Using CAE Software to Build a New Position Sensor

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The market pressures to create less expensive, competitive sensor designs in shorter time are forcing developers to search out better design technologies. Electromagnetic, thermal, and structural computer-aided engineering (CAE) software tools are good examples of the powerful resources available for simulating sensor properties, such as position, velocity, temperature, magnetic fields, stress, and strain. The ability to simulate the performance of a design prior to prototyping can result in significant time and cost savings (see Figure 1).

Sensor design and prototyping costs range from tens of thousands of dollars to hundreds of thousands of dollars per design/prototype, and in a traditional non-CAE development environment, with a minimum of two to five prototypes per design, the costs can easily multiply. In contrast, with an initial investment of less than $10,000, you can purchase CAE software that provides the ability to accurately and efficiently simulate sensor designs.

CAE Software for Sensor Design

True Position Magnetics (TPM) is a new Silicon Valley company that has technology (patent issued November 1997) that allows simultaneous 3-D position measurement relative to a special target through the use of magnetic fields (see "True Position Sensing in Three Dimensions," *Sensors*, February 1993). TPM sensors are being developed for integration into robotic systems in aerospace, semiconductor equipment, and industrial control applications.

TPM position sensors indicate position in space with reference to a 3-D coordinate system. The device electronically measures and compares the magnetic flux from a target moving through four geometrically equal magnetic paths arranged symmetrically around the sensor's axis. It is this precise symmetrical balance that requires the use of CAE software. To prototype such a structure by testing various geometric configurations and then determining the behavior of the electromagnetic field with varying geometries would have been prohibitive in terms of time and cost. Using Amperes, the 3-D magnetostatic CAE tool from Integrated Engineering Software, TPM engineers can test various physical and material configurations, examine design concepts, and optimize designs for a variety of scenarios.

Amperes is based on the boundary element method (BEM), which has inherent advantages over the more traditional finite element method (FEM). The open-region nature of electromagnetic and thermal systems requires an FEM solution to have a full-region, finite element mesh, with artificial truncation of the model's surrounding regions. In

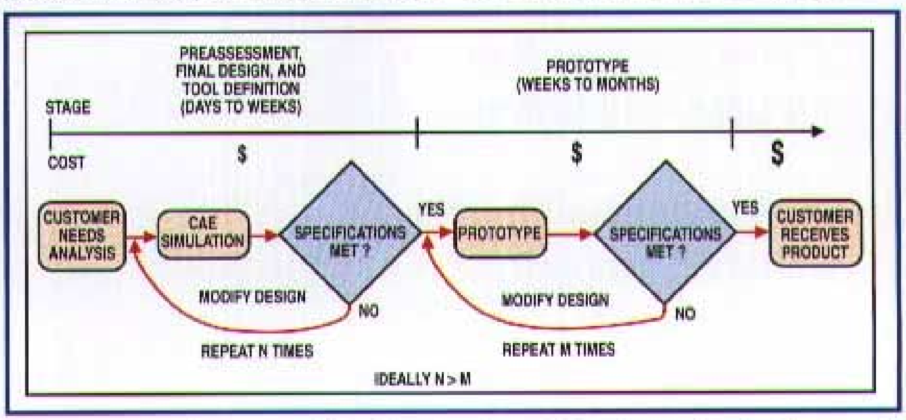


Figure 1. *As you move from concept to deliverable product, the cost of redesign increases. By using electromagnetic CAE simulation at the beginning of the product development process, you can save significant time and expense. Through virtual prototyping, designers can simulate various product configurations quickly, avoiding the traditional prototype build-and-test steps.*

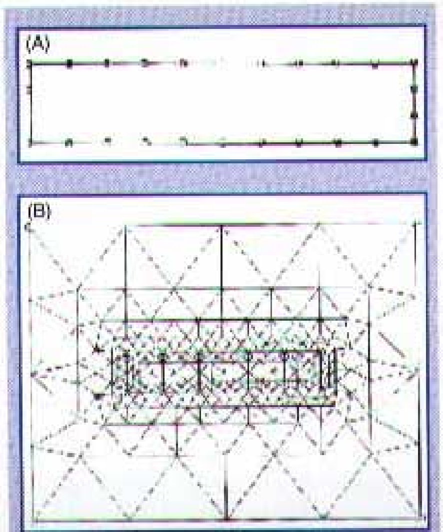
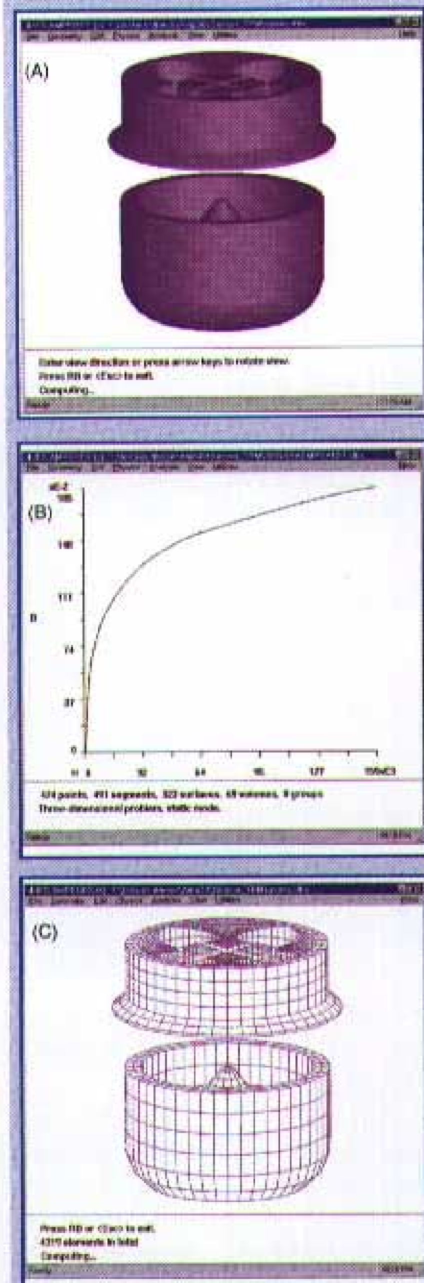


