Aalto University
School of Engineering

MEC-E6007 Mechanical Testing of Materials

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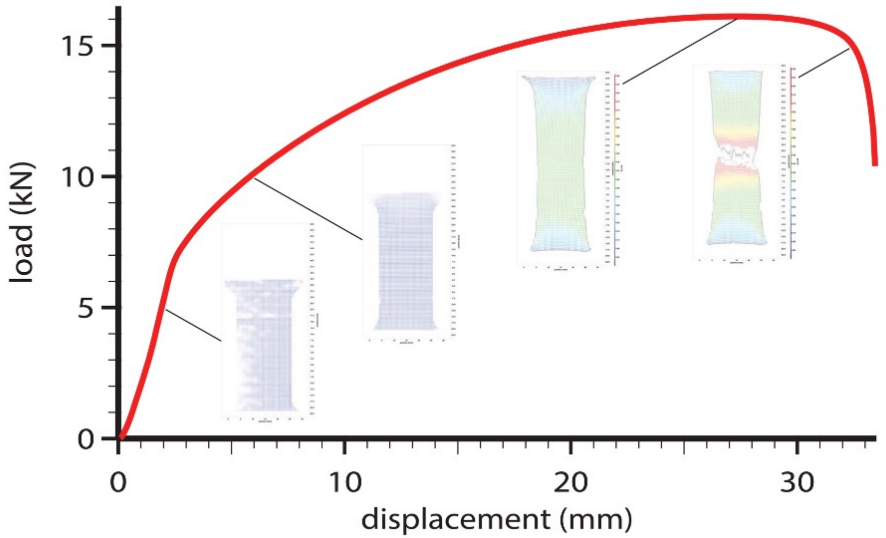
Aalto University
School of Engineering

measuring force, strain, and displacement

Course Content: *learning from breaking things*

- Load
  - *loadframes, actuators, and grips*
  - *quasi-static, dynamic, and cyclic loading*
- Measure
  - *measurement of force, displacement, and strain*
  - *digital image correlation and other full-field measurement techniques*
- Analyse
  - *selected special challenges in mechanical testing (ask for yours!)*
  - *introduction to inverse problem methodologies in experimental mechanics*



measuring force

definition of force:

- Newton's law
- force = mass × acceleration
  - *e.g. weights*
  - *not practical for measurement*
  - *okay for calibration*

Watt balance

- based on forces between wires carrying electrical current
- extremely precise measurement
  - *SI unit for mass to be redefined*

Fluid pressure

"dynamometer"

- Hooke's law
  - *ut tensio, sic vis*
- calibrated spring displacement proportional to force
  - *cantilever deflection for small forces*

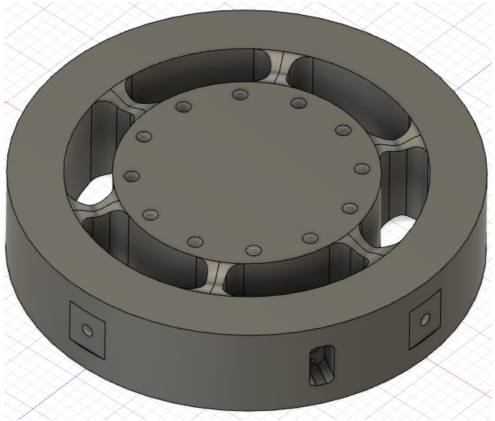
special materials

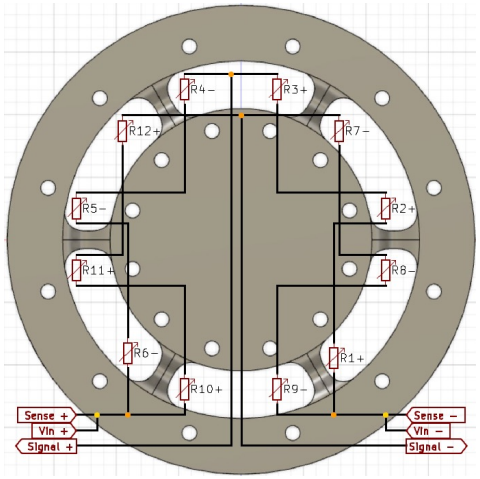
- piezoelectric
- piezoresistive
- magnetostrictive
- photoelastic
- colour change

