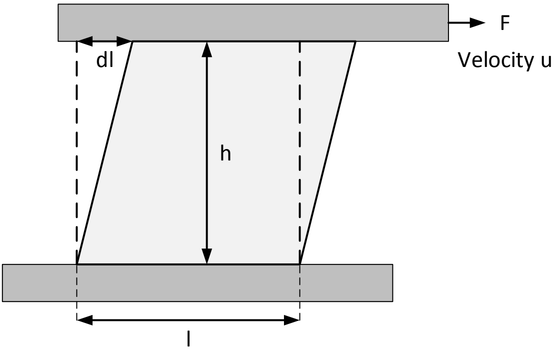
Viscosity measurement at high pressures

Peter Christiansen

DTU Mechanical Engineering
Department of Mechanical Engineering

What is viscosity?



$$\gamma = \frac{dl}{h} = \frac{udt}{h}$$

$$\dot{\gamma} = \frac{d}{dt}\left(\gamma\right) = \frac{u}{h}$$

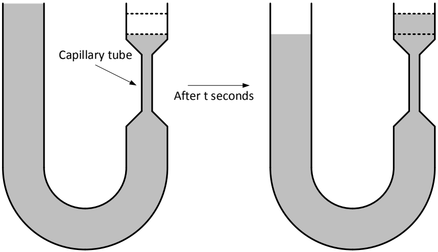
$$\tau = \eta\dot{\gamma}$$

Relationship between shear strain rate $\dot{\gamma}$ and shear stress τ

η is typically a function of both shear rate, pressure, temperature and fluid chemistry

Viscosity measurement

Capillary viscometer



$$\eta = k\rho t$$

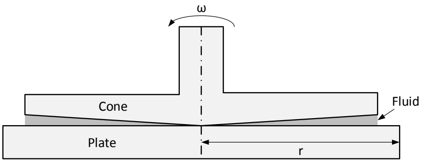
k is the capillary constant measured by a reference liquid

ρ is the density of the fluid

Temperature can be varied but not pressure or shear rate

Viscosity measurement

Cone on plate viscometer



$$\eta = kM/\omega$$

k is the viscometer constant measured by a reference liquid

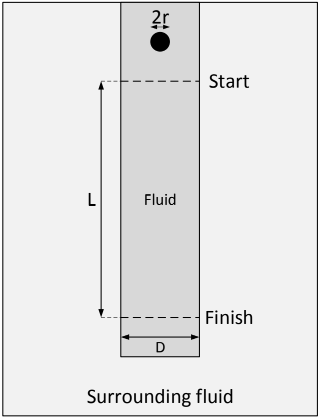
M is shear torque

ω is the angular velocity

Temperature and shear rate can be varied but not pressure

Viscosity measurement

Falling ball viscometer



$\eta = 2r^2 \left(\rho_s - \rho_f\right) gF/9u$

g is the gravitational constant

u is the velocity of the sphere

ρ_s is the density of the sphere

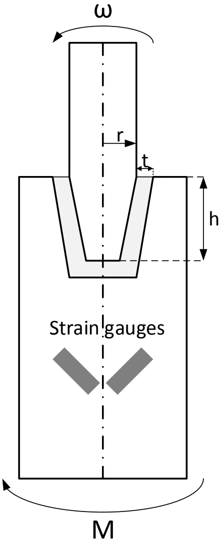
ρ_f is the density of the fluid

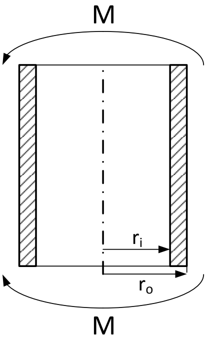
$F = 1 - 2.104\,(d/D) + 2.09\,(d/D)^3 - 0.9\,(d/D)^5$

$d = 2r$

Temperature and pressure can be varied but not shear rate

New viscometer concept





$$u = r\omega$$

$$\dot{\gamma} = \frac{u}{t}$$

$$\tau = \eta\dot{\gamma}$$

$$M = \tau A\,(r+t) = \frac{\eta\omega 2\pi r h}{t}\,(r+t)^2$$

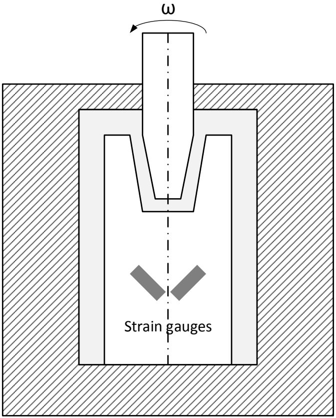
If $t \ll r$

$$M \approx \frac{2\pi\eta\omega h r^3}{t}$$

$$\tau_{max} = \frac{2Mr_o}{\pi\left(r_o^4 - r_i^4\right)}$$

Temperature and shear rate can be varied but not pressure

New viscometer concept



- Dimensions?
- Torque?
- Material?

