The use of Pulsed ESPI for the detection of subsurface defects

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Joining Forces

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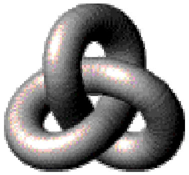


Vrije Universiteit Brussel

Department of Mechanics of Materials
and Constructions
Faculty of Engineering

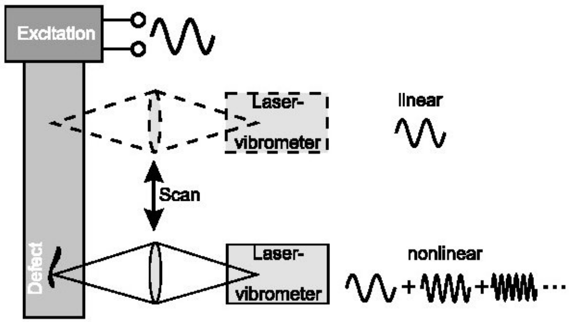
METALogic

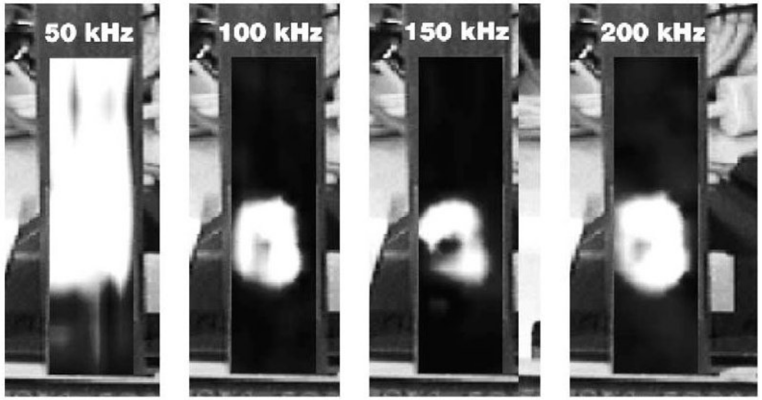
Active in the development of innovative solutions for materials research and corrosion control.

What is the basis of our methods?

- Full-field vibration characteristics evaluation based on speckle pattern interferometric techniques.
- The exploitation of non-classical nonlinearity originating from the presence of a defect to locate it and characterize its size.
- The use of high sensitivity techniques to visualize the transient full sound wave-field in its interaction with surface and subsurface defects.

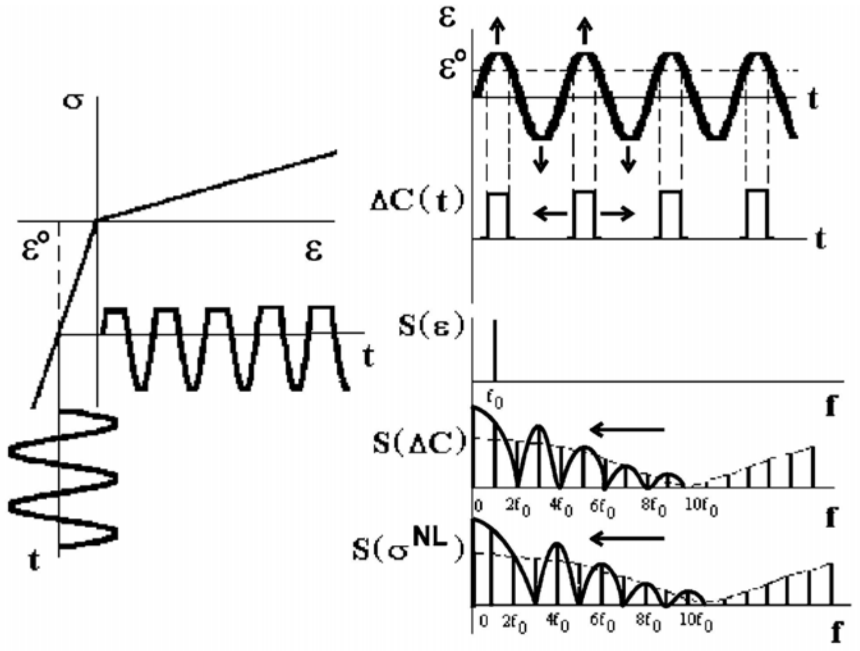
Motivation of the project





Nonlinear Laser Doppler Vibrometry (Busse et al.)

