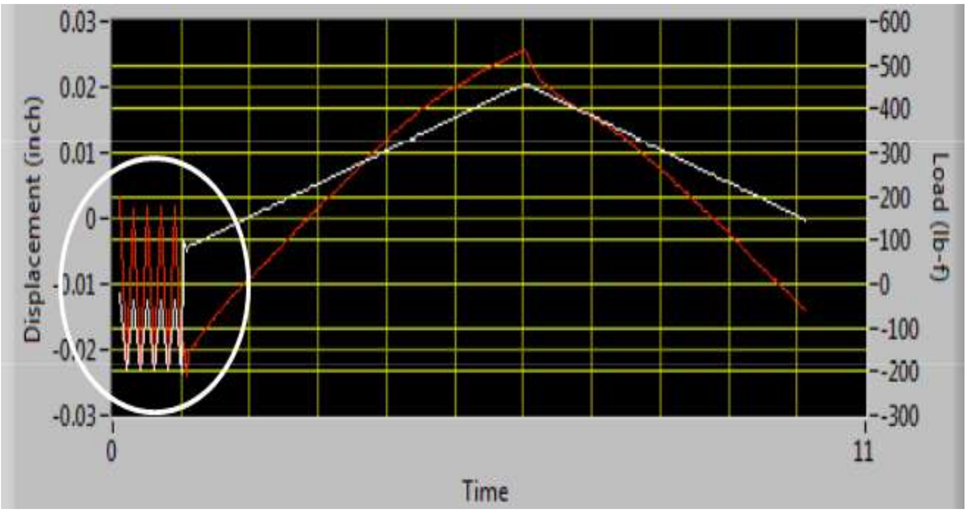
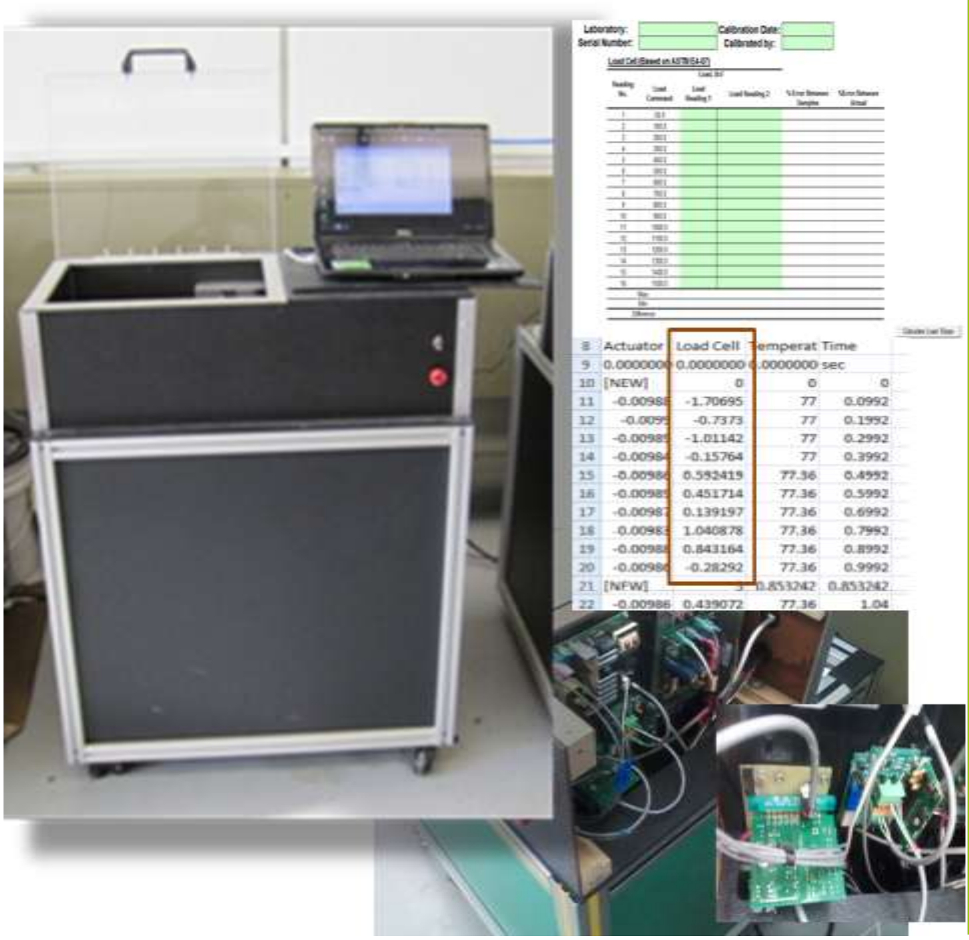


2012

OT Calibration and Service Maintenance Manual



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Calibration and Maintenance Manuals for

Shedworks Overlay Testing Machines

Contents

Chapter 1 : Introduction

The machine conditions, as well as the values at the calibration and control parameters, may determine the quality of each test results obtained. In order to keep consistency and accuracy, the conditions, performance and measurements of an OT must be checked regularly. This document summarizes steps for accomplishing these tasks.

This manual is divided into an initial part, including a description of the document contents and explaining the terminology used along the text, and 3 additional parts, that collect maintenance information on chapters according to their focus. Chapters explain suggestions and tasks that are necessary for accomplishing one specific topic.

It is highly recommended to be familiar with the terminology explained at the definitions chapter, to properly follow the suggestions that are described on the rest of the document.

The Part I, named "Control Tuning, Verification and Calibration", is aimed to identify and set correctly the machine's software parameters. This part is especially important since *measurements quality, test performance and outcomes* depend directly from the tasks described on each of its chapters.

On Part II, "Maintenance & Servicing", presents general suggestions for keeping the OT in operative conditions. Part III, describes "Troubleshooting" and trouble solving techniques. Known problems (common mistakes, software bugs) and their current solutions are covered on this part.

Finally, space for attaching additional information is left on Part IV named "Apendix". It is expected that future calibration, tuning and surveying routines will add reports, and diagrams as attachments on this Part of the manual.

Chapter 2 : Definitions

The following definitions are used to describe the terms and abbreviations used in this report

- **Calibration:** According to Wikipedia, calibration is " a comparison between measurements – one of known magnitude or correctness made or set with one device, and another measurement made in as similar a way as possible with a second device." For the purpose of this report, the term calibration will be used just to describe the procedures made for correcting *measurements* and not for procedures related to control tuning.

- **Verification:** It is a validation process, based on comparisons, but less extensive than calibration. The process compares measured values of one device to the ones coming from reference devices, with the purpose of checking if the specific calibration in question is valid or not.

- **Intercept:** A calibration intercept refers to a constant value that is added to the measurements for offsetting it, and improving their similarity with the reference values.

- **Calibration Block:** It refers to the Shedworks mechanical device used as a reference -or standard- for OT measurement procedures. It is comprised of a metallic structure attached to sensors. These sensors are a load cell and a dial gauge –or LVDT-, respectively, for giving reference measurements of load (lbs) and displacement (inches).

- **Noise:** For the purpose of this document, this is not necessarily related to any kind of unwanted sound. For the purpose of the OT test procedures, noise is a mostly unwanted random addition to a signal; which is electrical and, if properly scaled, will represent displacement (inches) or load (lbs).

- **Vibration:** Wikipedia describes this term as a reference to "mechanical oscillations about an equilibrium point". In this document and the OT implemented protocols, vibration was primarily defined as the shaking produced by the OT hydraulic pump.

- **Plant:** Within the context of this document, the term "plant" refers to the dynamical characteristics (stress/strain relation) that are present within the OT mechanical system. The OT mechanical system is majorly represented by the actuator and the specimen. It is clear then that the plant dynamics will depend on the OT conditions, and the tested element. In other words, the machine will respond similarly, but not exactly the same, to pressure changes in the actuator when testing different HMA mixes (obviously, there would be an inherent difference between different HMA mixes and the calibration block).

- **Controller:** This is the software component that commands the OT to increase -or reduce- the pressure in the actuator, for generating a movement that accomplishes the required displacement -or load- magnitude.

  The controller works taking corrective actions that depend on the dynamical characteristics of an error. *Error in the control context refers to the difference between an ideal set value and the real one observed in the plant*. In other words, a displacement controller will command an actuator to apply the needed load to compress –or stretch– a sample following the required displacement mode and magnitude (triangular). The better the control is, the more equal are the required and real displacement shapes. Obviously, the control is directly related to the plant.

- **P, PI, PD and PID Control**: P, I, and D stand for Proportional, Integral, and Derivative control actions, respectively. Consistent with the controller definition, corrective actions will depend on a scaled (P), integrated (I), and/or differentiated (D) error signal. With the Shedworks OT, these control actions are defined for the parameters *"Actuator/Load P", "Actuator/Load I"*, and *"Actuator/Load D".* The proportional parameter has no units, and the Integral and Derivative parameters are expressed in minutes.

- **Open and Closed Loop**: Within the context of this document, open loop refers to the way of producing an action over a plant without tracking a set point. A closed loop configuration indicates a feedback action, which in this case implies the use of a controller.

- **Control Tuning:** This process refers to the empirical procedures needed to find a stable control that to some extent is able to perform well for different plants. Since the OT has a PID controller, Ziegler Nichols techniques are typically used. The parameters to be tuned are the P, I and D for the OT machines. Note that control tuning procedures are not a calibration by definition. Oscillation and other control problems are not likely to be related to calibration conditions.

- **Oscillation:** Within the context of this document and the implemented OT test protocols, oscillation refers to the periodic variation of a magnitude (load or displacement) produced by the interaction between the controller and the plant. Oscillation is a sign of instability and it is undesired when testing HMA samples. Although it is undesired while testing, an oscillatory state provides information that can be used for tuning the controller parameters.

- **Ku:** This abbreviation refers to the "ultimate gain", which is the value of the proportional control parameter P at which the plant response becomes oscillatory. This value (ultimate gain) can be found by tuning the parameter P while keeping all the other parameters at zero magnitude (i.e. I=0 and D=0).

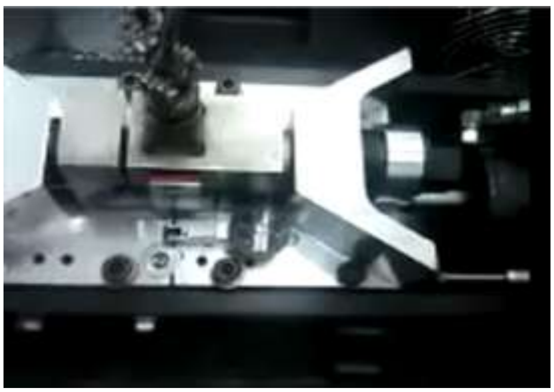
Pu: Within the context of this document, this abbreviation refers to the “ultimate period”, which is the time needed for the oscillatory signal -achieved with Ku- to complete a full period.

PART I. CONTROL TUNNING, VERIFICATION & CALIBRATION

Chapter 3 : Control tuning

Since the model of the plant is unknown, the controller parameters can be calculated just from a set of measurements. For this, and because the OTs cannot work in open loop mode, the Ziegler Nichol procedure for closed loop systems is used.

The calibration block is proven to be similar enough to the samples, since the parameters obtained from it are considered satisfactory for most of the cases. Therefore, taking into account that samples (expensive in terms of fabrication time) would be destroyed by the tuning procedures, it is ***strongly recommended to tune the controller with the calibration block***.



Calibration block is recommended as 1st choice for controller tuning

Figure 1. Calibration block

Assuming the OT is in perfect conditions, if the final tuning –made with the calibration block- is not good enough for the needed system (implying a peculiar sample for which the combination of mixture, geometry, and conditions is hard to test), there is no other choice than tuning the controller using the samples themselves. It is important to indicate that tuning procedures can be implemented equally for both: samples, or the calibration block.

Due to the OT's software characteristics, it is suggested to implement Ziegler Nichols procedure in the following manner:

1. Locate the oscilloscope probes to the output of the displacement signal conditioner; no matter if the tuning procedure is performed for displacement, or load control. The oscilloscope should be able to measure the frequency of the periodical signals resulting from the test.

