Low Temperature Lubricant Testing: Procedure and Results

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In the fall of 2006, the Tohoku Daigaku Antarctic Telescope group was asked by "..." to test the low temperature performance of a lubrication oil. As a 1st year masters student I was assigned to perform the research by Dr. Takeshi Ichikawa.

Here I present the procedures followed and the results obtained in January of 2007.

We were given a piston and ring assembly with the lubricant oil applied between the two parts. We were asked to check that the piston moved freely through the ring at temperatures down to -70 degrees Celsius (203 Kelvin).

My approach to the problem was to turn the piston with a motor modified to work at low temperature. Between the motor and the test part, I had planned to insert a torque sensor so that if the part became harder to turn, we could determine the minimum torque needed to drive the motion at any given temperature. But this was not possible due to shipping delays.

The motor used was a Super Vexta, model number UDX5107N from Oriental Motor Co. Ltd. This is a stepper motor. For each 5V pulse received on the control channel, the motor turns 1 step. There are control channels for both clockwise and counterclockwise motion.

To drive this stepper motor I used a Hewlet Packard 33120A function generator to generate a continuous 5V, 1 kHz square wave. To control the motor, I built a simple three-position switching box. The three possible settings for the switching box connected the function generator signal to either the clockwise input channel; the counterclockwise input channel; or to neither. The neutral or disconnected setting was located between the other two. This protected the motor from damaging itself. Baring an electrical short, it was impossible to send a signal to both the clockwise and counterclockwise channels at the same time. In addition, to switch the motor from one direction to the other, the switch must pass through the neutral position. These measures insured that the motor was never working against itself. The electronics are pictured in Figure 1.

Once the motor was decided upon, I designed, and had the Tohoku Aobayama machine shop build, a mount to hold the motor and piston with their axils aligned. Slots in the base plate allowed the motor position to be adjusted so that it could be connected directly to the piston, or have a torque sensor inserted between them (Figure 2).

On January 13, 2007, I placed the assembly in our Pentan freezer (model CLN-35C from Nihon Freezer Co. Ltd.) and began the cool down process. Dr. Ichikawa had informed me that it is possible to briefly open the freezer while it is running. Therefore I used visual inspection to determine if the piston still turned freely in its ring at various temperatures. To make motion easier to see, I marked the end of the piston with a black pen. I checked the freedom of motion in both the clockwise and counter clockwise direction at -10 degrees Celsius and every 10 degrees there after. The freezer has a integral thermometer with digital read out, which I used to determine the temperature.

The assembly worked down to -50 degrees Celsius, but at -60 degrees Celsius there was no motion when I turned the motor on in either direction. I waited several minutes and retested the motion to make sure that the problem was not transitory. These results indicated that either the motor or the lubricant no long worked at -60 degrees Celsius.

The entire freezer had to be allowed to warm up to room temperature before I could separate the parts and test the motor’s function at low temperature. The warm up time is approximately 5 hours.

On January 15, 2007, I separated the motor from the lubricated piston, and began the cool down process again. I rechecked the motor at -50 degrees Celsius, where I had already shown that it not only worked, but was strong enough to turn the piston. I also checked the motor at -55 degrees Celsius. At -57 degrees Celsius, the motor turned when a drive signal was applied, but the motor sounded as if it was straining. At -60 degrees the motor would not turn when a signal was applied in either direction.

At this point I consulted Dr. Ichikawa to determine what course of action to take. I demonstrated that the motor did not work at -60 degrees Celsius, and stated that I believed that something inside the motor must be frozen. Using only a handkerchief as insulation, Dr. Ichikawa reached into the freezer and twisted the motor shaft to verify that it was frozen solid in place. He then explained to me the procedure for cleaning moisture out of the motor in hopes of improving its low temperature performance.

As I was preparing to bring the experiment back up to room temperature. It occurred to me that if Dr. Ichikawa could test cold motor by hand, it should also be possible to test the lubricated piston by hand. In fact, dry ice (solid $C0_2$) has a temperature of -78.5 degrees Celsius and can be safely handed with a pair of winter gloves.

Using a pair of insulated leather gloves, I tested the freedom of motion of the piston at -62 degrees Celsius. (The refrigerator had continued run and cool the experiment during my discussion with Dr. Ichikawa.) The piston, now disconnected from the motor, turned freely. The technique is shown in Figure 3.

I continued checking testing the piston by hand and found that even at temperatures as low as -75 degrees Celsius, it turned with no appreciable difficulty. This demonstrates that the lubricant applied to the piston is suitable for use in Antarctic temperatures.

Figure 1: Electronics used: The stepper motor driver (black box) and function generator (device with digital display) are connected by the switching box (lower left corner).

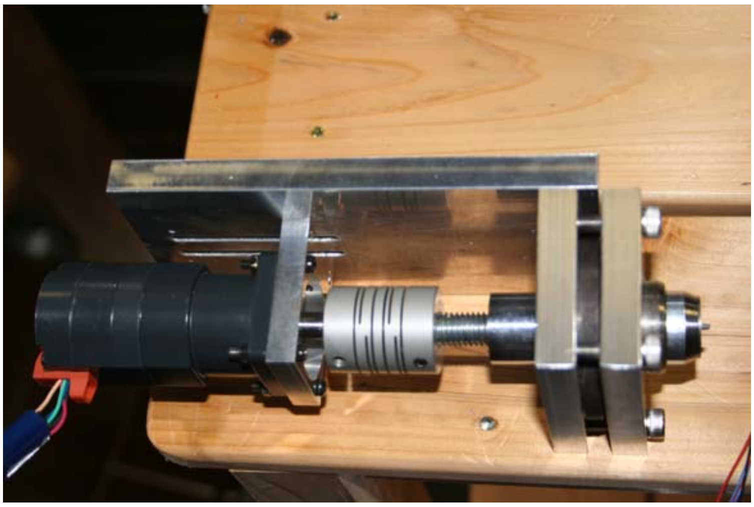

Figure 2: Motor and piston in mount. Shown connected here.

Figure 3: Low temperature testing by hand.