Contact acoustic nonlinearity (Gusev, Solodov)



(a) (b)

Piecewise stress-strain relation:

$$\sigma = C\left[1 - H\left(\varepsilon - \varepsilon^0\right)\left(\Delta C / C\right)\right]\varepsilon$$

ε^0 : initial static strain
C : the elasticity modulus of the intact material

$$\Delta C = \left[C - \left(d\sigma / d\varepsilon\right)_{\varepsilon > 0}\right]$$

For: $\varepsilon(t) = \varepsilon_0 \cos\omega_0 t$ → *ΔC(t)* is a pulse modulation type of function

$$\Delta C(t) = \Delta C(t+T) = \frac{\Delta C}{C} \quad \text{for } |t| < \tau/2$$

where: $\tau = \left(T/\pi\right)\arccos\left(\varepsilon^0/\varepsilon_0\right)$

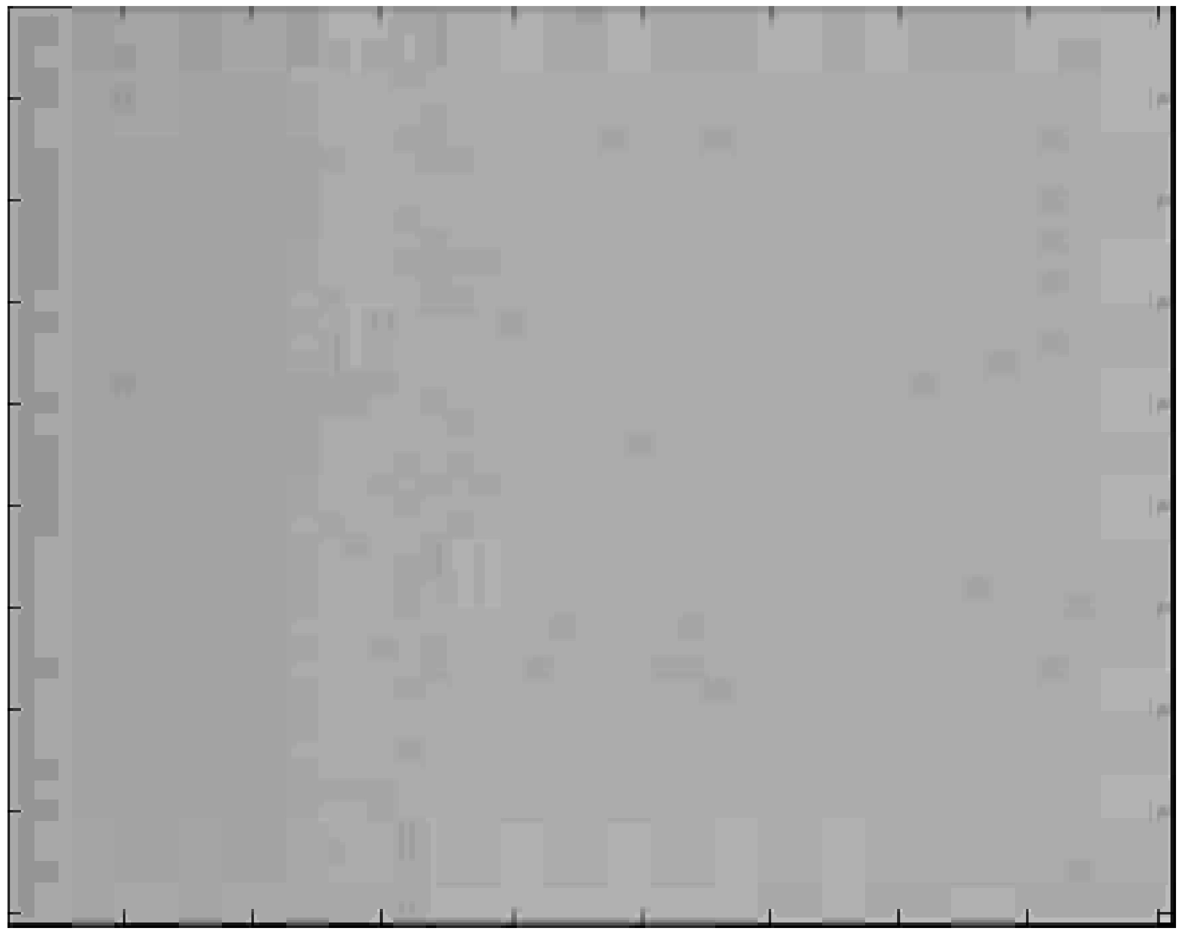
Sound wave interaction with subsurface defects