Temperature, shear rate and pressure can be varied

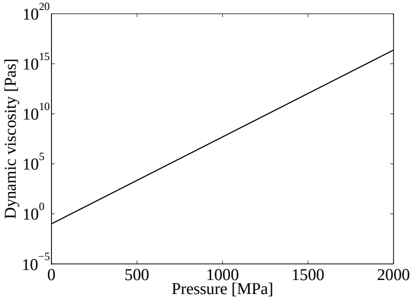
Torque estimation based on Barus equation

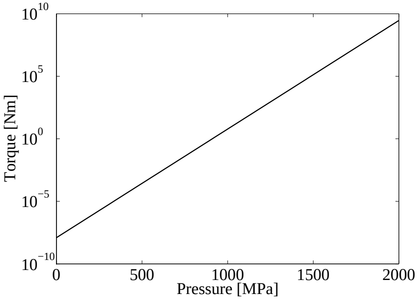
Barus equation: $\eta = \eta_o e^{\alpha p}$

$\eta_o \approx 0.1 Pas$, $\alpha \approx 20 \cdot 10^{-9} m^2/N$

$M \approx 2r^2\pi h\eta\frac{\omega}{t}$

$r = 5mm$, $h = 25mm$, $t = 1mm$, $\omega = 2\pi/s$





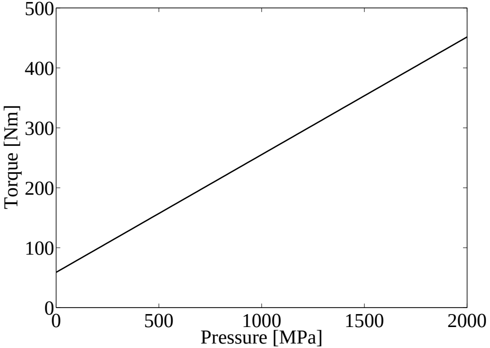
Possibility to encounter differences in torque during experiments.

Torque estimation based on maximum shear strength of oil

$$\tau_L = \tau_o + ap \qquad M \approx 2\pi h r^2 \tau_L$$

$$\tau_o \approx 15MPa$$

$$a \approx 0.05$$



Dimensioning torque: 40NM. Number with some uncertainty.

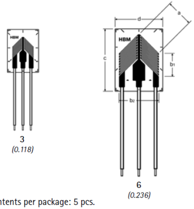
Design of strain gauge setup

Strain gauge from HBM

K-XY4x

Shear/torsion half bridge
Temperature response matched to customer's choice
see page 16

Illustrations show actual size



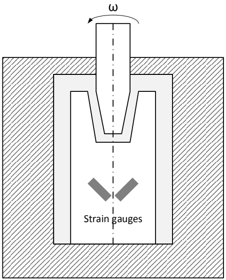
Contents per package: 5 pcs.

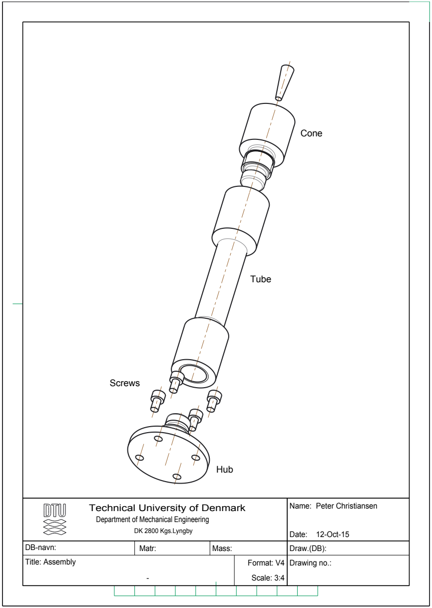
Types available at short notice		Variants(1)	Nominal resistance	Dimensions (mm/*inch*)					Max. perm. effective bridge ex. voltage	Solder terminals
				Measuring grid			Measuring grid carrier			not required
Steel	Aluminum	Other	Ω	a	b1	b2	c	d	V	
		K-XY4x-3/120	120	3 *0.118*	3 *0.12*	5.4 *0.21*	11 *0.433*	8 *0.315*	5	
		K-XY4x-6/120	120	6 *0.236*	6 *0.24*	10.2 *0.40*	16 *0.630*	12.2 *0.480*	9.5	
		K-XY4x-3/350	350	3 *0.118*	4.2 *0.17*	5.6 *0.22*	11 *0.433*	8 *0.315*	9.5	
		K-XY4x-6/350	350	6 *0.236*	6 *0.24*	10 *0.39*	16 *0.630*	12.2 *0.480*	16	
		K-XY4x-3/700	700	3 *0.118*	4.2 *0.17*	5.6 *0.22*	11 *0.433*	8 *0.315*	13.5	
		K-XY4x-6/700	700	6 *0.236*	6.1 *0.24*	9.9 *0.39*	16 *0.630*	12.2 *0.480*	23	

