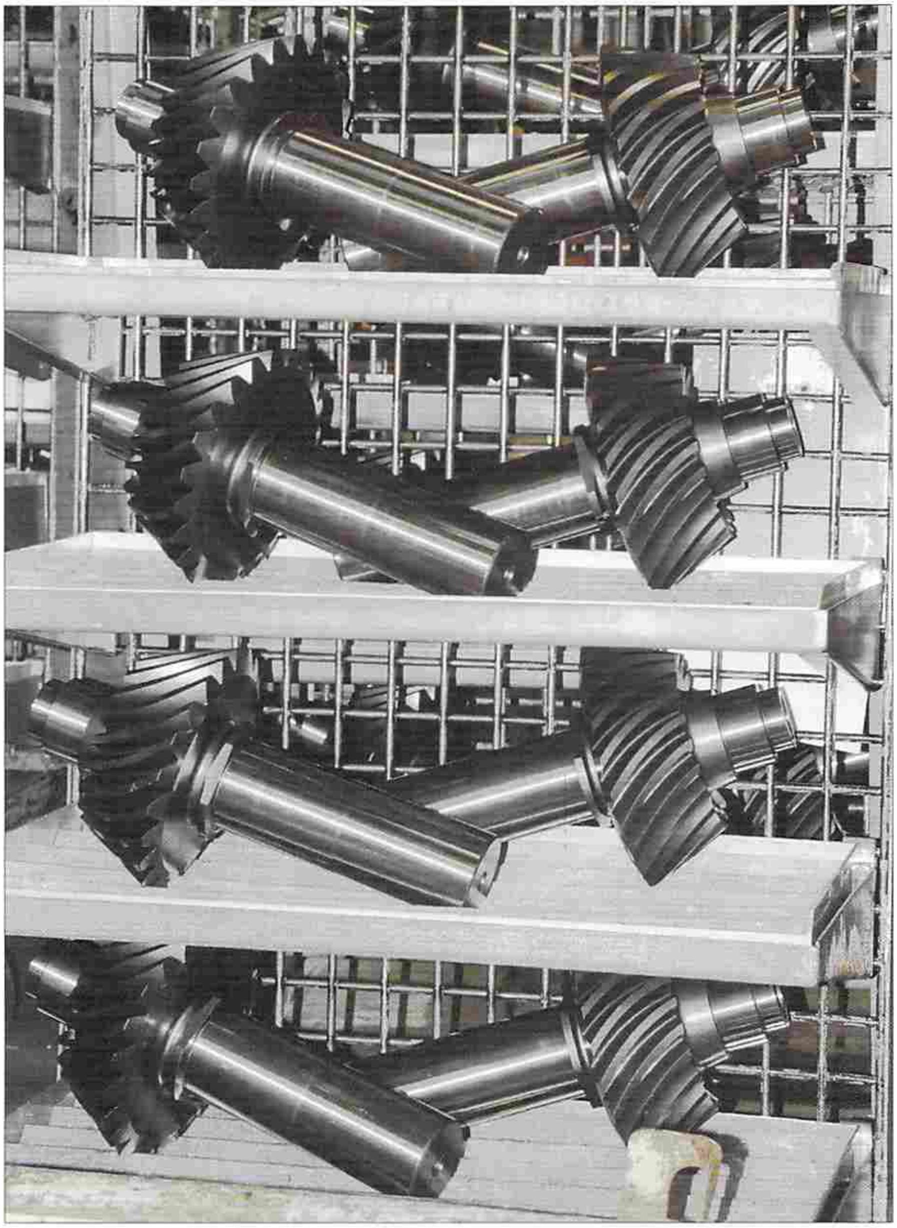


Racks of finely machined and hardened spiral bevel gears await installation at the marine division production facility of engineering giant ZF Marine, in Padua, Italy. The company's initials stand for Zahnradfabrik, *"gear manufacturer" in German, and* Friedrichshafen, *the city in which ZF was founded in 1915.*

