Cryomaser Assembly and Testing

David Phillips – following a discussion with Marc and Ron

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1 Testing the Cavity

1.1 Building the helium inlet

- Finish diagram of the copper plug and submit to shop.
- Build elbow for the outer connection. This must connect the short copper tube which leaves the Copper Pot to the flange on the remaining copper tubing.
  - Elbow should bolt into base of Copper Pot.
  - Flanged tube should be hard soldered into elbow.
  - Tube on Copper Pot should be soft soldered into the elbow.
  - Be sure the the flanged tube is long enough to leave the magnetic shields.

1.2 Testing electromagnetics

At this stage, we want to be sure at room temperature – where things are easy and reversible – that the spiral doesn't degrade the Q or shift the resonant frequency very much.

- Assemble cavity with spiral capillary and bulb in place.
- Compare cavity resonant frequency and Q with and without spiral superfluid He line in place and also compare to numbers in logbook from 1996.

1.3 Testing at low temperatures

Here we perform a test a liquid nitrogen temperatures. Almost all the thermal contraction that happens in going from room temperature to 0.5K has already happened by 77K. Therefore we can test the mechanical soundness of our design without assembling the refrigerator. Also, the Q improves when cooled to 77K, so we can further check that the cavity isn't degraded by the copper capillary. However, this test requires more preparation.

- seal off superfluid He entrance to cavity.

Table 1: Cavity frequency, Q and coupling versus temperature. Tuning the cavity to resonance ($\nu_c \approx 1420.405$ MHz wasn't difficult from the final frequency.)

temperature	center frequency	Q	β
room temp	1410.75	14100	0.1
LN_2	1420.7 MHz	26000	0.24
LHe	1420.95	40600	0.32

- Build superfluid He transport section that sits against the Copper Pot top.
  - Solder capillary into copper plug.
  - Epoxy plug in place with stycast 2850.
  - Place top copper endcap of cavity on Copper Pot.
  - If we were doing a final assembly, the next step would be to epoxy the bulb to the capillary. For this test, however, we'd be happier with them not fixed together.
  - bend capillary into place.
- Assemble cavity with quartz bulb.
- Make indium seal.
  - Make sure that we have enough indium. We may need more for multiple iterations of closing the Copper Pot.
  - The nuts on the Copper Pot should be tightened using a torque wrench to 35 in-lbs.
- Leak check to make sure that the Copper Pot is still leak tight and that the rebuilt superfluid He inlet is OK.
- Get big LN_2 bucket from Silvera.
- Insert jig in tuning plunger to keep plunger from being sucked in while under vacuum. (The piece from 1996 should still exist.)
- Slowly cool cavity to 77 K and check that frequency and Q agree with values from 1996.
- Test diode as we have done at room temperature. Make sure that it doesn't draw current and look to see how changing the biasing changes the frequency, Q and coupling of the cavity.
- Remove from liquid nitrogen and quickly leak check while it is still cold. We are basically trying to leak check the epoxy joints that we have made or remade on the system.
- Disassemble and make sure that all is still OK inside cavity.

1.4 Assemble for Final Mechanical Test

- Unwind spiral capillary and epoxy to bulb.
- Build a jig to support bulb.
- Reform the spiral with the bulb attached.
- Assemble cavity around bulb.
- Make indium seal.
- Leak check.
- Cool to 77K and test as before.
- Leak check while still cold.
- Open up again and visually inspect. (Do we need to do this?)

2 Final Assembly

- Assemble Copper Pot as in the previous section.
- Make indium seal.
- Leak check.
- It probably wouldn't hurt to do the nitrogen test one more time.
- Assemble without shield body on ^{3}He refrigerator.
- Build rig to connect hydrogen input (bottom) side of the Copper Pot to the lower pumping system for leak checking. This piece should be heat sunk properly so that it doesn't create too big a heat load on the refrigerator.
- Organize thermometry properly for these tests.
- Insert into dewar.
- Cool to LN_2 and test (cavity (includinging diode), leak test and thermometry).
- Cool to 4K and test (cavity (includinging diode), leak test (including superfluid He line) and thermometry).
- Cool to 2K and test (cavity (includinging diode), leak test (including superfluid He line) and thermometry).
- Cool to 0.5K and test (cavity (includinging diode), leak test (including superfluid He line) and thermometry (including heat loads)).
- Catch our breaths while it warms up.

3 My notes for maser assembly from October, 1996

3.1 Checklist before closing Copper Pot

1. ν_c, Q
2. diode is OK. (Check for high impedence when reverse biased.)
3. Zeeman coils: Check that their resistance is correct, that they aren't shorted to ground and that the relative orientation of the two loops is the same.
4. He line is clear.
5. Washer stack is electrically isolated from the cavity and the Copper Pot.
6. Endcaps shorted only through the braid.

