Folded Shell Projectors and Virtual Optimization

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Introduction

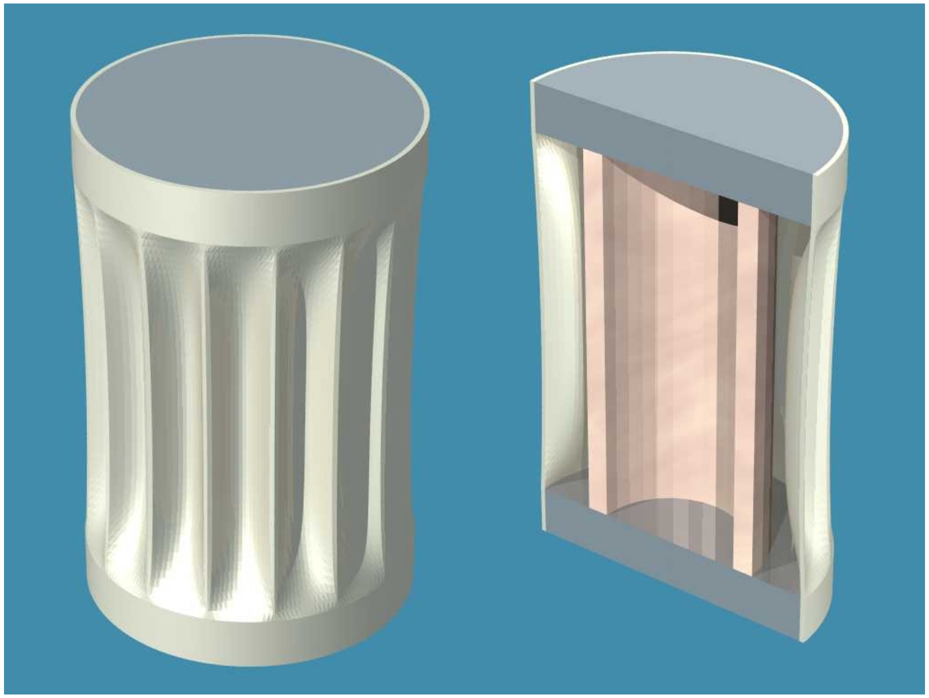
- **Present a study of the folded shell projector (FSP) described by Drozdowski and Purcell (DREA, Canada) at last year's ONR Transducer Workshop (**April 2000**)**

- **Describe a virtual optimization procedure for the FSP and other Naval transducers that combines the computational efficiency of PZFlex with a nonlinear least-squares inversion algorithm in a closed design loop**

Folded Shell Projector (FSP)

- Introduction -

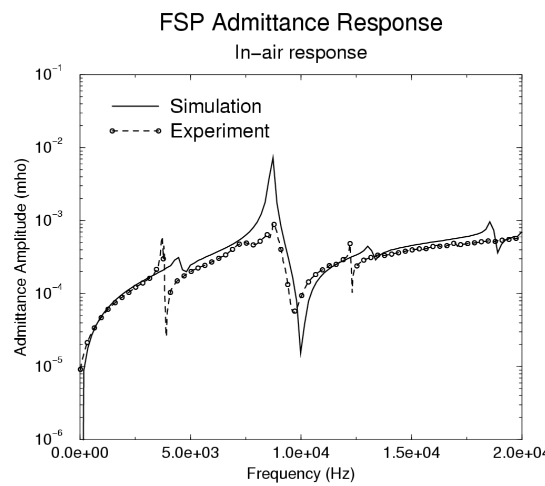
- Capped 'can' with longitudinal crimps to decouple circumferential stiffening from longitudinal bending
- Driven by a PZT stack or a Terfenol cylinder between stiff end caps
- Low frequency flextensional projector offers excellent pressure stability and avoids the fabrication and boot complexities of more traditional barrel-stave designs

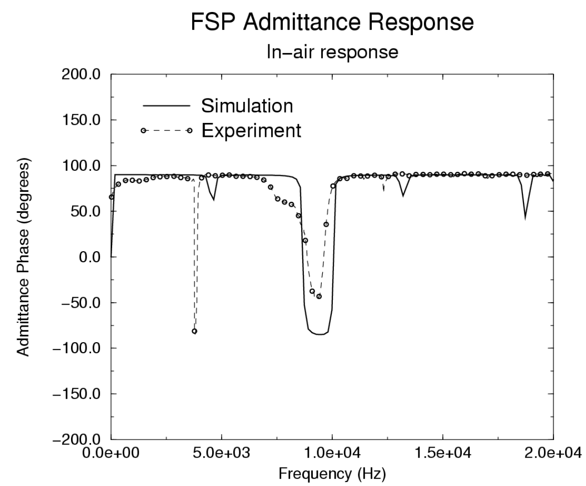


Folded Shell Projector (FSP)

