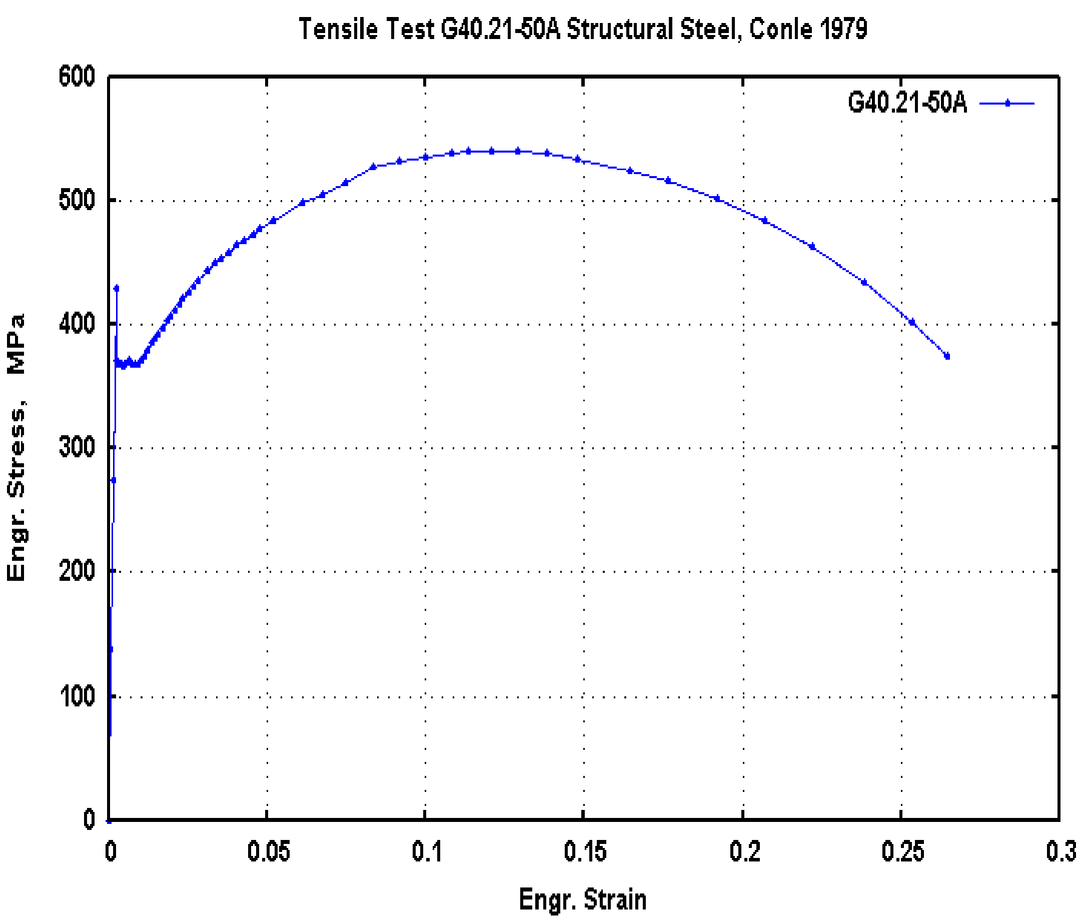
Typical Tensile Test: Raw data on X-Y Plotter Paper;
(most of grid paper removed)



After completion the test data can be digitized, or already may be in computer form. Using gnuplot one can created a gif animation of the test:

https://fde.uwaterloo.ca/FatigueClass/Videos/g40-21TensileData.gif (1.2 Mb)





Example of digitized data:
https://fde.uwaterloo.ca/Fde/Materials/Steel/Other/Astm-A588C/astm-A588C.html

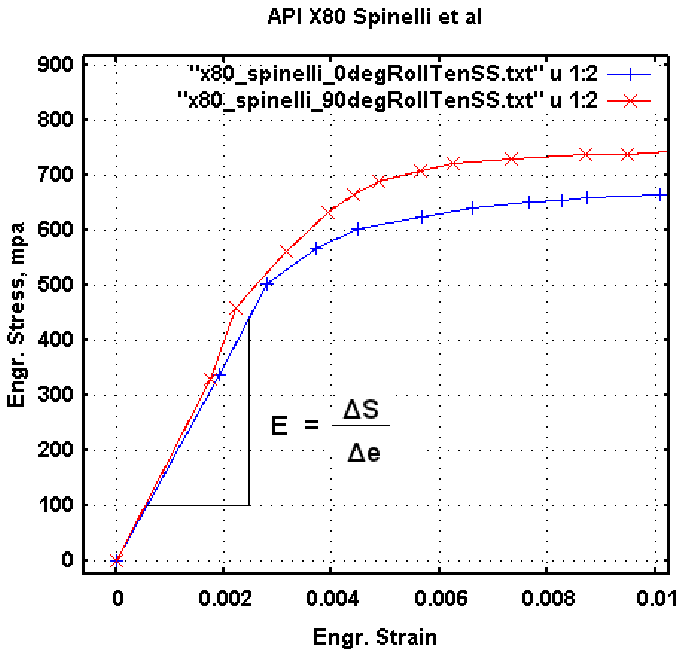
For fatigue design applications Tensile Test parameters serve primarily as material characterization values, much like a hardness test number.

The values are used as a check to answer: “Do I have the right material?”

Values you should request from a supplier or tester:

Elastic Modulus	E	(stress units)
0.2% Offset yield Stress	Sy	“
Ultimate Tens. Stress	Su	“
True Fracture Stress	σ_f	“
Strain at Ultimate	e_u	(strain units)
True Fracture Strain	ε_f	“

Hardness



If you are working with a component you should consider cutting a tensile sample from it and test it to check your assumptions. At the very least check the hardness.

Note that fatigue cycling can change some of these values, so use a new component/specimen.

