Marine Gears

Special Aspects for High Performance

Joseph L. Hazelton, Associate Editor

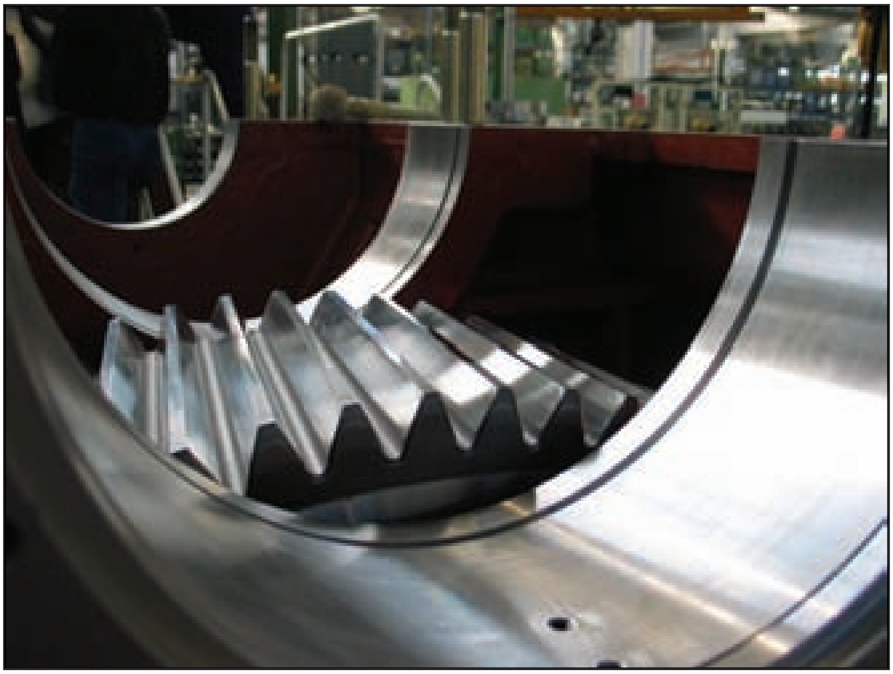

Photo courtesy of ZF Marine GmbH.

A gearbox that absorbs 30 percent of external forces, transmits power from two engines operating at different speeds, and uses gears that meet several design and specification standards at the same time.

Many gear manufacturers would wrinkle their brows at this unusual box. But what's odd to them would be ordinary to marine gear manufacturers. The above features are commonplace in high performance marine gears and their boxes, which are used in vessels as wide ranging as luxury yachts, fast ferry boats, frigates and workboats.

Given these features, marine gear manufacturers often have to create gearboxes that are much more complicated than their non-marine counterparts.

Connected to Multiple Engines

Whether a luxury yacht or a massive warship, many larger marine vessels have two or more engines and use certain ones based on whether they're in a small harbor or on the open sea. This situation, multiple sources of power, contrasts starkly with non-marine gearboxes.

"Normally, you have just one input for non-marine gears," says Franz Hoppe, general manager–marine for Renk AG. Hoppe estimates that more than 90 percent of non-marine gears have only one input.

In a larger marine vessel, the multiple inputs may be gas turbines, electric motors or diesel engines. Depending on the combination, the power sources often operate at different speeds, so they require gear trains with different reduction ratios.

The trains are usually combined inside a gearbox, with one train for the primary engine and one for the secondary. Further complicating the box's design is that both trains may be connected to one or more output shafts. Also, the gear trains can overlap; they can share gears.

Hoppe uses a modern naval frigate as an example to explain the need for multiple engines. A smaller warship, a frigate may have as many as three engines: a gas turbine able to transmit 20,000–30,000 kilowatts of power and two diesel engines, each one able to transmit 4,000–8,000 kilowatts.

The different engines are necessary because a ship operates in different environments and speed modes: loiter, cruise and fast. In a harbor, the frigate has to move slowly, carefully. Its speed engine, the gas turbine, isn't suitable, so it switches to its lower-power diesel engines.

To do that, the crew may also need to switch from one gear train to another. This switch involves activating and deactivating various clutches in the gear system, in a certain sequence, disengaging some gears and engaging others so the box achieves the right reduction ratio between the online engine and the propeller.

These gearboxes have resulted in an alphabet soup of marine gearbox types: CODAD, CODAG, CODOG and so on. For instance, CODAG refers to a combined gearbox able to transmit power from a ship's diesel engine and/or its gas turbine. The box can transmit power from both engines, driving two propeller shafts at the same time. CODOG, on the other hand, is the acronym for a combined gearbox able to transmit power from a ship's diesel engine *or* its gas turbine.

Marine gearboxes connected to two or more engines include commercial vessels, like ferries and other roll-on, roll-off ships. Also, high-speed yachts can feature two gas turbines with power output via waterjets, not propellers. Waterjets allow for much more condensed output of the engines' power.

