The Yerzley Oscillograph Revisited

Dr. Nuri Akgerman, Camtech Consulting, Dr. Ismail Saltuk, Tavdi Corp
January 2011

Abstract

Yerzley Oscillograph is the testing equipment specified in ASTM Standard D945-06 for determining static and dynamic mechanical properties of rubber and rubber like materials. The present version of the device has been improved with automated data acquisition and evaluations as well as including a calibration method and the addition of tan δ calculation.

Introduction

Yerzley Oscillograph is the testing equipment specified in ASTM Standard D945-06 (1). It is used for measuring static characteristics such as creep and set as well as dynamic characteristics such as capacity to absorb impact, resilience, dynamic modulus, hysteresis and tan δ among others. These parameters are evaluated at deformations of 20% or less, for materials with a maximum static moduli of 280 psi (2 MPa) under compression or 140 psi (1 MPa) in shear loading.

The principle of operation of the Yerzley Oscillograph is that of simple harmonic motion. Material properties are derived from the analysis of vibrational data, displacement versus time, as outlined in reference (2).

Our contributions are:

- Improved and automated data acquisition and evaluation.
- Added determination of tan δ.
- Developed calibration method.
- Possible use of non-circular test specimens.

Improvements

The original Yerzley Oscillograph recorded data on paper by means of an oscillograph. Data thus acquired had to be manually read off of the paper record. Further calculations may have been performed by means of a spread sheet by most users. In this latest version, the pen and paper oscillograph mechanism has been replaced with a displacement transducer, a data acquisition system and associated software running in a laptop as illustrated in Figure 1.

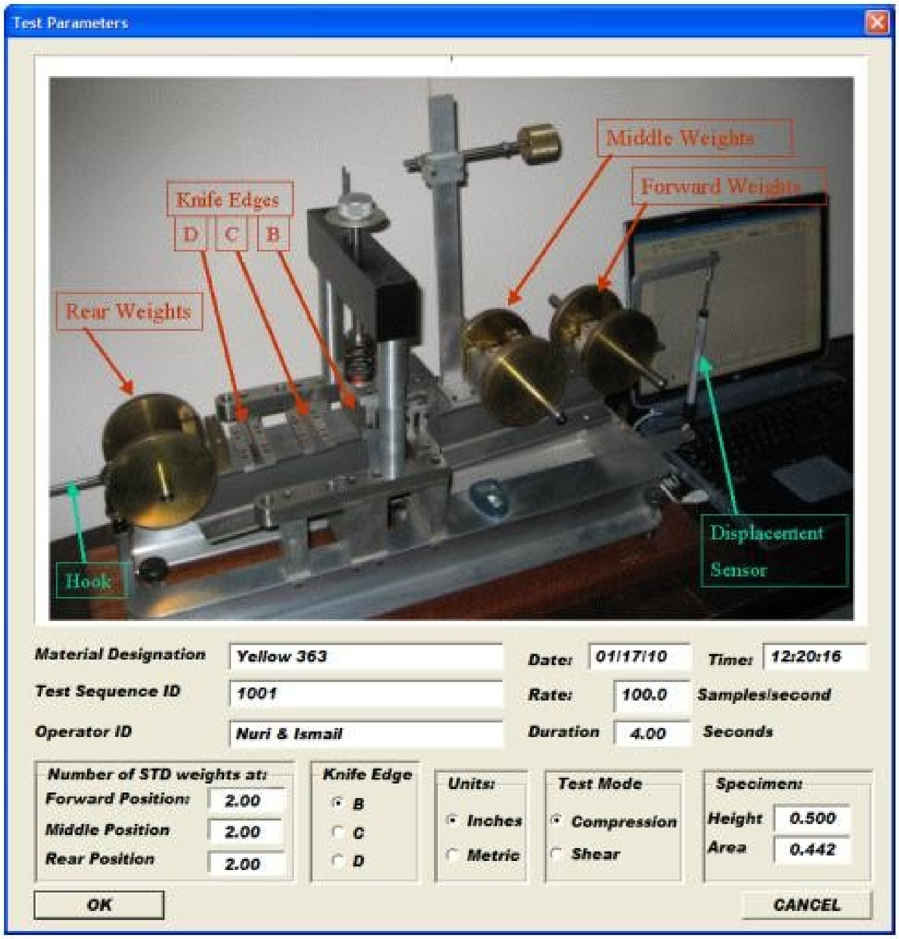


Figure 1. Test setup screen showing the Yerzley Oscillograph.