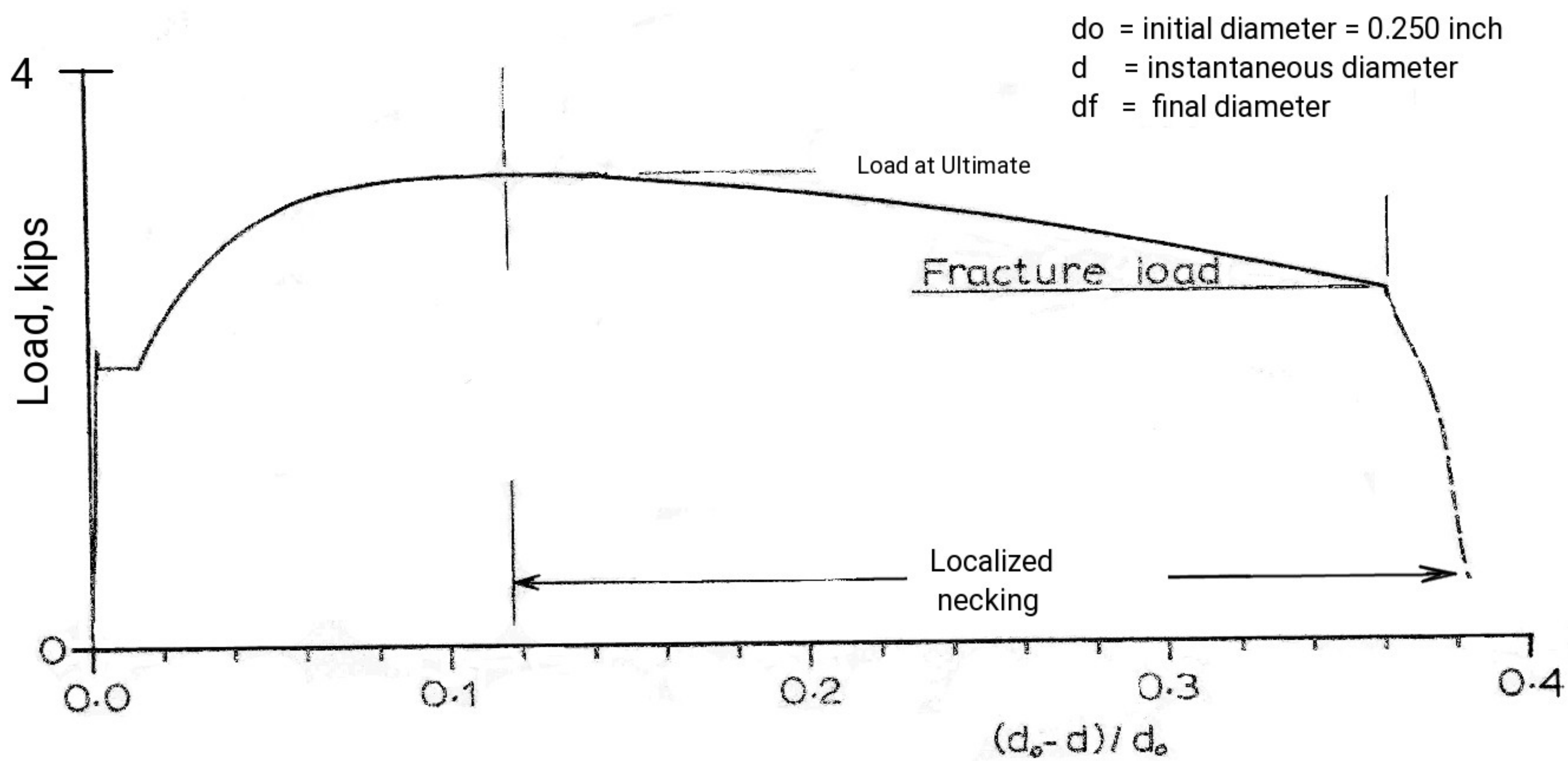
Exercise

Digitize and plot the tensile curve in picture below

1. Use a digitizer such as "engauge"
   https://github.com/markummitchell/engauge-digitizer/releases

2. Plot your digital results using "gnuplot"
   https://sourceforge.net/projects/gnuplot/files/gnuplot/

Diametral tensile test of Normalized SAE1015



See also next page

Notes for exercise on previous page;

(a) In order to use the engauge digitizer one needs to have an image of the curve(s). Thus for this exercise you will need to take a screenshot of the tensile curve on previous page.

(b) In engauge use the import option to load your image

(c) Select a Zoom level to make it easy to click on important points

(d) Check your Settings → Co-ordinates to ensure you have linear (in this case)

(e) Click on Axis Point Tool to set the three plane definition points

(f) Click on Curve Point Tool to pick the points on the curve

(g) When done File → Export the points to a *.csv file.
Use SPACE delimited data for gnuplot

(a) In gnuplot make sure you are in the correct folder which contains your data

(b) If you have saved the digitized data (space delimited) to example.csv you can use the following commands to create plots:

```
gnuplot> set term x11 enhanced font "arial,20"
gnuplot> set grid
gnuplot> plot "example.csv" using 1:2 with linespoints
                          or
gnuplot> plot "example.csv" u 1:2 w lp
gnuplot> set ylabel "Stress, ksi"
gnuplot> plot "example.csv"  u  1:($2/0.049) w lp
```

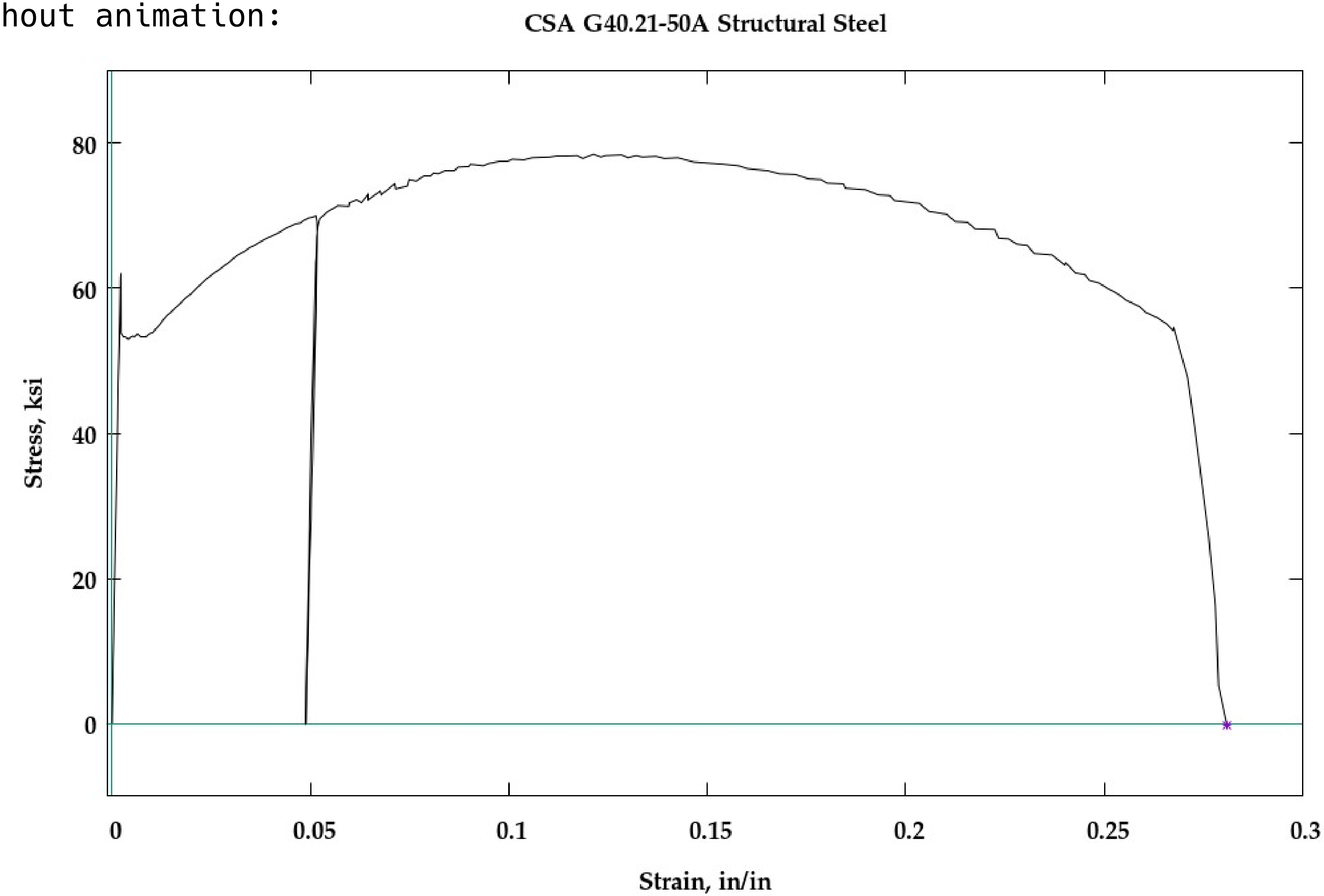
(c) You can zoom using the right mouse button. Then type “p” to go back.

