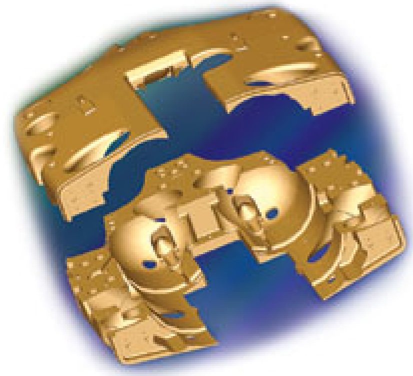


DIAB dives into deep water

...with Mastercam 5-axis programming

DIAB International AB manufactures and fabricates polymer core materials that add substantial value to its customer's products. The DIAB sandwich concept is a construction technique that combines low weight with exceptionally high stiffness and strength, making it ideal for a wide range of applications where weight is critical.

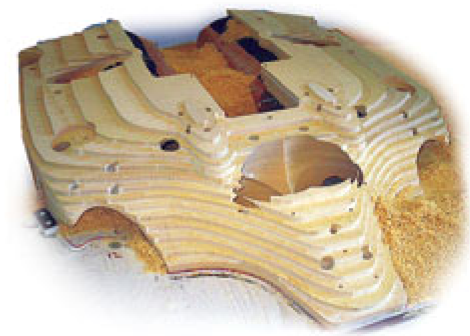
With ten subsidiaries worldwide, Laholm, Sweden-based DIAB serves the marine, wind energy, surface transport, industrial, oil and gas, and aerospace markets. Its products offer higher speed, longer range, larger pay loads, less engine power, and better operating economy through reduction in material weight.

One of DIAB Group's notable customers is SAAB, long known for the quality of its aerospace systems and its automobiles. The SAAB Group's Bofors Dynamics division designs, manufactures, and integrates the systems of Sweden's ground-to-air, air-to-air, surface, and underwater defense arsenal. Among these is a small, unmanned submersible used by military and corporate customers worldwide: the Double Eagle Mark II Remotely Operated Vehicle (ROV). It is the result of over twenty years of research and production of operational systems used in offshore exploration, environmental research, marine biology, nuclear power plant inspection, and a variety of military applications. It is controlled and powered via an umbilical cable from the mother ship rather than by telemetry, so that its operating signals cannot be intercepted or corrupted.

Stable material, platform

The upper and lower body halves of the Double Eagle ROV are also its buoyancy section. Hydrodynamic on the outside, its interior has been machined to accommodate drive and control motors, mounting hardware for accessories, and the ROV's own electrical and electronic control system components. The original body was produced from a syntactic epoxy and prototyped using a 3-axis CNC machine by a third party company.

In order to produce a shell with increased buoyancy and reduced weight while maintaining structural integrity, SAAB Bofors redesigned the Mark II using DIAB's Divinycell HCP closed cell structural foam. Developed for a variety of subsea applications, Divinycell HCP is half the weight of water and has a very high hydraulic crush point, excellent dynamic properties, low water permeability, and exceptional



thermal and acoustic insulation properties. With the material chosen, SAAB approached DIAB to see if they could produce the actual parts.

Henrik Ottosson, Production Engineer at DIAB's Lahlom technology facility, evaluated DIAB's capability to machine the Mark II body. DIAB had acquired its first cnc machine and Mastercam CAD/CAM software only a year before and Ottosson says he was "a little hesitant at first but then I realized that, if we could carry out this assignment for SAAB, we would markedly increase our capabilities. While the ROV tolerances and the complexity of parts were a challenge, our previous experience with Mastercam gave us confidence that we could meet or exceed SAAB's requirements."

SAAB Bofors sent the Mark II IGES files, which Ottosson opened in Mastercam (by CNC Software, Tolland, CT) as surface files. Rotating and examining the files, he decided which sides of each part to machine first and which tools, feeds, and speeds would best suit the often considerable depth of some of the parts' inner features and through-the-part holes.

"The ROV was the first machining job we had undertaken that required very large tools," says Ottosson. "With a tool holder capacity of 16 mm and the possibility of using 200 mm-long tools in conventional machining, I had some concerns. However, approaching the problem with Mastercam's 5-axis capabilities in mind allowed us to use more conventional tooling." Once Ottosson and his team set the tooling parameters and developed the machining objectives for each of the four shell sections, they completed the first rough pass on them with no CNC machining at all.

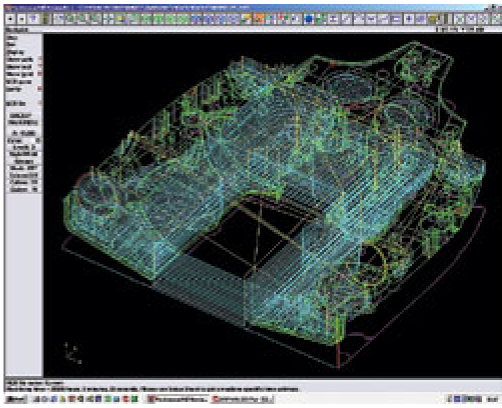
Piecemeal efficiency

The 37 mm Divinycell HCP sheets formulated for the ROV were about 2´ x 4.2´. These would be laminated with a proprietary adhesive into the basic 4.75´ x 15^2 bottom shell form. The three top shell components would be similarly laminated.