Glass sample:
18 x 18 mm

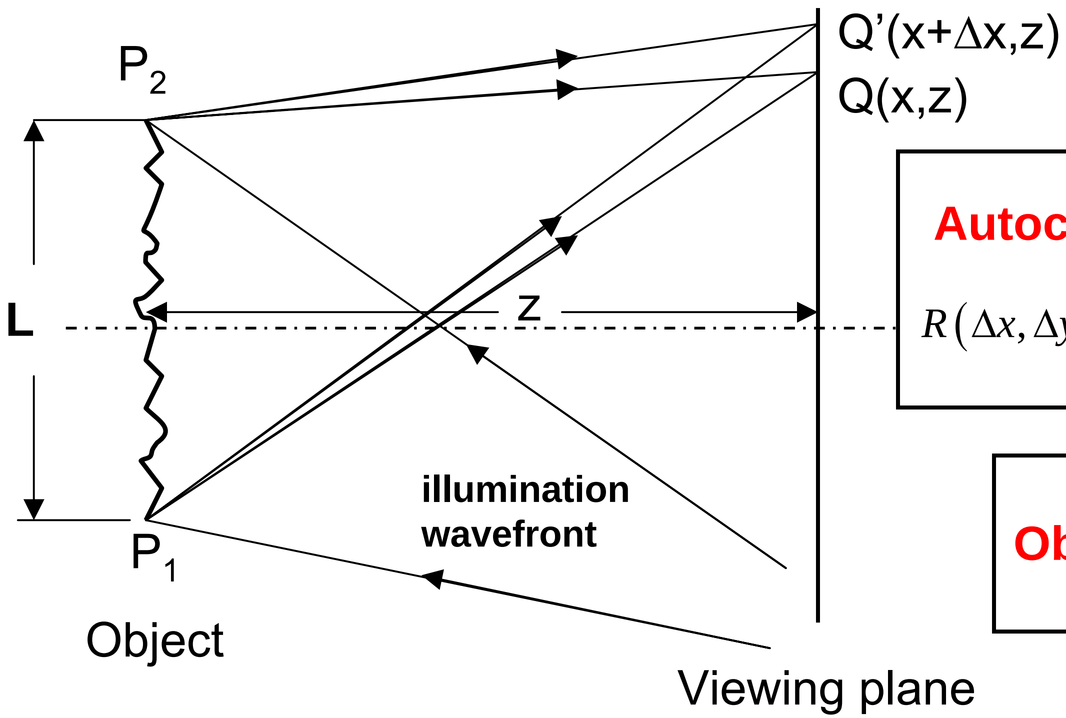
Defect size:
1 x 1 mm^2

Total movie time: 5 μs

Acquisition time: ~24h



Speckle Effect



Autocorrelation function (Goodman)

$$R(\Delta x, \Delta y) = \langle I \rangle^2 \left[1 + \mathrm{sinc}^2\left(\frac{L\Delta x}{\lambda z}\right) + \mathrm{sinc}^2\left(\frac{L\Delta y}{\lambda z}\right) \right]$$

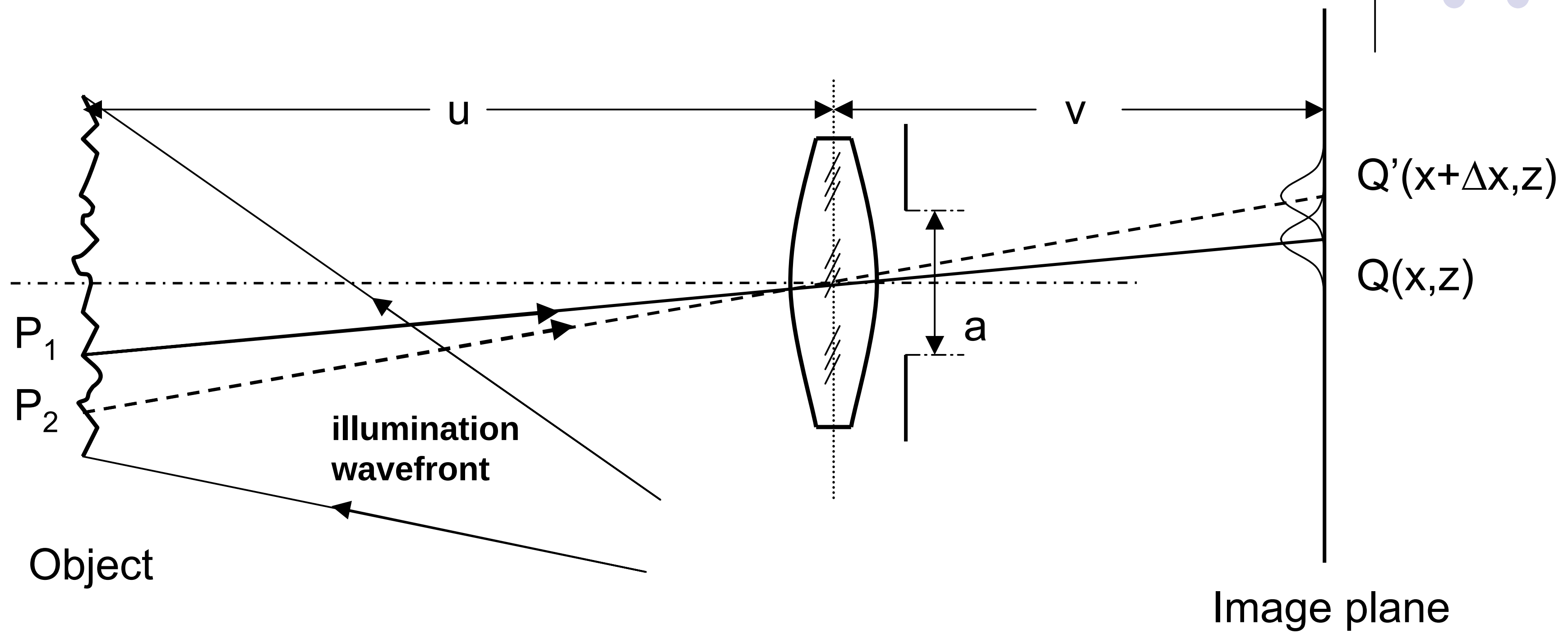
Objective Speckle size: $(\Delta x)_S = \dfrac{\lambda z}{L}$