(d) In lower left corner of window you will see the mouse co-ordinates in plot

In stress vs. strain co-ordinates the resulting digitization can be displayed in an animation. e.g.:

https://fde.uwaterloo.ca/FatigueClass/Videos/g40-21TensileData.gif (1.Mb)

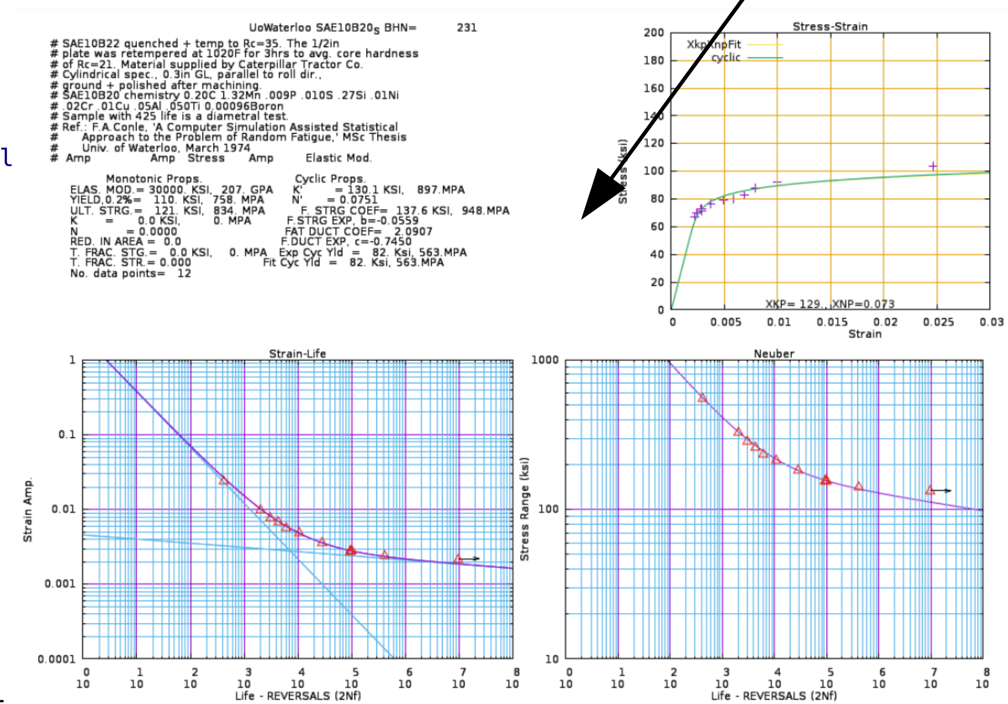
Plot without animation:



Un-notched Axial Specimen testing for basic fatigue properties

Objective: Create data for SAE standard fatigue file and make data plots

From:
https://fde.uwaterloo.ca/Fde/Materials/Steel/BoronSteel/boronSteel.html




```
#FileType= strain_life
#DataType= raw
#TIMEcol= 0
#NAME=  UoWaterloo
#NAME=  SAE10B20_Steel
#Stress_units= ksi
#Strain_units= strain
#Su=      121.00
#Sy=      110.00
#E=     30000.
#%RA=    0.0  Not reported
#BHN= 231.
#NO. FAT. PTS.=  12
#Tot Strain    2Nf    Stress  Mean  Plas.Strain   Initial
##  Amp                 Amp    Sts     Amp       ElasticMod.
  0.024650      425. 104.00    0.  0.021180      30000.   #Diametral
  0.010000     2031.  92.00    0.  0.006930      30000.
  0.007950     3076.  88.00    0.  0.005020      30000.
  0.006900     4283.  83.00    0.  0.004130      30000.
  0.005830     6201.  80.00    0.  0.003160      30000.
  0.004920    10611.  79.00    0.  0.002290      30000.
  0.003710    28893.  76.50    0.  0.001160      30000.
  0.002900    98546.  73.00    0.  0.000467      30000.
  0.002850   100012.  71.50    0.  0.000467      30000.
  0.002780    92800.  73.00    0.  0.000347      30000.
  0.002440   417400.  70.00    0.  0.000107      30000.
  0.002210  9661220.  67.00    0.  0.000000      30000. #Runout
```

Then check data and make "Fitted Curve" file for fatigue design.

Ok, lets simulate the fatigue test process.

Actions:

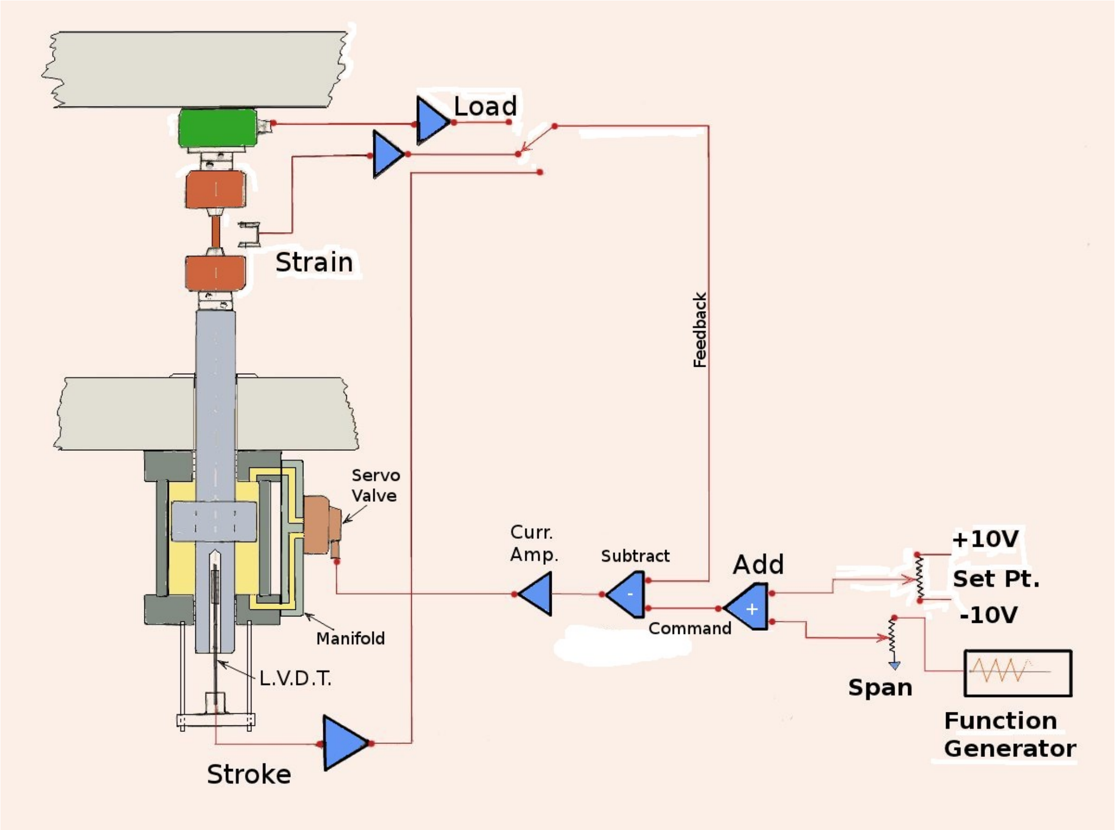
Set servo-hydraulics into Load feedback
(also called Load Control)

Place the axial unnotched specimen into the grips.