"They're providing much higher speeds," Hoppe says. "With waterjets, you can reach up to 50–60 knots [about 60–70 mph]."

No Infinitely Stiff Foundation

Marine gear manufacturers also have to keep in mind that their gears and boxes will lack what are considered infinitely stiff foundations. The problem isn't the gears, their box, its immediate base, or the ship itself. The problem is the water.

It's not stiff. Even when calm and in a sheltered harbor, water isn't a road or a rigid, stationary platform.

Still, gear mesh mustn't be affected by even rough waters.

"Stiffness is most important to have reliable tooth contact between the gears," Hoppe says.

That reliable contact is no small feat given that a characteristic of high performance marine gears is their mechanical efficiency. At ZF Friedrichshafen AG, Gerald Rowe, R&D manager–marine transmissions, puts that efficiency at 99 percent tooth contact between pinion and bull gear.

To keep gears in mesh, their casings are strengthened with ribs or built with a double-wall design. "The casing has to be as stiff as possible, always," says André Thuswaldner, chief design engineer for Maag Gear AG. Thuswaldner is responsible for the initial design of his company's marine gears.

Overcoming water as foundation is necessary, though, for high performance marine gears to provide their high performance. But what constitutes high performance? What measurable characteristics define a high performance marine gear?

What is a High Performance Marine Gear?

The answer is more elusive than might be expected because physical, performance and other characteristics vary considerably. A high performance marine gear's size can range from 300 mm to 5 meters. Also, marine gears can transmit as little as 225 kilowatts of power and still be considered high performance.

The other end of the power range is more open. Tom Wampler, chief engineer–marine design for Twin Disc Inc., says high performance marine gears' maximum power can reach "astronomical numbers." Renk's Hoppe provides a maximum—50,000 kilowatts—but he adds the upper end can go as high as a customer needs: "We are not limited on the upper side."

High performance marine gears can also mean speed, not just power. The gears inside "fast craft," vessels capable of at least 25 knots (29 mph), are considered high performance. These ships include luxury yachts, patrol boats and high-speed ferries.

A Complex Gearbox—The combined marine gearbox here, a CODAG, can simultaneously transmit power from a diesel engine and a gas turbine or can transmit power from one or the other separately. Such complicated gearboxes are common among many larger marine vessels. Photo courtesy of Renk AG.

Accounting for power and speed, Thuswaldner defines a high performance marine gearbox as having a power/weight ratio of more than 1.5 kilowatts/kilogram or operating at a pitch-line velocity of at least 120 meters per second.

Another characteristic is high reliability. Hoppe defines that as: "Never having a gear tooth or bearing failure." At Maag, Christoph Blättler, general manager for sales–marine gear units, is number-specific. He says naval gears have to be designed for 99.95 percent reliability, with the overall gearbox having a reliability of 99.8 or 99.9 percent.

The need to avoid tooth failure is critical, especially with larger ships. If the gears are in motion, the vessel is likely under way. If a tooth fails then, the ship isn't in charge of its movement anymore, the water is.

The problem is serious when it occurs on the open sea, like in the middle of the Atlantic Ocean. In that case, the ship would need to be towed into port. But it's more serious if the vessel is maneuvering in harbor. A tooth failure then and the vessel could collide with nearby ships, damaging them and maybe killing people.

Given these consequences, marine gear manufacturers are very much concerned with avoiding gear failure, whether due to the gears themselves or

Designed for Space, Weight—Marine vessels often require more complicated gear arrangements, such as planetary gear systems, so their gearboxes meet space and weight restrictions. Such complicated gearboxes are common among many larger marine vessels. Photo courtesy of Maag Gear AG.

An Unstable Foundation—A marine gearbox has to be designed and manufactured to compensate for the lack of stiffness in what is—in the ultimate sense—its true platform: water. Photo courtesy of Renk AG.

due to external forces.

Resistant to External Forces

Marine gearboxes must be able to resist external forces, like those introduced into the box's foundation from the surrounding structure or vibrational forces from the propeller and propeller shaft. To an extent, resisting external forces means being able to absorb them.

That extent can be considerable in high performance marine gears. Hoppe says gear assemblies for non-marine applications normally absorb a maximum of 20 percent of the amplitude of external forces, but marine assemblies absorb 30 percent of non-transient forces and up to factor 2 transient forces. The extra absorbency helps the marine gearbox avoid breakage.

Without the extra amount, the gearbox's bearing assembly could overload, disrupting the oil film, which would immediately damage the bearing, causing the gears to stop. At that point, the vessel wouldn't be propelling itself; the water would be.

Besides natural external forces, some vessels—naval vessels—have to be built to handle shock forces from man-made objects. Think large ammunition, like torpedoes. Hoppe says shock forces can be up to 50 g (500 meters/second^2). "These are very high acceleration forces."