$$U(r) = k \iint u(x, y) \exp\left[\frac{2\pi i}{\lambda} G \xi(x, y)\right] dxdy$$

$\xi(x, y)$: Surface height

G : Geometric factor associated with the illumination and viewing directions

Objective vs Subjective Speckle

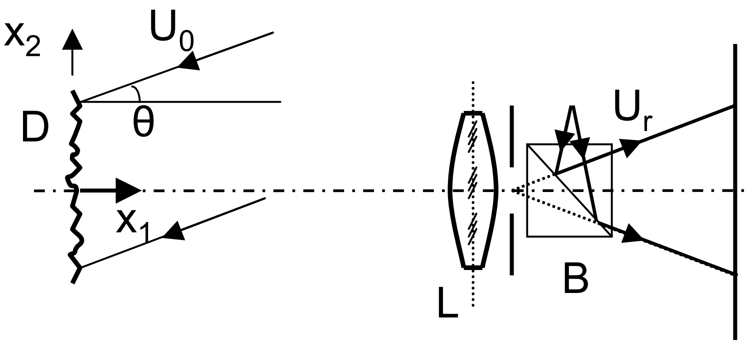


Autocorrelation function (Goodman)

$$R(r) = \langle I \rangle^2 \left[1 + 2\, J_1\left(\frac{\pi a r}{\lambda v}\right) \Big/ \left(\frac{\pi a r}{\lambda v}\right) \right]$$

Subjective Speckle size: $d_{Sp} = \dfrac{2.44 \lambda v}{a}$

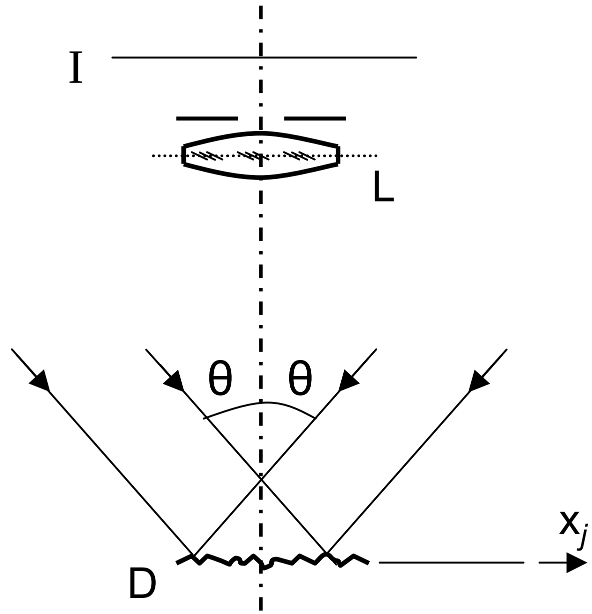
Speckle Pattern Interferometry (Leendertz, 1970)