Mount the calibrated extensometer on the specimen.

Set load to zero, strain to zero

Switch to Strain feedback (Strain Control)



Lets “test” a fatigue specimen. Place machine in Strain feedback control.
Set the program triangular waveform to achieve max strains of 0.01 in Tension and -0.01 in compression. Place “Set Point” at 0.0 strain.
Start the computer or function generator waveform.

Animation:
https://fde.uwaterloo.ca/FatigueClass/Videos/bSteel_tStart.gif(3.3Mb)

The max or mins at which the stress and strain change direction are called Reversal points

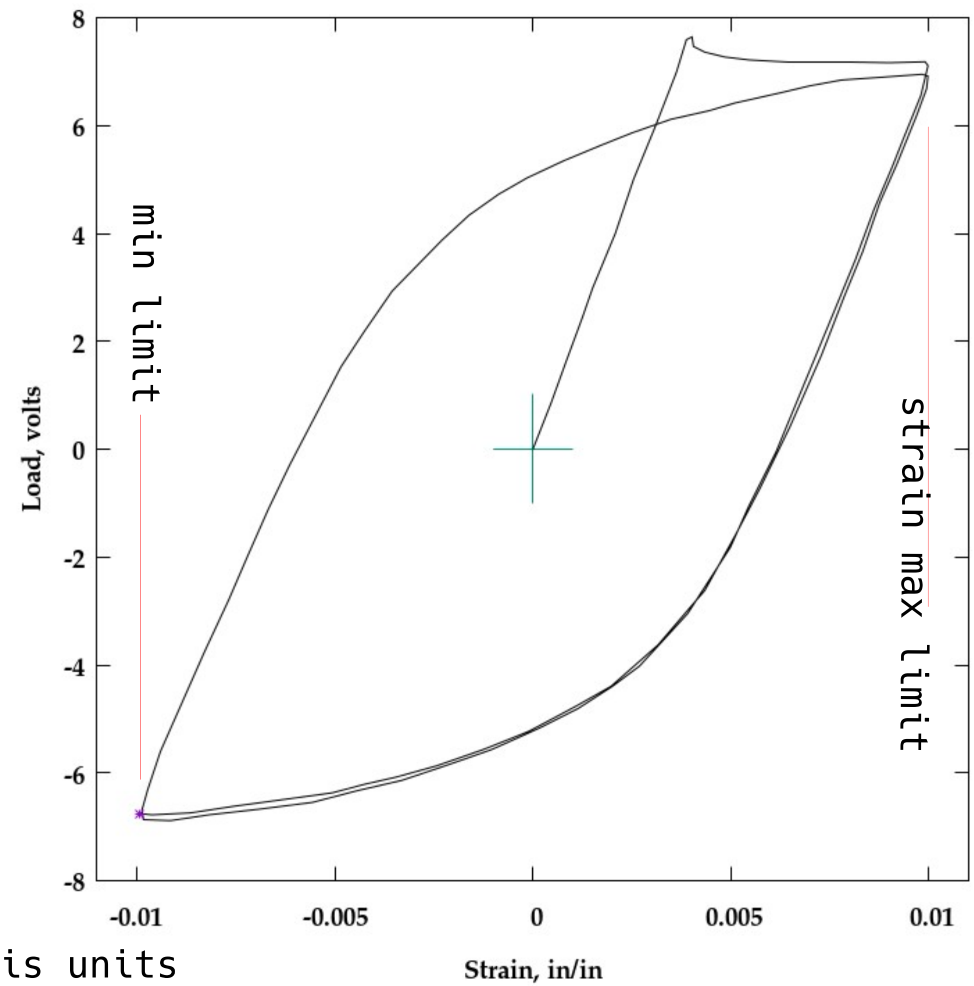
The curve between two reversals is called a Half-Cycle

and in the same vein two half-cycles constitute a Cycle.

The stress-strain shape defined by a cycle is called a Hysteresis Loop.

People generally count the number of cycles or reversals to define Fatigue life.

N_f = Cycles to failure
$2N_f$ = Reversals to failure



Y axis units have been left in volts

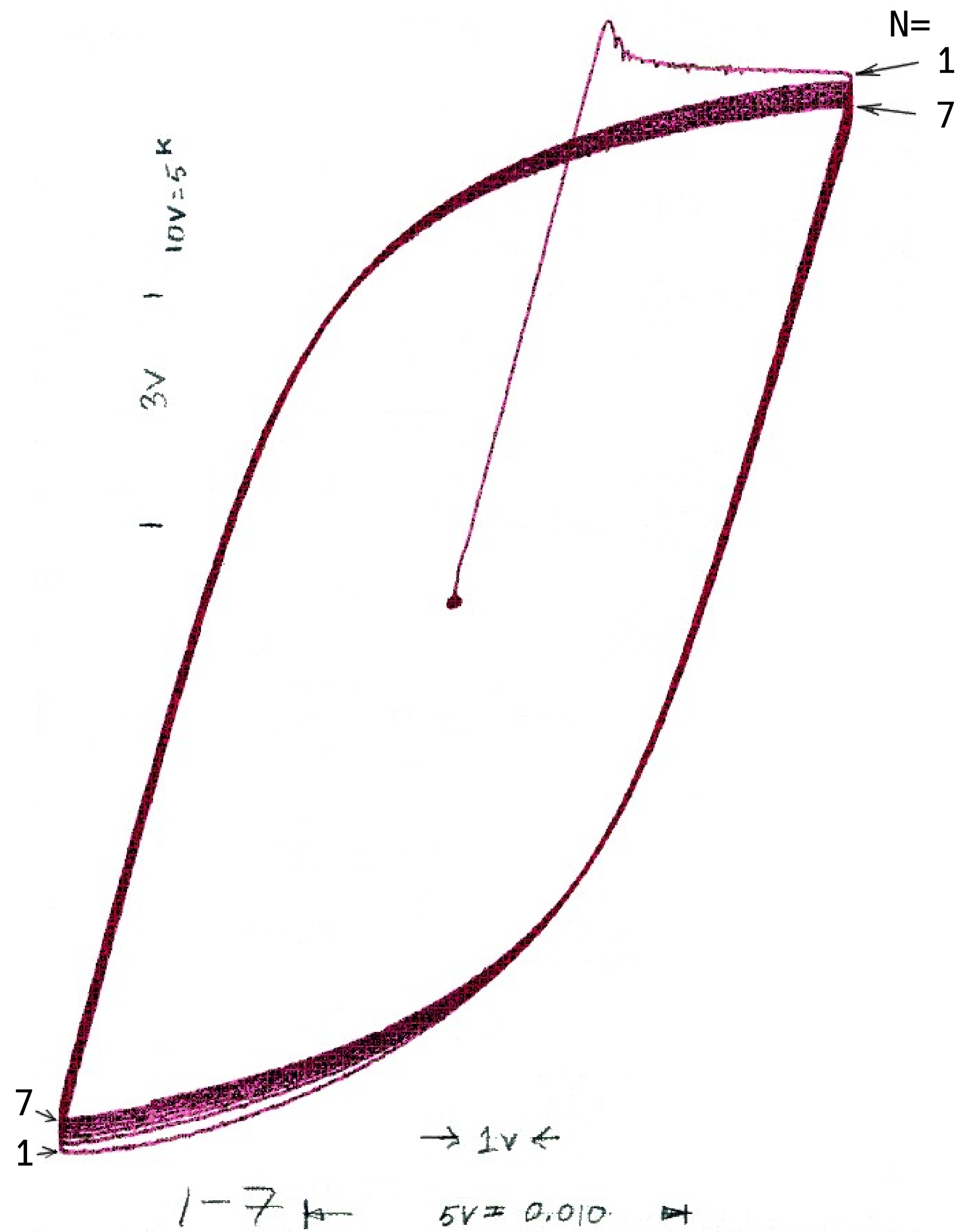
Here is the same plot as taken
directly from the graph paper.
The graph grid has been removed.
Only the first 7 cycles of the test
are shown.

