

DEVELOPMENT OF A SUPER-MINI UNDULATOR

A. Deyhim, J. Kulesza, ADC USA, Inc., NY 14882, U.S.A.
H.O. Moser, C.Z. Diao, SSLS, Singapore

Abstract

This paper describes the development and initial results for a small prototype superconducting undulator with a period less than 1 cm, referred to here as a “Super-Mini” undulator. The development of superconducting mini-undulators started in the early 1990s with work at BNL and KIT (Germany). In 1998, KIT demonstrated the first photon production with a super-mini of 3.8 mm period length [1,2]. This super-mini consisted of two coils wound bi-filarly in analogy to a solenoid. If such coils are arranged alongside each other, separated only by a small gap on the order of a couple of millimeters, a spatially alternating magnetic field is produced that makes a passing electron beam undulate and emit undulator radiation. Owing to the short period length, the photon energy is much higher than with conventional undulators at the same electron energy. Likewise, for a given photon energy, the electron energy can be much smaller entailing considerable cost savings of accelerators, building, and operations.

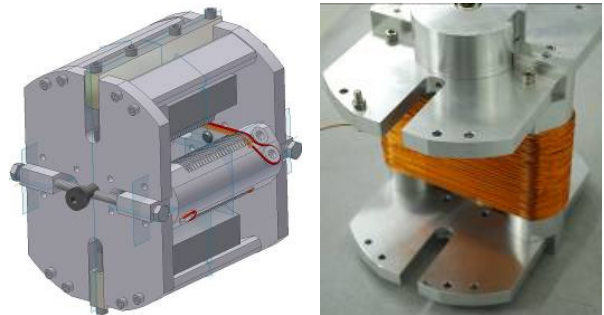


Figure 1: Poles in winding frame.

VERTICAL TEST FACILITY

A vertical test facility (VTF) was built that consists of a liquid Helium Dewar where the Super-Mini undulator is immersed. This Dewar is pre-cooled with liquid nitrogen as are the copper bus bars. The copper bus bars are the worst “heat leak” and so must be pre-cooled to reduce the temperature differential between the LHe bath and the outside room temperature. The copper bus bars are quite large (1.125 inches in diameter) to carry the required current density. A power supply with 1000A at 10V is also required. The power supply is connected to the buss bars with 8 “0000” copper cables (4 on each side) as shown in Figure 2 below. The resistance of the cable was .0035 ohms. The LHe level is monitored with a level detector as is the temperature of the undulator. A quench protection circuit is provided to shut down the power supply in the event of a quench. If a quench occurs, the power supply is quickly shut down allowing a high current freewheeling diode to shunt any high voltage spikes, caused by the collapsing field, around the supply thereby protecting the output circuitry. These can be seen in Figure 2 below.



Figure 2: Cable connections and free-wheeling diodes.

PROTOTYPE SUPER-MINI

The prototype Super-Mini undulator supports a 7.0 mm period, K factor of 0.72, gap of 2 mm, 10 periods with 2 end periods, and a field of 1.1 T with an expected current density of 1000 A/mm². The overall length of the prototype device is 80 mm. This device utilizes a unique winding pattern that facilitates the very short period. This sort of device has been called a “single-coil Super-Mini”.

SUPER-MINI BOBBINS

The Super-Mini built at ADC consists of a single SC wire that is wrapped around two spools or bobbins each about 50 mm in diameter. The SC wire is initially wrapped under tension in a “racetrack” formation. The bobbins are machined with grooves to accept the wires which are rectangular. The wires are wound around both bobbins with 4 turns per groove – two end section grooves have only 3 turns.

