Written 24 June 2004
(Much additional information, albeit in rougher form, is on pages 08 to 16 of Pascal's Lab Notebook 3; pictures available as well in Research/MOT Coils/Pictures/June 04)

Preliminary Work, June 14 - 16

Work on the coils went much more quickly and smoothly this time, mostly owing to our previous expertise. The biggest difference between the coils wrapped in November and these was the fact that the flange design changed. Instead of having big windows, the flange is mostly metal. It also traps the coils in (the 2 3/4" flange came welded on). That meant we had to wrap the wire directly onto the flange, with all the risk associated with a "one shot only" approach. The flange has a well which the coils slide into. The flange itself is far enough from the well that the coils can be wrapped and then pushed into the well afterwards.

The first order of business was designing a new construction apparatus. The most natural way to mount the flange in the lathe was to grab the 8" flange on the outside. That meant that the 2 3/4" flange stuck out. Because we wanted the flat surface of the coils to be closest to the atoms (towards the lathe), the wrapping process needed to be mirrored from the way we did it last time. That is, the direction of wrapping would be away from the lathe, not towards it. In addition, the minis that are built onto the flange were in the way of simply laying a plate down. Since the knife edges on the minis needed protection, I made a plate that gave ample room for the minis both horizontally and vertically (a recessed cavity). I also tapped some holes for 1/4-20 screws so that we could brace the coils as we wrapped them. To hold the plate to the flange, I drilled 1/4-20 clearance holes in the right place to see the tapped holes on the flange. This holes needed to be a little bit larger than a normal clearance hole so that the plates would be sure to fit. The last hole necessary was the center hole. Finally, I had the plate cut in half so that it would fit around the tube in the center. (Sampad added a small hole in the side for a thermocouple).

Above the coils (near the 2 3/4" flange), I made a flat plate with a thickness determined as follows: Total space available - Space needed for wrapping - Thickness of bottom plate
So, it really was a space-filler. Because it would be unsupported, some 1/4-20 holes were tapped into the plate horizontally (through the plane) so it could be affixed to the tube to prevent it from moving. Sampad also drilled a hole in it for the thermocouple.

The third piece was a tube in which to insert a cartridge heater. The inner diameter of the flange is 0.875". The largest cartridge heater we had not larger than the ID was 0.746". So, the tube would have an OD of about 0.875" and an ID of about 0.75". In reality, I had to make the OD smaller than 0.875 because the internal weld of the flange made it impossible to fit through. We cleaned this piece thoroughly with soap/water, acetone, and a TCE bath so that it wouldn't contaminate the inside of the new flange.

Obtaining teflon was easy this time because we already had a fair amount. Preparing

the epoxy was slightly problematic because both the epoxy and the catalyst had solidified. The epoxy liquified fairly well with heating, though the catalyst did not. I made do and it seems like the epoxy cured well in the end. Before we wrap again, we will need to order new epoxy and catalyst. Both are now well beyond their marked shelf-life. The wire on the already-used spool was loose. In the future, we will have to insure that it stays tight because unwinding the spool can become problematic.

Wrapping MOT Coil 1, 17 and 18 June 2004

We again used a cylinder of about 1.5 feet in diameter to pre-wrap the coils. Clamping the end of the wire to the cylinder provided the best results. Moreover, pre-winding around the lathe (bigger diameter) instead of the cylinder was a bad idea. The pre-wind diameter wasn't tight enough and too much twisting was introduced when winding the first turn. The excess wire needs to wrap toward the lathe because we've mirrored the system from the first time. That is, the excess must be out of the way.

Wrapping of the first turn proceeded in a clockwise direction. Once wire came off the spool, rather than from the excess, the winding direction reversed. That means that the majority of the coil, the middle turns and layers, was wrapped counter-clockwise. The initial "up" direction came from bend introduced by fingers and screw-driver. We used optics clamps (Thorlabs) to hold down the outermost edge of wire as we wrapped. This also served to maintain tension on the wire so no unwrapping occurred.

Once the first turn was complete, we applied epoxy to the parts far from the center tube and far from the bend "up". We let this set overnight. The next morning, we continued by wrapping the majority of the coil (by layers, up and down the tube). This portion of the wrapping is a little bit easier. The wire almost wraps itself. The things to look out for are that the wire is as closely-spaced as possible, that it is wrapped without any slack, and that it does not fall in at the ends. This last is important. What happens is that the layer below will have a bit of a gap when it changes direction. The layer being wrapped above it can fall part way in if care is not exercised. "Care" involves using screwdrivers to prevent the wire falling in. Once the wire makes it around to a more solid surface and changes direction, the danger is over and the screwdrivers can be removed. Typically, we apply epoxy to about a third of the surface of a layer before wrapping the next layer. We aren't too worried about spreading the epoxy because winding the coils tightly does that for us.