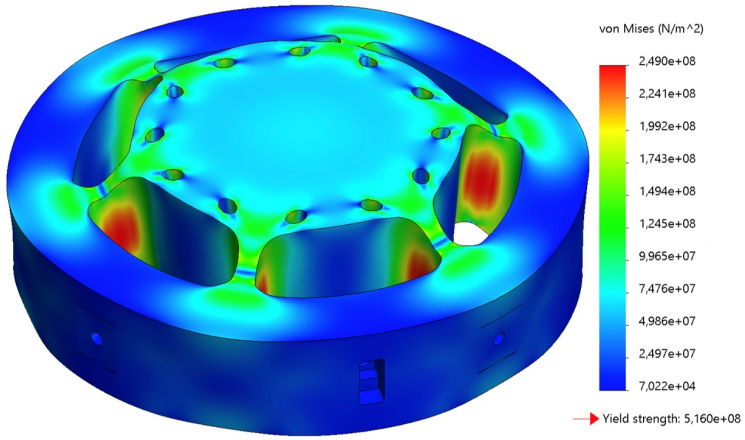
Load cell

mechanical amplification

- specially designed spring
  - *as stiff as possible*
  - *large strain in some parts*
  - *insensitive to other loads*
- electrical measurement of strain
  - *strain gauge or piezo-electric*
  - *temperature compensation*
- dynamic response
  - *usually limited by mechanical inertia*







L. Novio et al. “Development of a 650 kN tension and compression force transducer.” In *Proceedings of the 8th Baltic Mechatronics Symposium*. (2023)

measuring position or displacement

interferometry
- SI definition of meter
  - *count wavelengths*
  - *extremely sensitive*
- imaging interferometers
- speckle interferometry

visual comparison
- calibrated ruler
  - *minimize parallax*
  - *vernier scale for enhanced precision*
- calibrated imaging geometry
  - *photogrammetry*
  - *stereo views for 3D displacement*
- optical position encoders

mechanical amplification
- dial gauge
- clip gauge
- reflectometry

integrate strain
- or use known conversion factor for local strain

electrical capacitance
- inversely proportional to separation between conductive plates

magnetic inductance
- Linear Variable Differential Transformer (LVDT)

optical or electrical gates
- detect whether light or electricity can pass
  - *optionally measure how much*

range-finding
- RADAR (radio waves)
- SONAR (sound)
- LIDAR (light)

doppler effect
- sensitive to velocity differences
- integrate velocity over time

inertial measurement
- accelerometers and gyroscopes
- integrate acceleration over time twice

measuring strain

definition of strain
- calculate from displacement gradient
- extensometers measuring relative displacement between ends of gauge length
- full-field strains from full-field displacement measurements

diffraction
- specially designed fiber Bragg gratings
- atomic spacing from X-ray or neutron diffraction
- electron backscatter diffraction (EBSD) in scanning electron microscope (SEM)

interferometry
- coherent gradient sensing (CGS)
- shearing speckle interferometry (shearography)

moiré
- interference effect due to occlusion

strain gauges
- resistivity changes due to conductor geometry change
  - *even larger change possible with piezoresistive effect*
- serpentine geometry sensitive in one direction

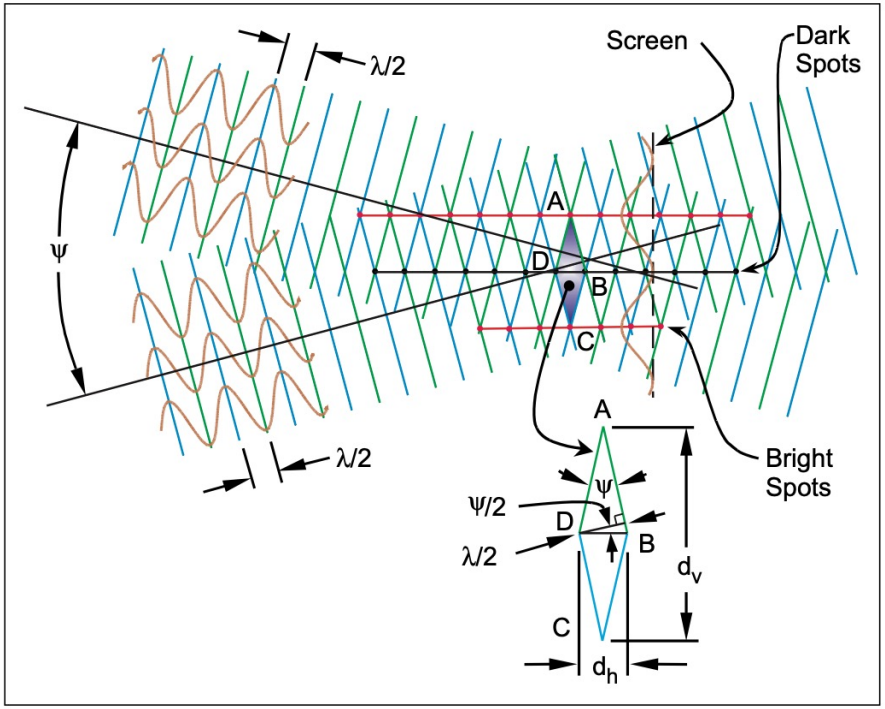
special materials
- piezoelectric
- piezoresistive
- magnetostrictive
- photoelastic
- colour change

percolation of conducting particles
- carbon-filled rubber
  - *widely used in old telephone sets*
- carbon nanofibers
- conductivity is extremely sensitive at percolation threshold
- electrical impedence tomography

