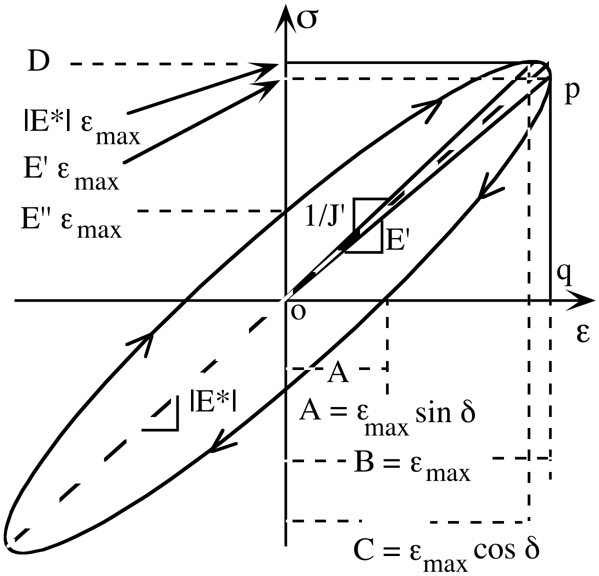
§1 Set-up Before lab, read web notes on viscoelasticity; review your class work on buckling.

§1.1 *Safety.* Servohydraulic machines can apply load rapidly. Therefore keep your hands away from the grips when a test program is applied. If brittle failure is a possibility, use a safety shield for protection from flying debris. Hydraulic grips exert considerable force. Be careful; keep hands out of the grips. Also do not put the compression grip all the way in the grips when mounting it or it can jam.

§1.2 Preparation. Measure the dimensions of the specimens provided.



§1.3 *Viscoelasticity*. Creep is the strain response to step stress; relaxation is the stress response to step strain. Stress σ vs. strain ε for a *linearly* viscoelastic material under oscillatory loading is the ellipse to the left; $\varepsilon = B \sin \omega t$; $\sigma = D \sin(\omega t + \delta)$. Observe that $\sin \delta = A/B$. The *dynamic modulus*, $\sigma/\varepsilon = E^* = E' + iE''$ is a complex quantity which depends on frequency $\nu = \omega/2\pi$. The phase angle δ also depends on frequency ν. The *loss tangent* $\tan \delta = E''/E'$ is the ratio of imaginary to real parts of the dynamic modulus. It is related to energy absorption per cycle, to attenuation of waves, and to damping of vibrations. The loss tangent is related to the slope of the log of moduli or compliances on log frequency or log time scales based on the *exact* relationship for a power-law relaxation, $E(t) = At^{-n}$, for which creep is also a power law and the loss angle is $\delta = n\pi/2$. $\tan \delta \approx -\frac{\pi}{2} \frac{d \ln E(t)}{d \ln t} \Big|_{t=1/\omega=1/2\pi\nu}$.

§1.4 Buckling. Consider elementary theory for buckling load $P_{cr} = \pi^2 EI/L^2$ for a simply supported column. For a column with built-in ends constrained so they cannot rotate, $P_{cr} = 4\pi^2 EI/L^2$. For tubes of Young's modulus E, Poisson's ratio ν, radius R and thickness h,

$P_{cr} = [1/\sqrt{3(1 - \nu^2)}\ ]\ Eh^2\ [(2\pi h/R)]$. [Bazant, Z. and Cedolin, L., *Stability of Structures*, Oxford, 1991].

§2 Testing

§2.0 Machine response Set up displacement control. Apply a sinusoidal signal at different frequencies. At what frequency does the machine have difficulty keeping up with the program signal? Repeat with load control. Is there any difference? If so, why? Can you improve the response by controlling gain? Plot displacement response versus frequency on a log log scale. If a rubber sample is in the test frame, capture data for it simultaneously.

§2.1 Relaxation test Conduct a stress relaxation test. How does the rise time depend on the servo gain? How does the rise time depend on the specimen stiffness? The rise time portion is not relaxation and does not belong in results for materials. If presented in context of machine response, use a separate graph.

§2.2 Creep test Conduct several creep and recovery tests at a stress comparable to the above initial stress.

§2.3 Constant deformation rate test Conduct a constant deformation rate test.

§2.4 Dynamic test Conduct dynamic tests of stiffness and tan δ vs. frequency. Take at least two or three data points per decade (a decade is a factor of ten in frequency or time). Obtain the modulus E' and the damping tan δ from the elliptic load deformation diagram on the scope.

§2.5 Buckling tests Available specimens include plastic rods, metal tubes, and aircraft honeycomb.

§3 Analysis and plotting

§3.1 What is the initial Young's modulus of the material? Compare with known materials.

§3.2 Plot both creep compliance and relaxation modulus versus log time t. Also plot compliance and modulus normalized to the value at one second to plot on the same scale. Also plot tan δ vs. log of frequency ν. Is there any overlap, assuming $2\pi\nu = 1/t$?

§3.3 Plot stress vs. strain for the constant deformation rate tests. Interpret the curve shape.

§4 Discussion Discuss your results, their implications, and comparison with theory. How do the materials studied compare with materials with which you are familiar? How do properties govern applications?

§5 Questions Please have a separate section for the answers.

5.1 How much noise occurs in the force and displacement channels? What is the ratio of signal to noise?

5.2 If you have done buckling, compare results with theory. Does it matter if you control load or displacement? Does your buckling test correspond to simple support?

5.3 If you have done viscoelasticity, how do your results compare with literature values? Discuss briefly.

§6 In-lab notes Attach in-lab hand written notes to the back of the report. Write the details of what you did and what you observed.