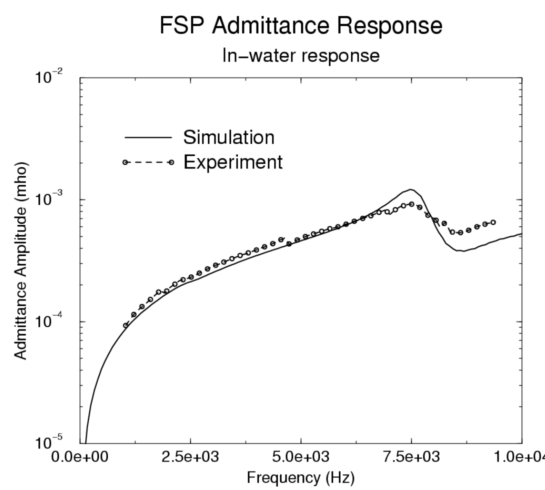
- Finite element analysis & experimental results-

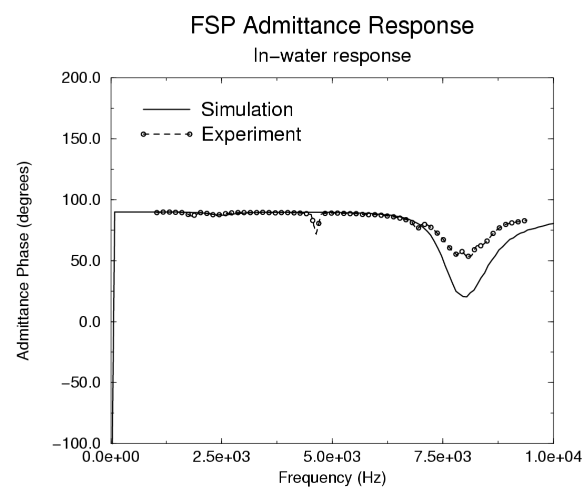
- In-air admittance





- In-water admittance

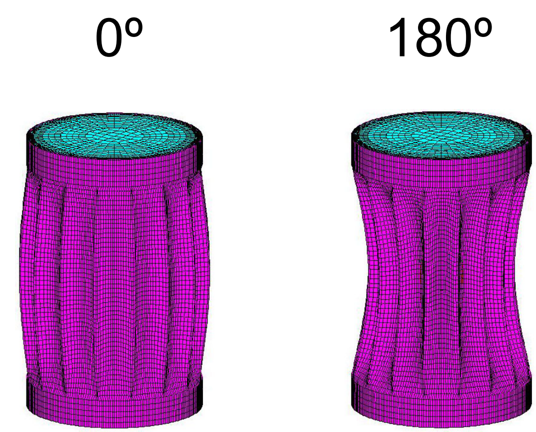




Folded Shell Projector (FSP)

- Finite element analysis & experimental results -

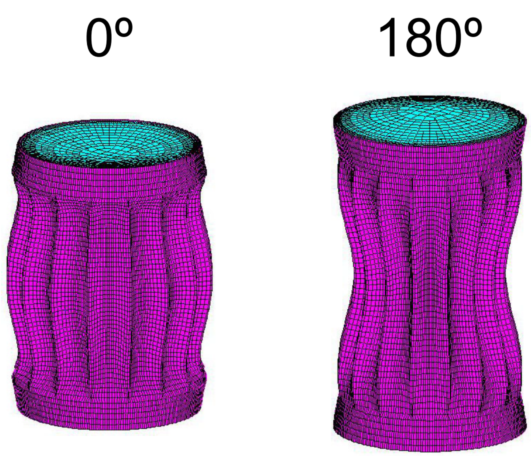
- **Mode shape at 1st resonance**



Folded Shell Projector (FSP)

- Finite element analysis & experimental results (cont.) -

- **Mode shape at 2nd resonance**



Virtual Prototyping and Optimization

- **Naval transducer designs are becoming more complex and are often non-linear in nature**
  - Expensive to prototype using conventional tooling for one-of-kind studies
    - DREA in Canada have developed laser consolidation fabrication processes for *functional* rapid prototyping of the FSP shell