2. Make a copy of the "settings.ini" in a different folder as a backup of the current controller parameters.

3. Set the Integral and derivative parameters to zero, and leave the proportional parameter in a typical value. It is:

   a. If the displacement control is tuned, then the parameters named "Actuator I" and "Actuator D" should be set to zero.

   b. If the load control is tuned, then the parameters named "Load I" and "Load D" should be set to zero.

   If the software version is related to issues on the control parameters window (see chapter about wrong input configuration), do this changes directly at the "settings.ini" file, and keep it open for further changes.

4. Perform procedures for avoiding balancing zero loads, as explained at its respective chapter. The sample –or calibration block- should be tightened at zero load, but test should not be started.

   - *If the software version is older than August 2012, effectuate procedures for avoiding initial jump, and oscillation before the test, as explained in their respective chapters.*

5. Place the controller in the mode you need to tune. For tuning the displacement PID controller, the software should be set in "displacement control" mode. For tuning the Load PID controller, the software should be set to "load control" mode.

6. Produce a step signal by commanding the machine to move.

   a. If the displacement controller is tuned, this step can be easily produced by clicking the displacement bar.

   b. If the load controller is tuned, an step signal can be created by changing the load Shift (it is recommended a value either plus or minus 100Lb-f) and updating the controller mode (clicking load/displacement button a couple of times)

7. If oscillation is not observed, increase the proportional value. If oscillation is observed, decrease the proportional value. Ensure that the new proportional values are saved, and make the machine to recover zero load.

   - *Some OT version has a known software bug that produces problems when the Settings window is used (see the chapter for wrong input* *configuration). Therefore, for this OT version, any change on the PID settings should be made directly at the "settings.ini" file. Additionally, for this version of OT the Shedworks software must be Reset (turn off and on) to make any change valid.*

8. Repeat these last two steps until you find the proportional value at which the oscillations appear. The proper name for this value is the "ultimate gain", and its usual acronym is Ku. This Ku value should be written down since it is important for calculating the PID operational point.

9. After the ultimate gain Ku is found and saved, the period of the oscillating displacement Pu should be measured at the oscilloscope display.

10. PID parameters should be calculated from the Ziegler Nichols recommended table. Since it is seen that the OT software has their time constants expressed on minutes, a slightly modification to this table is presented.

Table 1. Ziegler Nichols parameters for Stable Controllers

Parameter *Control mode*	**Actuator/Load P**	**Actuator/Load I**	**Actuator/Load D**
P control	Ku/2	-	-
PI control	Ku/2.2	(Pu/1.2)*(1/60)	-
PID control	Ku/1.7	(Pu/2)*(1/60)	(Pu/8)*(1/60)

P control is the simplest way to control the machine, and for many cases, it would be enough. PI control provides an additional correction for errors that are prone to be held on time, and it is the most recommended kind of control for this procedure. PID control includes corrective action for sudden changes, and therefore, improves the correction speed. Although the full PID control seems to be the most appropriate way to improve control, the derivative term is very sensitive to noise and sudden changes, and therefore, not necessary the best choice for every case.

The set of values calculated from this procedure should be saved. It is a good practice to check if these values are present at the used "Setings.ini" file.

It is important to note the following points:

- This procedure provides values for just one set of parameters at a time, depending if the control tuning has been performed for displacement or load. It is, either values for {*"Actuator P"*, *"Actuator I"*, *"Actuator D*"}, or {*"Load P"*, *"Load I"*, *"Load D"*} can be obtained at once. If both set of parameters need to be tuned, this procedure must be performed on each mode (Displacement/Load) separately.

- This control tuning is expected to perform well for samples that hold dynamical characteristics similar to the ones on the element (samples or calibration block) used for tuning the controller.

- The overlay testing machines do not adjust automatically to any plant (check definitions). Instead, it leaves the user the selection of the best parameters for the machine to behave correctly while testing a mixture. Therefore, it is responsibility of the user to recognize control necessities, and to ensure the control parameters are good.

Chapter 4 : Verification & Calibration

Verification and Calibration are procedures that collect and compare measurements from the OT and the calibration block. Verification is performed to check if -at any point- the OT measurements lose consistency. In the other hand, calibrations goal is not just checking, but correcting current measurements.

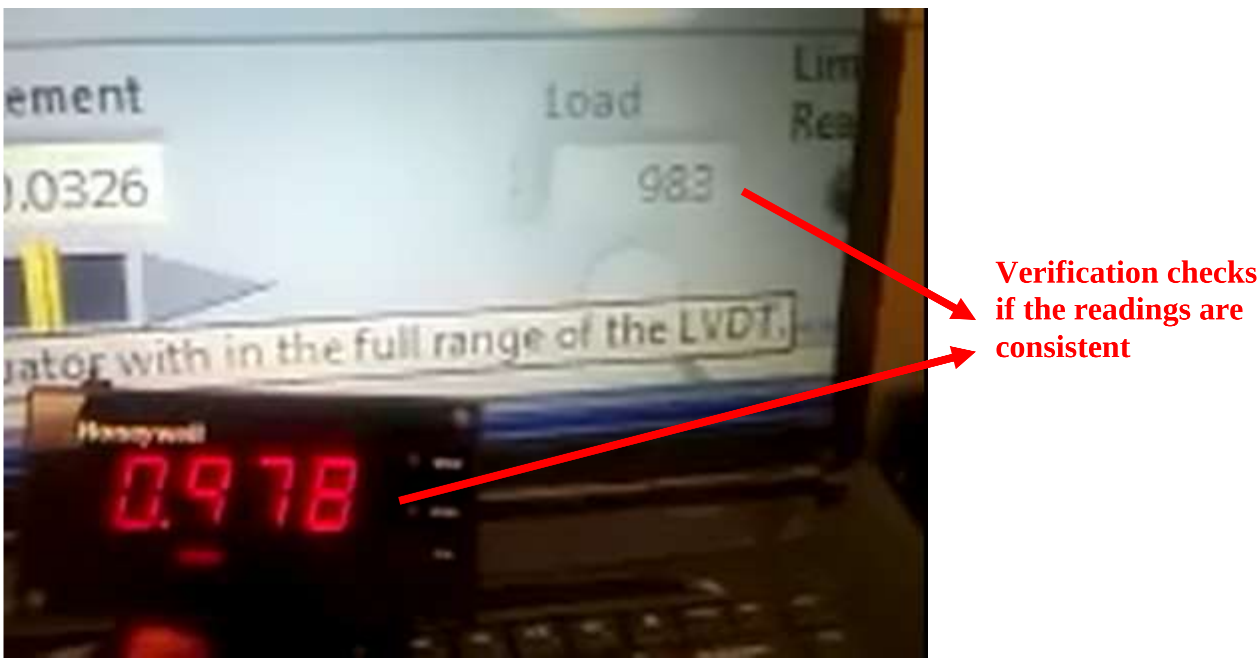


Figure 2. Example of Verification for one value

Verification will not require as many measurements as a calibration procedure, and therefore, it can be implemented more frequently. Used periodically it could help to keep good OT's performance and measurements, detect problems and avoid waste of batches on incorrect tests, and even predict the necessity of calibration.

After few measurements, Verification provides hard proof about wrong calibration values, zones of incorrect OT readings and movements, unexpected behaviors of the mechanical systems. Therefore, it can be used as the main debugging tool, especially for apparently correct tests with unexpected results.

A good calibration will ensure that the measurements on the OT are right. Unfortunately, calibration just compensates linear numerical unbalances. Control issues, Electrical or mechanical problems, and software bugs cannot be fixed with calibration.

Recommended methods with non-automatic calibration system.

A base load range has been chosen to check if the displacements are measured properly under the toughest load conditions that can be reached during the tests. It is seen that it is not likely to have load responses out of [-1000, 1000] lb-f. The displacement range that produces this load response includes the usual 0.025'', plus the gap variability, and an additonal zone covering for external variability.

The subsequent steps combine the objectives of ASTM practices -explained at E2309 and E74- with the necessity of quickly finding conditions that could affect OT tests repeatability, or correcting properly calibration parameters.

1. Create a backup copy of the "calibration.ini" file, which is under the "Shedworks" directory.

2. Initialize the machine;

   2.1. Be sure that each sensor is correctly located inside of the OT and the calibration block.

   2.2. Turn on the OT, the computer, and after Windows is ready with the network connections, turn on the OT software.

   2.3. Turn the pump on, activate load control, place and tight properly the calibration block to the OT moving plates.

   2.4. If the system has not had a warm up period yet, keep the calibration block powered for at least 10 minutes, meanwhile the environmental chamber's door has to be closed for regulating the inner temperature to 77F. This will ensure that the sensors at the OT, and the reference, reached electrical and thermal standard conditions.

3. Open the calibration window and for both, load and displacement fields, type 0 and 1 respectively at the A and B parameters (intercepts to 0 and slopes to 1). This scaling sets the OT for providing fine displacement, and readings in volts.

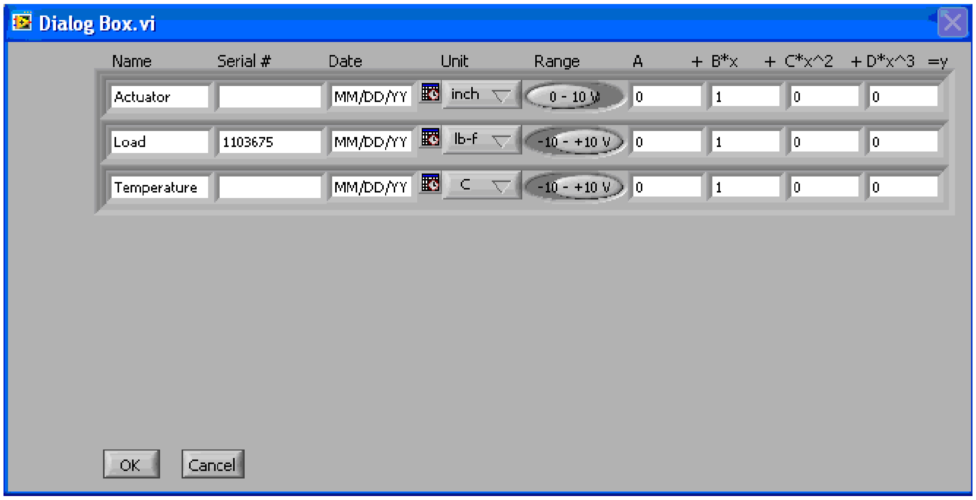


Figure 3. Intercept to 0 and slope to 1 for reading Volts in Displacement and Load

4. Select displacement control and make the actuator move a couple of times to both ends, as preloading of both load cells.

5. Starting from slightly above 1000 lb-f, produce displacements to the compression direction. The step size can be regulated by changing the displacement slope at the calibration window.

   a. For load verification,

      Take load data about each multiple of 100 lb-f, as ([lb-f],[volts]) pairs -which respectively come from the Calibration block and OT screens-. Data, should be taken over the span of [-1000, 1000] lb-f.

   b. For load calibration,

      Repeat the verification procedure, back and forth at least 3 times. It is, the ([lb-f],[volts]) pairs should be taken while travelling from above1000 lb-f to below -1000 lb-f, then increasing from below -1000 lb-f to above 1000 lb-f, and then decreasing one more time from above1000 lb-f to below -1000 lb-f. According to the standards, having at least 3 repetitions along the testing span will ensure measurements repeatability.

      Note that the number of points can be incremented or reduced depending on the available time. It is required a minimum of 10 measurements, uniformly distributed along the full measuring span.

   c. For displacement verification

      i. At the starting position (1000 lb-f), verify the displacement sensor is prepared to take measurements. If an LVDT is going to be used, double check it is firmly located inside of the calibration block . If the calibration block uses a dial gauge, double check if this gauge is set as for measuring compression displacements.

ii. While moving in the compression direction, for each 0.001'' displacement, write down the appearing ([Inch],[Volts]) pairs (respectively read from the Calibration block's dial gauge and OT screen). It should be collected as many pairs as needed on the span of [-1000, 1000] lb-f (usually around 50 points)

Note that:

- Load and displacement points are achieved by producing small steps (displacement control). The resolution of the calibration / verification procedures can be affected if the size of those displacement steps is too big. The "displacement step size" parameter at the "calibration.ini" file can be tuned according to the necessity. Changes in the step size can also be achieved by modifying the calibration slope B at the calibration window.