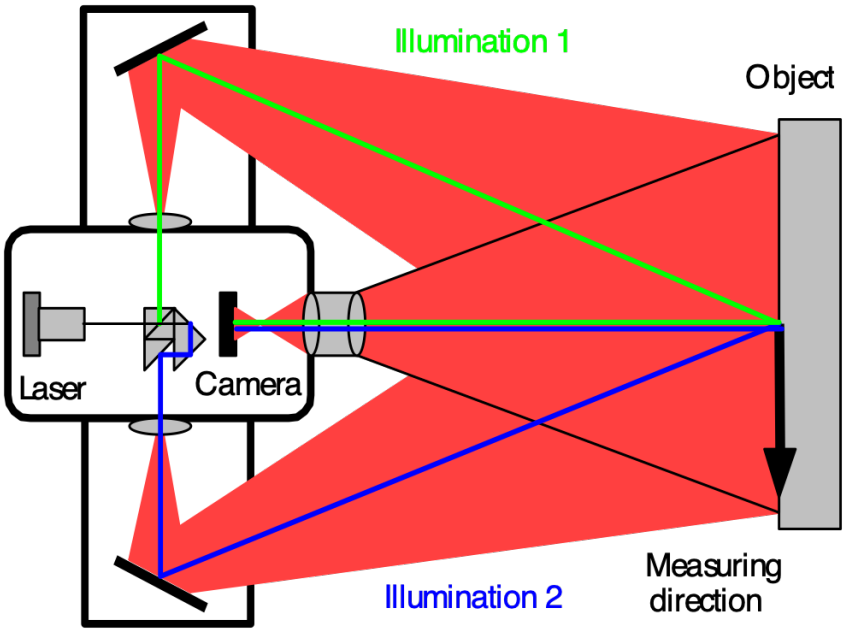
Interferometry

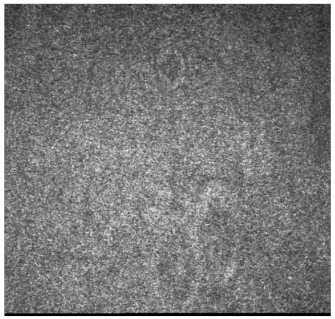
coherent light

- positive or destructive interference depending on differential phase between two light paths originating from same source
- setup designed so displacement causes change in optical path length
- measurement precision is a fraction of the wavelength of the light used