This test, if run to
failure, would fracture
in about
1000 cycles

Also notice that the
load peaks are changing slightly
with each half cycle.

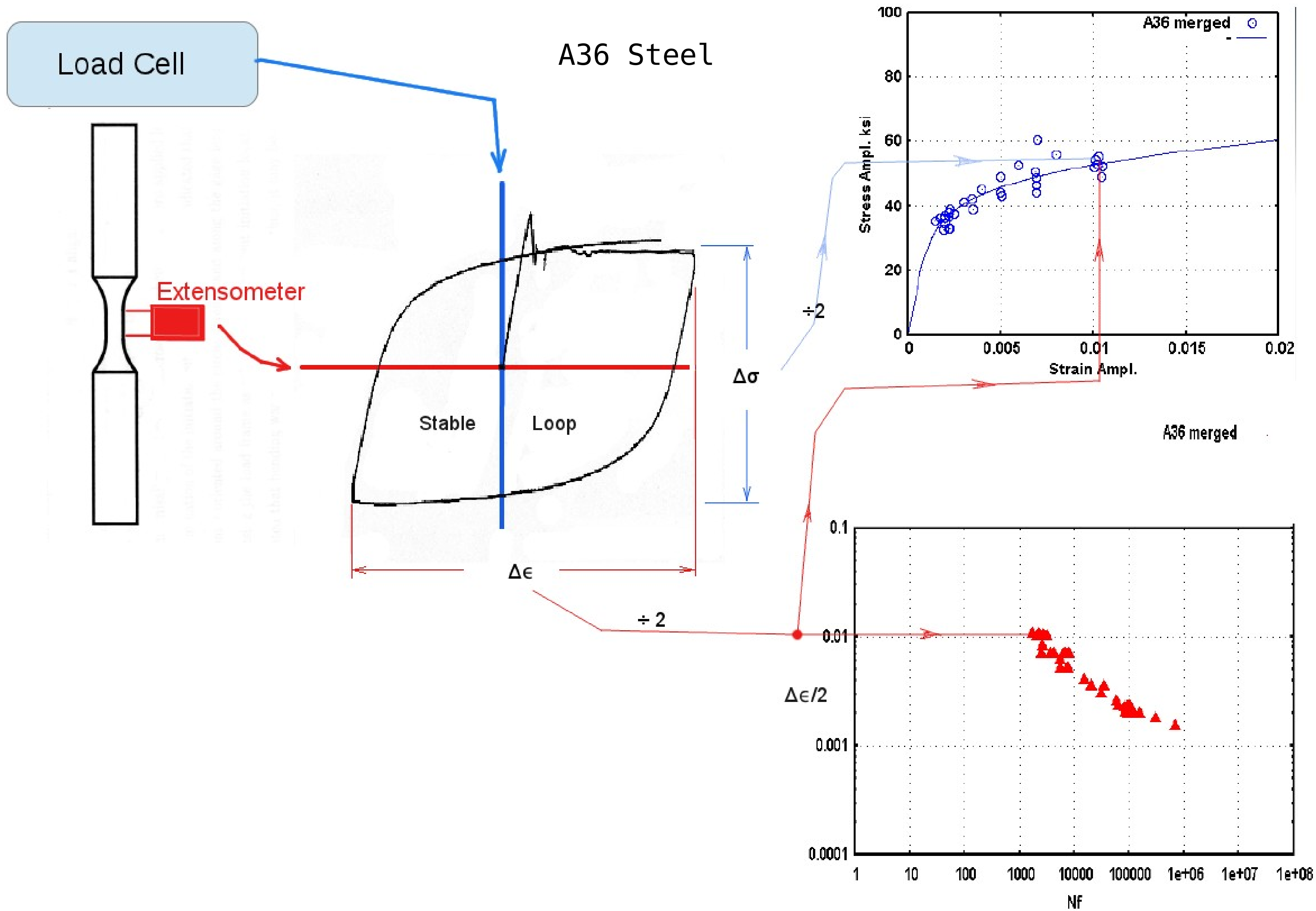
Decreasing in this case.

This material cyclically softens.
Plasticity is altering its microstructure



We need to record and graph stress, strain and life for this test.

The stress amplitude $\Delta\sigma/2$ is taken from the half life hysteresis loop.