- If the displacement slope is scaled at any point to improve the step size, this change should be written down with the affected readings, such that they can be transformed back to Voltage. It is, if B is changed to 0.1 for improving the step size, an OT reading equal to X would be equivalent to X/0.1 [volts]

- If a dial gauge is used, be sure to reset the dial gauge proper every 0.025''.

- The number of points can be incremented or reduced depending on the available time, and the required quality of the regression. It is required a minimum of 5 measurements, uniformly distributed along the full measuring span.

d. For displacement calibration,

Repeat the displacement verification procedure, travelling back and forth along the load span, for at least 4 times. It is, the ([inch],[volts]) pairs should be taken while travelling from above1000 lb-f to below -1000 lb-f, then increasing from below -1000 lb-f to above 1000 lb-f, then decreasing one more time from above1000 lb-f to below -1000 lb-f, and finally increasing one more time from below -1000 lb-f to above 1000 lb-f. According to the standards, having at least 4 repetitions along the testing span will ensure measurements repeatability.

6. With the obtained data, create a regression Line.

- The resulting data is expected to be linearly distributed along the measuring range. Therefore, F value should be very significant and R square should explain more than the 95% of the regression. Any source of non linearity should be checked.

- For verification purposes, the parameters of the regression line should be compared to the original ones saved at the backup "settings.ini" file. Slopes should not differ majorly. **In a formal way, the hypothesis that the parameters of this regression and the calibration lines are equal, should be tested at 95% confidence.** This criterion may differ depending on the experiments tolerance, clarity of the signals, accuracy of the calibration block, and time availability, among other constraints.

- Intercept values are not tested since, for versions of OT made earlier than 08/12, they are associated with irregular conditions. Displacement intercept must be always kept to 0 due to a known software bug that produces an undesired initial jump. Load signals are seen to have small shifts whose reasons are not completely clear. When OT is in good condition, it is believed that small but consistent variability is dependent on temperature and electrical factors that cannot be controlled. Therefore load intercept is recommended to be periodically corrected depending on the system zero load conditions, and without the necessity of any exhaustive Calibration. For more information, please check the parts of this document related to balancing zero load and troubleshooting.

- Load and displacement regression lines, obtained from the suggested [-1000, 1000] lb-f span, should appear linear. **In the case that non linear ranges are observed, they should be reported.** Under unreliable calibration, the results of testing can be misleading.

- If a non linear region appears at the displacement regression line, testing results can be trusted just if the sample's response lies inside of the linear zone that is represented by the current calibration values.

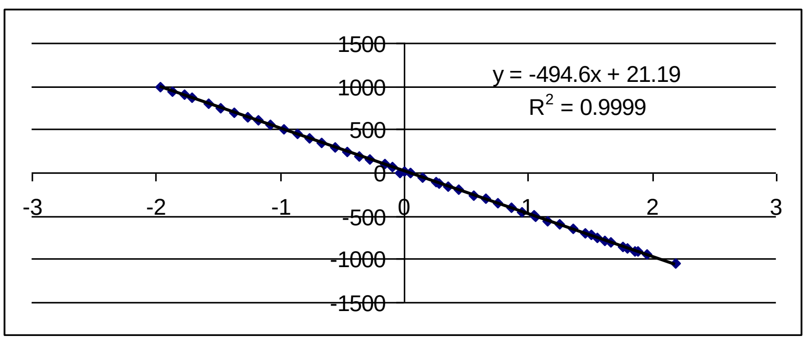


Figure 4. Classical Calibration curve for load: [Lb-f] vs. [Volt]

- It should not be forgotten that the displacement shift is associated to software issues that affect the result of the test. Although a displacement calibration curve would suggest include a shift value, this must be kept as 0 (check the sections related to the "initial jump" condition, and the procedures for avoiding it).

Manual Verification & Calibration Examples

a. Load verification

A report should clearly identify the machine ID, the technician responsible for evaluating the machine and the dates at which these procedures are done. Original conditions should be specified in such report. As well, data, data transformations, statistical analysis, should be presented.

In the following example, data was taken in the form ([Volts],[lb-f]) pairs, as explained in previous pages. In this case, the range [-1000,1000] lb-f is divided into measurements separated by 100 lb-f.

A regression line should be calculated from data points collected along the whole operation range of the OT procedures. If the parameters from the calculated regression line and the current calibration are not equal with a 95% of confidence, a calibration is needed.

Note:

- Under the suspicion of non linearity, verification should be made with more points.

LOAD VERIFICATION REPORT (PAGE1/1)

Machine: OT11ASN07231
Date: 07/05/2012
Technician: George P. Foreman

ORIGINAL CONDITIONS:

Intercept	-5.71	Last Calibration date	UNKNOWN
Slope	493.7	Quality	POOR

DATA

[lb-f]	[v]
1003	2.041
898	1.825
797	1.622
702	1.429
605	1.234
505	1.035
399	0.828
306	0.633
205	0.435
105	0.232
4	0.03
-102	-0.19
-199	-0.385
-304	-0.599
-402	-0.796
-500	-0.992
-598	-1.191
-698	-1.392
-799	-1.595
-895	-1.788
-1000	-2

OBSERVATIONS:

- Data lies linearly along the whole testing range. No signal of mechanical damage, or inconsistent calibration.
- Slopes and intercepts of the current calibration and the obtained regression line are not equal with the 95% of certainty.
- This OT is recommended to have a Load calibration.

SUMMARY OUTPUT

Excel produces these tables by using Tools/Data Analysis/Regression.

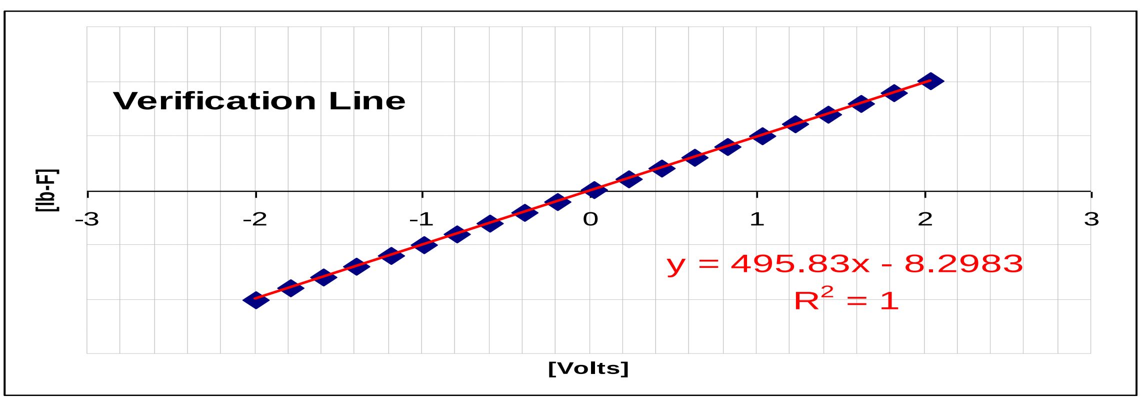
The current calibration slope must be inside of this interval to be considered equal with 95% of confidence

R square should be bigger than the 95% to be considered linear enough

REGRESSION STATISTICS	
Multiple R	0.999997
R Square	0.999995
Adjusted R Square	0.999995
Standard Error	1.429451
Observations	21

ANOVA	*df*	*SS*	*MS*	*F*	*Fsig*
Regression	1	7705550	7705550	3771073	8.48E-52
Residual	19	38.82329	2.043331		
Total	20	7705589			

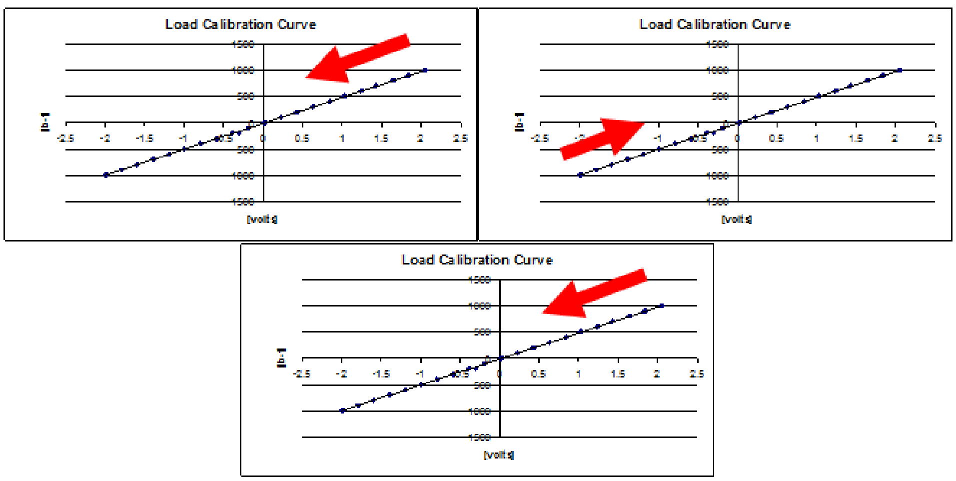
	Coef	*Std Error*	*t Stat*	*P-value*	*L 95%*	*U95%*
Intercept	-8.298	0.312	-26.599	1.69E-16	-8.951	-7.645
slope	495.828	0.255	1941.925	8.48E-52	495.293	496.362



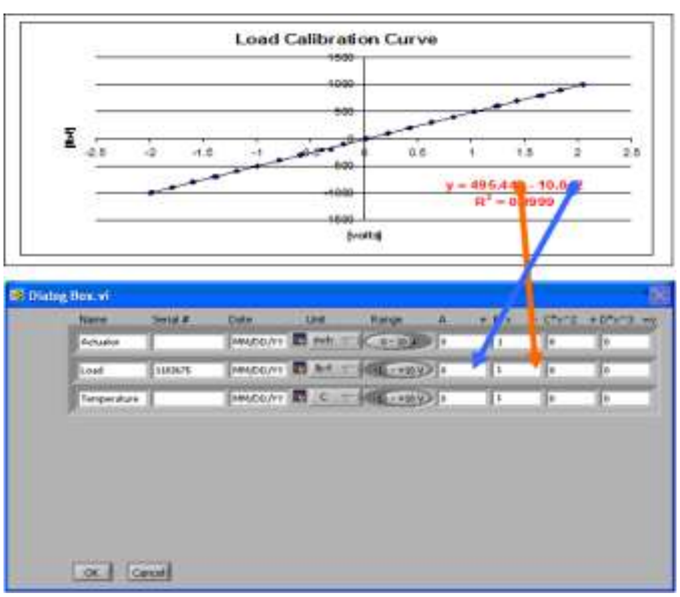
b. Load calibration

ASTM E74-06: "A total of at least 30 force applications is required for calibration and, of these, at least 10 must be different forces. Apply each force at least twice during the calibration"

In this example example, there is a total of 60 force applications distributed on 20 different positions (around each position, 3 load measurements were taken). The following figure indicates the way to take measurements, starting from 1000 lb-f



Repeating measurements in this manner will not just improve the regression by icluding more points, but would account for changes produced by possible Hysterisis in the system.



A regression line is calculated out of the collected data data. This line's parametes are the calibrations constants.

A report should be prepared in the same manner than for a verification. It is, older calibration values and settings, a summary of the used statistics, and the data acquired. If any of these is too extensive, this one could be attached in separated pages.