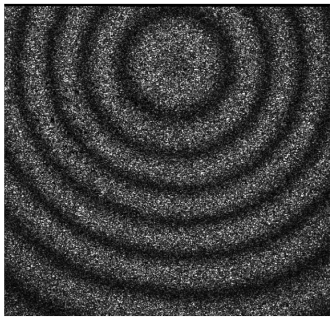


Electronic Speckle Pattern Interferometry

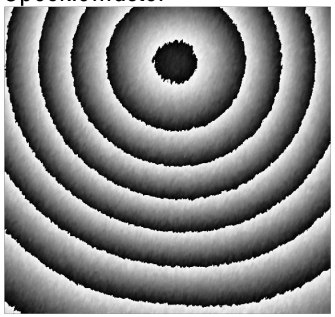




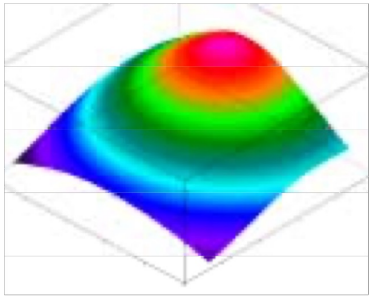
Specklemuster



Streifenbild

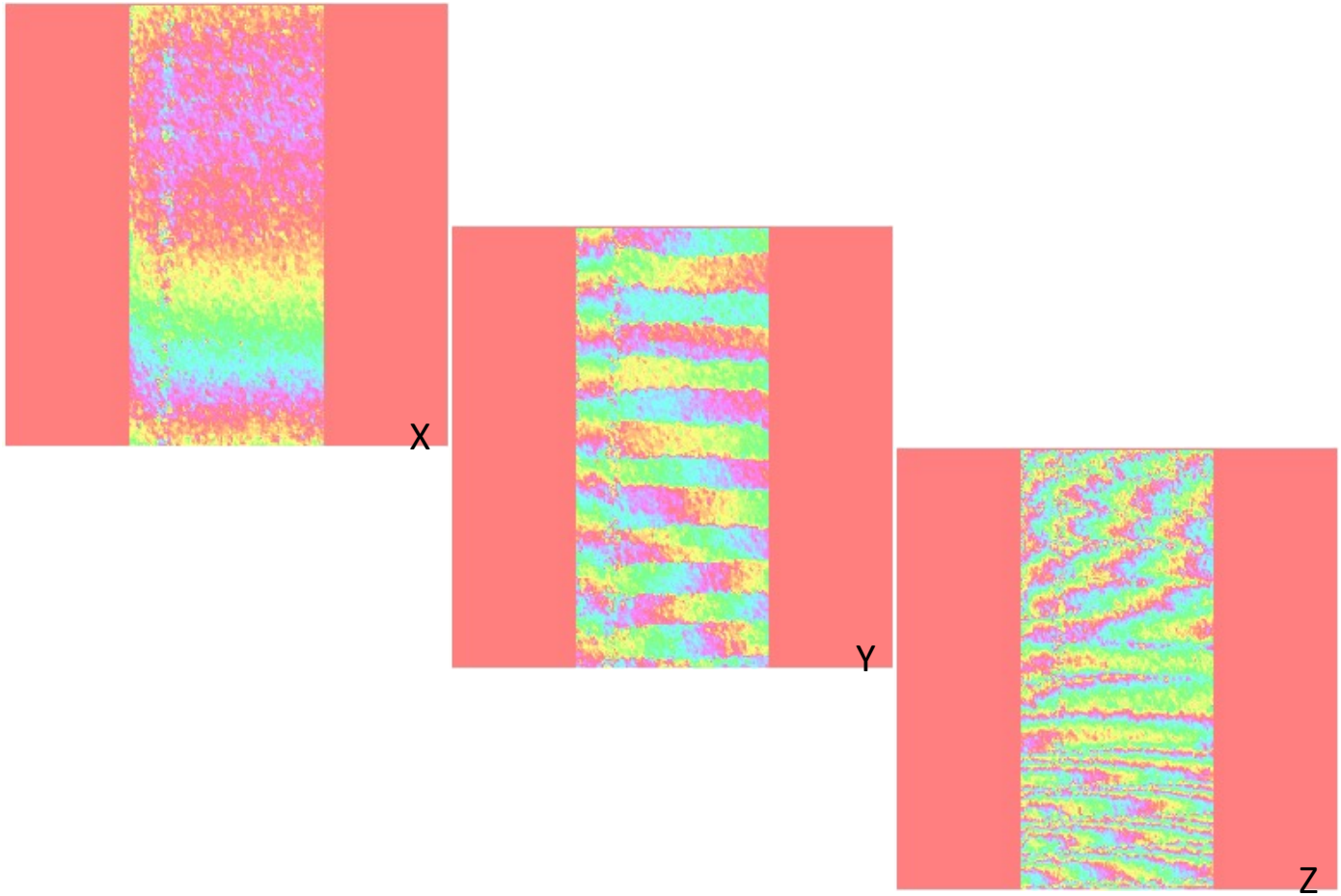


Phasenbild

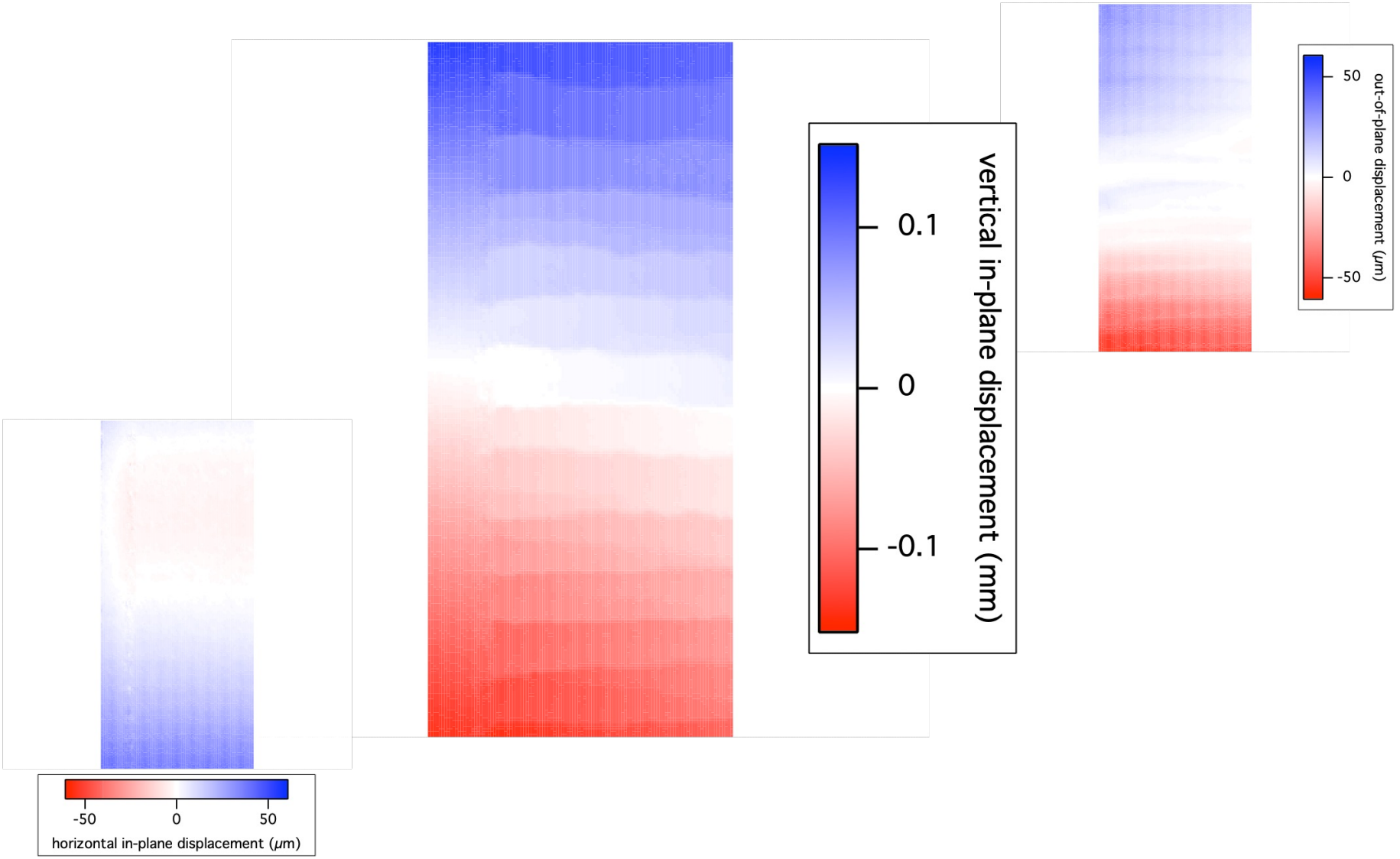


Verschiebungsfeld

ESPI Phase Maps



ESPI Displacement Fields



Advantages and disadvantages of ESPI

Advantages