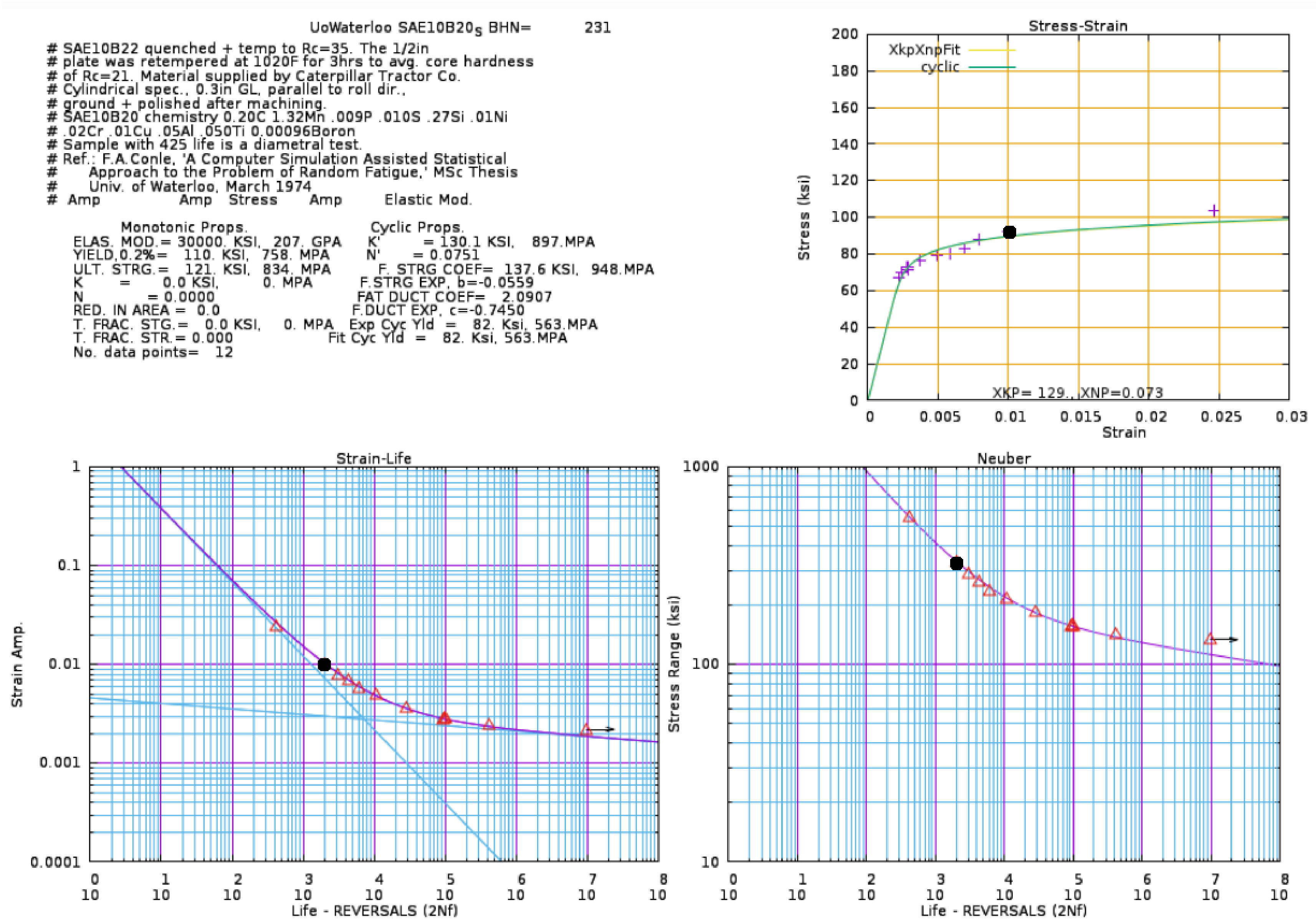
In our simulated Boron Steel test we would record the stress, strain, and life in a text file of SAE Standard format:

Here is our test

```
#FileType= strain_life
#DataType= raw
#TIMEcol= 0
#NAME=  UoWaterloo
#NAME=  SAE10B20_Steel
#Stress_units= ksi
#Strain_units= strain
#Su=      121.00
#Sy=      110.00
#E=     30000.
#%RA=    0.0  Not reported
#BHN= 231.
#NO. FAT. PTS.=  12
#Tot Strain    2Nf    Stress  Mean  Plas.Strain   Initial
##  Amp                 Amp    Sts     Amp       ElasticMod.
  0.024650       425. 104.00    0.  0.021180       30000.   #Diametral
  0.010000      2031.  92.00    0.  0.006930       30000.
  0.007950      3076.  88.00    0.  0.005020       30000.
  0.006900      4283.  83.00    0.  0.004130       30000.
  0.005830      6201.  80.00    0.  0.003160       30000.
  0.004920     10611.  79.00    0.  0.002290       30000.
  0.003710     28893.  76.50    0.  0.001160       30000.
  0.002900     98546.  73.00    0.  0.000467       30000.
  0.002850    100012.  71.50    0.  0.000467       30000.
  0.002780     92800.  73.00    0.  0.000347       30000.
  0.002440    417400.  70.00    0.  0.000107       30000.
  0.002210   9661220.  67.00    0.  0.000000       30000. #Runout
```

While the tests are underway you will probably only need to plot the Strain Ampl. vs 2Nf. When all are done make these three plots. (more on this later)