LOAD CALIBRATION REPORT (PAGE1/2)

Machine: OT11ASN07231
Date: 07/06/2012
Technician: George P. Foreman

ORIGINAL CONDITIONS:

Intercept	-5.71	Last Calibration date	UNKNOWN
Slope	493.7	Quality	POOR

OBSERVATIONS:

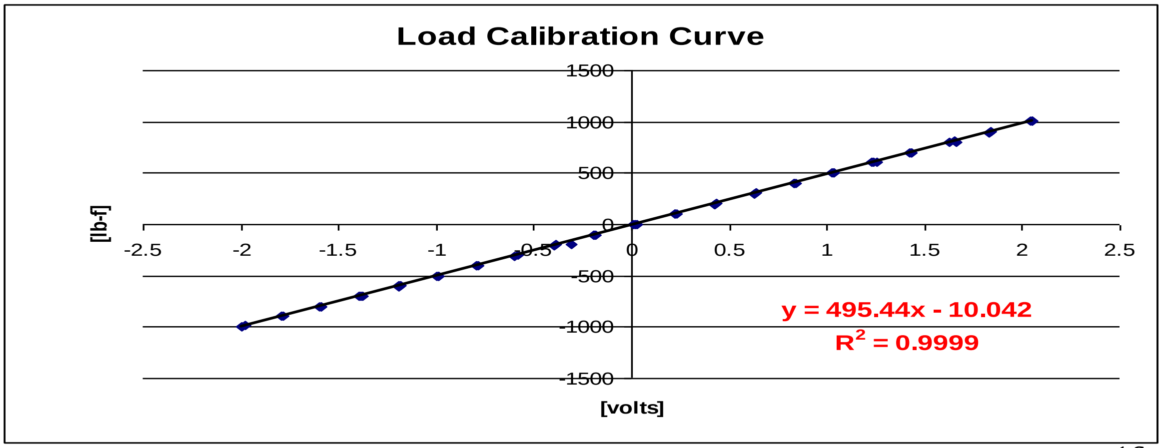
- On 07/05/12, it was determined this OT needs a calibration.
- Operator reported additional issues no related to Load calibration. Among them, premature test termination, increased noise, and some oscillation at load control.

SUMMARY OUTPUT

REGRESSION STATISTICS	
Multiple R	0.999956
R Square	0.999913
Adjusted R Square	0.999911
Standard Error	5.727548
Observations	61

ANOVA	*df*	*SS*	*MS*	*F*	*Fsig*
Regression	1	22189815	22189815	676419.6	1.8E-121
Residual	59	1935.484	32.80481		
Total	60	22191751			

	Coef	*Std Error*	*t Stat*	*P-value*	*L 95%*	*U95%*
Intercept	-10.0424	0.734307	-13.676	5.99E-20	-11.5118	-8.57306
slope	495.4416	0.602399	822.4473	1.8E-121	494.2362	496.647



LOAD CALIBRATION REPORT (PAGE2/2)

Machine: OT11ASN07231
Date: 07/06/2012
Technician: George P. Foreman

Data

[lb-f]	[v]	[lb-f]	[v]
1003	2.041	100	0.222
898	1.825	200	0.424
797	1.622	300	0.627
702	1.429	405	0.839
605	1.234	499	1.026
505	1.035	610	1.25
399	0.828	695	1.423
306	0.633	809	1.655
205	0.435	900	1.84
105	0.232	1005	2.052
4	0.03	1003	2.049
-102	-0.19	902	1.836
-199	-0.385	797	1.662
-304	-0.599	702	1.432
-402	-0.796	602	1.228
-500	-0.992	504	1.034
-598	-1.191	401	0.829
-698	-1.392	302	0.629
-799	-1.595	200	0.424
-895	-1.788	99	0.221
-1000	-2	0	0.017
-988	-1.976	-102	-0.193
-804	-1.593	-203	-0.396
-699	-1.385	-403	-0.796
-602	-1.191	-503	-0.998
-500	-0.99	-597	-1.188
-401	-0.789	-695	-1.381
-297	-0.58	-798	-1.591
-200	-0.307	-897	-1.793
-100	-0.186	-997	-1.995
-1	0.013		

c. Displacement verification

As for load Verification and Calibration reports, the machine ID should be clearly identified with the technician responsible for evaluating the machine, and dates at which these procedures is performed. Original conditions, the collected data, data transformations, statistical analysis, and observations should also be presented.

In the case of this example, the displacement measurements were taken from a precision dial gauge of 0.025''. Special attention was paid for each measurement due to the dial gauges sensitivity to mechanical vibration, and their necessity for being reset every 0.025''.

Data points collected along the whole operation range of the OT procedures. In this case, there were taken as many points as needed to completely cover the range [-1000,1000] lb-f. These displacement measurements were taken separated each by 0,005''.

A regression line should be made from the collected data. If the slopes from this line and the current calibration line should are not equal with a 95% of certainty, a calibration is needed.

Note:

- Under the suspicion of non linearity, verification should be made with more points.

- Calibration intercepts are always set to 0 since some Shedworks OT versions produce undesired initial jumps otherwise. Moreover, calibration slopes are determinant for Displacement control and measurement because of the testing nature.

DISPLACEMENT VERIFICATION REPORT (PAGE1/1)

Machine: OT11ASN07231
Date: 07/05/2012
Technician: George P. Foreman

ORIGINAL CONDITIONS:

Intercept	0	Last Calibration date	UNKNOWN
Slope	-0.00949	Quality	UNKNOWN

DATA

[lb-f]	[v]
8.35	-0.025
8.01	-0.02
7.45	-0.015
6.84	-0.01
6.36	-0.005
5.79	0
5.11	0.005
4.61	0.01
4.07	0.015
3.57	0.02
3.02	0.025
2.56	0.03
2.02	0.035
1.55	0.04
1	0.045
0.49	0.05

OBSERVATIONS:

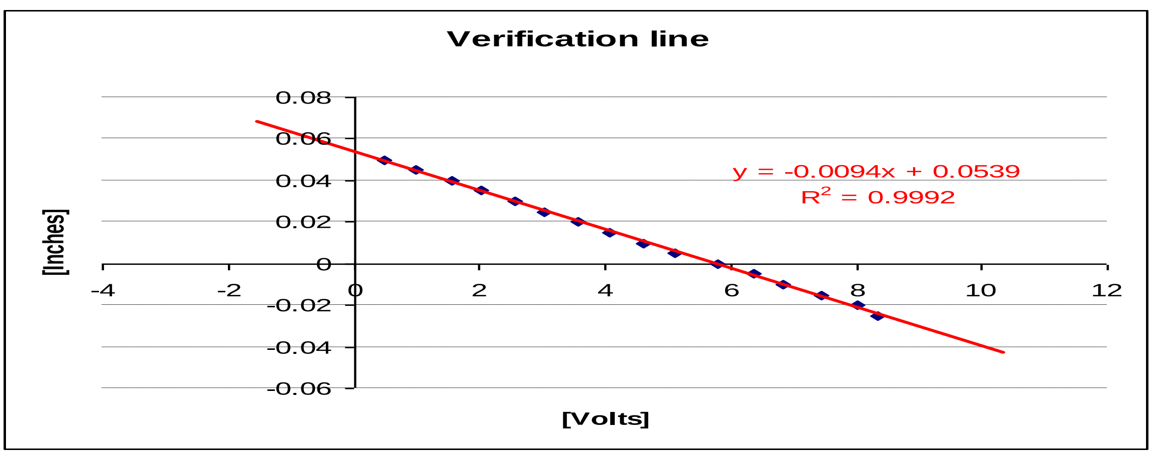
- Data lies linearly along the whole testing range. No signal of mechanical damage, or inconsistent calibration.
- Slopes for the current calibration and the obtained regression line are equal with the 95% of certainty.
- A displacement calibration is not needed, but suggested since the last calibration date is unknown

SUMMARY OUTPUT

REGRESSION STATISTICS	
Multiple R	0.999592
R Square	0.999184
Adjusted R Square	0.999125
Standard Error	0.000704
Observations	16

ANOVA	*df*	*SS*	*MS*	*F*	*Fsig*
Regression	1	0.008493	0.008493	17134.31	5.07E-23
Residual	14	6.94E-06	4.96E-07		
Total	15	0.0085			

	Coef	*Std Error*	*t Stat*	*P-value*	*L 95%*	*U95%*
Intercept	0.053922	0.000362	148.9143	8.34E-24	0.053145	0.054698
slope	-0.00936	7.15E-05	-130.898	5.07E-23	-0.00951	-0.00921

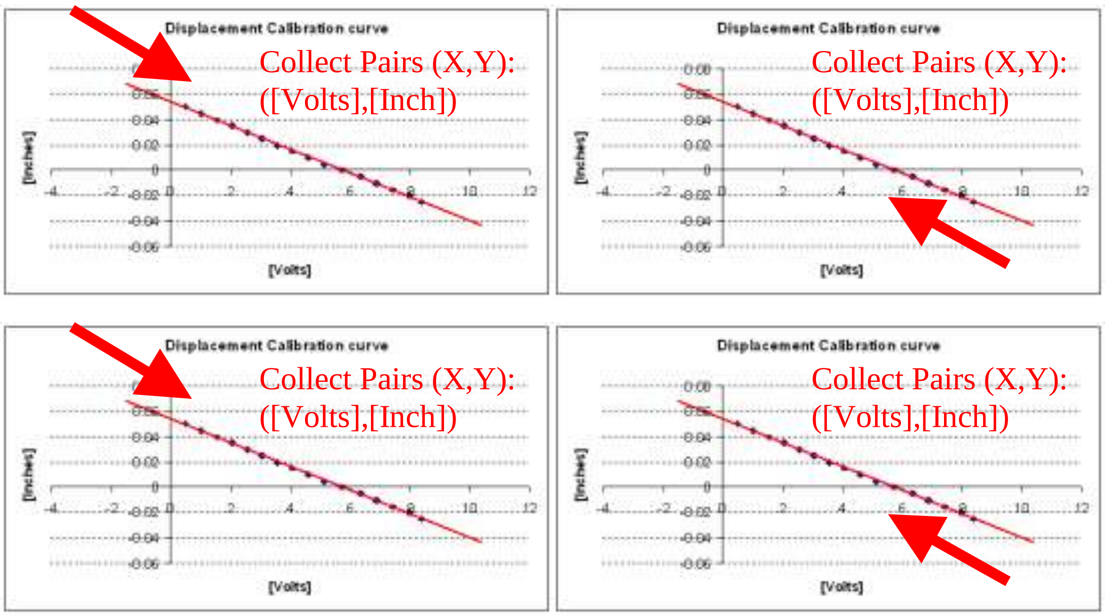


50

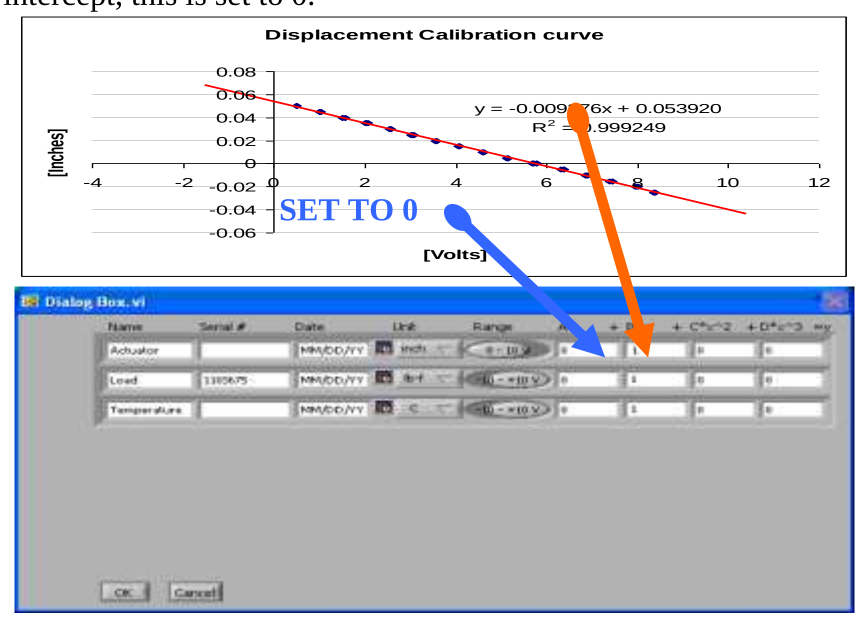
d. Displacement calibration

ASTM D6027-96(2004): "It is recommended that a minimum of five readings equally spaced throughout the sensor total linear range can be used"… "repeat these steps [collecting data in both directions] to obtain reproducibility data"

In the following example, there are as many displacement readings as needed along the [-1000,1000] lb-f range. Those measurements are separated 0.005'' one from the next, and were collected back and forth, at least two times.