Configuration for out-of-plane measurements

$$\Delta\phi = \frac{2\pi}{\lambda}(1+\cos\theta)\,d_1$$

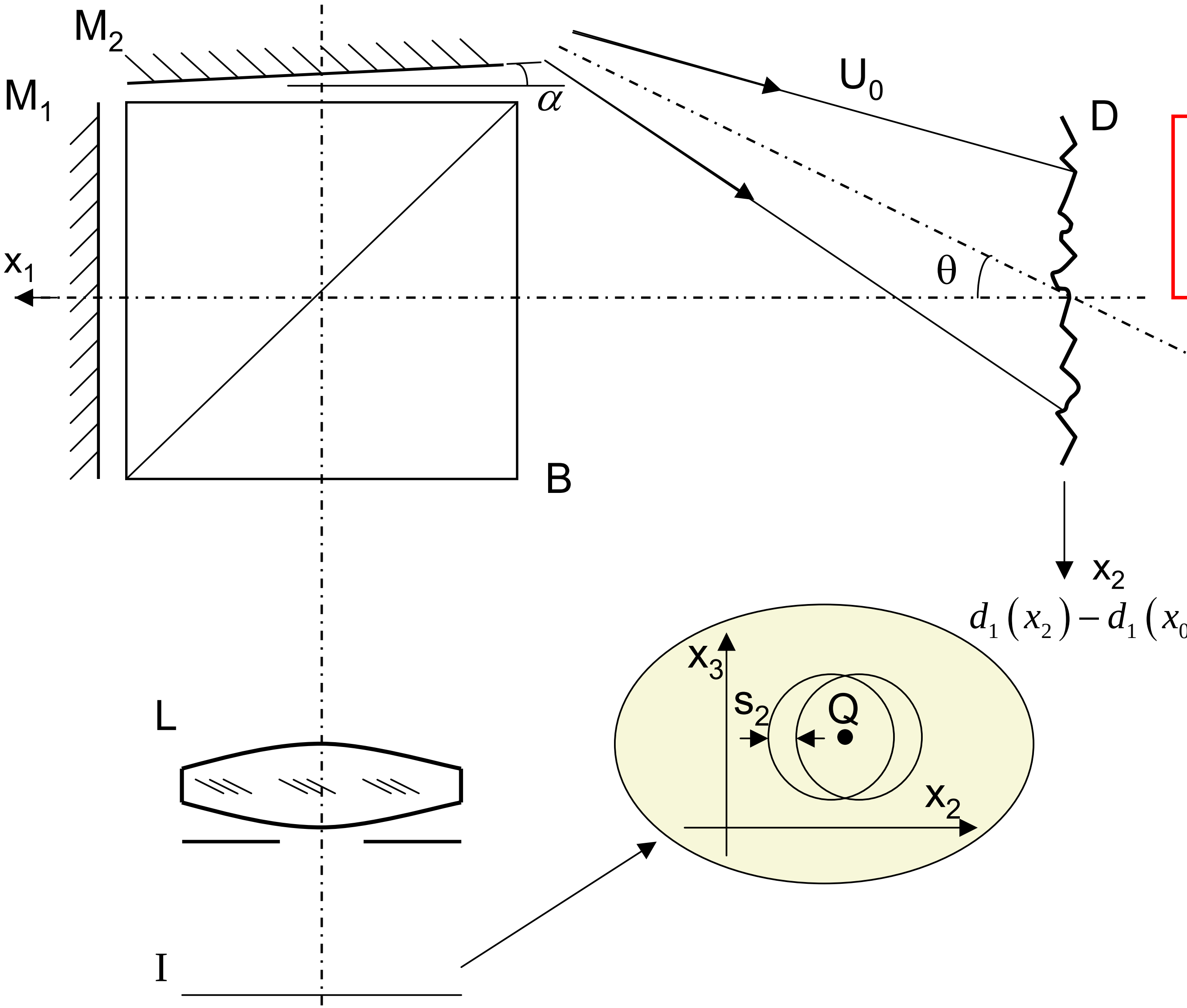
$$\Delta\phi = \frac{2\pi}{\lambda}(\mathbf{n_0} - \mathbf{n_s})\cdot\mathbf{d}$$