- Very high sensitivity
  - *especially to out-of-plane motion*
- Direct measure of displacement
  - *lens distortions affect only location of the measurement, not displacement amplitude measured*

Disadvantages

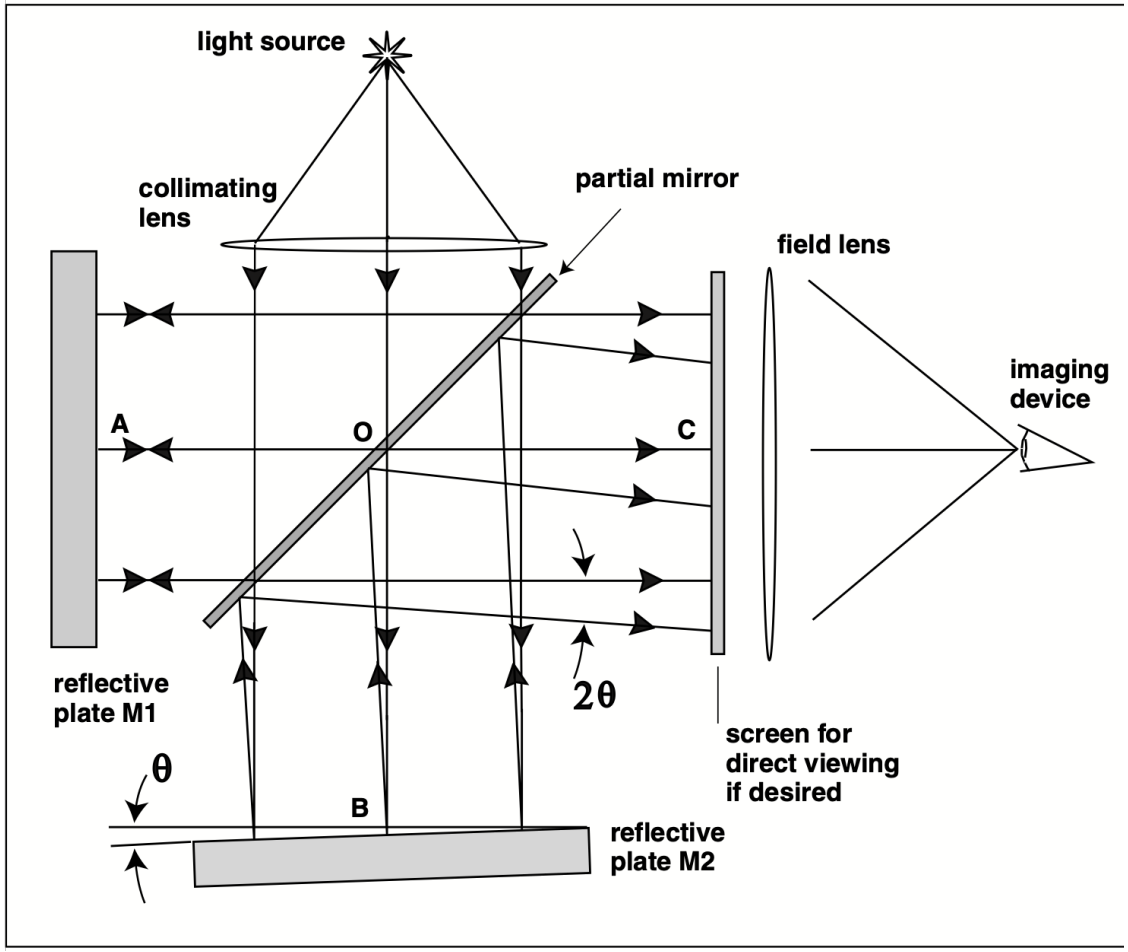
- Very high sensitivity
  - *especially to out-of-plane motion*
  - *vibrations!*
- Decoherence at large displacement amplitudes
- Coherent light needed