- **Virtual prototyping and optimization is a complementary approach that can help minimize prototyping costs**
  - Replaces many experiments - will <u>never</u> replace all experiments
    - Appropriate when experiments are costly or when time-to-market is critical

Optimization

- Application areas -

- **Characterization of piezoelectric materials**
- **Tonpilz transducers for high-power ultrasonic cleaning applications**
- **Broadband biomedical transducer arrays with multiple-matching layers**

Optimization

- Overview -

- **Ultimate goal is systematic device optimization using a forward computer model coupled to an inversion algorithm in a closed loop**
  - Use PZFlex as the function evaluator
  - Use PRAXIS as the optimization tool
- **Search algorithms can identify optimal solutions in significantly less than time than it would take using an OFAT (one factor at a time) type approach**
- **Need to identify appropriate figures of merit**
  - Transducer designer is still in complete control of design direction
    - Choice of the appropriate target functions requires careful consideration

Optimization

- Function evaluator -

- **PZFLEX**
  - Explicit time-domain finite elements
  - Transient (broadband) capability
  - Permits large-scale, 3D models (including device & environment)
  - Nonlinearity readily included in analysis

- **Approach is shown to be feasible on desktop PCs**
  - In the hands of a new generation of transducer designers, approach can yield better device performance at reduced cost in less time

Optimization

- Inversion algorithm -

- **Nonlinear least squares inversion algorithm**
  - Based on Brent's minimization code, PRAXIS
  - Does not require analytic derivatives nor approximate them via finite differences
  - Particularly useful when evaluation of object function is time consuming

Optimization

- Implementation of bound constraints -

- **PRAXIS is an unconstrained optimization code**
  - But, the problems considered here are constrained
- Each parameter, α_i, is subject to simple bound-constraints

$$\underline{\alpha_i} \leq \alpha_i \leq \overline{\alpha_i}$$

- Change of variable to χ_i transforms the problem to an unconstrained one

$$\chi_{i=} - \ln\left(\frac{\overline{\alpha_i} - \alpha_i}{\alpha_i - \underline{\alpha_i}}\right)$$

- Corresponding inverse transformation

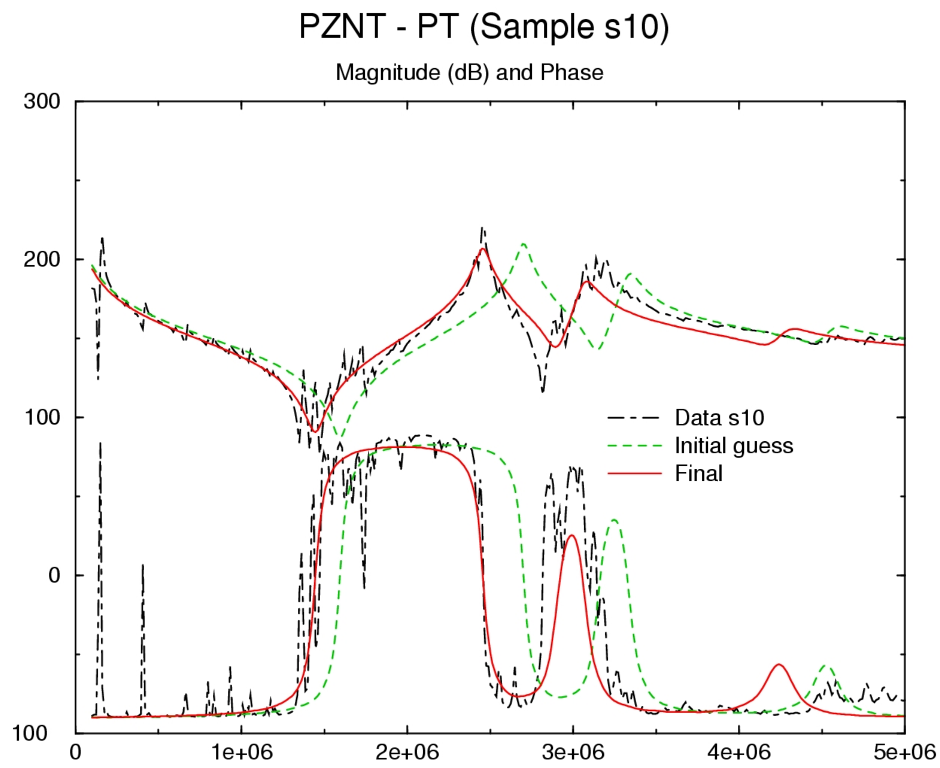
$$\alpha_i = \frac{\underline{\alpha_i}}{(1 + \exp(\chi_i))} + \frac{\overline{\alpha_i}}{(1 + \exp(-\chi_i))}$$