$$\Delta\phi = \frac{2\pi}{\lambda}(\sin\theta)\,d_j \qquad j = 2,3$$

Configuration for in-plane measurements

Shearography



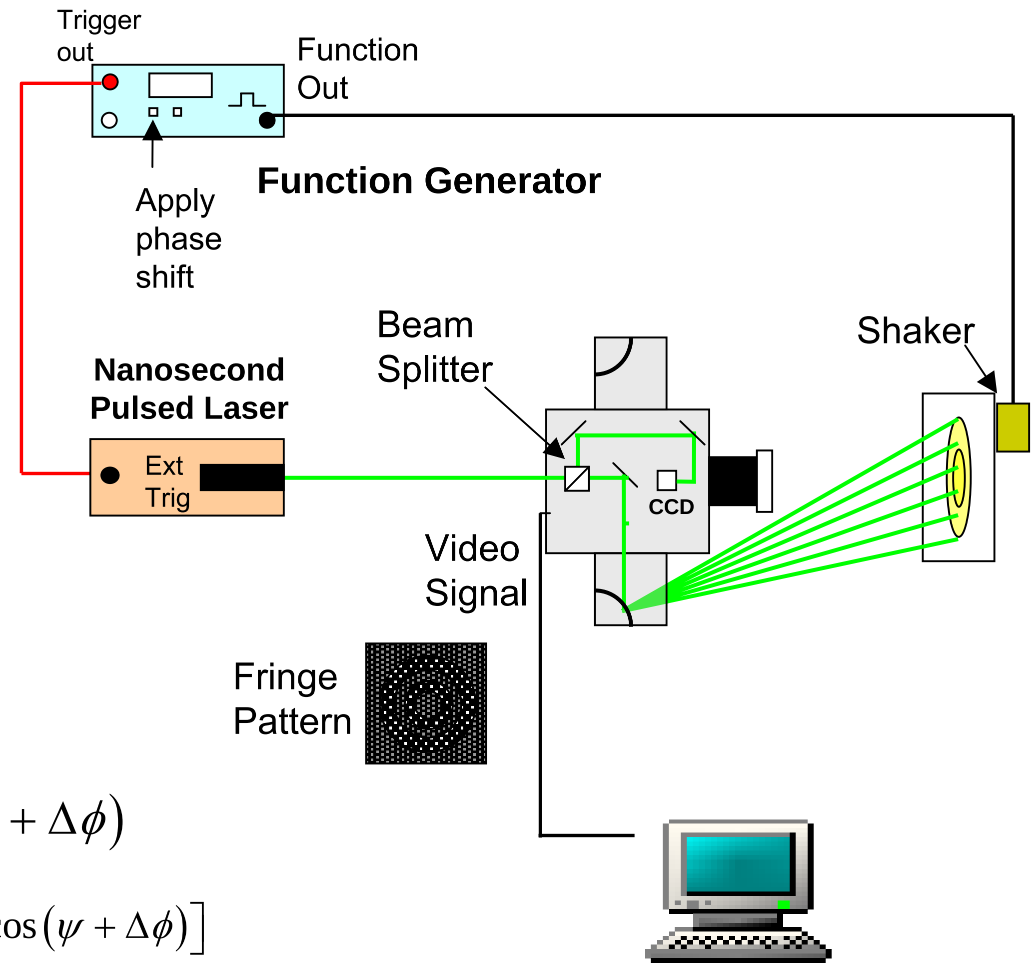
$$\Delta\phi = \frac{2\pi}{\lambda}\left(\mathbf{n_0} - \mathbf{n_s}\right)\cdot\left(\mathbf{d} - \mathbf{d}'\right)$$

$$\Delta\phi = \frac{4\pi}{\lambda}\Delta d_1$$

$$d_1\left(x_2\right) - d_1\left(x_{02}\right) = \frac{\partial d_1}{\partial x_2}\Delta x_2 + \frac{\partial^2 d_1}{\partial x_2{}^2}\left(\Delta x_2\right)^2 + \dots$$

$$\Delta\phi = \frac{4\pi}{\lambda}\left(\frac{\partial d_1}{\partial x_2}\right)S_2$$

Pulsed ESPI



Subtraction

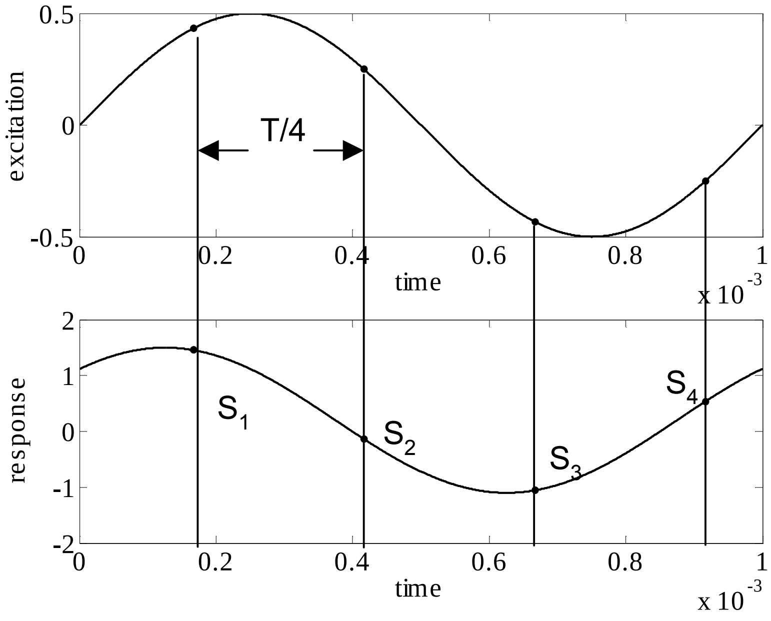
$$I_1' = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\psi$$