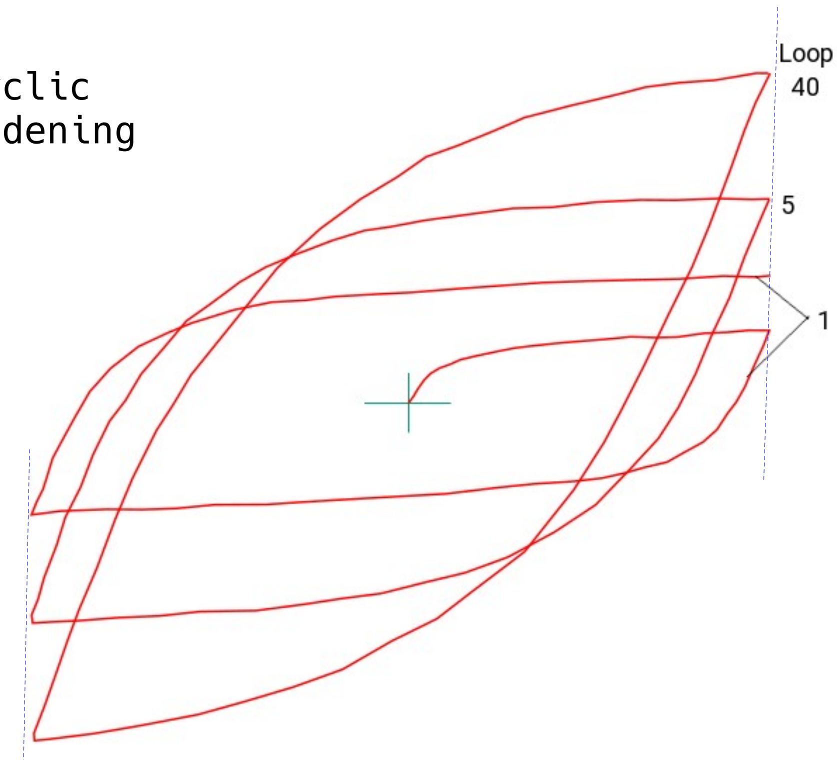
Our point in Black



Cyclic Hardening and Softening

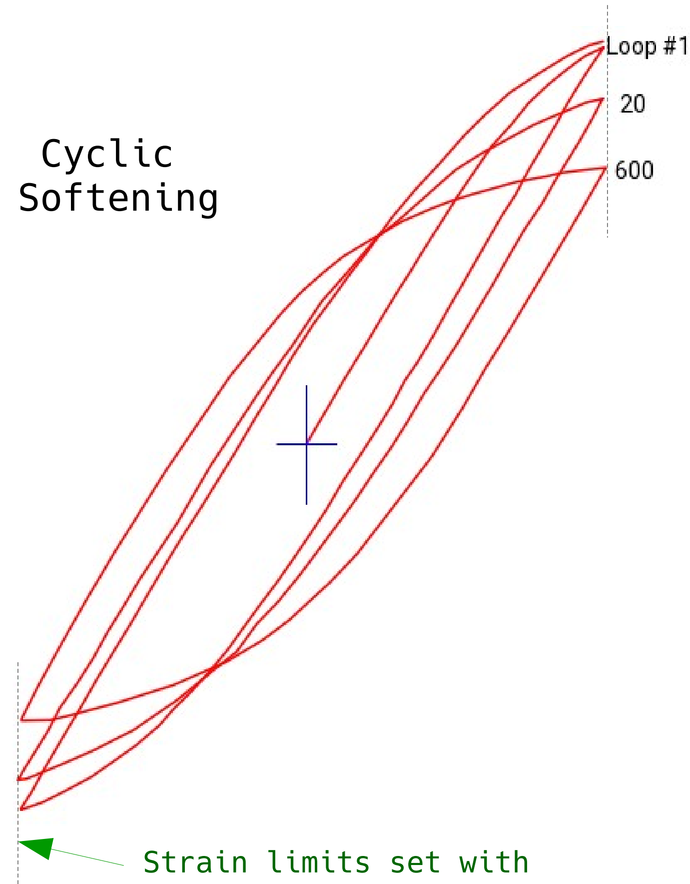
In a previous slide it was mentioned that we use the “Stable” stress-strain hysteresis loop to plot a test’s stress or strain amplitude. Typically the loop observed at ½ Life is assumed stable. This measure is needed because materials can harden or soften when fatigue cycles are imposed.

Cyclic Hardening



Strain Control

Cyclic Softening



Strain limits set with function generator waveform and SPAN

Video 5Mb
https://fde.uwaterloo.ca/FatigueClass/Videos/ohfcAnnealed.gif

Video 5Mb

https://fde.uwaterloo.ca/FatigueClass/Videos/ohfcCWorked.gif

Why use Strain Control?

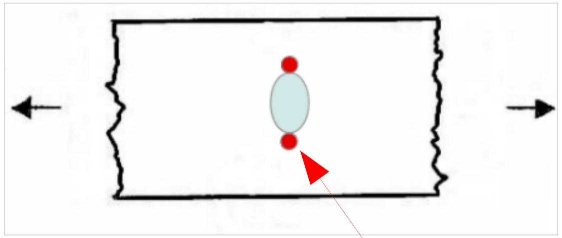
Primarily because of plasticity and cyclic hardening or softening

In this test the steel is initially elastic (Loop 1) and max load is below Yield.

After some cycles the energy input is sufficient to release the pinned dislocations, and the loop “Pops open”

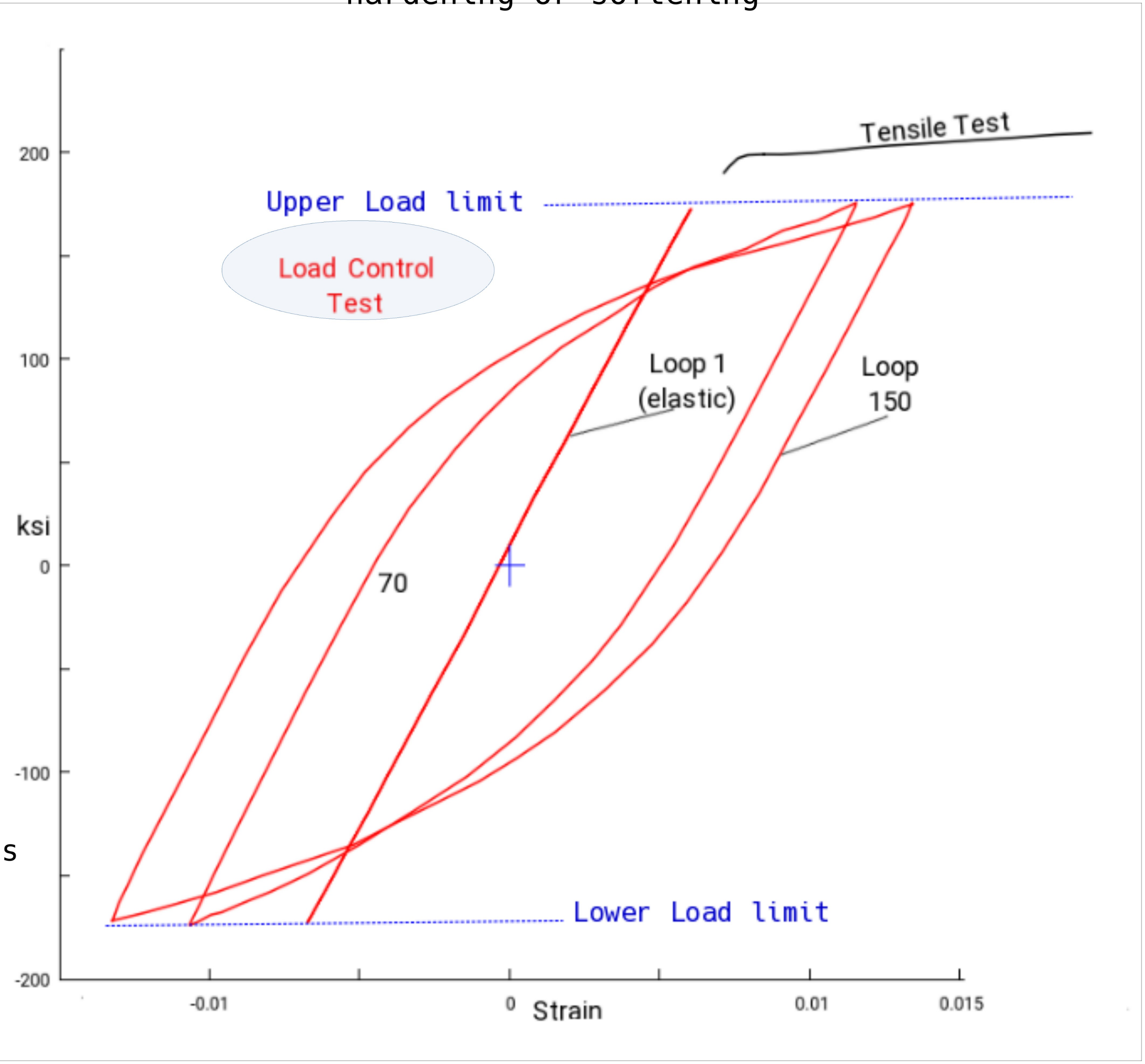
With additional cycles and cyclic softening the loops get very large.

If the upper load limit was above the yield the stress-strain could fracture the sample.



This does not happen in components where the fatigue hot-spot is constrained by the surrounding elastic structure.

Thus strain control is closer to conditions seen in real parts.



