Unreasonable

Challenging projects bring out the best in engineers, but sometimes we think 'you cannot be serious'. Brian Tinham talks to the team that built the world's biggest subsea motor

So how do you fancy a bit of unreasonable engineering? How about building a variable speed electric motor, rated at 2.5MW for pumping operations 3,000 metres down on the sea bed? Oh, and, for good measure, let's have it driven by an 11kV supply 30km away, and plan for a design life of 15 years, with minimum time between interventions of five years.

That's precisely what project engineering firm Hayward Tyler has done for oil industry integrator Aker Solutions. The first of its mega subsea motors – the largest ever produced – has now successfully completed full-scale tests in Norway, with another shipped and one more under construction and close to delivery. We're talking about a monster motor of vertical shaft design, weighing in at 12.5 tonnes and measuring 3.3 metres from top to bottom, capable of running at up to 4,000rpm.

Technical director Ken Sears shrugs his shoulders and says this is exactly the kind of engineering the company has always done throughout its 190-year history, serving not just the oil and gas sector, but industries ranging from chemicals to nuclear power, water, transportation and, latterly, renewables. In fact, this year marks the centenary of the firm's first subsea motor, which spawned its core specialism of big pump and fluid-filled motor technology – although Sears concedes that the specification for this latest development was a little daunting.

How did it come about? Quite simply, as oil prices rise, it makes economic sense to extend operations in the North Sea and extract remaining, more difficult, reserves from existing fields. That, in turn, requires more extreme technology on the sea floor, capable of delivering more power at greater depths, further out to inject more seawater into the wells. These particular units were ordered for Statoil's Tyrihans field off the Norwegian coast.

"The technology to do this simply hasn't been available, so there's been a lot of interest in our development," says Sears.

So let's take a look at the challenges. First, there are the obvious pressure (a horrible 420bar) and inaccessibility issues – meaning a requirement for ultra-strength and ultra-reliability throughout its electrical, hydraulic and mechanical engineering. Commissioning diving boats and remote subsea vehicles is a very costly business and one to be avoided. But Hayward Tyler also had to contend with the issues around power transmission across the 30km distance, cable entry at the phenomenal pressure, and the marine environment, with its fouling problems.

Its solutions are fascinating. Delving into the detail, Sears points first to a design condition that means the motor can be stationary, while its pump may be subject to full system pressure – which transfers straight back to the rotor shaft. "So there can be a huge end thrust load on the motor assembly, meaning that, when it starts, there are very big rotational friction forces on the thrust bearing. To solve that, we used a development of

engineering

our hydrodynamic bearing technology," he says.

These are tilting pad bearings (conventionally Mitchell or Kingsbury type), which the company has used for years, because they're capable of huge load capacity and, if you make them well enough, also exhibit extreme durability. "The pads rock slightly and rotation of the bearing results in a film of fluid being interposed between the bearing surfaces," he explains. "Others use oil, but our tradition is water/glycol filling, not only because it's less viscous, meaning less power loss, but because it's environmentally friendly."

But there's more to it: "The thrust bearing has to be very large, but that means it generates quite a lot of heat – not friction, but due to the shearing effect of the fluid keeping the surfaces apart. So we designed a sealed hydraulic fluid cooling circulation system that doesn't depend on valves or controls – their unreliability risk is too great. That now feeds lubricating and cooling flows in precise proportion to the requirements of the thrust and shaft journal bearings, as well as the rotor and stator windings of the electrical machine – with heat exchanger coils on the motor surface. That's effectively the life support system for the whole motor."

Bearings twist

However, there's another twist to the bearing issue. "When we calculated the breakout torque to get the motor moving, it was so high that there was some concern that 30km of cable might not transmit enough electrical power. Cost meant we couldn't increase the diameter of the cable, so we developed new, ultra-low friction bearing materials, using modern engineering polymers that greatly reduced the starting torque requirement."

Meanwhile, back on the extreme pressure problem, Sears points out that any change in temperature inside the motor, as it warms up and works, has to be accommodated by a pressure compensation mechanism. "It's only a small piece of kit and it's one of those things that's not part of the machine itself, but you have to get it right. Essentially, the junction box is filled with insulating oil, so the real issue is material compatibility. The compensator has to use a bladder or bellows type concept, rather than a piston, seal and spring [again, for reliability deep under water], and materials typically used to make these are by no means all compatible with transformer oil. That and the bellows wall thickness was another area requiring a whole series of tests," he explains.

"It also gets interesting," he says, "where the electrical connectors have to pass through the pressure boundary." Hayward Tyler has developed what he calls a penetrator – an assembly that Sears says also required a huge amount of material engineering, as well as consideration of the physical shape of the components. "We're talking about high voltages and high pressures in water, and one of the interesting phenomena in that environment is the potential for generating substantial electric fields, which are seriously influenced by the shape of the conductor. If that field is too intense, then you need extra duty on the insulation, so a lot of know-how and technology went into that one assembly."

There's also the problem, already referred to, of fouling. "These motors are going to lie under the sea for a long time so, apart from corrosion, there's the question of barnacles on the surface – which matters for the fluid heat exchanger. There's a series of coils around the main motor, so we had to think though material selection and coatings. Marine protective coatings are well known, but you have to do the engineering calculations and testing to examine their effect on heat exchanger efficiency. And then you have to do them again, allowing for some growth over, say, a decade undersea. Those are not exactly the kind of calculations you find yourself doing on our boiler circulating pumps."

One final thought: Sears' views on how to go about making something like this well enough are revealing. "Before even thinking about a concept for the machine, you have to start by understanding the problems – and that means building a good relationship with the customer and other partners in the project. That might not occur to engineers, but these are development projects, so there are bound to be difficulties and learning experiences."

Beyond that, it's about well-founded engineering principles, aided and abetted by know-how. "We've built machines of this size for other applications, although not as extreme as this. So we're able, for example, to start with our core fluid-filled motor technology.

"After that, it's an iterative process, looking at the power and duty, which leads to an electrical winding specification for maximum efficiency. Then you're into the trade-offs between electrical engineers, for example, optimising their design for long, thin rotor shafts, while mechanical engineers want shorter, fatter shafts with robust, dynamic characteristics. In the end, it's a feedback loop of experience, computer assistance and testing."

Pointers

- As oil prices rise, it makes sense to go for extreme extraction engineering
- Ultra-reliable, ultra-robust motor bearings rely on hydrodynamic technology
- Hydraulic fluid cooling circulation provides life support for the motor
- Ultra-low friction bearing materials reduce starting torque requirements
- Pressure compensation and electrical penetrator components rely on bespoke engineering
- Surface treatment relies on existing but extended marine technology

Left: Hayward Tyler technical director Ken Sears examines the company's massive subsea motor for Aker Solutions, prior to shipping