Folded Shell Projectors and Virtual Optimization

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U.S. Navy Workshop on Acoustic Transduction Materials and Devices
Renaissance Harborplace Hotel, Baltimore, Maryland
13th-16th May 2001
**Report Documentation Page**

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1. **REPORT DATE**
   - MAY 2001

2. **REPORT TYPE**
   - 00-00-2001 to 00-00-2001

3. **DATES COVERED**
   - 00-00-2001 to 00-00-2001

4. **TITLE AND SUBTITLE**
   - Folded Shell Projectors and Virtual Optimization

5. **AUTHOR(S)**
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6. **PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
   - Weidlinger Associates Inc, 4410 El Camino Real Suite 110, Los Altos, CA, 94022

7. **SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
   - Approved for public release; distribution unlimited

8. **PERFORMING ORGANIZATION REPORT NUMBER**

9. **SPONSOR/MONITOR’S ACRONYM(S)**

10. **SPONSOR/MONITOR’S REPORT NUMBER(S)**

11. **SUPPLEMENTARY NOTES**
    - U.S. Navy Workshop on Acoustic Transduction Materials and Devices, 13-16 May 2001, Baltimore, MD

12. **ABSTRACT**

13. **SUBJECT TERMS**

14. **DISTRIBUTION/AVAILABILITY STATEMENT**
    - Approved for public release; distribution unlimited

15. **SECURITY CLASSIFICATION OF:**
    - a. REPORT: unclassified
    - b. ABSTRACT: unclassified
    - c. THIS PAGE: unclassified

16. **LIMITATION OF ABSTRACT**
    - Same as Report (SAR)

17. **NUMBER OF PAGES**
    - 17

18. **NAME OF RESPONSIBLE PERSON**

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18
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 never 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, $\alpha_i$, is subject to simple bound-constraints
  $$\underline{\alpha}_i \leq \alpha_i \leq \overline{\alpha}_i$$

- Change of variable to $\chi_i$ transforms the problem to an unconstrained one
  $$\chi_i = -\ln\left(\frac{\underline{\alpha}_i - \alpha_i}{\alpha_i - \overline{\alpha}_i}\right)$$

- 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

![Impedance Response of Crest Device (Original Device)](image)

After

![Impedance Response of Crest Device (Device Configuration 1)](image)
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