Video: https://fde.uwaterloo.ca/FatigueClass/Videos/allsae1045Loops.gif 8Mb

Here is a video of some of the stress-strain loops of the previous slide:

Video: https://fde.uwaterloo.ca/FatigueClass/Videos/allsae1045Loops.gif 8Mb

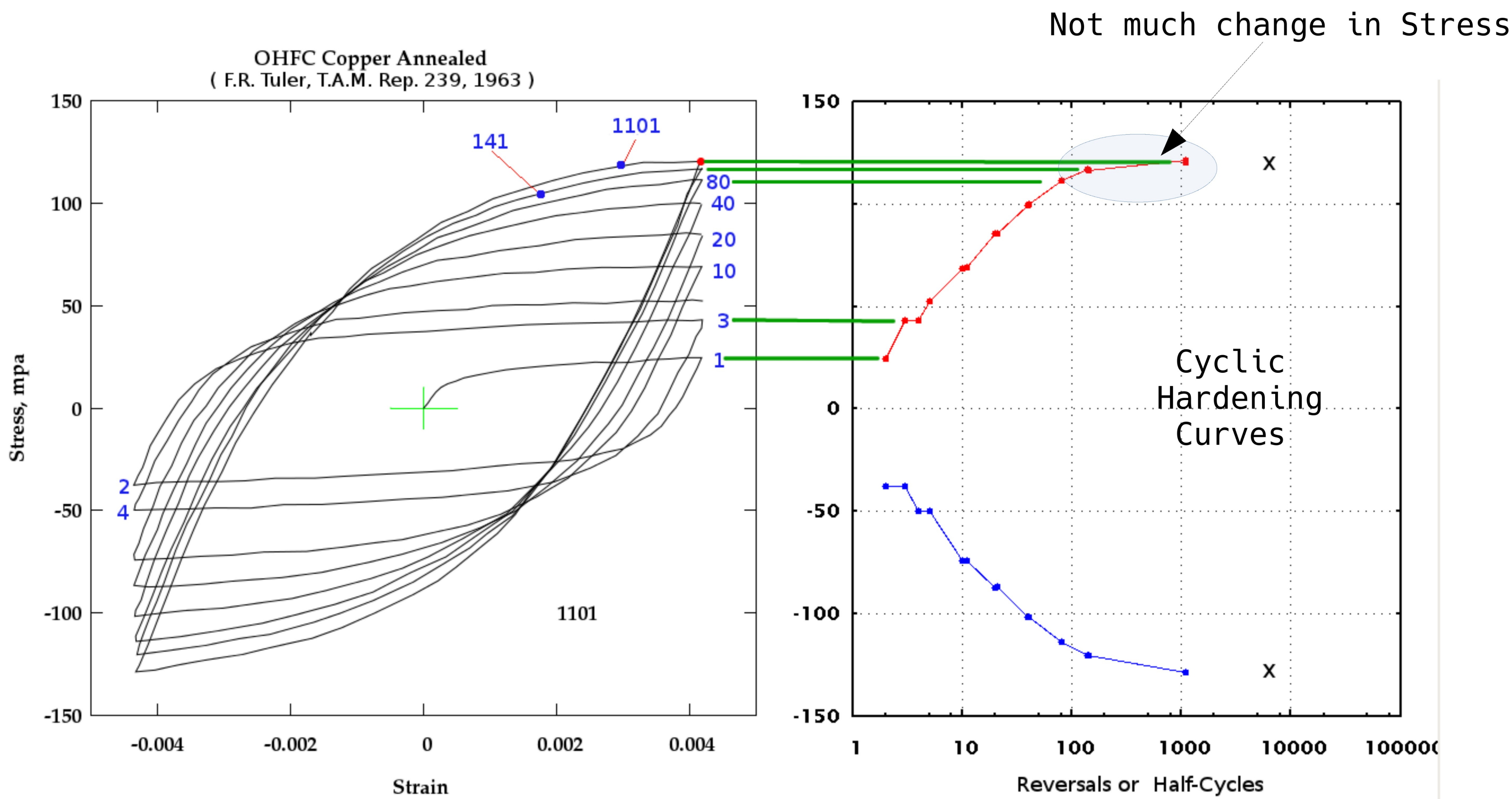
Note that in the first 20 cycles that there is little or no plasticity.

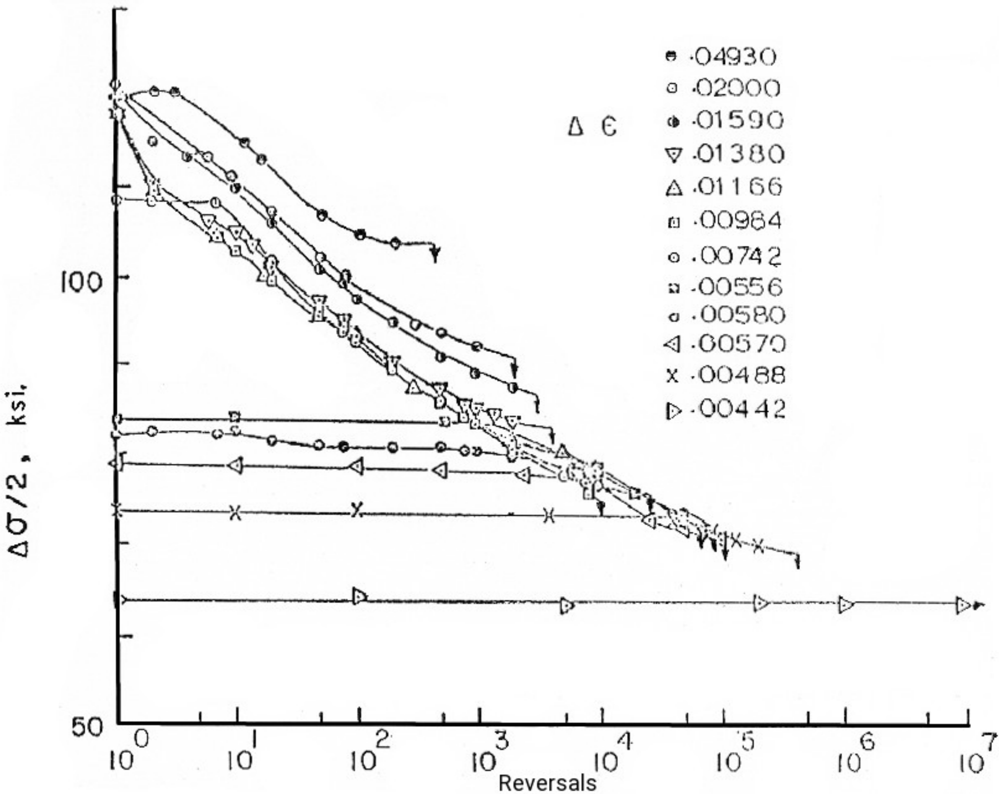
Suddenly around cycle 50 the loops “open up” and start to show some plasticity. One of the explanations is that the seemingly elastic cycles are actually imparting some energy into the steel Fe-C lattice, and given enough the dislocations that have been previously pinned by the carbon atoms are set free to move and multiply.

This behavior is seen in many steels that cyclically soften. It is one of the reasons that simple tensile test information is not enough for fatigue design.

For each strain controlled test one can collect the stress response and create a “Cyclic Hardening” (or softening) plot.

Note that the X axis is logarithmic, and that for this test there is not a big difference between stress amplitude at reversal 140 and reversal 1101. This steady state comprises most of the test life. One can conclude from this that ½ Life stress ampl. is representative of a fatigue test at this strain amplitude.





By plotting the half-life stress values for this Boron Steel vs. the test strain amplitudes the cyclic stress-strain curve can be contrasted with the tensile test result.

This material shows a drastic difference

For any fatigue analysis that requires the stress-strain relationship one should use the cyclic stress-strain curve.