Armed and dexterous

WHOI engineer Matt Heintz

Matt Heintz is a research engineer in the Deep Submergence Lab at WHOI. He started his career at WHOI as a pilot for the human-occupied submersible *Alvin*. In 1999, he began developing the second iteration of the remotely operated vehicle *Jason*. Both of those vehicles use manipulator arms to collect samples and conduct experiments on the seafloor. Heintz was responsible for developing a hydraulic power unit, sampling apparatus, and a manipulator arm with "good kinematics," or ranges of motion, for WHOI's newest deep-sea vehicle, *Nereus*.

Tell us a little about your arm—well, not your arm,* Nereus' *arm.

It's a seven-function, hydraulically powered, master-slave manipulator. It has shoulder elevation, shoulder rotate, elbow, wrist pitch, wrist yaw, wrist rotate, and wrist grip.

Whoa! And for those of us in the audience who aren't engineers?

It is an attempt to be similar to the human arm, but obviously, it is a bit more clunky. It moves a little slower, although surprisingly fast. We have a "master" control arm on the surface ship that we move, and then a subsea "slave" arm mimics what the master does.

What jobs do you do with the manipulator arm?

We pick up rocks, collect water samples, take temperature measurements, and collect biological samples, which means opening and closing sample boxes or moving around a scoop or a net. We also take push cores—that is, pushing cylindrical tubes into the seafloor to take sediment samples, as well as position and manipulate instruments on the seafloor.

What were some engineering challenges you faced to design the arm?

We had to think a lot about power and pressure. *Nereus* is powered entirely on batteries. There is no power going down the fiber tether. So the big issue we faced was: Would we have the kinematic versatility to perform a myriad of tasks that scientists like to do—and do it without eating all the energy that the vehicle has in 10 minutes of operating the arm? Manipulator arms typically use quite a bit of power. We designed our own in-house hydraulic-power unit, or HPU, and developed this manipulator arm in parallel to be more energy-efficient than other hydraulic manipulator systems.

Can you explain how a hydraulic-power unit works?

In the hydraulic system, oil is the blood. It is the fluid that forces joints to move in the manipulator. A gear pump forces the oil to create pressure to move the manipulator.

Each of the joints in the arm is rack-and-pinion, which means you move just enough oil to make it move the arm, and then the oil stops moving. Other rotary joints have a lot of leakage that wastes 1 to 2 horsepower just by turning them on. But in our hydraulic system, there is no leakage, so the motor stalls until the arm begins to move—saving power.

What brand of oil do you use?

Actually, one problem we have with the manipulator at great depth is that oil gets compressed by the pressure. The oil becomes much thicker as the pressure is increased. Effectively, it turns into molasses. So one of my big fears was that when we got down there, the oil would be too thick, and the manipulator would be too sluggish to get any work done. You could drive thick oil by dumping more energy into the pump, but that would kill our batteries too fast.

What did you do?

First, we determined how thick of an oil the manipulator and HPU could operate with. We bought an oil that is as thin as you can possibly get. On deck, it's almost like water. Then we calculated how thick this oil would get at 11 kilometers depth. The manipulator does not fit into our pressure test chamber, so we tested the manipulator in the lab with an oil that is thicker than the oil would be at 11 kilometers. And we ran the hydraulic power unit in our pressure test facilities with that thin oil and calculated how much more power was required to operate the HPU at 11 kilometers compared to on deck.

What other unforeseen issues came up?

Another thing we had to look at very closely is, when you're on the seafloor working, you're not just sitting there. So, for instance, if we're trying to push a core into the seafloor, and there's no external force holding the vehicle in position, the core won't go in. The vehicle will just push away from the seafloor. We need to use the thrusters to hold position when we're sampling, so we had to take into account how much power we needed to hold position.

That really drove us to a fast, easy-to-operate, and capable manipulator arm, because if the manipulator has poor kinematics and so it takes 40 minutes to do a push core, and we're using all that power holding position for 40 minutes, well, that is going to ruin mission endurance. It wasn't immediately obvious when we started the project that we had to have that kind of speed and capability. When we analyzed all the mission scenarios, we really realized how important it was for the arm to be able to do things quickly.

How did you go about building the arm?

We hired an outside firm, Kraft TeleRobotics, which developed hydraulic manipulator arms that were used on *Alvin* and *Jason*. We looked at some designs for arms and sent them a wish list. There was an iterative process and several visits. We showed them things they could do to save weight, and we modeled various lengths of the various joints on the manipulator and discussed with the manufac-

Tom Kleindinst, WHOI

Research engineer Matt Heintz tests *Nereus*' manipulator arm in a lab at WHOI. The arm is picking up a "push corer" designed to take samples of sediments from the ocean floor.

turer how we could lengthen that one there, for instance, to make it a little better. We worked with them to make a custom arm for *Nereus*. So there is only one of these arms in existence.

How did the arm turn out in terms of capabilities?

It can pick up about 36 pounds, and it is quite dexterous. And most important, it is capable of performing the tasks that we'll be asked to do with *Nereus*. Then it really comes down to practice and the skill of the pilot to be very careful to gently close the manipulator jaw on samples without crushing them.

You control the arm visually—basically by stopping the jaw at the right time. There are three cameras on the vehicle at different angles, and a pilot can triangulate the camera views and quickly piece together where the arm is.

Are there any other special features about the arm you'd like to mention?

Well, one big difference with *Nereus* is that it has that tiny little light fiber tether that breaks at 8 pounds, and if we lose that, we lose telemetry—that is, our communications link with the vehicle. If, for instance, we were sampling a rock and lost telemetry, *Nereus* would be attached to the seafloor. We don't want to stay attached to the seafloor. But the hydraulics are still there. There is no reason that the arm can't let go. It just doesn't *know* to let go, because the operator up on the surface can no longer talk to it. So we program the software that controls the manipulator to know that if we lose telemetry, it should let go of whatever it is holding and to shut off hydraulics.

There are other circumstances: What if the arm is holding a $150,000 scientific instrument? Well, we don't want to lose that $150,000 instrument, so before that operation, we would program the arm to *not* let go, in the event we lose telemetry.

That's cool. Those are things people don't think about.

Well, we have a lot of smart people here whose job it is to think about these problems.

—Amy E. Nevala and Lonny Lippsett