(1) Variants: Minimum order quantity: 3 packages
(#) Types are only available with matching to aluminum, ferritic or austenitic steel

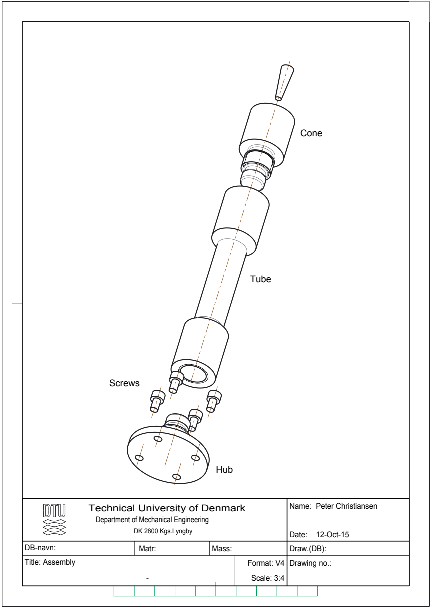
Strains < 0.001 and uniform

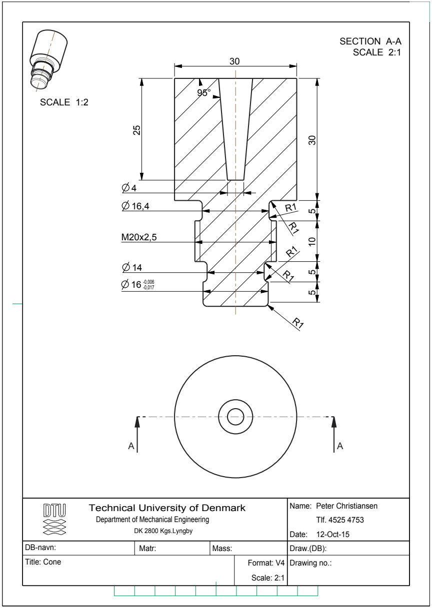
Design of strain gauge setup



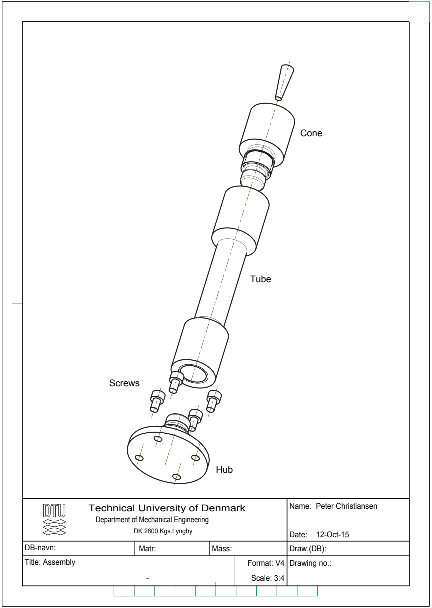


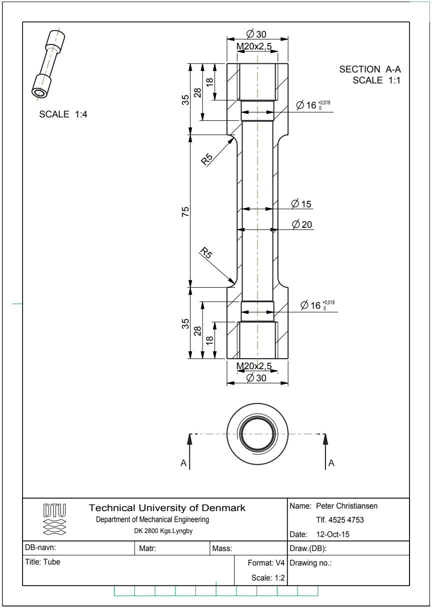
Design of strain gauge setup