Figures 2 and 3 show examples automated test output for soft and hard rubber specimens. The automatically generated data analysis report test setup information as well as the calculated results. The acquired displacement data is included at the end of the report in a form suitable for input to popular spreadsheet software.

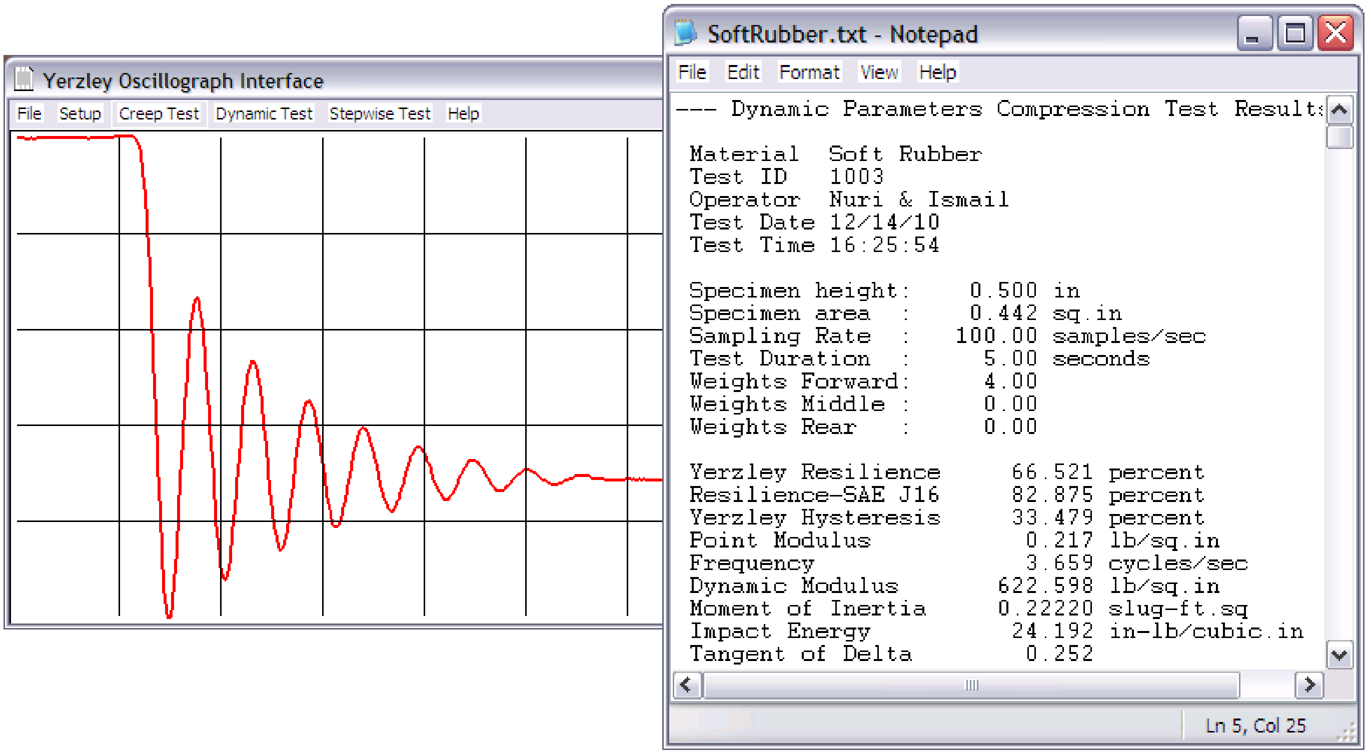


Figure 2: Example of dynamic test output for soft rubber sample.