Ottosson achieved materials savings by using the SolidSEP feature of Mastercam's Moldplus add-on to divide the solid model into an integrated series of 37 mm layers. With the parting line at the ROV's maximum outer dimensions, the greatest surface area of each piece lay flat on the machine's vacuum table, immovable during machining.

The maximum outline of each 37 mm part layer was expanded to allow for machining overage, drawn full-size, and cut on a band saw. Gluing the HCP into position, layer-by-layer, created ziggurat-like structures of the shell parts, extending amply beyond the design envelope and ready for the first set of roughing toolpaths.

The adhesive itself imposed an unanticipated restriction of its own. It was so hard that it quickly wore down normal tooling, leaving surface striations and changing the



dimensions of successive cuts. The solution required special tooling alloys to cope with the rigid adhesive and maintain optimum feed rates. The pre-roughed lamination technique also contributed to tool life. Not having to hog out great areas of waste material saved tool erosion from the glue holding the waste together.

As the laminate stock was in assembly, Ottosson began a toolpathing process resulting in a series of 500 operations. “With such complex parts, having access to all of the features of Mastercam, including multiple layers, gave us options we were able to use in ways specific to this project,” Ottosson recalls. “For example, the software made it easy to rotate the arm of the machine to reach surfaces we needed to machine inside the deep holes for drive motor mounting. Our ability to produce SAAB Bofors’ dimensions exactly contributed substantially to the proper hydrodynamic performance of the ROV.

“To perform the rough machining we wanted, I needed a single outer boundary along the edges of all the complex, intersecting surfaces. This is a great example of the payoff of flexible software tools—I used a couple of features that are normally used for viewing and testing your toolpath, and I created the outer geometry I needed to start my roughing.”

Even the three smaller components of the top half of the shell required more than one roughing operation. The surfaces of all of the shell components were machined in 3-axis, generally parallel flowline toolpaths. Ottosson reports from his notes, “For finished surfaces, we used combinations of parallel, flowline, contour, leftover, and scallop toolpaths.”

The flip side

“The six big holes going through the parts posed a problem in the beginning. By design, the pieces get thicker—a distance varying from 300 mm to 400 mm for the deepest hole—so we could not drill though the entire detail. The maximum tool length from the holder was 175 mm. We rough-machined the holes part-way through with a corner bevel tool using a parallel toolpath,” says Ottosson.

The holes in the aft section, though more shallow, were also concentric cylinders of different diameters to provide a stop-collar for the servomotors. These were machined through the full depth at the lesser diameter in 3-axis with the head tilted. Then a 5-axis roughing pass at 30 degrees cut the major diameter down to the motor shelf. All holes were finish-machined with 5-axis parallel toolpaths, plus curve, flow, and swarf operations.

The remaining depth of each hole, designed to be 24 mm greater in diameter to provide the seat for a motor mount at its inner terminus, was finished when the part was turned over and aligned on a special fixture. A similar process was used for all but the shallowest holes. Similar to the top-side methods, the subsequent 5-axis finish operations specified a 60 mm long 16 mm ball-end mill to make many passes at a 0.5-3 mm stepover, with the head rotating around the z-axis at 30 degrees.

Pocket options

The variety of cavities needed to accommodate the Mark II's operating equipment was more than met by the full selection of Mastercam's pocketing options. "I could choose what suited my needs and, beyond need, I could indulge my personal machining taste," says Ottosson. With the pocketing toolpaths ready and stored, and easily accessed by Mastercam's operations manager, each was run when the appropriate side of its corresponding part was upward on the table.

Some special considerations were created from toolpaths derived from the major toolpaths for the ROV's exterior surfaces. SAAB Bofors determined that stresses measured in the tapered aft end of the ROV during water tunnel testing called for extra layers of fiber reinforcements on both sides.

Ottosson continues, "I simply cut them with existing curves, lowering the surfaces at those specific places in the roughing and finishing operations. Now, once each piece is ready, we fill it with the additional 1 mm layer of fiberglass matting. We also designed a channel into which a wire is cemented from the stern forward, again to deal with stresses to the thinner aft section. Other places were also laminated, mostly to reinforce against the thrust and weight of motors."

The finished vessel is first laminated with an epoxy layer that adds strength, disperses collision forces, and decreases the ROV's hydrodynamic drag. The ROV is then spray-painted, dried and ready to ship. The top half of the body is hinged to expose the interior pockets and spaces, soon to be filled by SAAB Bofors with sensors to send data for advanced signal processing, image processing as well as various types of correlation techniques and neural networks.

These contribute to effective systems such as torpedo homing systems, and search and surveillance systems. Advanced underwater sensors using acoustic signals and variations in electrical fields—signals that are undistorted by the ROV's electrically neutral Divinycell construction—are constantly being developed for various types of surveillance systems. Manufacturing complex acoustic sensors with miniaturized electronics allows the ROVs to be equipped with high-resolution sonar systems, making objects visible under water.

More than 40 SAAB Bofors/DIAB Group Mark II ROVs are currently in use, some for training by the navies of countries including Sweden, Finland, Denmark, Australia, and the United States. With the Mark II they can locate and safely detonate mines in waters at depths to 500m (over a third of a mile). Ships send the ROV hundreds of meters ahead of them by commands through the umbilical control cable. Fiber-optic, sonar, or digital video images return to the ship and the ROV is directed to place a detonating charge near the mine, then withdraw to a safe distance. The charge is remotely detonated and the ROV, the ship, and the lives on board remain safe from the resulting explosion.