TRANSFORMATION

The racetrack orientation is “transformed” into the final configuration by moving the poles and bobbins closer together but by differing amounts. The final gap between the poles is 2 mm. The winding frame with the pole piece mounted is shown in Figure 1. Screw combinations on either end of the bobbins and poles are used to manually reduce the gap between the spools and poles during transformation.

too thick to fit within the 2 mm gap. The Hall probe is attached to a rod that moves up and down within a central tube. Guidance for the Hall probe is provided inside the tube. The tube is then attached to a framework that attaches to the end of the undulator. Heat shield baffles are attached to the central tube. Similar but smaller baffles are attached to the copper bus bars to take advantage of the cold He gas at the top of the Dewar, see Figure 3 below.



Figure 3: VTF and controller.

An ADC stage located in room temperature above the top cap of the Dewar connects to the central rod and moves the Hall probe up and down while keeping track of position with an encoder. The top of the central tube is sealed with a metal bellow, see Figure 3. The Hall probe must be able to travel 5 periods beyond each end to attain a reasonable zero field. The expected field has been predicted to be 1.1T at 1000A using RADIA calculations.

TEST RESULTS

Several sets of tests were performed that were conducted at liquid helium temperature (4.2 K). Data was taken at 50, 100, 200, 300, and 400 amps. The initial results are shown in Figure 4, the analog output was scaled so that 0-1 volt output was equivalent to +/- 5T with a probe calibration of 12.2 mV/T. However, later it was learned that the Hall probe calibration factor was mis-programmed and should have been 8.52 mV/T. Therefore, the data shown should be reduced by 30.2 percent to get the true field result.

The device, which was known to have a short to frame in the windings, consistently quenched at 420 A indicating a problem other than SC training was at work. We believe to know the cause is due to a small amount of unsupported SC wire between the bobbins and poles.

Nonetheless, the field was smooth and repeatable over several current settings as can be seen in Figure 4. The steps in the field are due to a slow (2 second) Hall probe analog update rate. The sample spacing was programmed to be .1 mm and the sample velocity was .5 mm/sec. All

data was collected in IGOR and transferred to Excel, both files are available on request.

This plot also show a gradual increase in field which may be attributed to a narrowing of the gap and/or a slightly inclined path of the Hall probe through the guides in the gap.

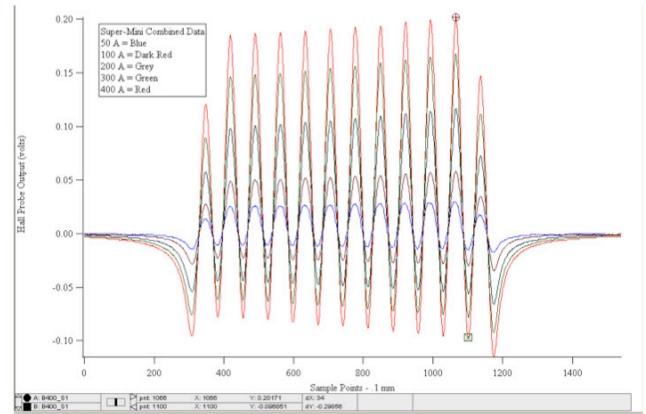


Figure 4: Combined current data.

The peak field at 400 A is measured at the cursors in Figure 4 to be .20171 and -.096851 (the background is removed). The range was set at +/- 5T for 0-1 volt. The sensitivity was .0122 volts/T. This places the measured field at 2.017 T and -.97 T (2.985 T total). Later comparison with a reference magnet showed the Hall probe was reading the field high by a factor of 3.436! Correcting the measured field by this amount brings the field down to +/- .434 T which falls more in line with the +/- .4 T prediction. This result is also skewed a bit because the highest peak was chosen for the cursors. An average of the P-P field would result in the measured field that is very close to prediction.

The data in Figure 4 above also shows more positive field than negative which is typical for an uncorrected short undulator [3]. However, the present super-mini is designed with correction ends and would be expected to produce a magnetic field like that shown in Figure 5. Work on elucidating the reason for the discrepancy – manufacturing or Hall probe artifact – is going on.