In Gear

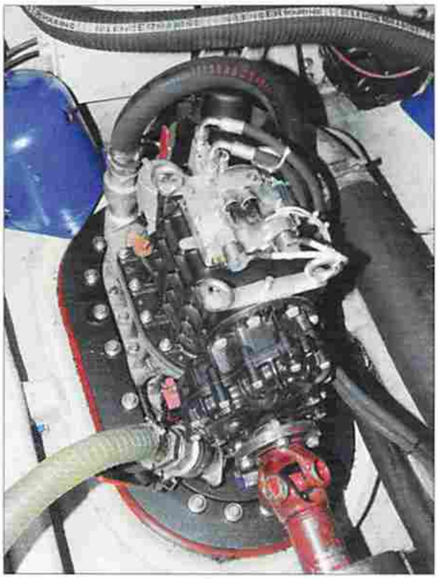
A tradition of precision manufacturing, started in 1915 with Zeppelin transmissions, motivates ZF Marine to continue developing new drive systems, joystick controls, and hybrid propulsion.

Text and photographs by Steve D'Antonio

As I boarded ZF Marine's 40′ (12.2m) test boat for sea trials on Lake Garda, Italy, I eyed the seatbelts on the twin helm seats with a mixture of trepidation and curiosity. These guys weren't fooling around.

We departed from the company's testing facility in Arco driving a boat equipped with a pair of ZF 2000 series pod drives and ZF's Joystick Maneuvering System (JMS), both recent innovations. For the past five years, the industry has been abuzz with accounts of the improved handling and efficiency made possible by pod drives (see *Professional BoatBuilder* Nos. 106, 115, and 129). In the still-small field of pod drives engineered for recreational boats, ZF's relatively new addition didn't disappoint. I piloted the boat aggressively in ever-tighter, higher-speed maneuvers with hard accelerations and sudden shifts. Turns were comfortable, not banking excessively inboard, and with none of the vibration one expects and accepts from conventional shafts, struts, and rudders. During acceleration the bow never rose to block my view, and I'm only 5′7″ (1.7m).

The joystick system worked through moderately low speed, above which conventional throttle and helm took over. ZF's skipper had no choice but to show off the test craft's low-speed maneuverability as we pulled away from our mooring. Neighboring boats, Med-moored with their bow lines



***Left—**This company test boat exhibited superb maneuverability with fingertip control, two virtues of marrying ZF's pod drives to the company's joystick for low-speed operations. The shift/throttle control is mounted temporarily to ease installation of new models for testing. **Right—**One of the test boat's two pod drives. The engine is located just forward of the drive, linking to it through the driveshaft and universal joint at the bottom of the photo.*

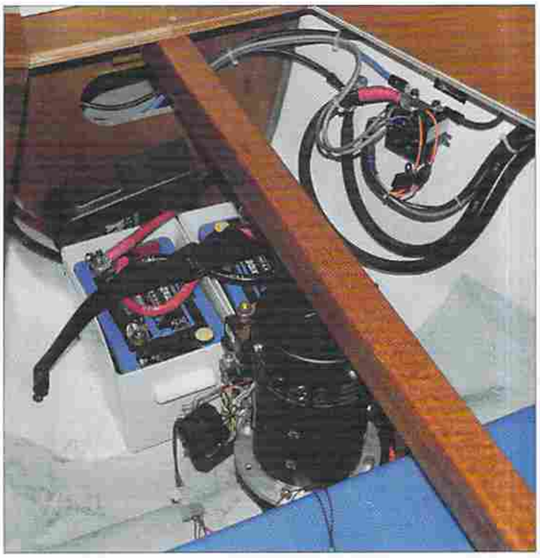
extending into the water on either side of a channel, presented potential hazards, especially in a strong crosswind. The skipper manipulated the joystick to almost effortlessly keep the boat safely in the middle of the narrow lane.

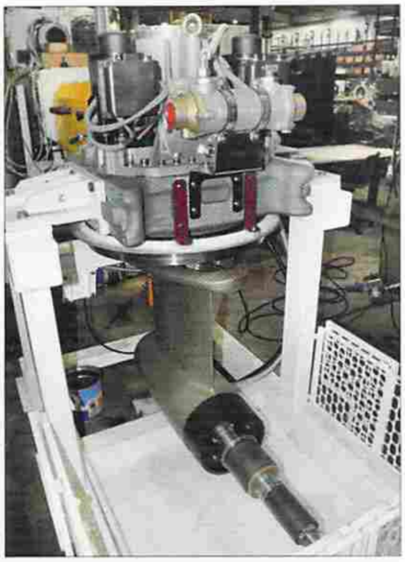
Next, I tested a 46′ (14m) Beneteau sailboat powered by ZF's Hybrid SailDrive—another variation on an emerging technology that's had much recent press (see PBB No. 130, page 12). This parallel hybrid propulsion system performed well, moving the hull with ample reserves of thrust. As you'd expect, the unit was extremely quiet while in electric mode, with typical but not unpleasant diesel din while on "thermal" power, as ZF's staff refer to the engine drive. The system is designed to be seamless, much like that in a hybrid automobile, so it switches automatically between diesel and electric power depending upon load and the duration of operation. As the throttle is advanced, the engine eventually kicks in, and as it's pulled back, the system reverts to electric propulsion.

