STEP

Electromechanical Response Characterization Program

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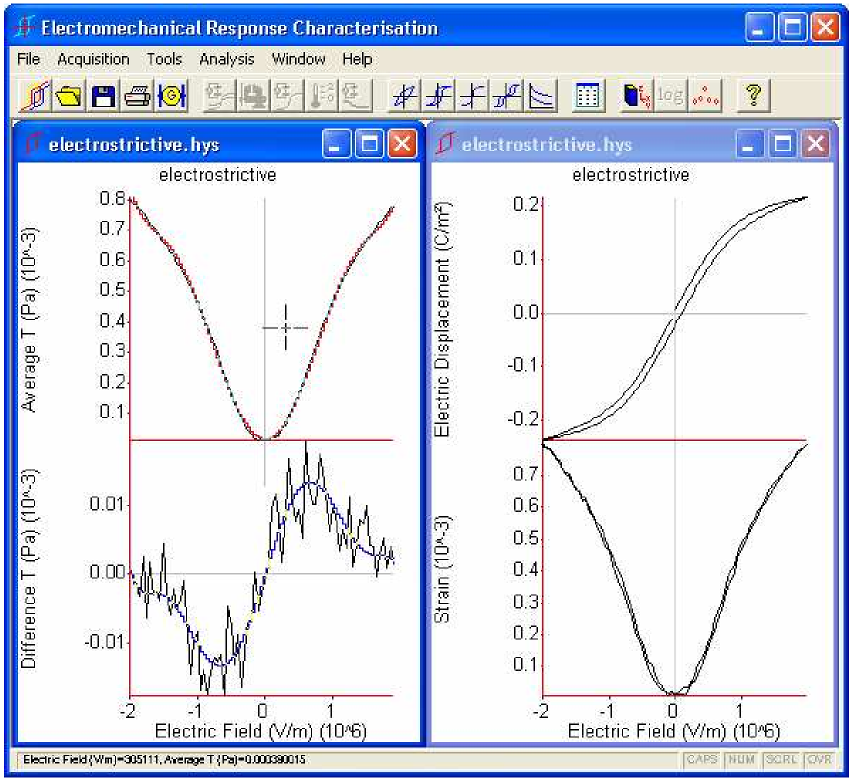
- Determine large field electromechanical properties of piezoelectric, ferroelectric, electrostrictive and anti-ferroelectric materials
- Four parameters of response are strain (S), stress (T), electric field (E) and polarization (P) where electric displacement is related to polarization as follows:

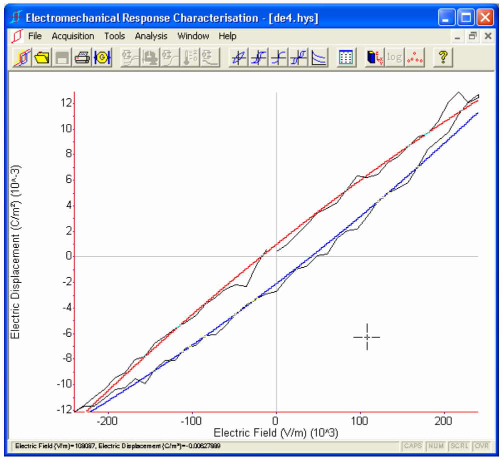
$$\vec{\mathbf{D}} = \varepsilon\vec{\mathbf{E}} + \vec{\mathbf{P}}$$

- In all measurements, one parameter is varied, the opposite electrical or mechanical parameter is fixed and the other two are measured
- Comprehensive data acquisition module allows automated control of electromechanical measurements to collect data sets including support of aging and temperature dependency measurements
- STEPHV provides all instruments, protection electronics and the enclosure necessary to perform comprehensive electromechanical measurements
- Runs under all Microsoft Windows operating systems

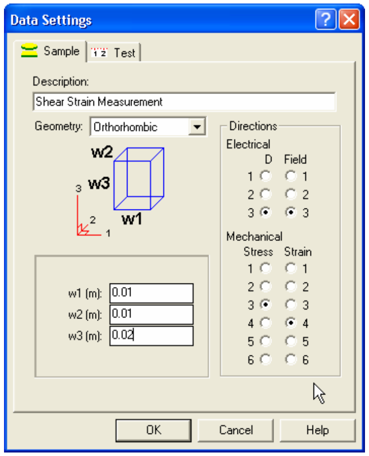


Analysis

- Rich set of fitting and graphic tools to manipulate and analyse results.
- The STEP non-linear regression engine simultaneously fits electrical/ mechanical curves including hysteresis in those curves
- Results can be saved, printed or copied to the Windows clipboard
- Four analysis modules for four material types
  - ⇒ Ferroelectric Module
  - ⇒ Piezoelectric Module
  - ⇒ Electrostrictive Module
  - ⇒ Anti-Ferroelectric Module