Shearography

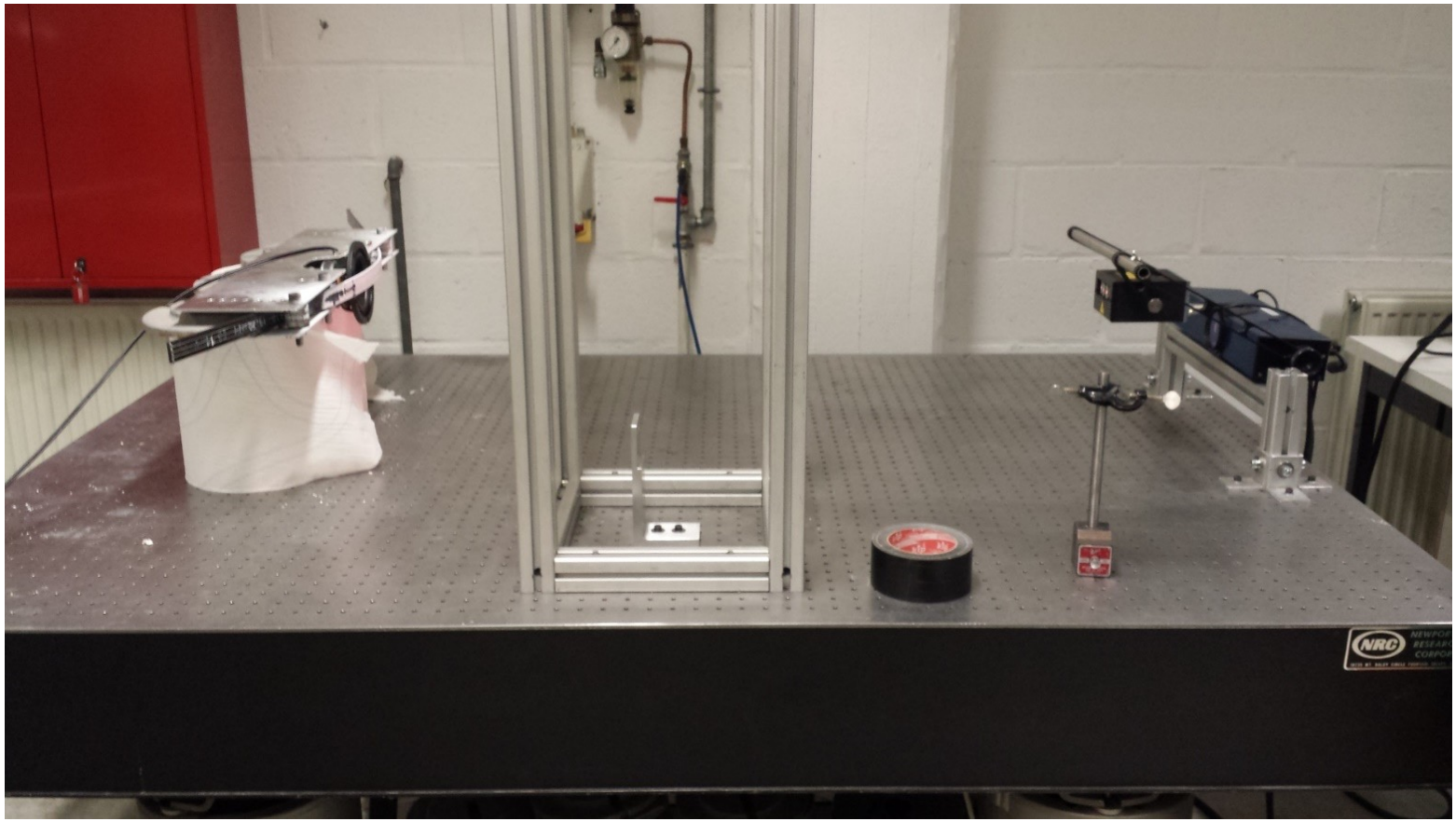
"Misaligned" interferometer gives double image

Speckle Pattern Interferometry is then sensitive to displacement difference between two neighbouring points on the object