Designed to Fit Space

Less unusual than being built for extreme external forces, marine gears, like other gears, have to be designed to fit in a limited space with a predetermined shape and still provide all their required performance.

"That is the challenge for the design engineer when it comes to marine gears," Thuswaldner says. He adds that the space can sometimes require making the gearbox more complicated than it would otherwise have to be: "But that's life in marine gearboxes."

As an example, Thuswaldner compares a marine gearbox for a gas turbine capable of generating 22 megawatts of power at 330 rpm and an industrial gearbox capable of the same output but built for a mill drive. The boxes' lengths and heights would be the same but the industrial gearbox would be more than 50 percent wider than the marine one.

The smaller width would be achieved with a different basic design. The marine gearbox would be a double-stage planetary gear system with as many planets as possible, while the industrial one would be a double-stage parallel-shaft gearbox.

The marine box would have 16 gears, an input shaft and an output one. The industrial box would consist of four gears and three shafts: an input, an intermediate, and an output. "That makes the gearbox very simple and very cheap, but heavy," Thuswaldner says.

The heaviness would be a main problem and a major reason for a planetary gear design. Weight matters, after all, in terms of a vessel's fuel consumption and handling characteristics. The planetary gear design's overall effect would be to allow the marine gearbox to be smaller and weigh less.

Built to Meet Multiple Standards

Whatever the gear arrangement, though, high performance marine gears often have to be manufactured to meet several standards simultaneously.

This situation can occur, for example, if a prospective owner isn't sure in what country he'll register the ship he's having built. The country matters because each one may have its own design and specification standards for marine vessels, and all ships registered with that country must meet those standards, which are administered by classification societies. In the United States, the society is the American Bureau of Shipping, known as ABS. In Italy, it's the Registro Italiano Navale, RINA.

"Each society has its own methods for calculating gears," says Rowe of ZF. He adds that calculation results can vary as much as 65 percent from society to society.

Knowing the various standards is also necessary when a company makes marine gears for customers from many different countries. In either case, when the marine gear manufacturer doesn't know which classification rules may be applied, it designs its transmissions to account for all possibilities.

Having to meet several standards at one time, to design for different power sources in one gearbox, and to compensate for the lack of a stiff foundation—these considerations increase the complexity of designing and manufacturing high performance marine gears and gearboxes, especially when they're used in vessels as diverse as coastal workboats, luxury yachts and oceangoing warships.

As Twin Disc's Wampler says:

"There's no such thing as a run-of-the-mill, suits-all-things marine gear."

For more information:
Maag Gear AG
Sulzer-Allee 46
P.O. Box 65
CH-8404 Winterthur
Switzerland
Phone: +(41) 52-262-8888
Fax: +(41) 52-262-8732
E-mail: *maag-gear@maag-gear.ch*
Internet: *www.maag-gear.com*

Renk AG
Gögginger Straße 73
86159 Augsburg
Germany
Phone: +(49) 821-5700-0
Fax: +(49) 821-5700-460
E-mail: *info@renk.biz*
Internet: *www.renk.biz*

Twin Disc Inc.
1328 Racine Street
Racine, WI 53403
Phone: (262) 638-4000
Fax: (262) 638-4481
Internet: *www.twindisc.com*

ZF Marine GmbH
D-88038 Friedrichshafen
Germany
Phone: +(49) 7541-77-2207
Fax: +(49) 7541-77-4222
E-mail: *info.fastcraft@zf.com*
Internet: *www.zf.com*

Comment on this article by sending e-mail to *publisher@geartechnology.com*

Correction 1

Gear Technology's January/February 2006 issue included a paragraph that required additional information to be understandable. The paragraph appeared on page 54, in the article "Investigation of the Noise and Vibration of Planetary Gear Drives." The paragraph was under the subsection heading "Measured vibration results for planet gears in vehicle tests."

The additional information, underlined here, should have appeared in the paragraph as follows: ". . . were made under a condition of gradual acceleration in first and fourth gears. Another way to achieve a meshing phase difference is to use unequally spaced planet gears as shown for planetary gear set II in Table 2. As seen in the figure, the vibration acceleration level of planetary gear set II with a meshing phase difference achieved by the use of unequally spaced planet gears was approximately 3–12 dB lower than that of planetary gear set I without a meshing phase difference. Better results . . . ."

Correction 2

In the March/April 2006 issue of *Gear Technology*'s article titled "Medical Device Manufacturing Keeps Gear Industry Healthy," we mistakenly identified Precipart Corp.'s location. Precipart Corp. is located in Farmingdale, NY, not Farmingdale, CT.

Correction 3

In the March/April issue of *Gear Technology*, the Gleason Genesis 130H CNC was featured with a misleading headline. The cycle time of the *loader mechanism* was one second and the machine's cycle time is two or two-and-a-half-seconds.

We apologize for the errors.

—The Editors