A regression line is calculated out of the collected data data. This line's parametes are the calibrations constants. Since this version of OT has problems associated with the calibration intercept, this is set to 0.



DISPLACEMENT CALIBRATION REPORT (PAGE1/2)

Machine: OT11ASN07231
Date: 07/06/2012
Technician: George P. Foreman

ORIGINAL CONDITIONS:

Intercept	0	Last Calibration date	UNKNOWN
Slope	-0.00949	Quality	UNKNOWN

OBSERVATIONS:

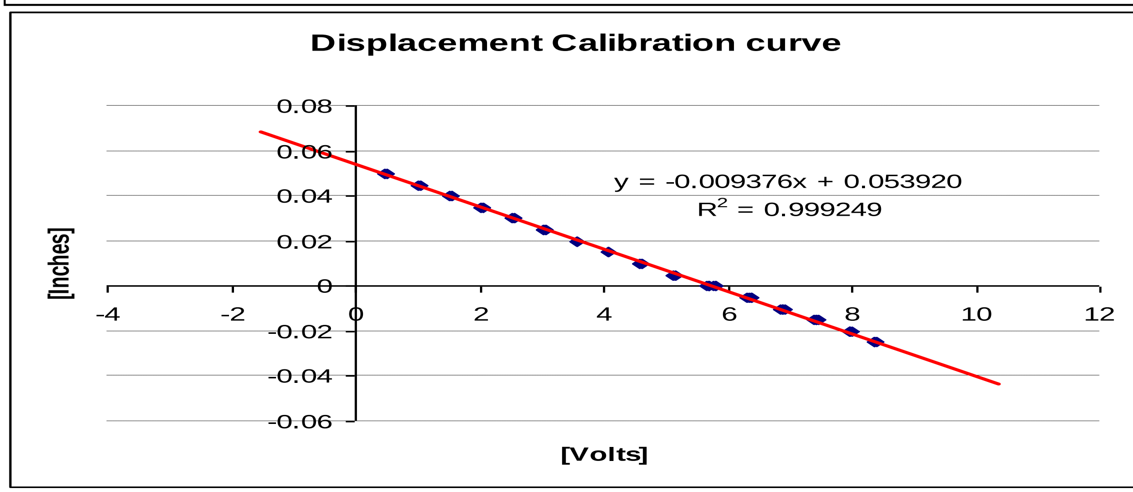
- On 07/05/12, it was determined this OT needs a calibration.
- This version software is seen to react to intercept values different than 0. The "initial jump" situation is found and the calibration intercept is kept as 0

SUMMARY OUTPUT

REGRESSION STATISTICS	
Multiple R	0.999625
R Square	0.999249
Adjusted R Square	0.999238
Standard Error	0.000618
Observations	71

ANOVA	*df*	*SS*	*MS*	*F*	*Fsig*
Regression	1	0.035065	0.035065	91836.43	1.5E-109
Residual	69	2.63E-05	3.82E-07		
Total	70	0.035092			

	Coef	*Std Error*	*t Stat*	*P-value*	*L 95%*	*U95%*
Intercept	0.05392	0.000156	346.481	1.5E-113	0.05361	0.05423
slope	-0.00938	3.09E-05	-303.045	1.5E-109	-0.00944	-0.00931



DISPLACEMENT CALIBRATION REPORT (PAGE2/2)

Machine: OT11ASN07231
Date: 07/06/2012
Technician: George P. Foreman

ORGANIZED DATA

Volts	Inch	Volts	Inch	Volts	Inch	Volts	Inch
8.36	-0.025	5.78	0	3.55	0.02	1.51	0.04
8.35	-0.025	5.79	0	3.57	0.02	1.55	0.04
8.39	-0.025	5.68	0	3.56	0.02	1.51	0.04
8.35	-0.025	5.71	0	3.57	0.02	1.55	0.04
7.96	-0.02	5.68	0	3.04	0.025	1	0.045
7.98	-0.02	5.67	0	3.07	0.025	1.04	0.045
8.01	-0.02	5.69	0	3.02	0.025	1	0.045
7.96	-0.02	5.79	0	3.02	0.025	1.03	0.045
7.38	-0.015	5.11	0.005	3.07	0.025	0.48	0.05
7.43	-0.015	5.14	0.005	3.03	0.025	0.49	0.05
7.45	-0.015	5.13	0.005	3.06	0.025	0.48	0.05
7.43	-0.015	5.14	0.005	2.54	0.03	0.49	0.05
6.84	-0.01	4.59	0.01	2.56	0.03		
6.89	-0.01	4.61	0.01	2.53	0.03		
6.91	-0.01	4.6	0.01	2.56	0.03		
6.89	-0.01	4.59	0.01	2.01	0.035		
6.3	-0.005	4.06	0.015	2.04	0.035		
6.36	-0.005	4.07	0.015	2.02	0.035		
6.37	-0.005	4.09	0.015	2.06	0.035		
6.37	-0.005	4.09	0.015				

a. ADDITIONAL DESCRIPTION UPON FINDING PROBLEMS.

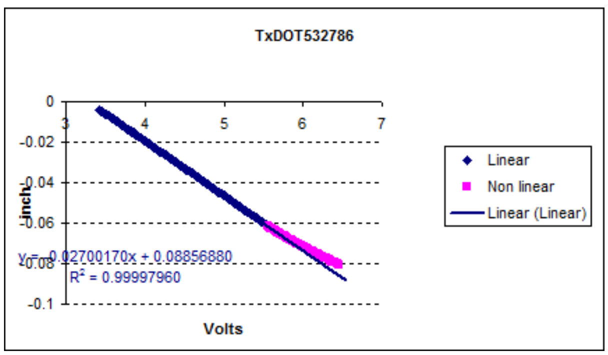
Additionally to the formal report described on previous pages, some detailed description of problems should be included. It is extremely important to attach the last test log file in *.csv format), to this report. This is an important step to identify variability sources, and debug possible error causes.

The following figure is an example of an extra page with additional comments on an issue experienced at

DISPLACEMENT VERIFICATION REPORT (PAGE 2/2)

Machine: TxDOT532786
Date: 07/02/2013
Technician: George P. Foreman

Additional Observations:



- This behavior would distort the OT displacement readings if the specimen goes into high compressions. Since the displacement controller uses those readings in a closed loop feedback, the movements at the plates will correspond to the distorted readings, even if the test plot window shows perfect lines.

- Results may be different if the sample response passes through the distorted readings zone. If this machine is going to be used, take into account that results may be misleading if the sample was compressed out the levels that are shown to be linear

- It is proven that the measurements from both, the calibration block, and the OT's LVDT are independent of this condition. Newer calibration experiences at other OT demonstrated that the calibration block reads with no distortion at high compression loads.

- For different positions of this OT's LVDT, it was found the same levels of compression. Therefore, this distortion might appear as a result of the movements in high compression at this OT, and not as a result of the measuring systems.

- This condition is believed to be a misalignment of the OT movable frame, produced at high compression. It is recommended mo

Automatic calibration

Some of the major problems while performing manual calibration/verification procedures are the long times needed to take information, and the additional uncertainty included by the manual procedure itself. As a solution for these, newer software versions (08/2012) offer compatibility with a calibration device

The automated device gathers more information, in a more precise way, with more precise instruments, saving time to the technician, and providing a better picture of the measurements environment.

The following figures provide a clear picture of the calibration devices output.

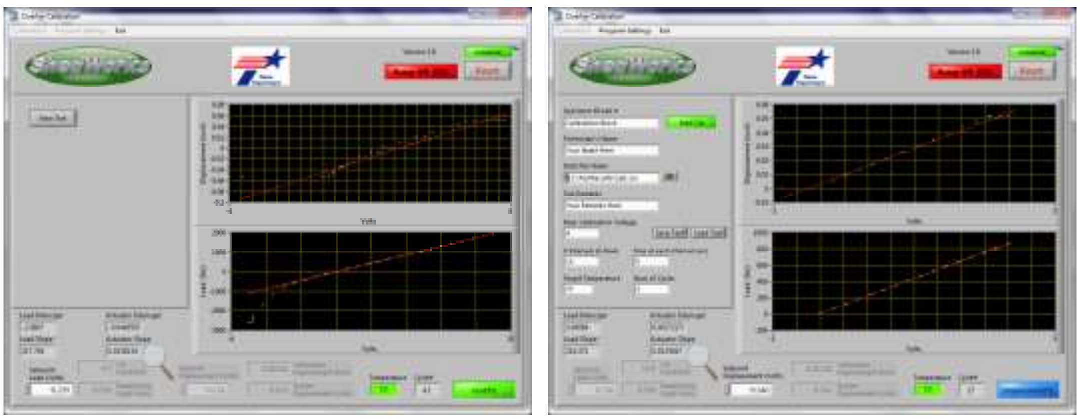


Figure 5. Calibration device output for different domains

At the picture in the left, the data acquisition clearly depicts curves that define the limits for which the measurements are valid, be it for Displacement or load. Therefore, saturation zones, and non linearity regions can be easily identified by specifying a broad voltage domain and clicking the start button.

The picture on the right has a smaller domain, identified as linearly related to the measurement units, by just checking the left figure. From these linear regions, valid calibration parameters can be obtained for Load and displacement.

Note that Calibration values, and utilization domains are two very important characteristics of an OT, and special care should be taking on identifying them properly.

Chapter 5 : Balancing of Zero-Load:

Constant shifts may appear in the load measurements. The OT may experience this shifts due to small imperfections in the electro mechanical system, thermal effects on the sensors, and even dust in the signal conditioners.

It is considered ideal if these shifts are kept between ±10 lb-f. A value larger than ±15 lb-f is indicative of maintenance necessity. If for some reason, the value of the load is extremely high (more than 75 lb-f), it could imply the circuit boards need immediate cleaning, due to the risk of misleading results. After a cleanup, the zero load uncertainty is seen to be smaller than 10 lb-f.

Large load shifts usually do not appear alone, but with increased noise. A detailed explanation of this problem will be presented in the following chapter.

Load shift should be periodically checked, since neglecting high load shifts may bring wrong tests and misleading outcomes. Signs of increased zero load are:

- Specimen does not easily fit on the testing plates at zero load.

- High load readings when the machine is empty (i.e. without specimen, nor calibration block installed)

The following procedure will accomplish this improvement on the load measurements and control, and is suggested to be performed periodically.

1. Turn on the machine and let it warm up, with the environmental chamber closed, for 10 minutes.

2. Turn on the pump and set the OT on displacement control.

3. The value of the load is observed at this point.

4. Balance the zero load by placing the shift value in the respective cell for the parameter A at the load row, in the calibration widow. If the correspondent gain B is negative, change the sign of the load shift when placing it on A.

5. If high load sifts have been observed, schedule maintenance promptly. Some maintenance suggestions are presented in the chapter

   An example of zero load balancing is presented with the following picture, which represents the case of a machine with a high load shift (i.e. it is needing maintenance).