3.2 Assembling Copper Pot

1. Place Copper Pot over cavity.
2. Check alignment of bulb.
3. Begin tightening nuts.
4. Recheck the above list.
5. Tighten the nuts until there is $\approx$ 40 mil gap between the two halves of the Copper Pot. Now it is safe to flip to its upright position as the belville washer should begin to compress at 50 mils.
6. Invert the Copper Pot and continue tightening until you apply 35 in-lbs to the nuts. The gap should 5-7 mils.

3.3 Preparing for mounting the cavity

1. Put kapton insulation on maser pole and mount mu-metal magnetic shield tops. Check that they are electrically isolated from the Copper Pot.
2. Put stiff stainless steel micro-coax through the shields and tighten it down.
3. Mount copper piece which holds cavity to 0.5K plate and provides tuning nut with an anchor.
4. install tuning nut and test that it tunes the cavity.

3.4 Mount the Copper Pot on the refrigerator

1. Use Al and wood to make $\approx 71/2''$ base on which to put the lab jacks as they are too short to get the maser cavity onto the threaded mounting rods on the 0.5K plate.
2. Tighten all the nuts. This may require demounting some of the pieces on the refrigerator. In the past I have not had a good thermal connection because there were two nuts I couldn't thoroughly tighten.
3. Bolt the superfluid He line thermal link to the maser pole.
4. Bolt the Ge and RuO_2 temperature sensors in place. They will probably need to be regreased to make a good connection. (I note that the bolt is too long and that I needed some washers to tighten it down.)
5. Attach microcoax to its mate on the refrigerator.

3.5 Magnetic Shields

If this was a normal assembly, we would now attach the rest of the magnetic shields to the shield tops. In the past, I found this very difficult. We might look at the shields to see if we can find a way to make this proccess easier. I'll include my notes (which I describe as tricks) on this process here, too, for future reference.

1. Make sure both kapton shields (top and bottom) are tight so that magnetic shield endcaps can slide easily on them.

2. Tape up sharp edges of copper straps on shields. The copper pokes little holes in the tape. If in doubt, tape it.

3. Don't push the inner-most shield top down too much. It will bend the He line and may open up a leak.

4. When all four shields are installed, the inner two shields will probably short to one another. This is because their tops are probably touching. Push the shields down as far as you dare. Then pull them all up again so that they seat in their insulators at the bottom. Be sure that there is insulation at the top so that they don't short there.

3.6 Assembly continued

I'll continue describing the assembly process even though several of these things won't matter during the present tests.

1. Wire Zeeman coil. It goes to J2 12 and 13. There are two J2 posts on the ^{3}He pot assembly. The inner one holds the Zeeman coils on pins 5 and 6 from the top.

2. The three solenoid coils are wired to the outer J2 post. They are currently wired to the six bottom pins.
    - Main (1,2)
    - Top (3,4)
    - Bottom (9,10)

3. Next, degauss the shields.
    - Protect the diode by grounding the signal line with a 50 Ω terminator at the top of the refrigerator.
    - Attach the thick jumper cables to the maser pole and the flange which connects the Copper Pot to the sorption pump.
    - Energize the variac slowly (over 30 seconds or so) to full power. The current should rise to about 300 amps. Do this three times.
    - Insert thinner cable in series with jumper cables and repeat three more times. This time the current should only go to 10 amps.

4. Check thermometry. Make sure that all the thermometers have their nominal room temperature values and that none of them are shorted to ground.

3.7 Mount Sorption Pump

1. Get alignment right from bolts for support rods.

2. Use special allen key (shaped sort of like a door key) to tighten bolts on indium seal.

3. Attach HM1 sensor on top of sorption pump

3.8 Install 2K shield

1. Raise fridge with crane.
2. Put shield on labjacks that are on a few inch tall Al box.
3. Lower labjacks so that sorption pump won't reach small diameter section when lowered back onto unistrut.
4. Make sure "touch sensor" is out of fridge (one wire).
5. Lower the fridge. Make sure the alignment is correct. There are two arrows pointing to a bolt slot on the shield and one taped above a screw on the fridge. Also, one screw is missing and the corresponding slot is taped up.
6. Raise labjacks carefully so as not to hit the sorption pump in the narrower section. Jiggle the shield as necessary to keep it free.
7. Make sure that the shield is high enoough. There is a knife mark on the bottom side of the sorption pump that should just be visible.
8. Tighten down bolts. (5/32″ allen driver)
9. Attach the touch sensor. (Shield end is stainless steel. Use acid flux.

