Fishing with Multiphysics

Direct coupled-field simulation including piezoelectric, acoustic and mechanical analysis enables engineers to tune transducer performance for monitoring huge trawler nets.

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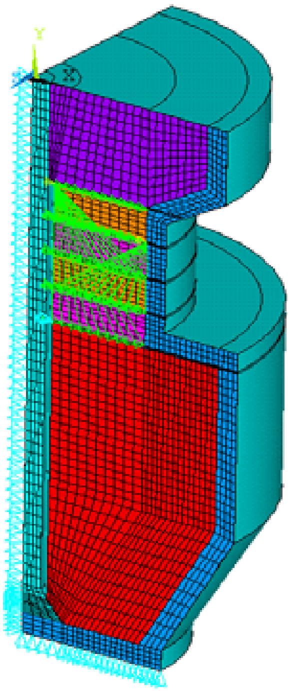
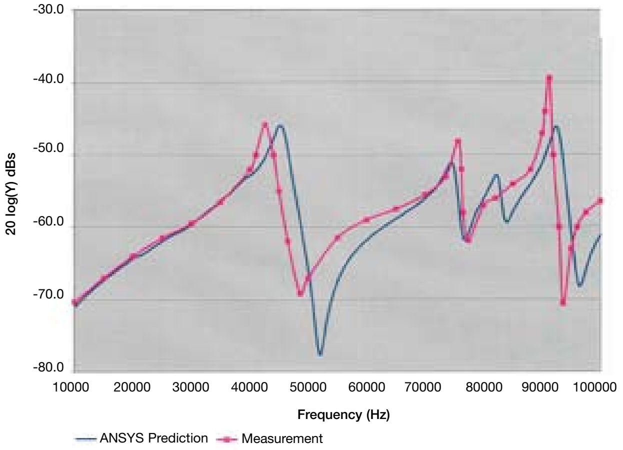


Model of a tonpilz ready for analysis

Designing piezoelectric transducers to meet particular performance requirements is a demanding and traditionally time-consuming and imprecise engineering process. Characteristics such as power, sensitivity and bandwidth depend on highly complex and interrelated electrical, mechanical and piezoelectric material properties, part size and shape, and other electrical and mechanical parameters. Difficulties are compounded when transducers must operate underwater. To optimize these, designers must take into account specialized acoustic and fluid behavior.

Historically, engineers develop designs for such transducers with computations from one-dimensional (1-D)-equivalent circuit models. These 1-D tools provide only approximations of transducer behavior based on simplified, lumped circuit representations of transducers using inductors, capacitors and resistors. The resulting models do not accurately represent the true distributed characteristics and multiple-degree-of-freedom dynamics of complex transducers. Consequently, numerous prototypes must be built, tested and re-designed — often with hit-or-miss changes — until the transducer performs satisfactorily, or at least until it comes close to meeting most of the target requirements.



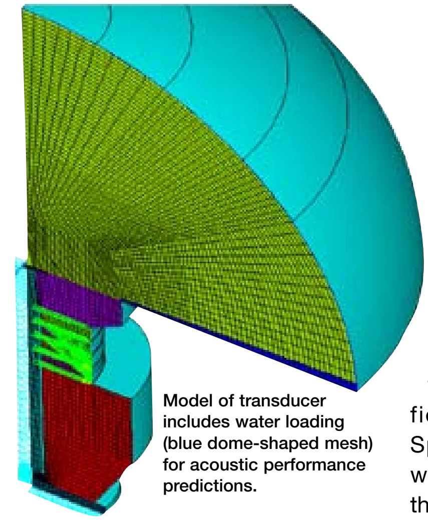
Admittance curves show good agreement between simulation predictions and measurements.

Using the direct coupled-field analysis capabilities of ANSYS Multiphysics software, engineers at ITT Acoustic Sensors (ITT-AS) have implemented a better approach based on finite element analysis to quickly and effectively arrive at optimal transducer designs without the delays, guesswork and inaccuracies of other methods. FEA utilizes a full 3-D simulation of the transducer with piezoelectric, mechanical and acoustic formulations to characterize dynamic responses of the transducer. Fluid structure interaction (FSI) and acoustic elements model water-loaded behavior in determining attributes such as frequency-dependent beam patterns, directivity, transmit power and receive sensitivity.