The Beneteau was also equipped

***Left—**The helm of a Beneteau sloop fitted with ZF's Hybrid SailDrive. Note the joystick control, which allows the helmsman to power the boat sideways or turn in virtually its own length when navigating tight channels and mooring situations, as seen at **right**, or when operating in a strong crosswind.*

__Right__—A bow thruster and designated batteries are networked into the joystick controls to allow for lateral maneuvers of the single-screw sail drive. ***Far right***—*In ZF's Padua factory a 2000 series pod drive is put through its paces on a test bench.*





with JMS, which controlled the pod and the bow thruster. The response time is particularly quick in this integrated system. Because the thrust is vectored by the drive leg, there's the possibility of near-sideways movement at the stern—an unusual sensation, especially on a sailboat. With slight joystick movements the skipper easily maneuvered the deeper-draft sailboat through the narrow channel.

Hybrids are unfamiliar to traditional-diesel-engine owners, so I looked over the installation carefully to determine its service-friendliness. Access to all the seemingly important components was certainly acceptable. The cast-aluminum electrical distribution and control box covers the top of the engine, giving it an automobile-engine-like look. This being a test boat, wiring runs and plumbing were all sound, if not tidy. Cabling and control wiring connections and jacketing were heavy duty and appropriate for the marine environment.

While I believe traditional shafts and propellers won't be listed as endangered species anytime soon, it's difficult to deny the appeal of smooth acceleration, efficient operation, and superb maneuverability of the combination of pod drives and a joystick. ZF has played an active role in the recent pod revolution, first working with Cummins MerCruiser Diesel to introduce the Zeus drive, and now as a strong contender under its own brand. The new line of ZF pod drives includes the 2500 and 2800, which transmit their thrust directly to the boat's hull. The larger 4000 series is more easily adapted to existing designs, without having to substantially rework the vessel's scantlings to support the drive's thrust or to tolerate grounding impacts. That's because, unlike most other pods, the loads from a ZF 4000 are carried where a conventional design carries them—on the stringers rather than through a beefed-up hull structure.

A collaborative effort by ZF and Foundation Beneteau (the nonprofit arm of the French yacht builder Groupe Beneteau), the Hybrid SailDrive has turned many heads. It relies on lithium-ion batteries and a Volkswagen Marine diesel engine in its integrated approach to create a parallel diesel-electric hybrid system capable of producing 110/220 VAC and 12/24 VDC power, as well as propulsion. By rotating the drive unit 180°, it is also capable of generating electricity while under sail. A metallic shell encloses nearly everything electrical, particularly the high-voltage components, on the engine, which means do-it-yourselfers and the otherwise untrained can forget troubleshooting this system. And that's not necessarily a bad thing given the

The Hybrid SailDrive, developed in collaboration with Foundation Beneteau, is a parallel diesel-electric hybrid powered by a Volkswagen Marine diesel and lithium-ion batteries. The cast-aluminum electrical distribution and control box atop the engine encloses nearly everything electrical, particularly high-voltage components. Pictured with the hybrid propulsion package is Vittorio Rasera, ZF Marine's executive vice-president and general manager of the pleasure craft business segment.

Far left—*Toothed gear hobs like this one are ubiquitous in ZF's production facility, where they are employed to cut gears.* ***Left***—*A technician selects cast blank forms to be machined into finished gears.*

complexity and voltages involved. However, the hybrid drive system is engineered for reliability.