Optimization

Example #1 - Piezoelectric material characterization (PZNT-PT)

- The 12 unknown material constants are typically determined using different experimental samples that operate in different frequency regimes

- Using the nominal set of material properties, the values were refined using an iterative virtual optimization procedure



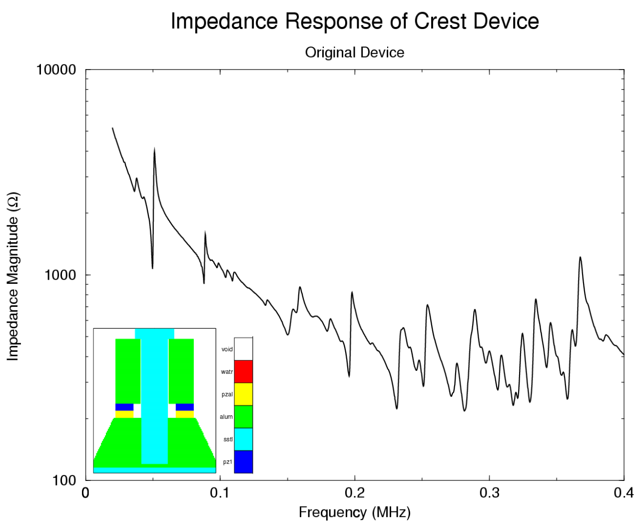
Note: The spurious resonant behavior can be attributed to localized changes in material composition and domain structure - these resonances would NOT exist if the material was homogenous.

Optimization

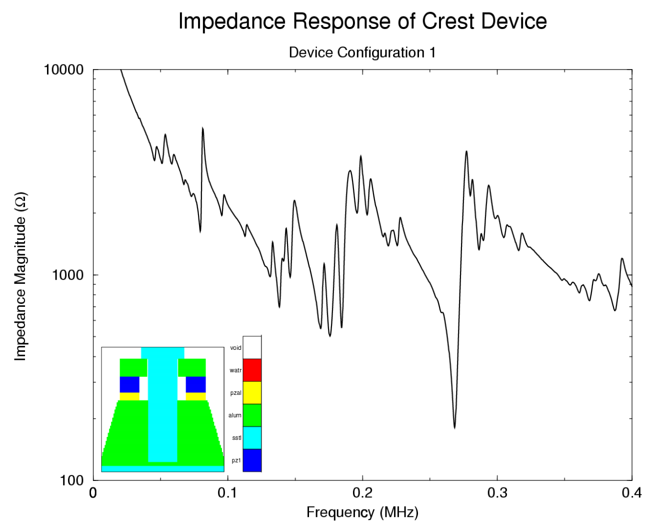
Example #2 - Tonpilz transducer for ultrasonic cleaning

- **Objective:** Maximize power output from Tonpilz transducer used in ultrasonic cleaning applications
- **Parameters varied:** ceramic thickness, head-mass & tail-mass

Before



After



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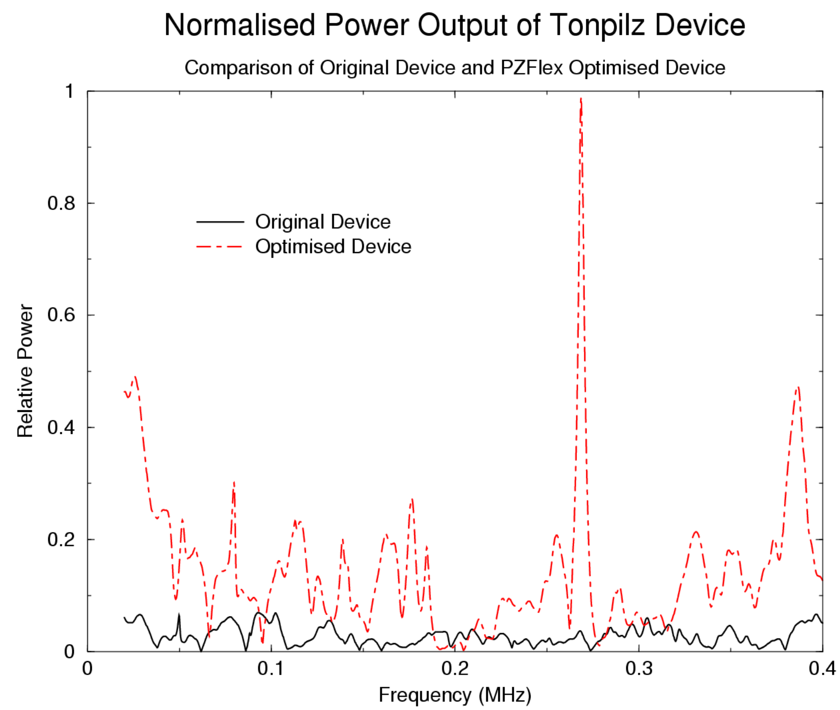
Optimization