The FEA approach was applied in one recent project in which an ITT-AS tonpilz transducer was redesigned to meet particular requirements for a customer using transducer arrays in their commercial fishing operations. The component was part of a system for detecting when huge trawler nets are full and subsequently when entry portions of the net are closed. Specifically, this required ITT-AS engineers to develop a drop-in replacement for the tonpilz with greater transmit-and-receive response over a broadened frequency band with a particular resonant frequency and beam width.

With these performance objectives in mind, the ITT-AS team used their extensive transducer engineering experience in iteratively making various changes to the design and simulating device performance for each modification. Major changes included:

- Significant transducer shape modification with heavier material used for the tail mass
- Four piezoelectric elements, each with larger area and thinner depth, replaced two; transducer length remained unchanged
- Decreased diameter of stress bolt to reduce the force it generates in opposition to head motion

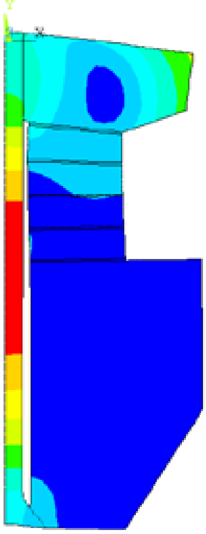


Model of transducer includes water loading (blue dome-shaped mesh) for acoustic performance predictions.

By exploring these modifications with simulation, engineers quickly reached an optimal design — one that significantly improved transducer performance beyond the requirements specified by the customer. Specifically, bandwidth was widened by more than a factor of three and transmit level increased by 56 percent. Receive response decreased by 7 percent with reduced element impedance but remained above the required value. The approach avoided the delays of numerous prototype testing cycles and the inaccuracies of 1-D calculations. ITT-AS performed a single prototype test cycle near the end of development to validate the design, instead of the five to six cycles typically needed with the traditional build-and-test development methods.

The simulation-based redesign began with engineers importing CAD geometry (partitioned into its various parts of the transducer) into software from ANSYS to create the analysis model. This model was meshed using axisymmetric structural elements for the passive transducer components and direct coupled-field axisymmetric elements for the active piezoelectric ceramics components. Anisotropic material properties (including elastic compliance, piezoelectric strain and relative dielectric permittivity) represented the active materials. Engineers entered piezoelectric material properties in ANSYS format for polarization along the Y-axis density, and the loss tangent was included for the dynamic simulations. Linear isotropic properties, including density and damping, represented passive structural materials.

To determine the harmonic response of the transducer, engineers applied symmetry displacement boundary conditions to the central axis, constrained the base along the Y axis, and applied voltage boundary conditions to nodes representing equipotential positive and negative electrodes. Short-circuit resonance was computed with both electrodes grounded (0V), and open-circuit anti-resonance was computed with the negative electrode grounded (0V) and no voltage applied to the plus electrode. Engineers performed harmonic response analyses to determine in-air admittance of the transducer with +/-0.5V applied across the active elements. ANSYS post-processing tools displayed and animated results, including mode shapes, providing good insight into the mechanical behavior of the transducer.



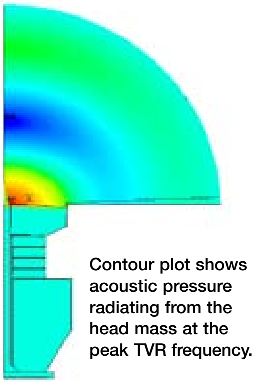
Displacement contour of the first interference mode indicates it arises from longitudinal extension of the stress rod.

Tonpilz transducers from ITT-AS come in a wide range of shapes, sizes and configurations for various applications.

Basics of Piezoelectricity

Piezoelectric ceramic materials generate an electric voltage in response to applied mechanical force, usually a vibration or pressure variation. Sensors based on this technology are used in the automotive industry for detecting exhaust pressures and engine vibrations, for example. Conversely, piezoelectric materials produce a force when voltage is applied in actuator applications, such as in some ink-jet printer heads and diesel engine fuel injectors.

Piezoelectric transducers — the generic name for these types of devices — can serve the dual role of generating and sensing vibrations, generally airborne sound waves and underwater acoustics. This is the principle behind sonar systems in which arrays of transducers are used to detect underwater objects by sending out a “ping” and measuring the time taken for a return echo. One example of the many types of transducers from ITT-AS is the tonpilz, which is widely used in sonar applications for its precision, low cost and reliable performance.