Diversified Product Lines

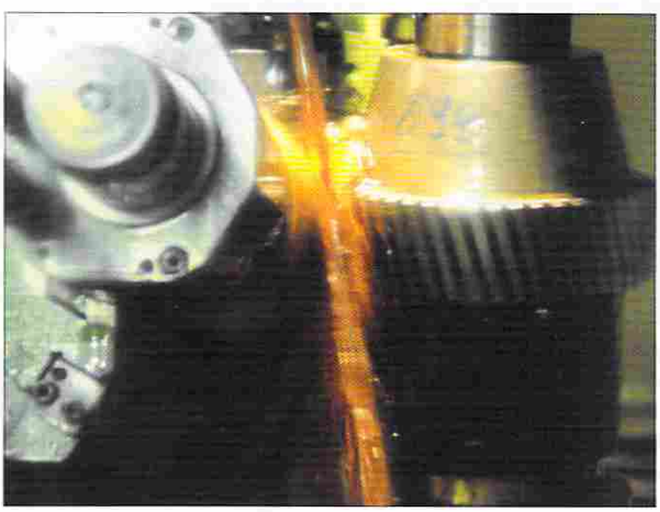
While I had the pleasure of testing several ZF offerings on Lake Garda, that experience was to judge only on-the-water performance. I also saw the internal components of all those systems among many others in the controlled environment of the ZF Marine production facility in Padua.

Like many industry professionals, I thought I knew what ZF Marine manufactured: transmissions or marine gears. And for practical purposes, that's true. But ZF is a huge company that also supplies a multitude of automotive, marine, and industrial products. When I first met with ZF's marketing and communications manager, Martin Meissner, in Miami, Florida, he said, "See that cement mixer? That and the majority of cement mixers use a ZF gearbox to turn the drum. Most BMW, Audi, Porsche, and VW suspension, steering, and drivelines use ZF components. ZF also supplies most of the transmissions for large motor coaches." Also included is the four-speed overdrive manual transmission in my Ford diesel pickup truck. The list continues: 5 million passenger car axles and 10 million passenger car transmissions; marine transmissions from the diminutive mechanical boxes in small sailboats to the larger hydraulic models in large motoryachts, commercial tugboats, and ships. The list of other marine products is extensive as well, from electronic shift and throttle controls, to pod drives and thrusters.

At the Padua headquarters and factory, I met again with Meissner, and Thomas Jaffke, the marine propulsion systems marketing manager. The facility's lobby houses a small collection of ZF display products, including a sterndrive once produced by ZF, a variety of gear sets, a marine hydraulic transmission (naturally), a controllable-pitch propeller, and a railcar electric-propulsion motor.

Inside the factory is a world dominated by gears. While the blanks are cast in another facility, the vast majority of ZF gears destined for marine applications are cut on-site with a device called a gear hob (these multi-toothed wheels are ubiquitous throughout the facility). Machining a gear casting-blank into a precision component involves a seemingly incongruous mixture of sparks and cutting lubricant that looks like a glowing waterfall enveloping a shower of fireworks.

ZF Marine relies extensively on computer numerically controlled (CNC) machining. But because gear interface and component reliability remain



Left—*A computer numerically controlled (CNC) cutter guides the hob that mills gears into the blank in a shower of sparks and cutting lubricant.* ***Right***—*In addition to its reliance on CNC precision in manufacturing, ZF hand-measures with calipers, dial indicators, and feeler gauges to ensure consistent quality.*

Left—*Newly machined gears have been heat-treated in the oven,* ***right,*** *and quenched in a liquid bath to harden them. Next, they are reheated in the oven to a lower temperature to reduce brittleness imparted by the abrupt cooling.*

important aspects of manufacturing, there's still considerable hand fitting and quality assurance at Padua. Calipers, dial indicators, and feeler gauges are everywhere. As someone who has rebuilt many engines and sterndrives, I appreciated seeing the continued importance of the human element, particularly in backlash measurement, in what could otherwise be an entirely computer-driven manufacturing process. I saw other examples of this in the factory.

During my visit, the heat-treating area was operating at a furious pace, with glowing sets of gears emerging from the hardening oven every few minutes. An operator arranged the freshly machined yet-to-be treated gears on a large rectangular table adjacent to the oven. Standing 30′ (9.1m) away, I could feel the heat when he opened the furnace door. He then picked up the gears one at a time with a set of power-assisted tongs and placed each one into the glowing cavern. Each gear would then be rotated through the furnace, and when it came out, it glowed to the point of appearing translucent. Next, it was quenched in a liquid bath, followed by the final step of reheating at a lower temperature to reduce brittleness induced by the initial quenching. It seems a troublesome step, but properly cooling down the gears is essential to their high quality, durability, and long life.