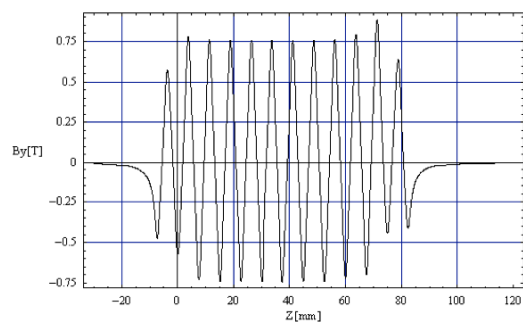


Figure 5: Data simulated in the midplane at 400 A.

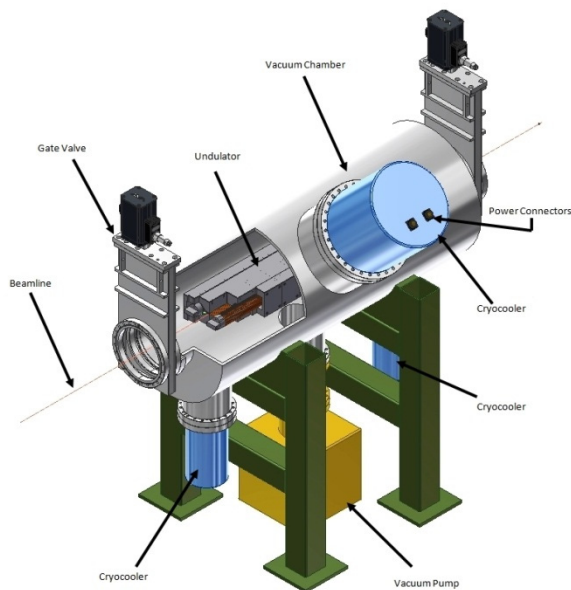


Figure 6: 1 m Super Mini concept.

A hand calculation of the phase error was made based on the 400 A data set. This was performed by fitting parabola to each peak, positive and negative, and then finding the location of that peak in mm based on a sample spacing of .1 mm and then calculating the relative position of each peak to the next. This analysis, shows the half period to be 3.586 mm with a first standard deviation of 36 microns, the phase error calculates to 2.919 degrees (assuming no taper). There was no prior expectation for this value; however, we are pleased with this result.

The device, which was known to have a short to frame in the windings, consistently quenched at 420 A indicating a problem other than SC training was at work. We believe to know the cause is due to a small but significant amount of unsupported SC wire between the bobbins and the pole pieces.

NEXT STEP

ADC proposes to take this device to the next level of development which we envision consists of a 1 meter device. To be sure, many hurdles have already been overcome with this design; however, several (surmountable) challenges remain to extend this technology to a full meter.

Figure 6 shows the overall concept design that ADC plans to construct in collaboration with a synchrotron light source. It contains cold mass with support structure, radiation shields, cryo-coolers, and current lead assemblies. Cold mass includes SC magnet with thermal links to cryo-coolers. Cold mass is structurally supported by a base frame. Only one vacuum shell is foreseen as the cold mass is either permanently kept cold or the gate valves separate the vessel from the accelerator vacuum.

CONCLUSION

ADC concludes that the feasibility of this Super-Mini design is proven. We feel that while the test results are not perfect, the imperfections can be explained. We have learned a great many things from this experience and we are certain that we can carry our knowledge forward to a new, longer design. ADC is confident that this design, machining, and winding process can be extended to 1 meter length and perhaps more. The standard challenges for horizontal operation are present as with any SC undulator, however, the opportunity for non-cryogen based cooling exists with cryo-cooler attachments to the poles and bobbins. Shorts to the bobbins and poles can also be mitigated with controlled plating and machining of non-conductive materials applied to the surface of these components.

We look forward to the actual build and measurement of this device with possible installation in a suitable storage ring as a first customer. ADC will be tendering a proposal in the near future.

ADC wishes to thank SSSL and NUS for the opportunity for us to work on this project.

REFERENCES

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