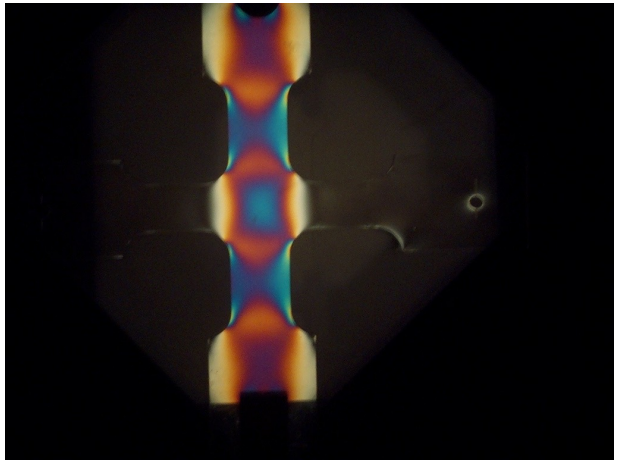
- More difficult to analyse quantitatively
- Less sensitive to vibrations

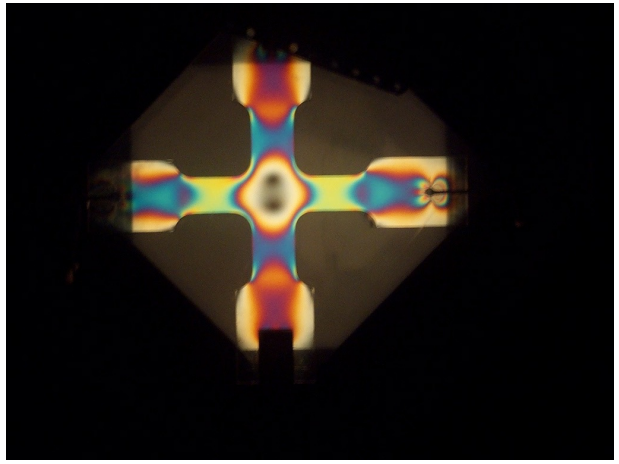


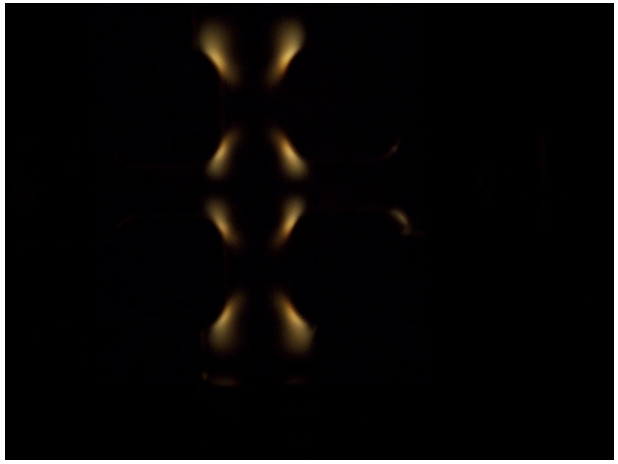
Shearography example

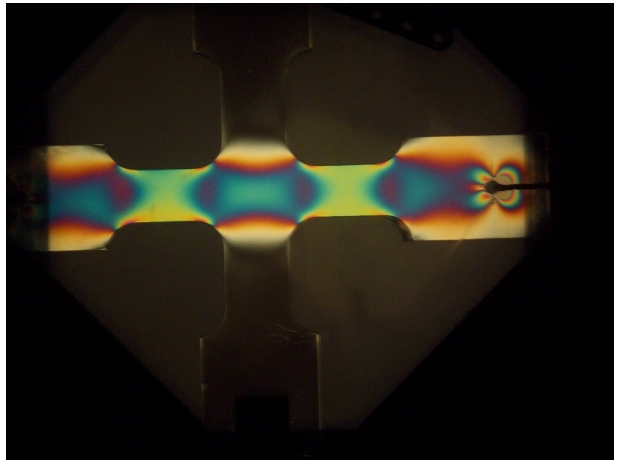


Photoelasticity imaging birefringence with polarized light

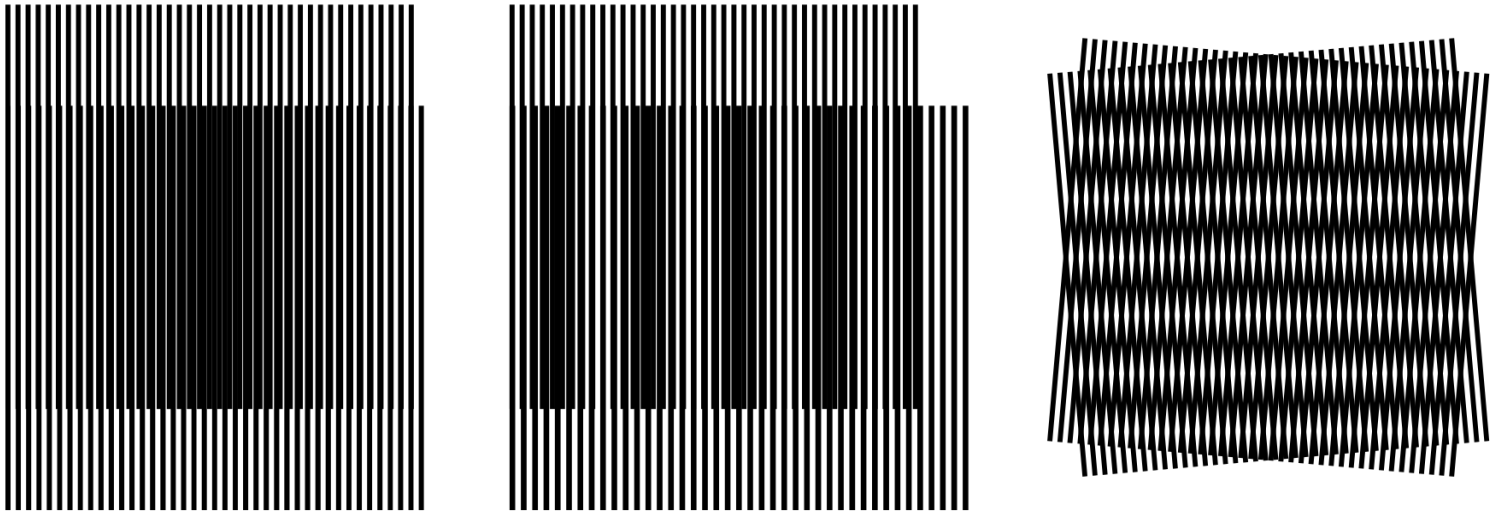






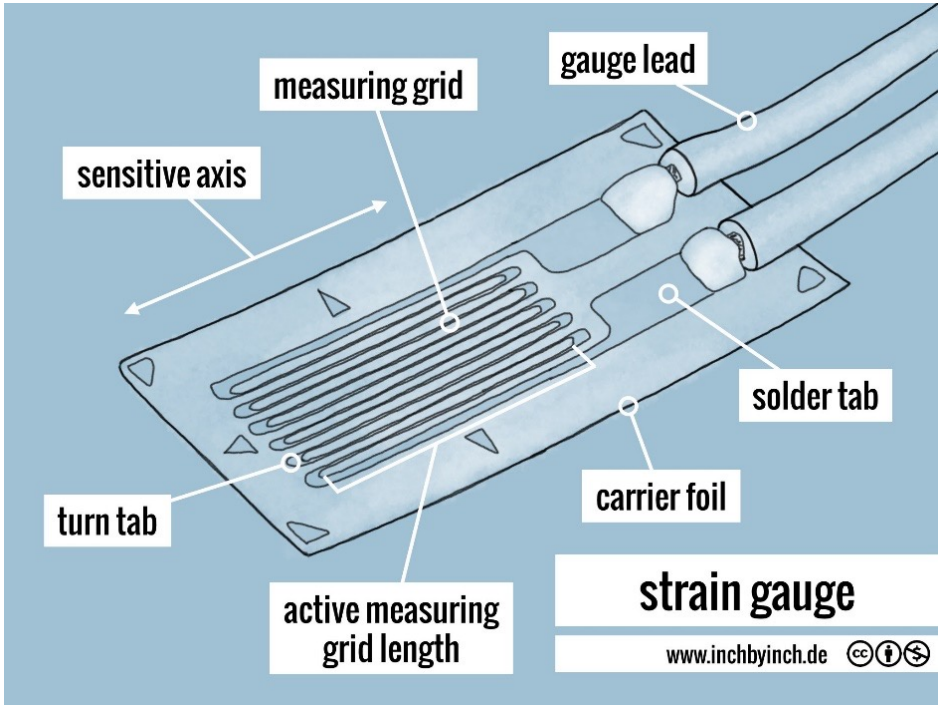


Moiré



Strain Gauges

- widely used in instrumentation
  - *e.g. most digital scales use strain gauges*
  - *usually in pairs or fours for differential measurements*
- bonded to surface
  - *need to choose appropriate glue*
- cable management
- rosette for calculating in-plane strain components
- Wheatstone bridge directly gives differential measurements



electrical measurements
and digital signal acquisition

ADC – Analog to Digital Conversion

- fast dedicated circuitry to digitize voltages with high impedance
  - *other quantities amplified (or scaled down) to convert to 10V range*
  - *quantisation at a certain number of bits in the binary number*
  - *as expansion board in a computer or stand-alone*
- multiplexed to measure multiple channels in parallel
- care needed to ensure synchronous acquisition

coaxial cabling with standard connectors

- shielding from electrical interference
- spurious signal transmission issues if cables kinked or crushed