I observed similar attention to detail through the manufacturing facility, particularly in the case of technicians attending to precision machine work, which is the majority of what's done here. For example, finished gears were hung on copper rods, each separated by corrugated aluminum plates, all designed to prevent even the lightest incipient damage (copper and aluminum, being much softer than the finished gears, afforded protection).

Having toured many manufacturing facilities, I know the look of a bored worker carrying out repetitive tasks. It often doesn't bode well for the quality or reliability of the product. I saw none of that at the Padua shop; workers on the shop floor were focused on their work and responded eagerly and knowledgeably when queried about their tasks.

Above—*Finished gears are hung on copper rods and separated by aluminum plates. Because both metals are softer than the finished gears, the latter are protected from damage prior to installation.* ***Left***—*A skilled technician assembles precisely engineered components into a nearly completed transmission.*

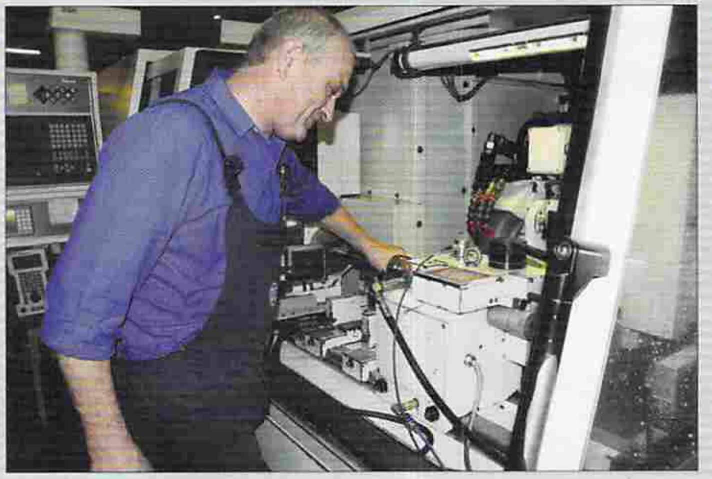
History

ZF's interest in marine gears began in the 1930s, but the firm's history dates back earlier in the 20th century. The company was started in the southern German city of Friedrichshafen, on Lake Constance, by none other than Ferdinand von Zeppelin (of airship fame) in 1915. As part of his vision to produce reliable, long-range airships, he tried to find a manufacturer of precision transmissions to couple with the Daimler Benz diesel engines he intended to use. When his search tuned up nothing, he opted to establish a company that could manufacture the transmissions to his satisfaction. The new firm was ZF (pronounced "Zed Eff"), the letters standing for Zahnradfabrik (German for "gear manufacturer") and Friedrichshafen (the city "Friedrich Harbor"). The venture successfully produced the gearboxes Zeppelin needed for his airships. The charter of the company stated that it would manufacture gears and transmissions for aircraft, motor vehicles, and motorboats (remember, this is 1915).

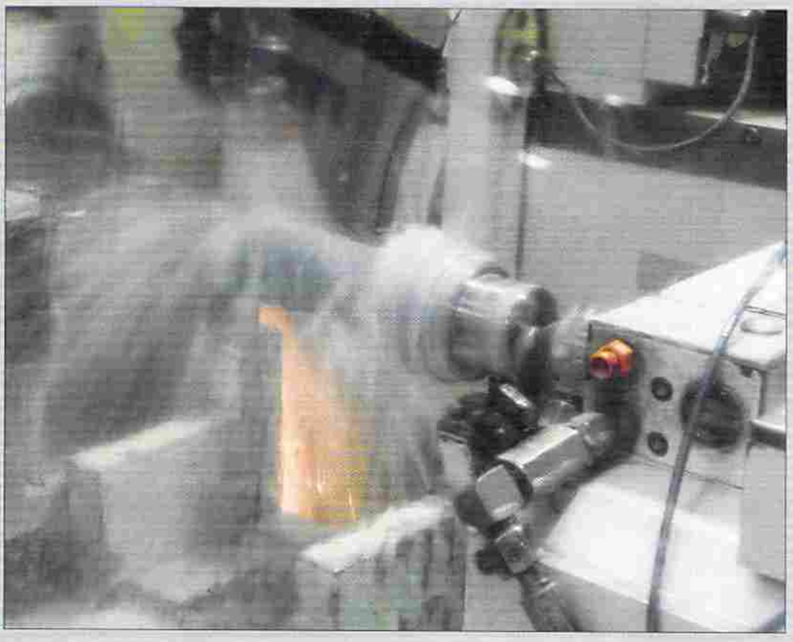
Within the first few years, the order books were filled for war production (Europe was engulfed in WWI at this point), and ZF's hardening and annealing shop gained a reputation for producing high-quality metal components for military and other machinery. The tide would change for ZF as social and political events in Europe unfolded in a way no one could have predicted. The path