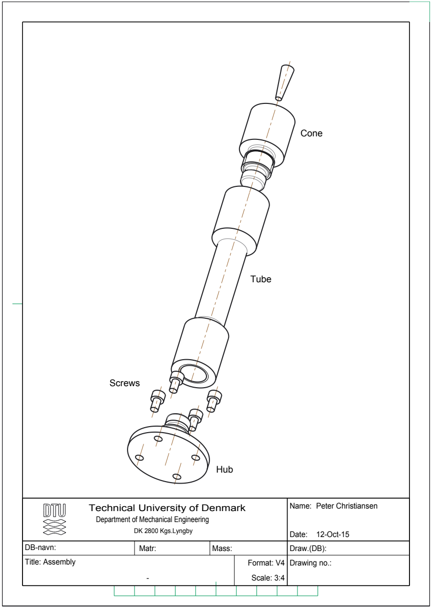


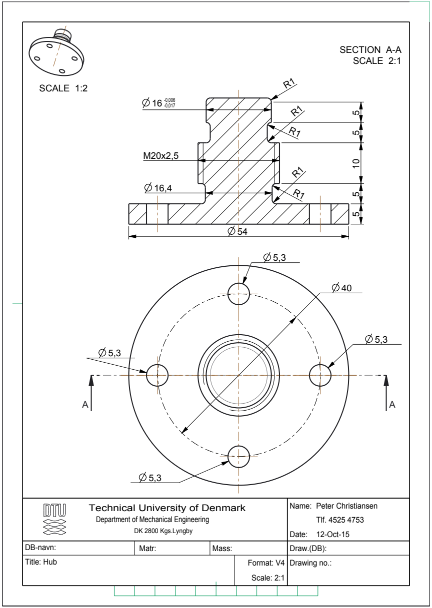
Design of strain gauge setup





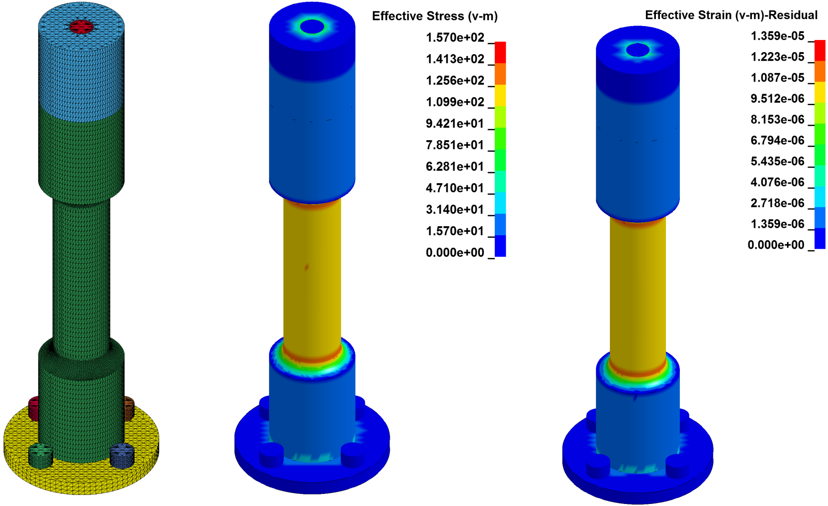
Design of strain gauge setup





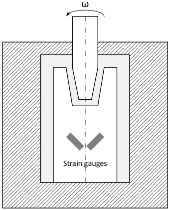
Design of strain gauge setup

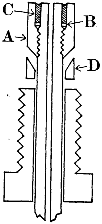
LS-DYNA simulation



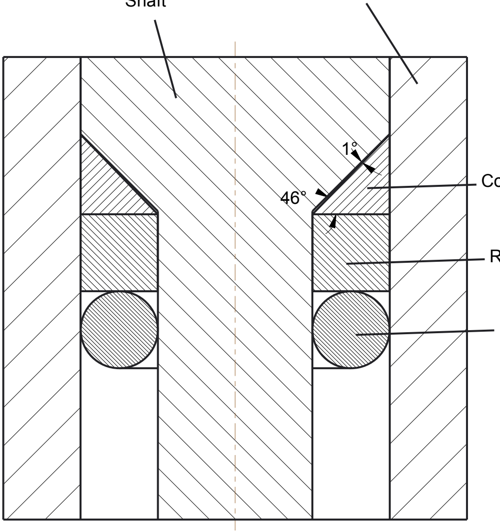
Sealing between shaft and chamber

Bridgman seal. 44º or 46º?