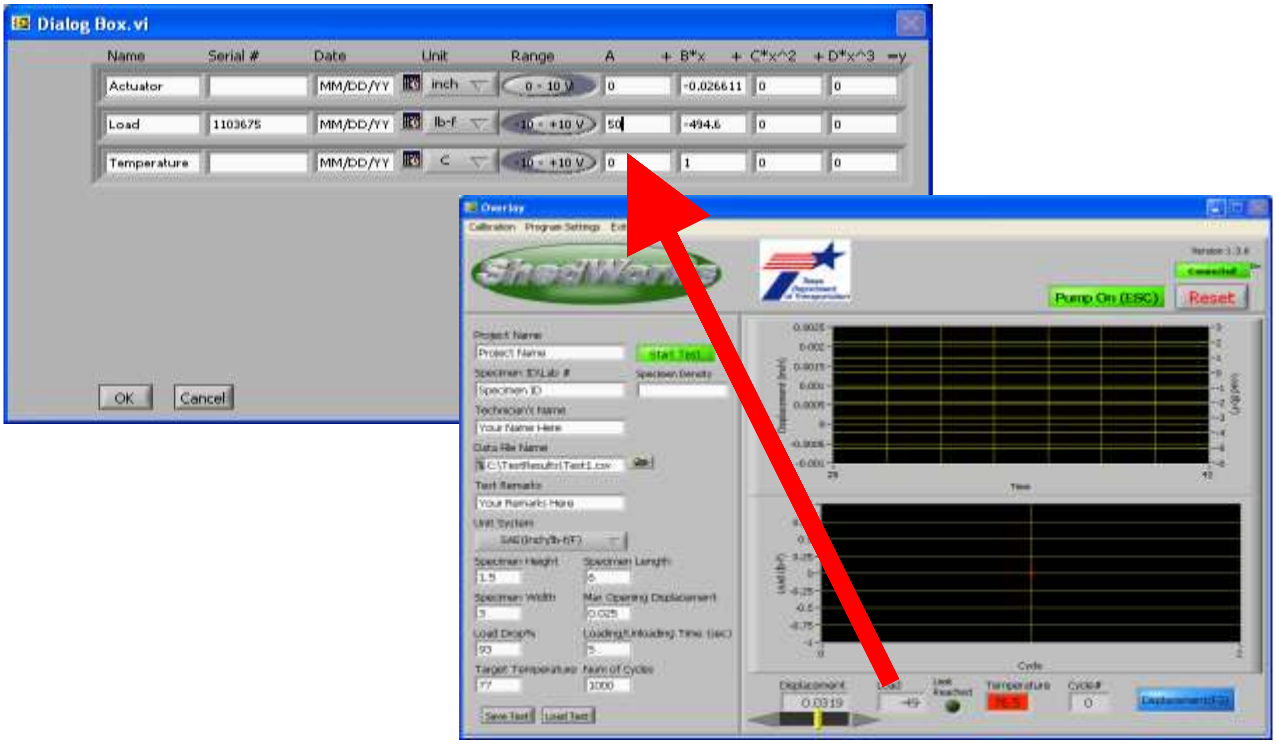


Figure 6. Zero Load Balancing

In the example, it is seen that the load shift is around Lo=[-49,-51] pounds, therefore the parameter A= - Lo= + 50. Note that the sign of the load shift is changed at the cell A due to the negative sign of the gain (B= - 494.6). In the case of positive gains (B>0), the parameter A should be equal to the load shift. In this example, this machine would be also recommended to maintenance since the load shift is large.

Initial Load should appear stable, with no oscillations and close to zero in the file. The following figure indicates the data recorded for a test with not initial oscillation.

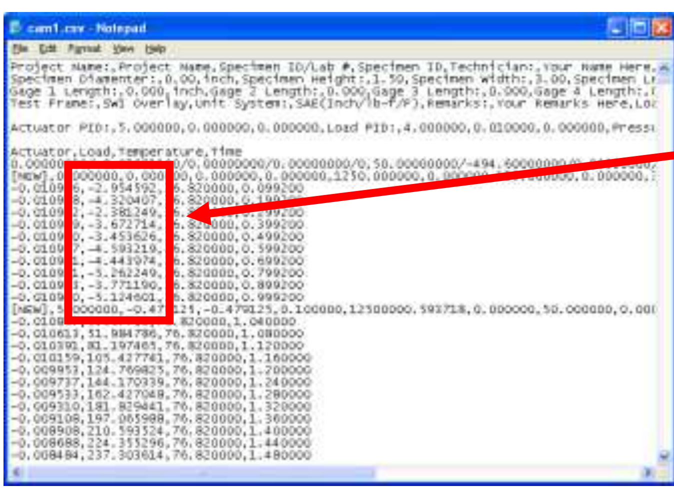


Figure 7. Records for stable load before the test

PART II. MAINTENANCE & SERVICING – GENERAL

Chapter 6 : General Guidelines

Calibrations on sensing equipment

According to ASTM D6027 and E74.

- Sensors must be calibrated before initial use,
- At least annually thereafter,
- After any change in the electronic configuration that employs the sensor,
- Any significant change in the test conditions using the transducer that differ from conditions during the last calibration
- After physical action on the transducer that may affect any response.

Hydraulic and Mechanical Components.

As per manufacturer recommendations, the following considerations should be taken under normal circumstances.

- The hydraulics system can be accessed by opening the rear panel.
- The system uses ISO 46 hydraulic oil.
- Oil cooler is a fragile component, and it is strongly recommended to be careful about hitting it, or applying any overload while checking for other components.
- Servo valve is the most expensive component of the hydraulic system. It can easily be damaged by dirty oil. Therefore it is strongly suggested to avoid any contamination of the oil, or internal parts while providing maintenance.
- Oil levels should be checked every 6 months. Oil top level must be kept around 1'' from the top of the tank.
- Hydraulic Oil filter should be replaced every 3 years in normal lab operations.

Electrical Components

- One of the causes of sudden extraneous readings has seen to be related to accumulation of dirt in the circuit boards, and signal conditioner connections. It is recommended that signal conditioner connections would be cleaned every 6 months, or more frequently upon finding any extraneous peaks on the readings. A more detailed description of this activity can be found at the "cleaning circuit board, and signal conditioner connections"

- If the OT software is a version older than 07/ 2012, it is strongly recommended to upgrade the OT software version. It has been proven that on some OT, a combination of software bugs and machine characteristics may produce results with an increased variability.

PART III. TROUBLESHOOTING

In this part, each of the most common problems observed at the OT are described with the technique used to overcome it.

Chapter 7 : Oil leakages

As per manufacturer comments, “Oil leakages are common situations in the OT that are seen to disappear after some time”. The most apparent cause of this situation may be small failures of sealing rings -at multiple parts of the hydraulic system- due to some change in the oil’s pressure and temperature.

It is considered that the oil leakage would affect the performance of the machine if the oil levels drop to less than half tank, or the pressure levels get reduced to around 500 PSI.

Figure 8. Normal pressure levels

If Oil leakages are observed, it is recommended to check for damage on sensitive parts, such as heat dissipater, servo valve connections and pipelines. If any sensitive part appears affected, the manufacturer should be contacted, as it would need to be changed. But, so far, it has not been observed any case due to physical damage of sensitive elements. As the hydraulic components are covered inside of the OT chassis, they are not likely to have any physical damage.

Oil leakages have been observed shortly after oil changes and refills, around the servo valve base, some hoses connections, and the tank borders. Such leakages are seen to disappear after some time, presumably as the oil in the tank reach the proper levels.

It is believed that the use of better sealing rings would reduce the frequency of oil leakages.

Chapter 8 : Vibration

This is not a general case and it has been observed in one machine so far. For this OT, the mechanical vibration produced by the pump is seen to be a potential cause of distortion. In some cases, such vibration appears in the displacement measurements, and can even make calibration/verification procedures harder than they should.

Vibration situations have been improved by the change of the “vibration isolators” that attach the pump feet to the chassis frame.

Since vibration is seen to majorly affect readings on a dial gauge, It is strongly recommended to perform calibration/verification procedures with calibration blocks that use LVDTs to read a displacement reference. LVDTs can reject some mechanical vibrations, and therefore, minimize their effect on calibration/verification measurements.

Chapter 9 : Avoiding small undesired peaks:

It has been experienced that pump’s current peaks can produce small electrical interference with OT signals. Interference of this type could imply transitory effects (movements of very short duration, but potentially harmful) on placed samples and readings. Although these conditions have not been found as major contributors to misleading results, it is always better to have the OT measuring and moving as best as possible.

These small jumps have been observed:

- Before the test, when the implied OT’s pump is turned on and a sample is already tightened in.

- During the tests when pumps in other OT’s –connected to the same electrical circuit- are turned on.

- During the tests, when the used OT has a defective pump.

Therefore, it is recommended that

- The pump should not be turned off after the sample is tightened in the machine. If this happens, it would be a safe and conservative measure to unscrew the sample from the machine, for tightening in after the pump is on again.

- The OT’s should be connected in a different circuit (different outlet, protected by a different breaker if possible).

- Pumps should be completely operational, and mechanical/electrical issues should be addressed promptly. Any sign of mechanical damage, rotor retention, could end up damaging the pumps internal electrical system. coils and producing

Chapter 10 : Procedure for avoiding oscillation before the test:

This Oscillatory condition is considered as important problem since it produces load peaks that clearly deteriorate the HMA sample before the test starts, which is undesired. An example of these oscillations is shown in the following Figure.

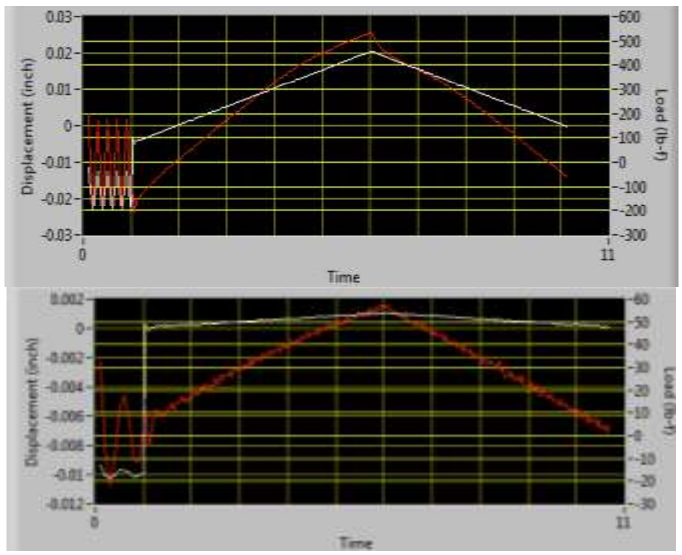


Figure 9. Oscillations before the Test.

This problem is a known software bug, solved for OT versions newer than 08/2012. Older versions of the Shedworks OT, automatically used incorrect control settings for taking the sample to zero-load, the ideal initial condition. This situation produced unstable tracking of 0lb-f for stiff -typically intact- HMA samples.

It is highly recommended to:

- Upgrade the Shedworks OT software, and

- After this, perform Load and displacement control tuning.

In the case that problem is observed and software upgrade cannot be immediately obtained, it is recommended to do the following:

1. Contact and encourage software upgrade for this OT

2. Open and make a backup copy of the settings file, whose location is typically “C:\Program Files (x86)\Shedworks\settings.ini”

3. Put the variable “Actuator compensation” to zero, as explained in the following figure.

4. If oscillation persists, put the variable “Actuator I” to 0 and decrease the absolute value of “Actuator P” until oscillation is not observed. If there is needed a big reduction of the parameter “Actuator P” a distortion of the quality of the triangular waves may be observed.