Close Tolerances

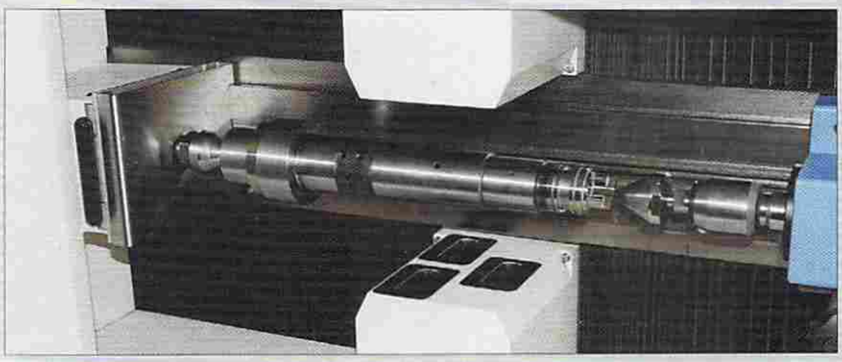
At ZF Marine's Padua factory, precision counts. The following images document the computer-controlled turning of a gearbox pinion, followed by a technician's careful check of the quality and exact shape of the new part.

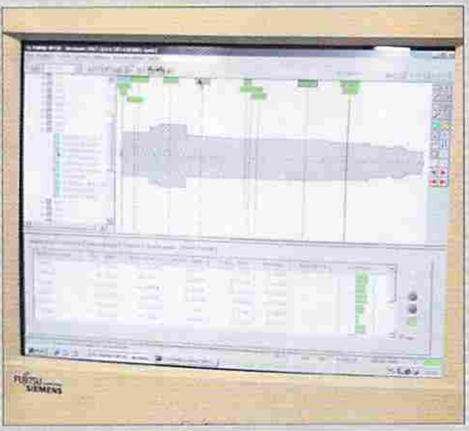


Before running the cutting program for the part, a technician fixes a roughly shaped metal gearbox pinion into a CNC milling machine.



Above—*Behind safety glass and obscured by a spray of cutting lubricant, the machine automatically mills the pinion to programmed specifications.* **Right**—*The human touch is evident in checking the exact diameter of the pinion cone with a measuring ring.*





Above—*The part is subjected to more exacting measurement and analysis in this optical measuring instrument.* ***Right***—*Readout of the measured pinion comes up on a computer screen, where it can be compared to the measurements specified in the design. In this case, the green squares indicate that the new part is within acceptable tolerances; red squares would indicate unacceptable variation.*

ZF was forced to take was often circuitous, but unlike many of its peers, the company persevered through Germany's disastrous post-WWI economic climate. There were times when, because of mass inflation and the dramatic fluctuation in the value of the currency, workers were paid daily and in the company's own script. Even in the face of such difficulties, or perhaps because of them, as early as 1918 ZF offered its employees a health insurance plan.

A peculiar side note involves ZF's ownership. When Count von Zeppelin died in 1917 he willed his shares and patents to the City of Friedrichshafen. To this day, the mayor of the city sits on the supervisory board, and because the company has no public shareholders, it commonly reinvests roughly 5% of its profits (estimated at $1 billion in 2010) back into research and development.

In 1935, drawing directly on its experience with airship gears, ZF tested its first reversing marine transmission. Models for fast craft began production in 1938. Coupled to a Daimler Benz engine, they transmitted 2,500 hp (1864 kW) at 1,600 rpm.