One other note about the middle section: we keep track of how many turns fit in each layer. We should be at 8 for each layer, though there is a bit of variability. This time around, we average a little bit over 8 turns per layer. The actual data (add one for the bottom-most, flattest layer that was already wrapped):
Layer 1: 7 3/4 turns
Layer 2: 7 turns
Layer 3: 7 1/4 turns
Layer 4: 7 turns
Layer 5: 7 1/4 turns

Layer 6: 7 turns
Layer 7: 7 1/4 turns, though the last 1/4 fell in a little bit.
We considered this a successful wrap. We applied the last bit of epoxy and set the cartridge heater up.

Only the final layer remained to be wrapped. Most of that layer is straight-forward. It was necessary to unwrap the bottom turn a little bit in order to make the transition up more smoothly. Keeping the tension on the wire by twisting the excess wire along with the wrap worked well. The tricky part of the wrap, however, was the exit strategy. When we got to the 7th or 8th turn, we had to watch how much the wire would drop in as well as trying to figure out where the coils would end up leaving the well. For the first coil, we took off the top plate to give us room to maneuver the coils into a more advantageous position. This worked relatively well, allowing us to seat the coils nicely. The outer diameter of the coil was also relatively even. After clamping the coil down on opposite sides with the Thorlabs clamps, we epoxied the outside of the coils and parts of the top of the coil and heated it overnight.

Typical curing temperatures and times for the first coil were Tset = 440ºC, Tcartridge=340ºC, Tbottomplate=60ºC, and Ttopplate=100ºC. When we wrapped in November, we covered the coil with a lot of aluminum foil during heating to reduce radiative losses. This time, we put a single sheet of aluminum over the coil assembly. Though the max temperatures were not as high, it did not seem to impact the quality of the cure. The shortest amount of time we allowed epoxy to cure was 4 hours. More typically, we would leave it overnight, amounting to 12+ hours of curing. The 4 hours seems like it is sufficient (i.e. the coils aren't coming undone), but it is difficult to tell without a more careful study.

Wrapping MOT Coil 2, 21 - 22 June

The wrapping of the second coil occurred very similarly to the first. There were a couple of exceptions. As mentioned earlier, we made one attempt to pre-wrap the wire around the lathe instead of around the cylinder. This proved problematic, so we back-tracked and rewound it about the cylinder.

The second difference was that the bottom-most turn ended up at 7 instead of 8 layers. This was fine because we wanted to wait until after the bulk of the coil was wrapped before determining how to bring the last layer around the rest.

The other big difference occurred when we came to the very top turn and outermost layer: Sampad and I did not remove the top plate which meant we could not guide the coils into as optimal a position as the first coil. This meant there was more unevenness on one side of the coil that could have been avoided. Other than that, the coil ended up looking pretty good, though there were some dints in the insulation which could have been avoided by taking the plates off earlier.
Post-wrapping Activities, 24 - 25 June

I did not write much about this in my last narrative, but I'll do a better job this time. We decided to apply a final coating of epoxy to much of the coil. Around the outside, on the top, and around the places where the wires go up and away from the coil-proper. I accomplished the bending of the coil using a 1" tube to avoid over-bending and cracking the insulation on the wire. I also tried to keep the wire going with the curvature of the coil so it would fit inside the well of the flange. Both ends of the wire come up in about the same spot...in the 8th turn, they wrap around and cross each other...just after crossing, they bend upwards. Naturally, one of the wires goes inside the radius of the other in that 8th turn, but the inhomogeneity isn't consequential for the turns that are far away from the atoms.

I also epoxied thermocouples onto the coils. This allows us to monitor the coils' temperature during curing and, later, during operation.

The last time, we made some Delrin cylinders, or half cylinders, with about a 1" radius to support the wire coming out from the coils. I don't yet know what the equivalent will be in this case. There is no longer an outer plate to mount those cylinders onto.

Unlike last time, we were unable to reuse the cartridge heater to cure the coils after they were removed from the lathe. Instead, I wrapped a band heater around the perimeter of the 8" flange. This proved sufficient for curing this last time. The temperatures were decidedly higher this time (50 V on variac = ~90ºC in the coil and 100ºC in the aluminum plate. After all was said and done, the top of the coils were lumpy and uneven. This is the same as it was last time. The epoxy evens things out a bit, but not exactly.

Next, I'll begin noting the properties of the coils, resistivity and the like. Also, I'll need to make wire-to-water connectors. That will involve some hard soldering.