$$I_2' = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(\psi + \Delta\phi)$$

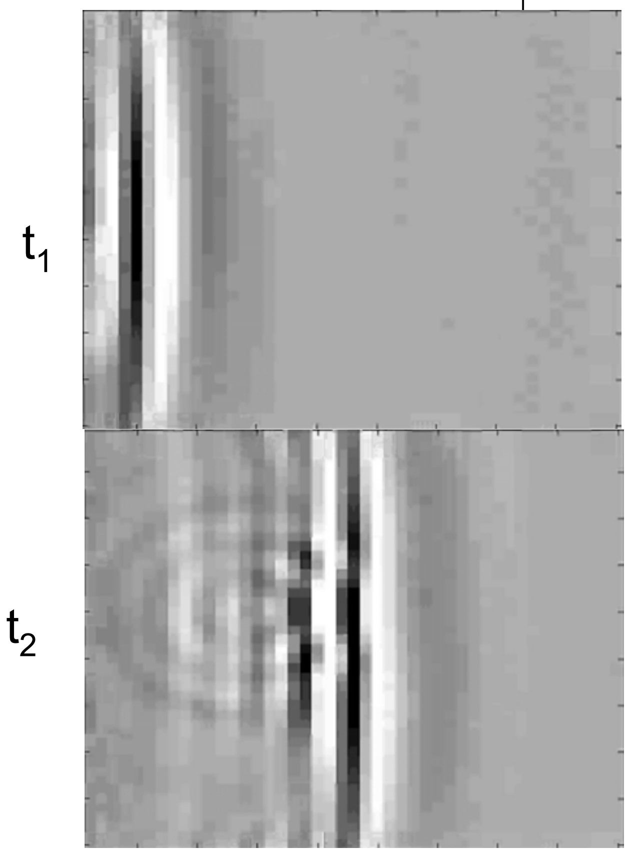
$$V_S \propto (I_1' - I_2') = 2\sqrt{I_1 I_2}\left[\cos\psi - \cos(\psi + \Delta\phi)\right]$$

$$= 4\sqrt{I_1 I_2}\sin\left(\psi + \frac{1}{2}\Delta\phi\right)\sin\left(\frac{1}{2}\Delta\phi\right)$$

Stroboscopy



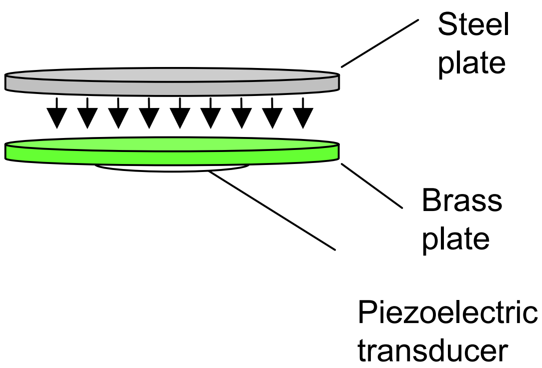
'Lockin' operation

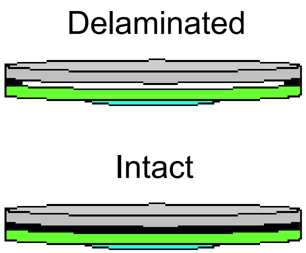


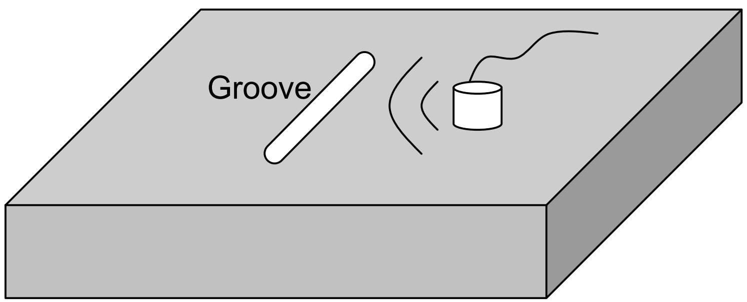
$$\Delta t = \frac{\Delta \varphi}{2\pi f}$$