Piezoelectric response with hysteresis



Piezoelectric Module

- Assumes Rayleigh Models of piezoelectricity
- Assumes maximum field is well below coercive field
- As an example, for an unclamped sample (T=0), we might apply a known field (E) and measure D and S:

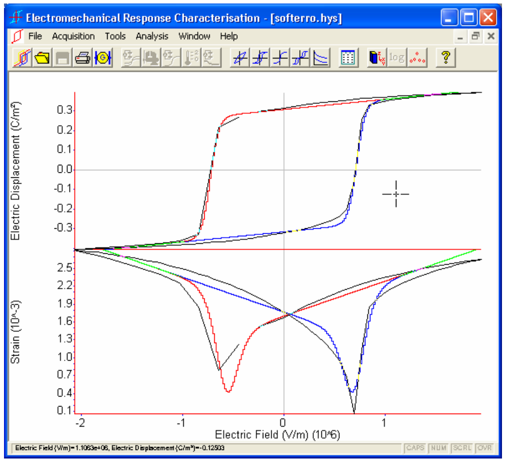
$$S_p = s^T_{pq}T_q + d_{pm}E_m$$
$$D_m = \varepsilon^T_{mn}E_n + d_{pm}T_p$$

simplifies to

$$S = dE$$
$$D = \varepsilon^T E$$

Ferroelectric Module

- Ferroelectric response is characterized by a coercive field and saturation polarization
- A variety of models are supported, each optionally modified to support hysteresis if required
- Strain is modelled by applying the quadratic relation of electrostriction to the models of ferroelectric polarization
- Terms are added to correctly model curves that do not saturate



Ferroelectric response with hysteresis

Electrostrictive Module

- The quadratic relation between strain (S) and electric displacement (D) seen in most materials is termed electrostriction
- A general relationship between S, T, E, and D was derived by Mason:

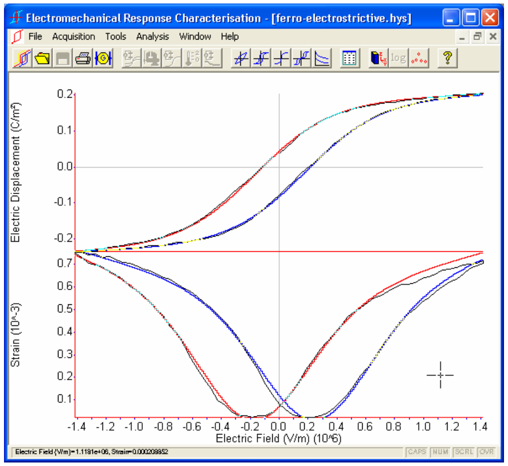
$$E_i = -2Q_{klij}T_{kl}D_j + [\beta_{ij}^T + R_{ijmnkl}T_{mn}T_{kl}]D_j + \sum_{ijkl} D_j D_k D_l + \sum_{ijklmn} D_j D_k D_l D_m D_n$$

$$S_{ij} = [s_{ijkl}^T + R_{ijmnkl}D_m D_n]T_{kl} + Q_{ijmn}D_m D_n$$

where Q is the coefficient of electrostriction, subscripts represent anisotropy, and superscripts represent boundary conditions.

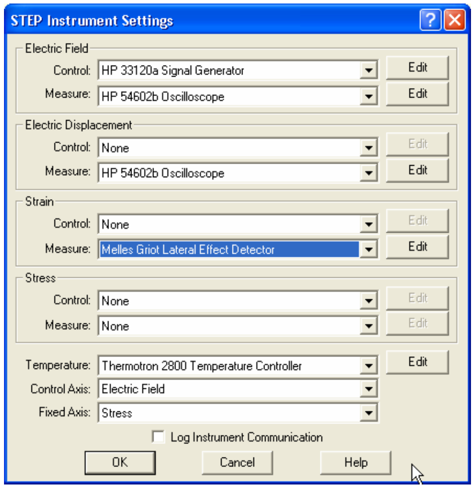
- In addition to a variety of other specialized models of electrostriction, these models are applied in several forms according to measurement boundary conditions

Electrostrictive response with hysteresis



Instrumentation

- A comprehensive instrument abstraction layer allows acquisition of electromechanical curves from virtually any set of polarization and strain measurement systems
- Quasi-static and dynamic measurements supported
- Modules available for collecting single, aging, temperature dependence, and transient response data sets



STEPHV

- Measurement hardware, enclosure and protection electronics for performing large signal electromechanical measurements
- Basic system supports up to a 20 kV field and 1 kHz quasi-static waveform. Displacement resolution is 10 nm using contact DVRT
- System components can be exchanged on request to modify specifications
- STEP and STEPHV work together to provide the complete solution for turn-key large signal electromechanical measurements

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