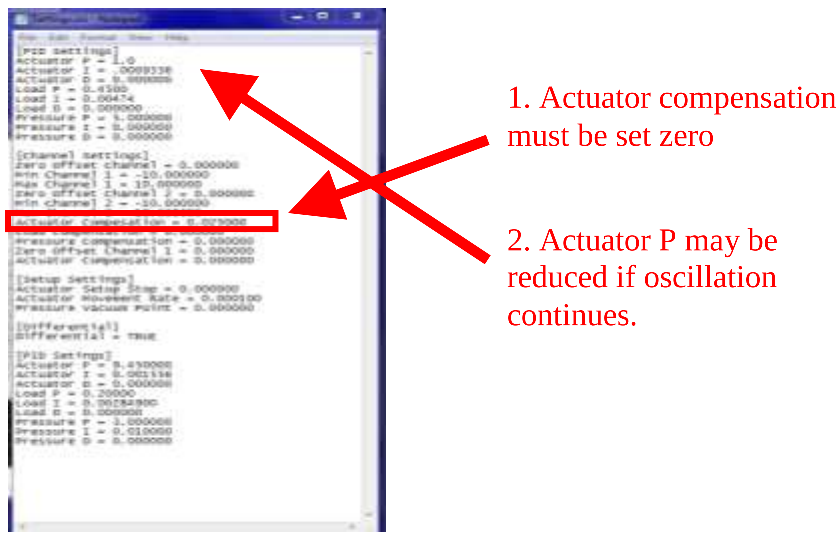


Figure 10. Actuator compensation correction

In practice, it has been observed that keeping the “Actuator compensation” to zero, and even reducing the absolute value of the “Actuator P” to 50%, along with keeping “Actuator I” as zero, produced an almost insignificant change on the triangular waves, keeping good testing outcomes. Therefore, this technique has been considered better than letting the oscillations change completely the outcome of the test.

Although you can avoid oscillations and proper results can be obtained from the OT by using this technique, it is recommended to upgrade the OT. The new OT software does not have such glitch and can perform with no problem under the best settings for Displacement and Load.

Chapter 11 : Procedures for avoiding "Initial jump" condition.

A rapid change in the gap opening before the first cycle, or a jump -as seen in the figure- is another undesired condition, currently known as a software bug of OT versions older than 07/2012. This glitch responds to the intercept value of the displacement calibration parameters.

This undesired jump is an important problem since it may damage the HMA samples, thus affecting the outcome of the test, even before the test starts. Additionally, it is considered that conducting triangular shaped waveforms that do not start at zero-load (deformed sample) would imply HMA samples deteriorating differently than expected.

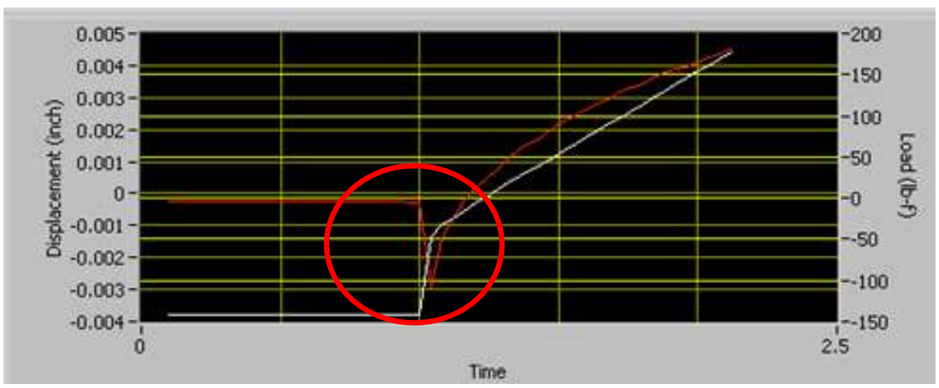


Figure 11. Initial Jump.

It is highly recommended to:

- Upgrade the Shedworks OT software, and

- After this, perform Load and displacement calibration.

In the case that problem is observed and software upgrade cannot be immediately obtained, it is recommended to do the following:

1. Contact and encourage software upgrade for this machine.

2. Turn on the OT software and open the calibration window. Displacement calibration intercept must be set to zero (first row of the A column is 0)

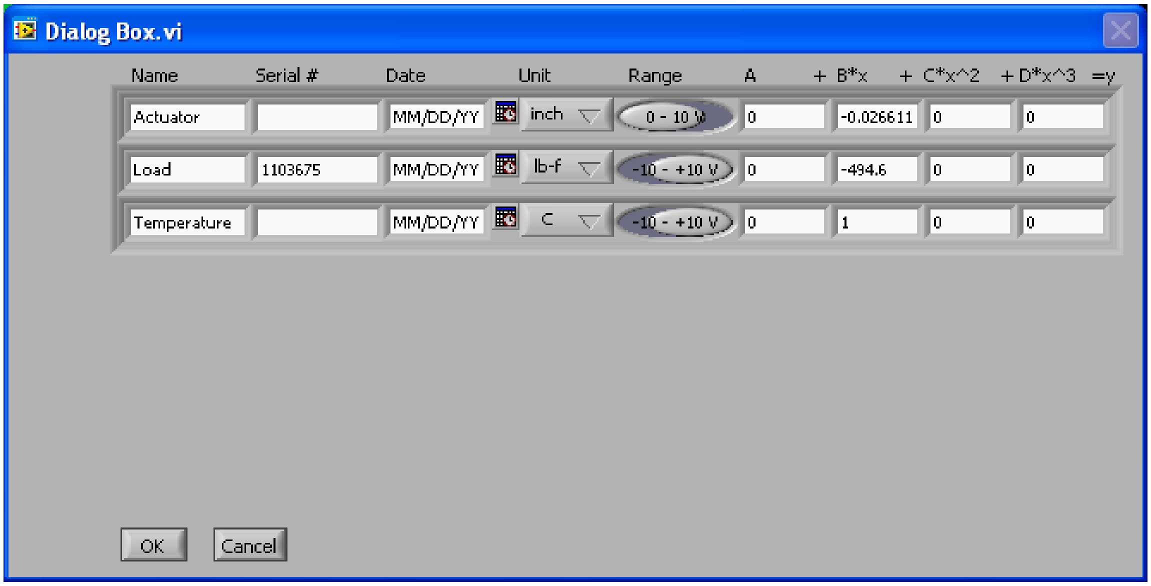


Figure 12. Calibration window

3. Displacement control is set, and a gap is fixed to a typical value.

4. After adjusting the shifts for Displacement and Loads, the sample can be placed and tightened at zero load control.

5. After the test is properly named and started, the shape in the screen should appear with the Load (red curve) starting from 0 Lb-f, moving up as the triangle shape starts. No sudden load jumps should appear.

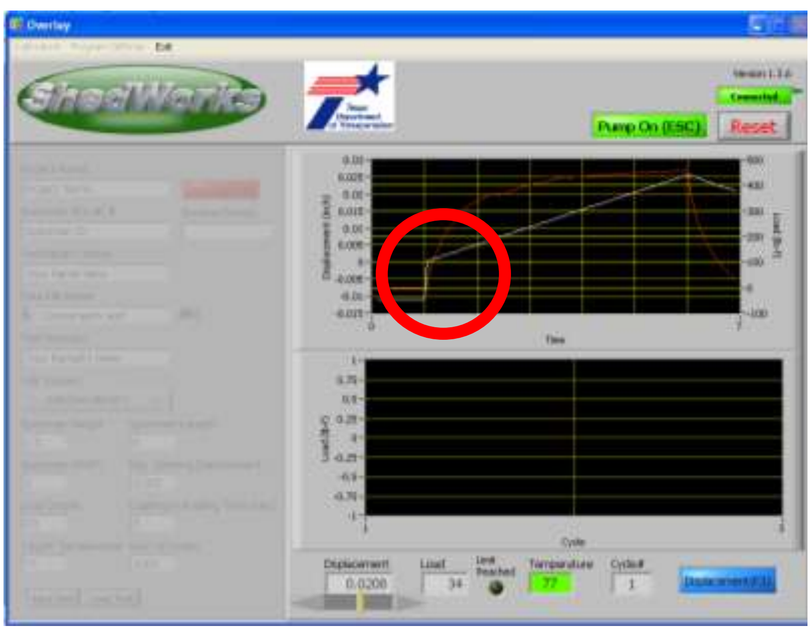


Figure 13. Testing screen and correct starting

Chapter 12 : Cleaning the circuit board, and signal conditioners

Unusual, extraneous load shifts with increased noise components may appear suddenly on an OT. As a result, zero load control may produce undesired jumps, incorrect load readings, and even premature testing terminations (i.e., tests stopping at 89% load drop instead of the set 93%), leaving no conclusive results from an experiment.

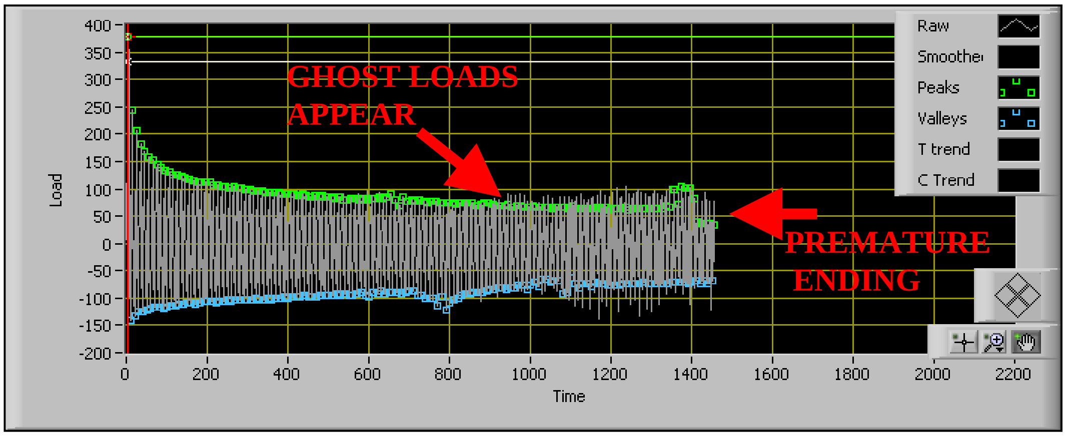


Figure 14. Ghost loads and early termination

The last figures describe an example of premature termination of the testing procedure. This situation appeared at TxDOT 532786 and was named "ghost loads" and described in the Maintenance Report (last revision presented in 05/2012). **It is believed that many similar problems can have the same causes.** At the OT named TxDOT 532786

- These "ghost loads" and high load offsets were corrected simultaneously by cleaning thoroughly the board and the signal conditioners connections. Therefore, these ghost loads are seen to be related to high load offsets, and the condition of the connection of the signal conditions (specially the one for the Load signal) at the internal board.

- Load offsets are considered high when the value of load *while the plates are empty* is very different than zero. If there is a value larger than 15 compression/tension pounds, it may be considered the case of High load offsets. In some cases, it has been seen steady offsets around 75 compression/tension pounds.

Therefore, in similar situations the following steps are recommended:

1. Check if the machine is off, and unplugged from the power outlet.

2. Open the board box, located under the laptop place, by taking off the screws of the lateral and top covers.

Figure 15. OT circuits without superior and lateral covers

3. Locate the board, the signal conditioners and survey connections. Check for orientation of the signal conditioners respect to their slots. Additionally check for plugs and connectors.

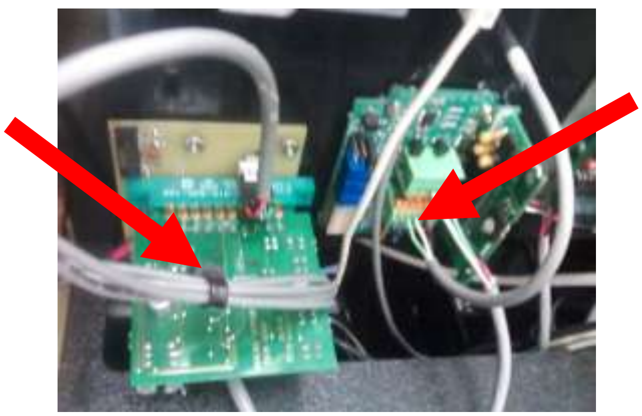


Figure 16. Main board and signal conditioners

4. Be sure of handling properly the boards. Do not touch chips or circuits. Be prepared to pull any part from the edges. If you consider creating signs, use non conductive, non abrasive marker.