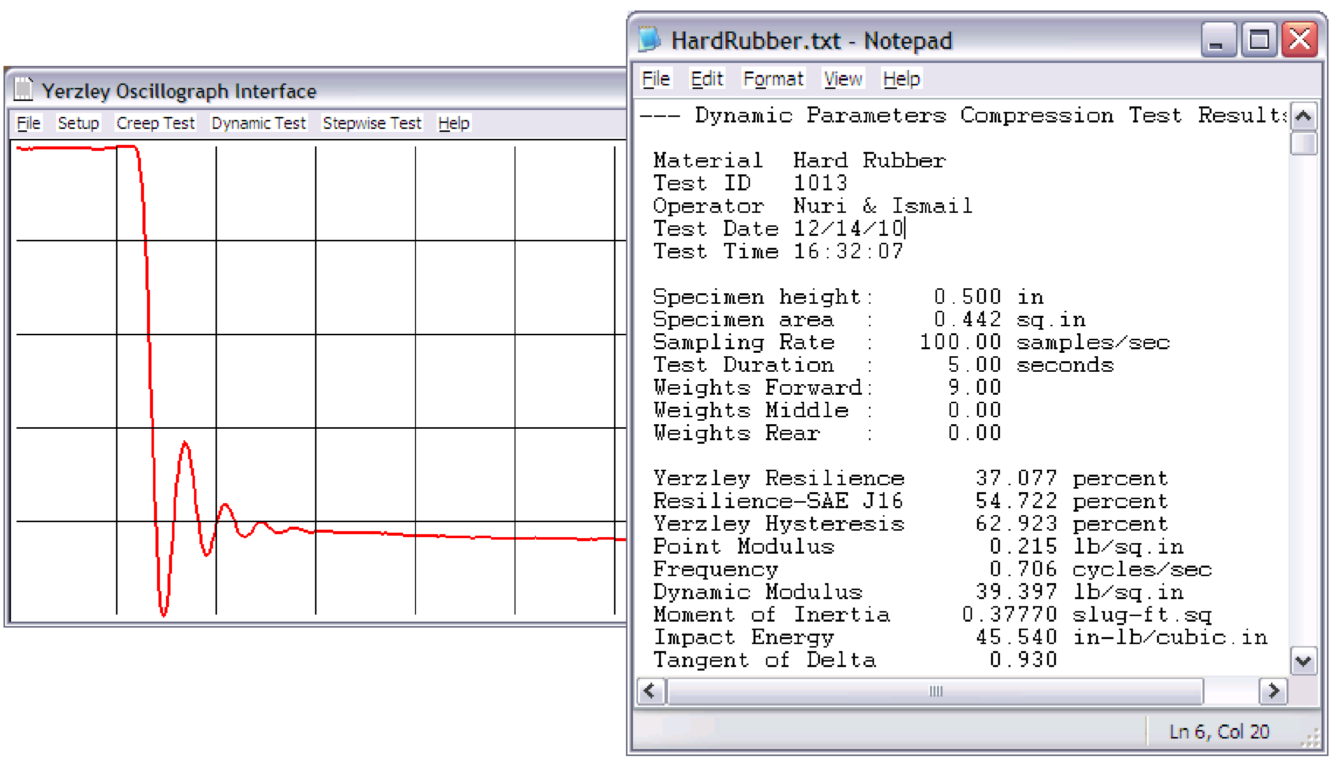


Figure 3: Example of dynamic test output for hard rubber sample.