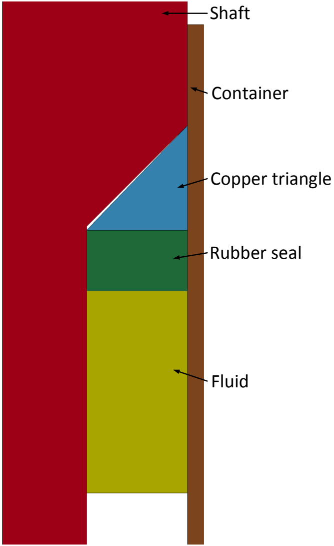


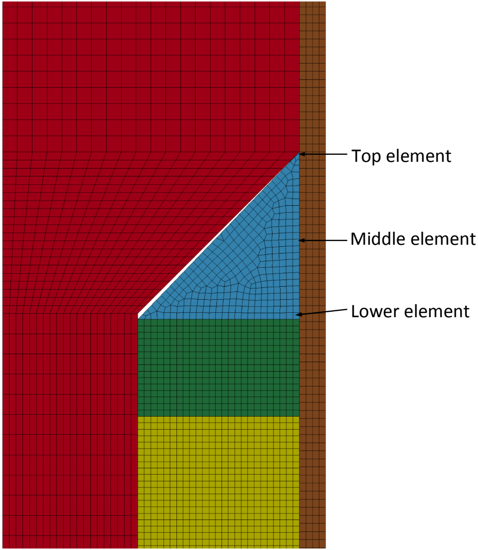
Bridgman (1914)



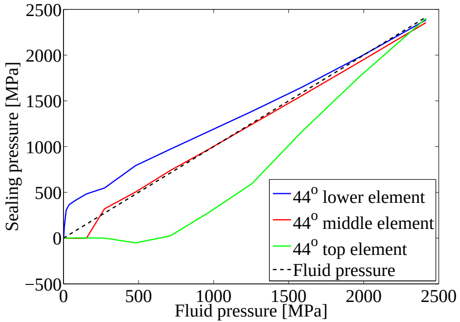
Bridgman seal

LS-DYNA simulation

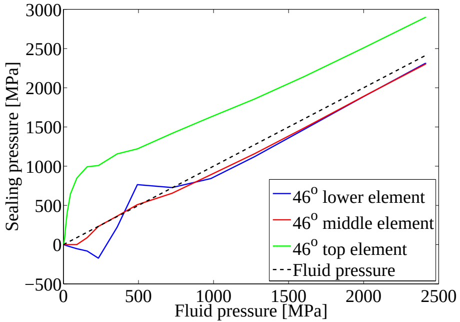




Bridgman seal



44° triangle



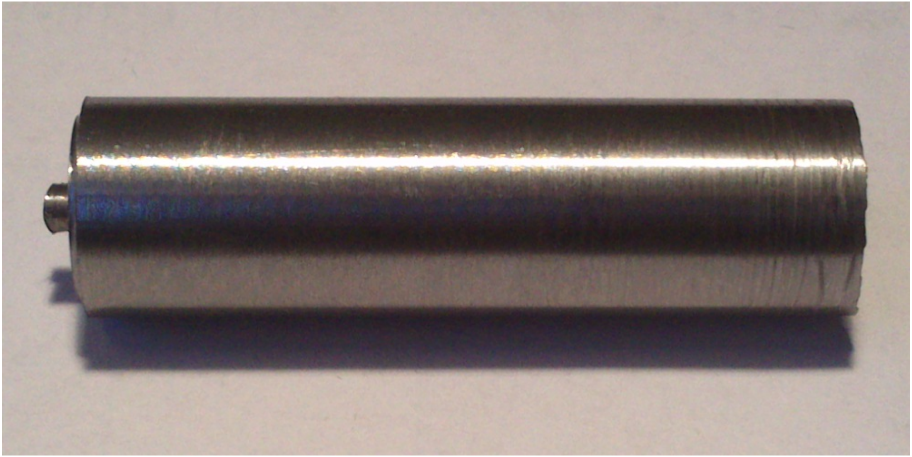
46° triangle

46° gives larger closure pressure

Possible material for construction

Uddeholm suggests to immerse possible tool steel candidates for construction into relevant oils for corrosion testing.

Sverker 21 after immersion into TDN81 (chlorinated paraffin oil) for 14 days.



Future challenges

- Chamber pressurization

- Wires from data aquisition inside chamber to outside

Questions?