Example #2 - Tonpilz transducer for ultrasonic cleaning (cont.)

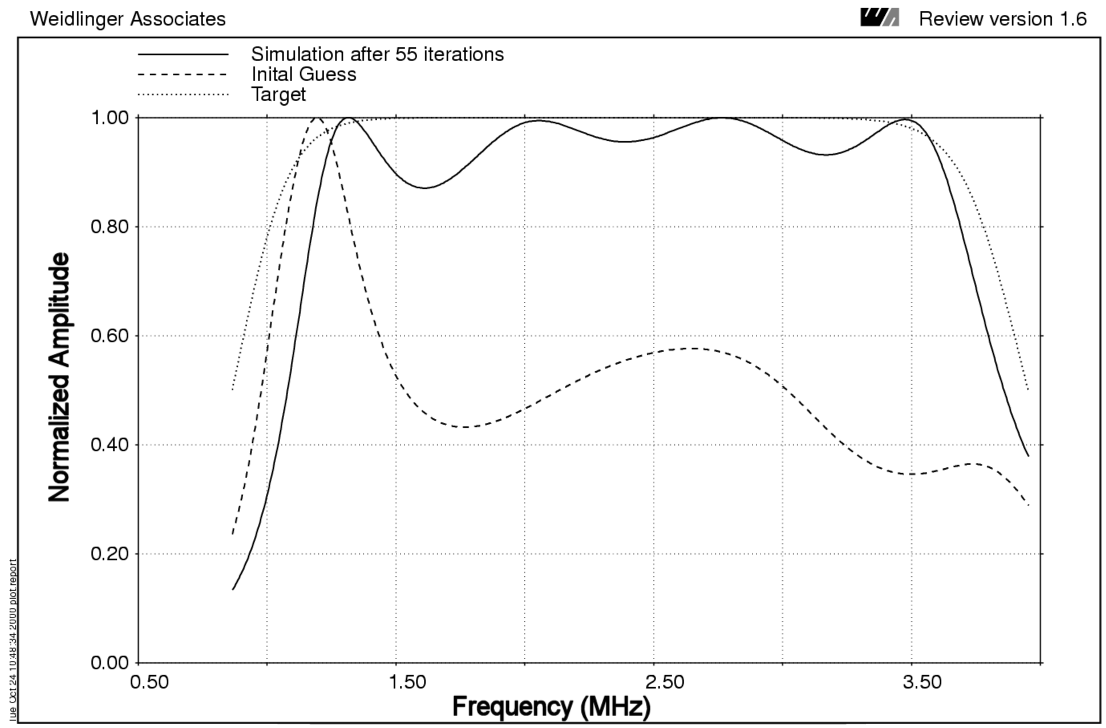
- After the iterative optimization process, power output has improved significantly
- A very strong resonance has been identified at 270kHz, which falls within the frequency range of interest (200-300kHz)



Optimization

Example #3 - Structural optimization for broadband imaging array

- Material properties and device dimensions initially selected based on “rules of thumb”
- A broadband target functional is specified
- After 55 iterations, system performance has improved dramatically



Conclusions

- Virtual optimization allows more rapid convergence towards optimal solution than possible via a simple sweep of multi-dimensional parameter space
- Choice of target function (figure-of-merit) can prove problematic and requires skill on the part of the designer
- PRAXIS proves effective for applications where evaluation of object function is time consuming e.g. large 3D nonlinear transducer structures
- Virtual prototyping and optimization leverage R&D dollars, allowing novel designs to be explored more readily, and transforming innovative ideas into optimal designs more quickly and cheaply