3.9 Steps before putting on 77K shield

1. I'm always paranoid so I check all the electrical connections again including the downward leads that come out of the bottom of the sorption pump. I've been burned by skipping it at this stage.
2. Put the spring for the tuning chain in place. It is a little rolled up piece of copper foil. It goes onto a bolt of the 2K shield where the tuning chain comes out. It keeps the chain under tension.
3. Check that turning the dial on the top of the maser moves the chain and tunes the cavity.
4. Put stainless steel belows in place. It needs an indium seal on its outer edge. Do inner bolt circle first. Tighten down the indium seal. Then do the outer bolt circle. It is a pain. The 1/4-28 bolts may need to be re-threaded and even filed down a bit on the leading edge of the thread. Tighten these to lift the 2K shield snuggly against the sorption pump. Don't do it too tightly, though, or you'll make the bolts even worse.
5. Put 77K shield on. Use wooden stand to hold shield. There are big ink arrows on insulation and pairs of small "2"s stamped on copper for alignment.
6. Put copper straps which compress the belows in place. They are numbered and corespond to circles (o, oo, ooo) stamped in the stainless steel belows.
7. Put bottom flange in place.
   - Make up indium seal on outer edge of flange.
   - Ron worries about alignment. It is off by 1/2 a bolt on top bolt circle. Live with it.

- Get the teflon tube which transports the atomic hydrogen to mate with sorption pump. There is a little plastic tool to help widen the teflon tube. There is also a long plastic stick to feel what's going on. Ron says there are three tests to see if all is going well.
  (a) Should see teflon meeting sorp pump as you put the flange on.
  (b) Teflon should grab sorp pump and support some of the weight of the flange once it is on.
  (c) When it's all on, with a light, you should see the sorp pump.
- Do electrical test of downward leads again.
- Tighten bolts for indium seal on flange.

8. Check that the cavity tunes one more time.
9. Put thermal insulation around belows and flange.
10. Carefully install fridge in the vacuum can. Do not hit the belows or the bottom flange against the walls of the dewar.
11. Put bottom outer flange in place.
    - Attach bottom electrical leads to feedthrough on outer flange.
    - Two stainless steel tubes come through. To ease their passage, remove O-rings from bottom flange.
12. Attach electrical leads to breakout box and do yet another electrical check.
13. Attach H discociator. Tighten water fittings and make sure there are no leaks.

3.10 Mounting external pieces

1. Mount ^{3}He drag molecular pump on fridge and connect line from mechanical backing pump.
2. Make VCR connections to
   - ^{3}He turbo pump (big)
   - ^{3}He return line (small)
   - ^{4}He superfluid line (small)
3. Connect KF vacuum
   - ^{4}He pot pump line from wall (also mount gauge to T)
   - ^{3}He turbo pump backing.
   - pumping line to ^{3}He panel.

3.11 Start Pumping

4 Marc's list

1. The first straightforward test will be a look at the electromagnetic effects of introducing the coiled copper tube into the cavity. The coil will have the copper plug for attachment to the copper plate installed, but the copper tube/bulb joint will not yet be completed.

2. If the tube has little EM effect on the cavity, we will move forward with the mating of the tube to the bulb. Possible methods are to introduce a copper spacer or a dielectric spacer between the very fine tube (OD $< 0.020''$) and the bulb aperture (ID $\approx 0.100''$), or to simply fill this space with epoxy. Ron suspects that 1266 may be a superior seal here due to it thermal expansion properties. Before anything is done a careful comparison of quartz and copper expansion coefficient will have to be made.

3. Once this connection is made it will be necessary to check its mechanical effects upon thermal cycling. Two methods were suggested. The first would be to slowly dip the coil and then the bulb directly into LN_2 and then withdraw it. This could be repeated and the joint/bulb could be examined for mechanical defects. The second method involves placing the bulb/tube assembly into the copper pot and cooling this down; the bulb would then be cooled via buffer gas cooling. Again, after several thermal cycles, the joint/bulb could be analyzed for structural integrity. The test could be done in Silvera's lab or in our fridge, the latter option offering us the chance to check out the thermal link problem. With hope, there will be no cracks and we will manage to avoid the deep doodoo.

4. If the system seems electromagnetically and mechanically sound, we must decide if we try and leak detect it. Knowledge of this would be helpful but difficult to obtain. Of course, down the road we will indirectly gain clues as to its leak-tightness by learning if our films are thick enough or not. Still, this is not direct evidence of whether or not we have achieved a superleak tight joint. Two methods were proposed to check leak-tightness (here is where I become a little bit confused, please correct me if I've misunderstood!!!); either seal off the H inlet and drip helium into the tube, detecting outside for He leaks, or leak detect on the inner space, connecting at the copper tube and applying helium (liquid? gas?) around the outside. Both of these methods involve significant risk for damaging the bulb, and it is not clear whether such a leak-test is worth it.

5. Whether leak-tested or not, the next step would be to install the bulb/copper tube assembly (along with the remaining tubing to finish the system).

6. One additional topic discussed was the Zeeman coils. By increasing the number of turns in these coils, we may generate greater transverse magnetic field to drive the Zeeman transitions without increasing the heat load (through Joule heating). This should be completed before the first full maser assembly.