Figure 2. The boundary element method (BEM) requires discretization of surfaces only—no air gap meshing. For this simple capacitive plate example, the BEM requires only nodes on the plate (A). For the same example, the finite element method (FEM) requires nodes on the surrounding region, and these nodes must be artificially truncated at some point in the open region—which results in more computation time and less accuracy (B).

contrast, the BEM requires only discretization of the model's surface(s)—the free space regions (i.e., air) require no boundary element discretization (see Figure 2). (Discretization is the process of placing nodes—numerical computation points—on the CAD model. The nodes are then used to produce the model's numerical solution.) This unique BEM property is advantageous in TPM's sensor design efforts because it requires less computational time than previously used methods. For each new position of the target relative to the sensor, the BEM can use the same discretization, and for small air gaps, there is no need to pack the air gap with a computationally demanding finite element mesh.

By using Amperes, TPM can develop concepts faster and with more variety. With the software, moving from design to prototype takes anywhere from a few days to two weeks; in the past, it took six to nine months. According to Ron Smith of TPM, "The cost to create a salable product is reduced 80–90%, and in many cases, deriving certain operating characteristics is impossible without the use of Amperes."

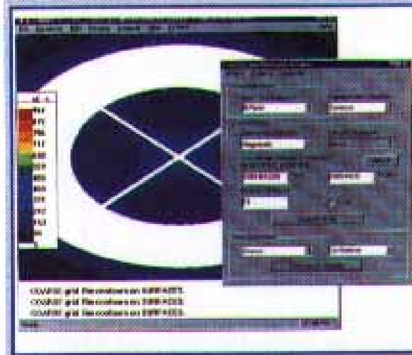
TPM's responsiveness to modification requests from customers is also improved significantly. Customer suggestions can quickly be tested and verified, and simulation results can be communicated to the customer in a day or two. In many cases, a one-day turnaround on several scenarios is possible.



Screen 1. Creating the CAD model (shaded) of TPM's position sensor is the first step in CAE design (A). Next, physical properties are defined and assigned to the model. These properties include nonlinear B-H curves (B), current sources, and magnets. The final step prior to actual simulation is boundary element discretization of the CAD model's surface (C).

Designing a Position Sensor

TPM follows five basic CAE steps in designing its position sensor. First, it creates a CAD model using Amperes' built-in CAD system [see Screen 1 (A)] or by reading in Initial Graphics Exchange Specification/ Drawing Exchange Format (IGES/ DXF) geometry files from other standard CAD systems. Second, it assigns the physical properties (e.g., materials and sources) by selecting options from the software's materials library or by defining materials itself. In this example, the material is a user-defined nonlinear B-H curve [see Screen 1 (B)]. The sensor's coil winding source is modeled by specifying various Amp Turns in the coil region. In the third step, TPM places boundary elements on the surface of the CAD model [see Screen 1 (C)]. In the fourth and fifth steps, engineers analyze the model and review the results.



Screen 2. After BEM simulation is performed, various electromagnetic postprocessing output options are possible, such as force, magnetic field arrow plots, and magnetic flux graphs. The image above shows the magnetic field contour of the underside of the position sensor.

Running on a 200-MHz Pentium computer, Amperes provided TPM with magnetic flux vs. position characteristics, force at specific points, and the minimum material thickness required. In a few steps, Amperes' 3-D parametric simulator generated magnetic B-field plots in the regions of interest (see Screen 2). This particular position sensor [see Screen 1 (A)] was designed for use with an air gap of ~0.50 in. and to provide positional accuracy of 0.002 in. to 0.003 in. TPM verified that the simulated B-field results of the sensor were within 4% of expected values over the operational range of interest.

Next, TPM engineers optimized the original sensor design by improving the SNR by more than 300%. The company achieved this by taking the sensor's original complex geometry and combining several sensor parts into one, altering the sensor's overall shape. These changes also allowed less expensive parts to be used when making prototypes and in production. More importantly, TPM was able to design a new position sensor that would have been prohibitive under the current funding constraints.

Based on these results, TPM believes CAE software tools permit virtual product design and greatly reduce the risk involved in introducing new sensor technology. The risks for developing a new sensor in the pre-CAE environment were simply unacceptable.

TPM must commit to a product price and delivery schedules for a sensor before it is built and still maintain a profit. According to Ron Smith, "By using CAE tools, TPM can build and test a virtual product in the software prior to committing to price."

When the virtual product meets customer specifications through Amperes testing, TPM requires a financial commitment contingent on the TPM sensor's meeting specifications in actual testing. At this point, TPM is willing to risk the unit construction cost, knowing that the predicted performance derived from Amperes analysis and the actual measured performance are very close. The CAE design process is driving the entire TPM strategy for introducing new sensor technology to various industries.

The new TPM position sensor design reduced the original sensor's material requirements, significantly improved the sensor's performance, shortened the design cycle, and lowered design costs. It's understandable why CAE software is becoming an accepted tool in the sensor design process. ■

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