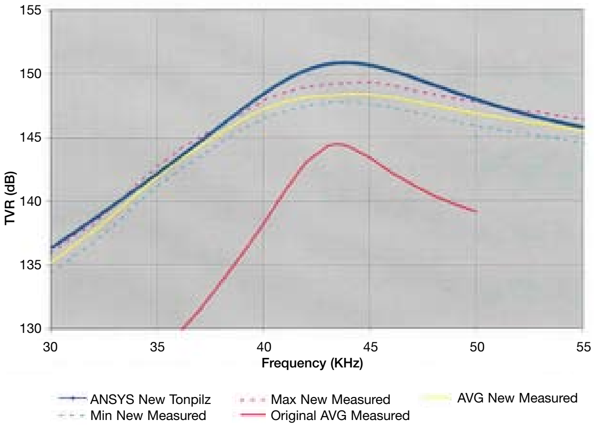
Contour plot shows acoustic pressure radiating from the head mass at the peak TVR frequency.

For example, the displacement contour of the first interference mode indicated it arose from longitudinal extension of the stress rod.

ANSYS simulations continued to include the effect of water loading for acoustic performance predictions. Water was modeled using axisymmetric acoustic elements, and fluid–structure interface nodes were placed at the radiating face of the head mass. Far-field boundaries of the water were modeled by axisymmetric acoustic line elements that represent a nonreflecting boundary. Material properties required for the acoustic elements included density and speed of sound. Boundary admittance was set to 1 for the acoustic elements representing baffle and far-field surfaces where sound is fully absorbed. Away from the absorbing surfaces, the boundary admittance was set to 0 (no sound absorbed).

Using this model, engineers performed in-water harmonic response analyses for +/-0.5V (1V total) applied across the ceramic elements in the tonpilz stack. From this, they then calculated acoustic performance characteristics (including transmit and receive response and impedance) over the frequency range of the analysis. This calculation showed significant improvement in acoustic performance over the original design of the transducer.

Upon completion of the harmonic response analysis for the tonpilz models in water, ANSYS post-processing tools were used to study solution results. The time-history post-processor defined acoustic pressure and electric current variables from which frequency-dependent transmit response, impedance and receive response acoustic performance characteristics were derived and graphed. Engineers reviewed contour plots of displacement and stress variations throughout the new tonpilz, and they generated contour plots of acoustic pressure radiating from the head mass at the peak transmit voltage response (TVR) frequency. Beam patterns and directivity characteristics were also derived from acoustic pressure distributions computed at the harmonic response analysis frequency steps.



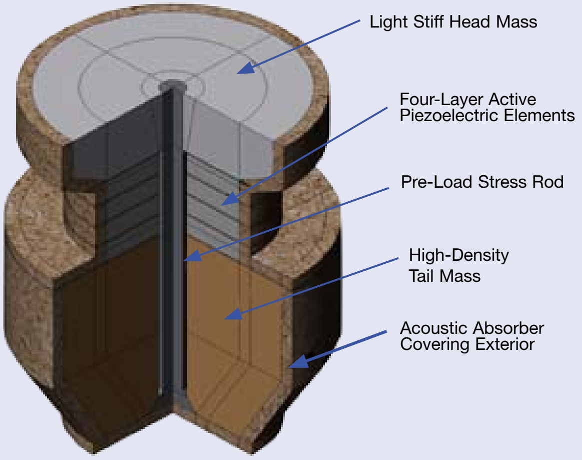
The new tonpilz design shows significant improvement in transmit response and bandwidth

This project clearly demonstrated the versatility and utility of ANSYS Multiphysics technology as a powerful tool for the design of complex coupled field transducers. The solution significantly improved performance of the tonpilz exceeding all customer requirements. ■

Ins and Outs of the Sound Mushroom

A typical ITT-AS tonpilz (a German word meaning “sound mushroom”) transducer consists of several active piezoelectric layers sandwiched between a stiff, low-mass radiating head and a much heavier tail mass. The devices may be designed with various part configurations and mounts for different underwater applications, in which the transducer can serve as a sound-producing projector, an acoustic hydrophone sensor or both. Transducers can be used independently or grouped into arrays with particular beam width and directivity at selected frequencies.

The tonpilz is one of numerous types of transducers designed and manufactured by ITT-AS. With over 50 years experience, the company is a leader in designing and manufacturing piezoelectric transducers — and the related electronics for controlling, processing, conditioning and displaying signals — in a variety of applications including naval and industrial sonar, medical equipment, oil and gas systems, motion control, and health and safety.



Major parts of the tonpilz transducer design