5. Take the signal conditioner off the main board (by pulling its edges) and use an electronics cleaner spray to blow dust. Take especial care at the part that will connect with any slot or plug. If dust is not coming out, you could try rubbing cotton swab with isopropylic alcohol in the problem zone. ***Do not change any calibration potentiometer, dip switch, or jumper.***

Figure 17. LVDT signal conditioner

6. Use spray to blow off any dust at the main board, especially at the signal conditioner slot, and high density connectors. If dust is not coming out, you could try rubbing cotton swab with isopropylic alcohol in the problem zone

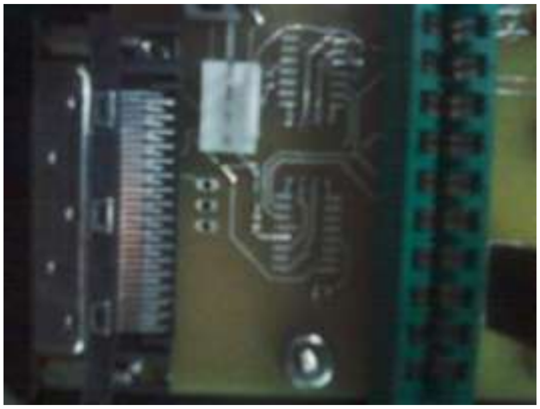


Figure 18. Main board Slot and High density connector

- Reconnect properly the signal conditioner to the main board and close the OT covers. Place the laptop in its proper place.

- Run the OT and proceed to verify measurements. Calibrate the device if necessary, by using the Shedworks software. Do not attempt to calibrate the signal conditioner.

After this maintenance procedure, the TxDOT 532786 presented a load shift similar to zero, and the “ghost loads” that produced premature testing termination disappeared.

Chapter 13 : Control Problems

Control problems may appear when the system acquires characteristics that the current set of parameters is not adequate for. It may be the result of testing a specimen with completely different characteristics, or a substantial change in the OT response due to damage, or wrong calibration.

The control problems that could easily appear are as follows:

Distorted displacement shapes and Displacement/Load Oscillations

These problems are a sign of improper control parameters. It is recommended to be familiar with the Control Tuning chapter before taking in consideration the following suggestions:

a. Generally, it is always recommended to complete a full control tuning routine, as explained in a previous chapter. If the distortion/oscillation problems do not look aggressive, and if the **calibration block** is not available -or there are not enough specimens for performing a tuning procedure- a “quick tuning” of the Proportional control parameter can be effective for finding a temporary operation point.

   It is to the user experience and discretion to determine the percentage to change on the P parameter. For some cases, it has been seen that an increase of the 50% *Displacement P* parameter may improve a slow triangular shape. In the same manner, it has been seen that decreasing the *Displacement/Load P* parameter by a 50% can stabilize an oscillating behavior. **These parameter changes should be done after saving a copy of the “settings.ini” file to be modified**, in such a way that the OT can come back to the original settings if these quick tunings are not effective.

   It is not recommended not to try this quick tuning more than once. In the case these quick tuning suggestions are not effective, the necessity of a full control tuning routine is imminent.

b. If the tuning results obtained from the **calibration block** do not provide an adequate controller, it is recommended to check for correct oil levels, or any blockage/friction at the OT mobile parts. If any mechanical problem appears, and it cannot be solved immediately by the technical personnel, it is recommended not to perform testing on that OT, since misleading results can be obtained.

c. If the hydraulics and mechanical parts at the OT appear to be correct, and the calibration block does not provide good tuning results, it is recommended to perform the control tuning with specimens from the batch where the distortions/oscillations appear. This practice may use several specimens but it is the only choice if the calibration block fails to provide an appropriate controller for the studied mixture at which oscillation appears.

d. If the observed distortion/oscillations are linked strictly to that kind of specimen, and cannot be solved easily by performing full tuning routines, it would be recommended to take into account specimen with different geometries. For implementing this last suggestion, the researcher should determine what would be the needed changes on the test, and the interpretations of the implied results.

e. If distortion/oscillation problems are generalized, and all the other suggestions have been exhausted, please contact the OT provider for more information, or maintenance support.

Significant zero load error

If, after applying Load Control, the OT sets itself at a value that is not close enough to zero (farer than ±10 lbs-f, or ±5lbs-f depending on the tolerance of the testing), then the load control needs to be improved.

This behavior is normally the result of having no Integral control. It is recommended to perform a full control tuning routine for load, calculating parameters for a PI controller (see definitions).

Chapter 14 : Extraneous temperature readings

If the “Calibration Editor” window has “F” as the units for temperature, wrong conversions will be presented in the screen. It is also seen that the temperature control is also linked to these wrong conversions since red color is consistently highlighting the incorrect temperature readings.

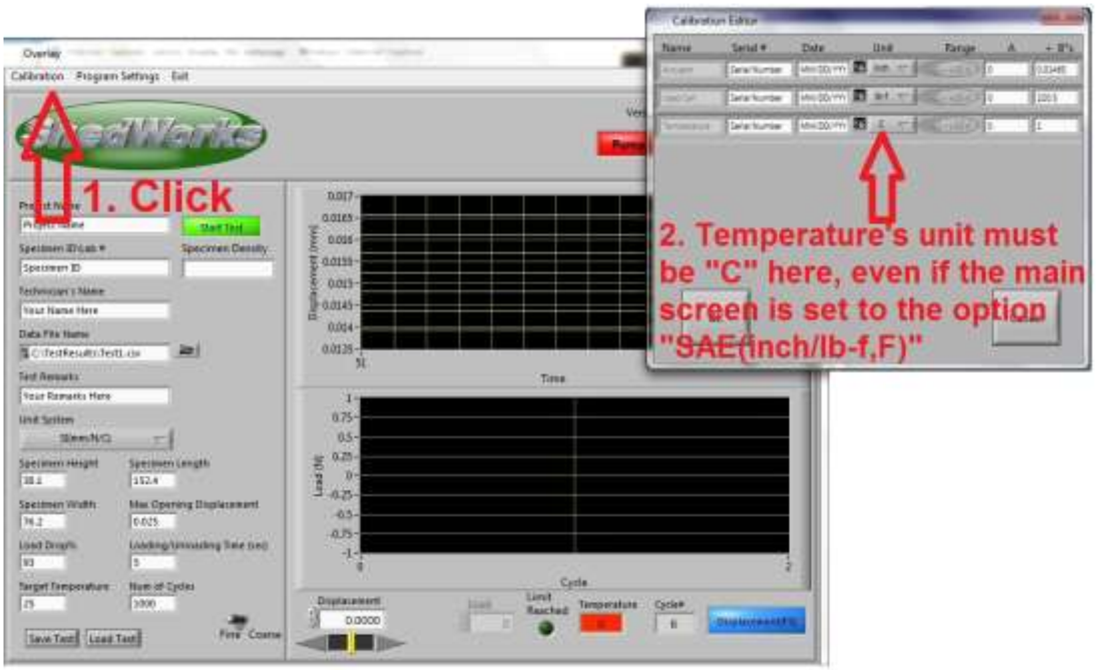


Figure 19. Incorrect Temperature Units.

This problem is avoided by setting the calibration units to “C” (at the calibration window), even if the work is performed on “F”; refer to last Figure. If any unit conversion is needed, it can be commanded from the main screen by changing the unit system. Therefore, if the temperature readings and controls are required to be in Fahrenheit, the main screen should show “SAE(inch/lb-f,F)”

This issue seems to be an inconsistency of the software that tries to scale digital values that are already expressed in Celsius. Although this is not a critical factor on the testing procedures, an operator who is not aware of the issue could easily change the units back to “F” triggering wrong temperature conversions and regulation. Thus, it is important to always check the temperature including the units prior to testing.

Chapter 15 : Wrong Input configuration

If the electrical input configuration is changed to a mode for which the machine is not wired for, the measured volts would be wrongly referenced. As a consequence, signals may appear shifted, including a significantly increased noise component.

This case has been observed in a particular version of the OT where, a known software bug, changes the electrical input configuration (to "Differential = FALSE") at the settings file. That situation appeared to be triggered by pressing the "save" button at the Program Settings window.

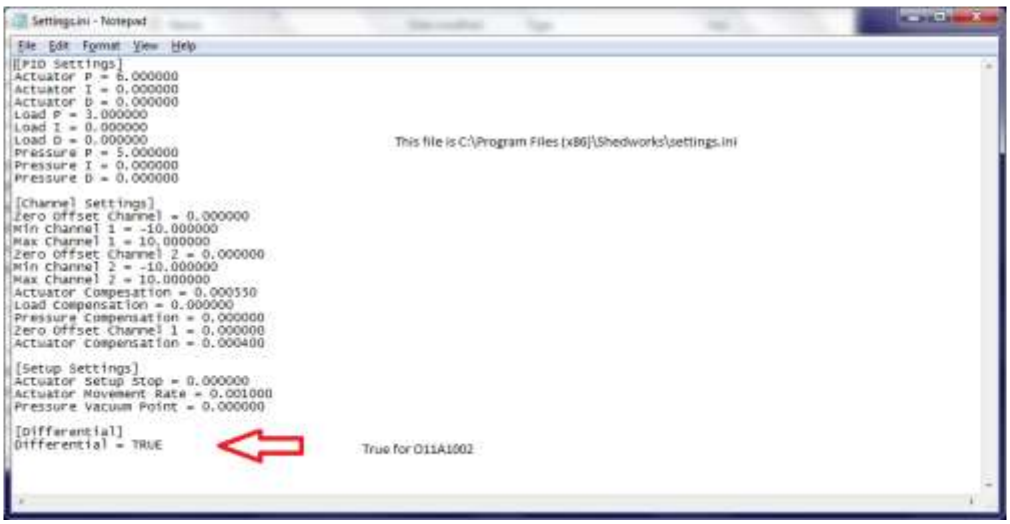


Figure 20. Differential mode must be kept as TRUE

Although this problem is not present in all the OT versions, it is very significant on the OT versions that have the described bug. It is because Control tuning routines strongly depend on changes at the program settings window.

This situation was solved for versions newer than 7/2012. If a software upgrade cannot be immediately done, the only patch procedure that can be performed is summarized as follows:

- When a change on the PID parameters would be required, this should be done directly from the Settings.ini file
- Avoid opening the "Program Settings" window.
- If readings appear to be wrong with increased noise levels, change the Differential mode to TRUE at c:/Program Files/Shedworks/settings.ini file.

Chapter 16 : Fault Index

Checking for the following signs will help to identify problems in the performance of the OT.

Before the test

Sign	Chapter Information and Comments
- Temperature units are not consistent	Extraneous temperature readings
- Temperature controller is not stable	
- Increased noise levels and non referenced signals.	Wrong input configuration
- High load shifts	Cleaning the circuit board, and signal conditioners
- Vibration	Changing Vibration Isolators, tighten the pump connection to the frame

During the test

- Initial jump	Upgrade Software, check Procedures for avoiding “Initial jump” condition
- Oscillation before the triangular waves	Upgrade Software, check Procedure for avoiding oscillation before the test:
- Oil leakage	Oil leakages, general Hydraulics checkup.
- Distorted triangular waves	Control tuning
- Oscillation	Control tuning

After the test:

Upon negative results, the identification of problems is necessary.

- Premature termination	Cleaning the circuit board, and signal conditioners
- Non consistent results.	Check for bad control, calibration. Use control tuning, calibration and Verification

Chapter 17 : Software Problems and Upgrading

Testing procedures presented conditions that were identified as causes for high variability at some OT. These problems were software issues at OT versions older than 08/2012. Therefore, a software upgrade to newer version is recommended.

Two of the most important problems are described on previous chapters as “initial jumps”, and “oscillations before the test”. Those conditions implied the damage of the HMA sample due to the action of wrong actuator behaviors, producing high loads and oscillations depending on the machine parameters. Although for some machines, the parameters coincidentally did not produce symptoms, the potential risk of testing with such situations is there if software upgrade is not performed.

Less significant issues present on old software were explained at chapters related to “wrong input configuration”. Although there is not a direct influence of this problem to the machine performance, it makes task such control tuning more extensive and difficult than it should.

Newer versions of OT software include additional features, like timer and a better presentation. As a complement of newer versions, calibration software is available. This calibration software is able to perform automatically calibration/verification tasks, saving time and effort to operators and technicians.

In conclusion, variability van be reduced, and operability can be improved by using new available software