Tangent of Delta (tan δ)

This parameter is not specified in the standard. It is a measure of energy dissipated by the rubber as it is subjected to vibration. Tan δ is defined in detail in reference (3), specifically in equation 26 on page 235 :

(Energy dissipated / Energy restored) = π/2 * tan δ

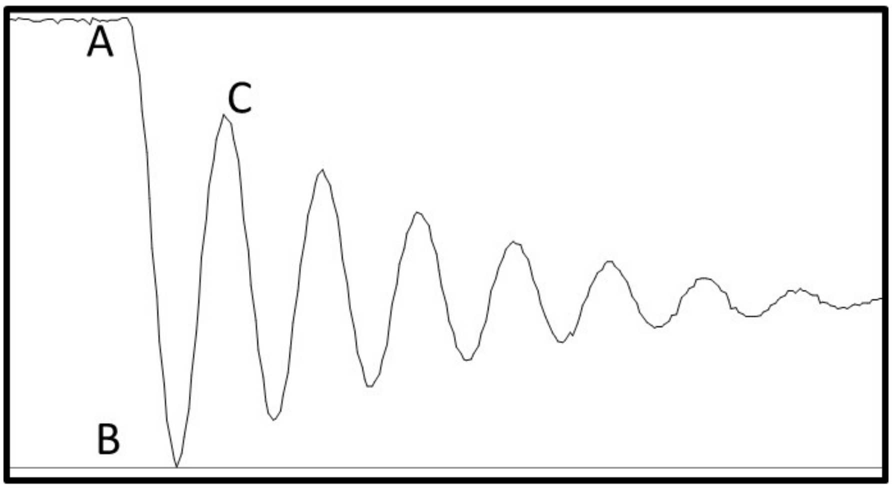


Figure 4. Example trace from Yerzley Oscillograph.
Displacement versus Time

Referring to Figure 4:

Energy dissipated = (Displacement@A – Displacement@C)*Weight

Energy restored = (Displacement@C – Displacement@B)*Weight

The Weight components cancel out and we are left with:

tan δ = 2/π * (*dsp*A-*dsp*C)/(*dsp*C-*dsp*B)
Where *dsp* stands for displacement@

System Calibration

The calculations for dynamic properties rely on the "moment of inertia – I" of "the beam". The component of the oscillograph, called "the beam" does not have a simple geometry; so it is not easy to determine it's "I" value purely from geometry. Furthermore, there are many components attached to this beam that affect the actual moment of inertia. The ASTM Standard D945-06 on page 9, in paragraph 13.10 mentions that **0.100 slug-ft.sq** is an approximate value that has historical acceptance. The standard does not specify a calibration method.

It is possible to determine the moment of inertia of the beam together with all it's attached components experimentally. The method below is based on the paper by Dr. F.L.Yerzley, published in the proceedings of the ASTM in volume 39, 1939.

In this method, we replace the rubber specimen with a suitable spring. The rubber specimens have large energy losses compared to a spring. During the motion of the oscillograph, part of the energy of oscillation is converted into heat in the rubber and as a result, the motion dies out relatively quickly. In contrast, a steel spring has fewer losses. A typical rubber specimen might oscillate for two to three seconds; whereas, a steel spring may still be oscillating after twenty seconds.

1. Measure the unloaded height of the spring.
2. Install the spring in the oscillograph.
3. Set zero on the displacement sensor window.
4. Add weights till you observe approximately 20% deflection. Note the deflection amount.
5. Determine the weight/force acting on the spring. The standard weights are 1.41372 lb and the moment arm to the forward position F is 6.25 inches. Therefore if two weights are used the force on the spring would be (2)(1.41372)(6.25) => 17.6715 lb.
6. The spring constant K' is defined by the following equation:

   Force = K' (deflection)/(Initial height)

   Where: F is the force on the spring in pounds
   K' is the spring constant
   Deflection is the amount measured in inches
   Initial height is also in inches.
7. Equation 9 on page 4 of the 1939 paper defines K' as follows:

   $$K' = 4\pi^2 h\, I\, f^2 \;/\; l^2$$

   Where h is the initial height
   I is the moment of inertia of the beam + weights
   f is the frequency in cycles/second
   l is the moment arm spring to fulcrum.

8. Run a Dynamic Parameters test with the spring. The frequency will be calculated for you by the analysis software.
9. Initial height "*h*" and the moment arm "l" are known quantities. We can solve for I, the moment of inertia.

Example:

Unloaded height of spring: 1.756 in => 0.146 ft
Moment arm: 1.600 in => 0.133 ft
Frequency = 2.479 cycles/second.
Used 4 weights at position F; therefore force on spring is 35.34 lb.
Two weights were used during the dynamic parameters test for frequency.