War matériel, primarily transmissions for German tanks and other vehicles, dominated ZF's production until 1945. But after WWII the company once again found itself struggling, but only briefly. Occupying powers encouraged reconstruction, and ZF wasted little time in getting back on track. In the 1950s and 1960s ZF developed a series of large and small marine transmissions. The former were mechanical, while the latter relied on electromagnetic couplings. Eventually, hydraulic controls supplanted the electric models and have remained the primary design used by ZF and other transmission manufacturers ever since.

Acquisitions

In 1986, with a growth in the demand for recreational craft gears, ZF acquired Meccanica Padana Monteverde, now ZF Padua, the facility I visited. This addition extended ZF's range of marine gears to

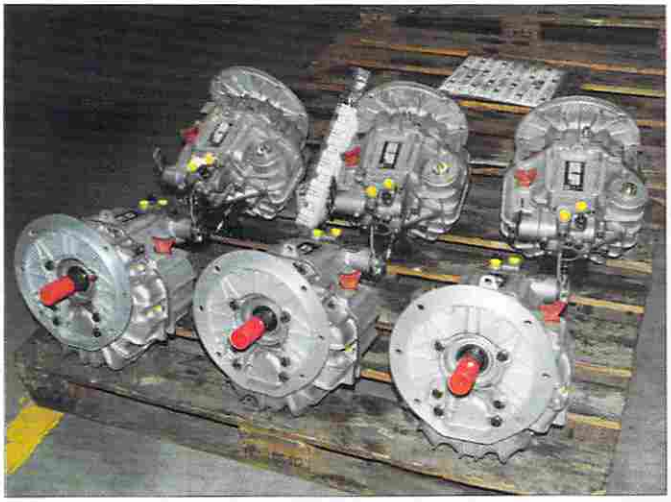
ZF's corporate practice in developing its marine division has been to purchase companies that have capacities ZF lacks. For example, well-known Italian transmission manufacturer Hurth was bought in 1995 to fill a need for transmissions to match with lower-powered engines.

lower-power demands, complementing products already manufactured by the company's home plant in Friedrichshafen. In 1995 ZF acquired the northern Italian gear manufacturer Hurth, a name familiar to thousands of sailboat owners and to those who install or service its propulsion systems.

When ZF wants to add a product or expertise, it often acquires a company, but prefers to maintain the new acquisition as a separate entity. The thought is that smaller divisions are more manageable and can adapt to changing markets more easily than a giant conglomerate can. They are also more adept at research and development of their own specialized

products, yet benefit from the depth of the mother company's resources and infrastructure.

ZF appears to be a conglomerate with a work force currently around 64,000 in 123 production companies in 27 countries, but the reality is that the company is composed of many smaller, specialized companies. The marine division has approximately 1,500 employees in 14 plants in 11 countries in Europe, Asia, South America, and North America. In short, ZF's approach is a comprehensive one, striving to provide virtually everything related to boat propulsion and control, and the support thereof,

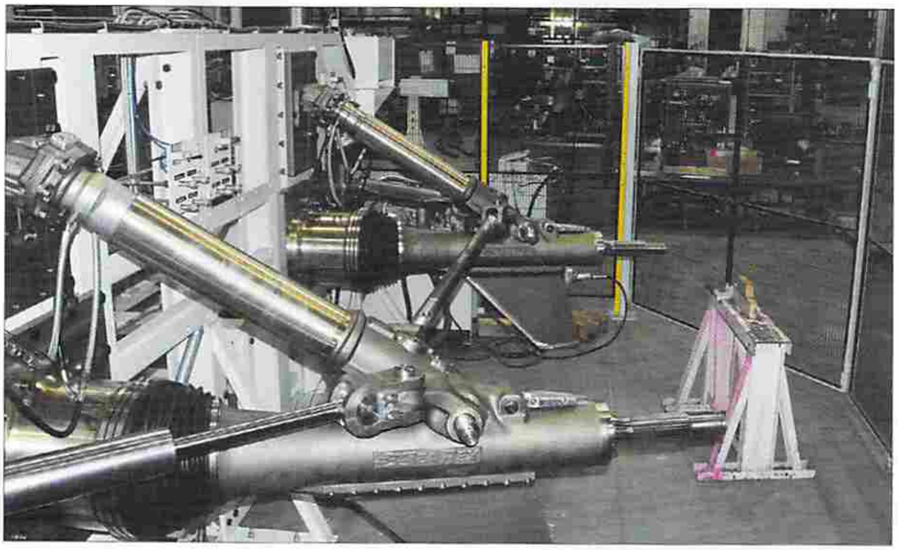


Left—*ZF builds transmissions to be fitted to specific models from numerous engine manufacturers. This pallet of six transmissions is bound for Volvo Penta.* ***Right***—*The SmartCommand control system test platform is composed of a mock-up of networked electronic steering and twin-screw shift and throttle-control systems.*

other than the engine (for now). Here's a look at some of those components.