'Transient' operation

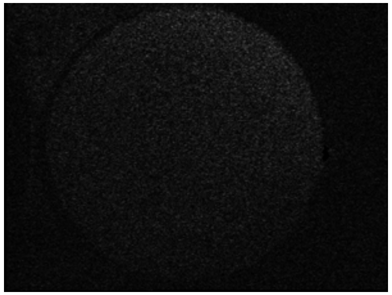
Preliminary experiments



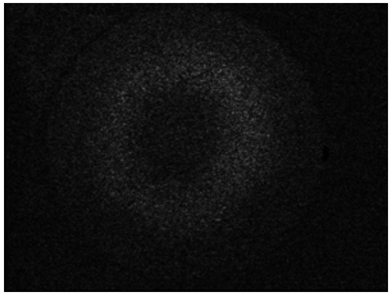




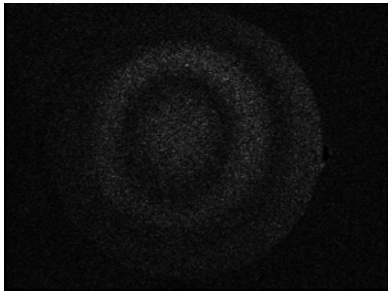
Dynamic ESPI - Stroboscopic imaging
‘Lock-in Operation’



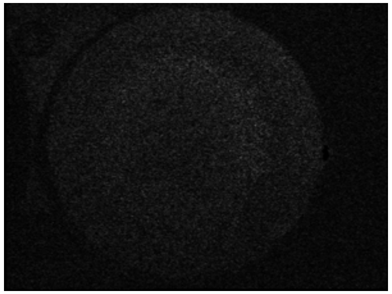
$\varphi = 0^{\circ}$



$\varphi = 90^{\circ}$

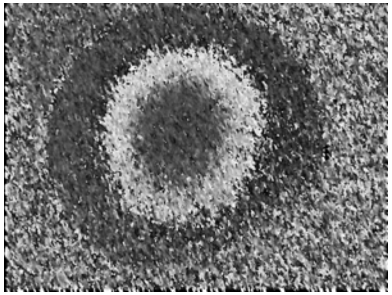


$\varphi = 180^{\circ}$

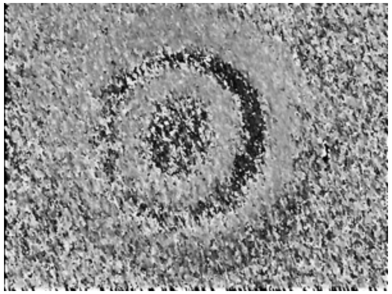


$\varphi = 270^{\circ}$

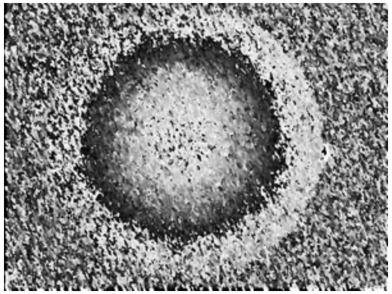
$\varphi = 0^{\circ}$



$\varphi = 90^{\circ}$

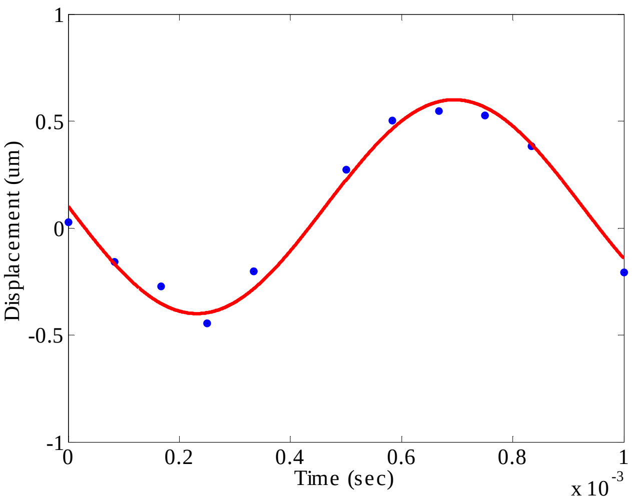


$\varphi = 180^{\circ}$



$\varphi = 270^{\circ}$

Displacement of a single point as a function of time



Thank you!

Questions?