Measured a deflection of 0.191 inches.

K' = (35.34)(1.756)/(0.191) = 324.9 lb.

$I = (K' l^2) / (4\pi^2 h \ f^2)$

I = (324.9)(0.133)(0.133) / (4π)(π)(0.146)(2.479)(2.479)
I = 0.162248 slug-ft.sq

This value is the combined moment of inertia of the beam and the two weights used during the dynamic parameters test for frequency.

Moment of Inertia of Beam = 0.162248 – 2(0.03220) = **0.0978 slug-ft.sq**

This is the measured value for the moment of inertia of the beam. Notice that is very close to the historically accepted value of 0.100 slug-ft.sq.

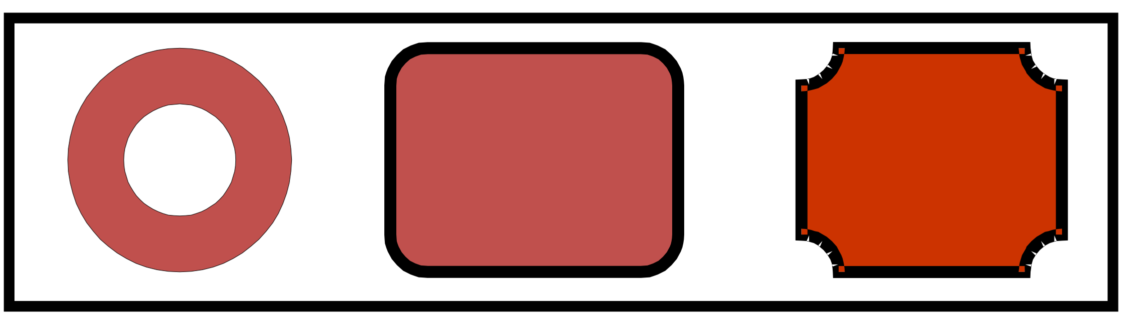
Non-Cylindrical Specimens

ASTM D945-06 specifies the use of a circular cylinder test specimen. The dimensions of this test specimen are also specified. It is not always possible to obtain a properly dimensioned test specimen. Frequently it is desirable to test a coupon of the actual parts/components delivered by a vendor.

A close reading of the standard ASTM D945-06 as well as a study of prior publications by Dr. F.L.Yerzley shows the way for a scientifically valid method for using sections of actual components as test specimens.

Requirements:

1. The part geometry must be an "extruded shape". The current official specimen is an extruded shape. The shapes below are some of the possibilities.



2. The shape factor of the new specimen must be consistent with that of the standard specimen.

Method:

Calculate the cross sectional area and the perimeter of the specimen. The height is to be determined by the shape factor specified in ASTM D945, which is 0.375 for inch-pound units. The definition of the Shape Factor (Sf) is stressed area divided by unstressed area.
Thus for the standard specimen it is:

$$Sf = (\pi*d*d/4)/(\pi*d*h) \Rightarrow 0.375$$

where **d** is the diameter and **h** is the height.

Expressing the same equation in terms of height, perimeter and area, we have

$$Sf = Area/(P*h)$$

where P is the perimeter.

Using the same shape factor as the standard and solving for height, we have:

$$h = Area / (0.375*P)$$

Thus, knowing the area and the perimeter of the shape, we can determine the height of the specimens for a Yerzley Oscillograph test. Note that the equations in the ASTM D945 standard have been reduced. They do not include area or height as separate parameters. AYO-IV software on the other hand allows the user to enter both area and height as parameters. This feature allows the testing of non-standard shapes as long as the shape factor is consistent with D945.

Conclusion

The venerable Yerzley Oscillograph has been automated and modernized improving efficiency of use.

References

1. ASTM Standard D945-06
2. F.L.Yerzley, “A Mechanical Oscillograph for Routine Tests of Rubber and Rubber-like Materials”, Proceedings of ASTM, volume 39, 1939.
3. Science and Technology of Rubber, Second Edition, 1994, page 235.