In 2000, ZF acquired Faster Propulsion Systems of Kaoshiung, Taiwan, which allows ZF to offer a full line of controllable- and fixed-pitch propellers. Also added to the company's stable in 2000 was Mathers Controls of Mukilteo, Washington. To bolster its small and midsize commercial marine offerings, ZF formed a joint venture with the Chinese firm Nanjing Highspeed and Accurate Gear. Named ZF Nanjing Marine, it assembles and markets products for commercial vessels and workboats. These corporate pieces complement one another in the overall catalog of ZF Marine capabilities and products. This sort of planned synergy becomes even more evident in the company's latest networked controls.

When the SmartCommand control



ZF also manufactures SeaRex surface drives, which provide propulsion as well as steering and trim functions. This newly finished pair was set up on the factory floor for testing.

system is linked with ZF's JMS joystick, boats using conventional propeller shafts and rudders can maneuver much like those with pod drives. A ZF bow thruster can be interconnected to round out this package (units made by other manufacturers can work with the system, provided they possess the required 30-minute duty rating). ZF acquired Holland Roerpropeller of The Netherlands in 2009. Now ZF Marine HRP produces a wide range of fixed and azimuthing commercial thrusters and related controls for large vessels.

Other ZF systems include MiniCommand, 5200 SmartCommand, MC 2000-2 series electronic shift and throttle systems, the J5000-JMS joystick control, and SteerCommand electric/electronic steering. The variety of features and interconnectivity of these systems is mind-boggling. Most control systems, except for SteerCommand, operate on 12V or 24V. The SmartCommand options include a low-profile control head for enclosed stations. Tournament levers with a detached selection panel for sportfish applications are available, as are a handheld hard-wired remote and a two-speed processor model that controls upshift and downshift transition based on engine rpm—yes, ZF makes the two-speed transmissions, too. The joystick interfaces with SteerCommand, which can be interfaced with an autopilot.

A collaborative effort between ZF and Italian yacht builder Ferretti,

SteerCommand employs a CAN bus communication protocol to operate what is essentially a steer-by-wire system. It relies on an "electronic helm," with a standard linear actuator capable of delivering as much as 7,300 pound-force feet of thrust (10 kN) for rudder actuation. Requiring 24V, it offers a variety of features such as multiple helm stations (up to six), independent control of rudders, and simple installation with no bulky hydraulic lines, fluid, leaks, or bleeding.

The SmartCommand central processor acts as the hub for steering, shift, and throttle, an NMEA-controlled area network display, and multiple stations. It's a single point of failure, so one might well ask: "What happens if it dies?" That is a concern, but how often do you think about the steering, shift, throttle, or brakes failing on your automobile? Today, those systems rely on much of the same technology that ZF already provides to a host of automobile manufacturers. Failure, while still possible, has been relegated to the realm of the extremely unlikely. And just in case, ZF offers an Automatic Power Selector function for redundant power supply input and Smart Backup for shift and throttle override, so there's always a way to get home.

Some of ZF Marine's commercial transmissions are so large that one needs a ladder to properly view them.

◆

As much as I hated to leave the Padua factory, my day came to an end with a final stop on the shop floor to review a series of transmissions destined for large workboats. These behemoths ranged from man-high to some that required a ladder for viewing. Whatever their size, they all appeared to be beautifully machined and assembled, and all were ready for service. It occurred to me that they were a vision that held remarkably true to the original inspiration and intent of Graf Zeppelin when he founded the company out of a need for reliable precision engineering and manufacturing of transmission gears nearly 100 years ago. PBB

About the Author: *For many years a full-service yard manager, Steve now works with boat builders and owners and others in the industry as "Steve D'Antonio Marine Consulting." He is a contributing editor of* Professional BoatBuilder, *and awaits the publication (by McGraw-Hill/International Marine) of his book on marine systems.*