

Laboratory and Vendor Visits, January and March 2006

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Visit to the Forschungszentrum Karlsruhe (FzK), Karlsruhe Germany

I visited the Forschungszentrum Karlsruhe (FzK) formerly the Kernforschungszentrum Karlsruhe (KfK). I met with Professor Peter Komarek the director of the Institute fur Technischephysik (ITP). ITP has for years been an institute that specializes in fusion and the superconducting magnets that go with fusion experiments. Prof. Komarek was very helpful in identifying possible vendors for the MICE magnets. He suggested that I meet with two German companies Accel and Babcock und Noell. He told me that the reason that Bruker responded negatively concerning the construction of the coupling solenoid was that they would prefer to concentrate on their core business, NMR magnets. The other continental company he suggested contacting were Alstom in Belfort France and Ansaldo in Genoa Italy. With the help of Prof. Komareks secretary Marian Gillian, visits were arranged with Accel and Babcock and Noell.

I saw the facilities at the Institute fur Technischephysik while I visited professor Komarek. I had not visit ITP for over ten years. The TOSCA facility and its large refrigerators have not operated for some years. There is a 300 W at 1.8 K Linde refrigerator (about 650 W at 4.5 K). There is also a 2 KW (at 4.5 K) at the institute as well. The last things that were tested at ITP were the 75 kA HTS leads (between 4 K and about 60 K) with the upper leads being cooled by 50 K gas from the upper stages of the refrigerator. About 7 g s^{-1} of gas at 50 K is needed to cool the upper 75 kA leads. If the leads were cooled with 4.5 K gas, at least 700 W of 4 K refrigeration would be needed to cool the gas cooled leads. If the gas comes from the refrigerator cold box at 50 K, the capacity of the refrigerator is reduced by only about 60 W instead of 700 W.

Karlsruhe is doing work on HTS conductor. This work also includes MgB_2 . Sonja Schlachter showed me a reacted MgB_2 conductor clad in 304 stainless steel that can be bent to a radius of 10 mm without degradation. This conductor has been used to fabricate superconducting liquid hydrogen level sensors. She said she can produce a enough of this conductor to fabricate sensors that could go around the MICE absorber liquid volume (in the slots in the shell). If someone is interested in pursuing the use of MgB_2 for hydrogen gauges they should contact Sonja at Sonja.schlachter@itp.fzk.de.

Visit to Accel Instruments GmbH, Bergisch Gladbach Germany

I visited Accel on January 10, 2006. My contacts were Dr.-Ing Detlef Krischel, Dr. Hans-Udo Klein, and Paul Schmidt. I was picked up at the ICE station at Siegen-Bonn and was taken to the magnet plant where the LHC quadrupole cold masses are being fabricated and assembled. Accel is a company that spun off of Euratom (a Siemens company). Accel specializes in the production of RF cavities (both conventional and superconducting), superconducting magnets, and accelerator beam lines. Over the years, the magnet work has been primary dipoles and quadrupoles. In recent years Accel has been manufacturing potted solenoid magnet. Some of these magnets are cryogen free and are cooled by small coolers, including 1 W (At 4.2 K) Cryomech pulse tube cooler.

Accel has engineering capability along with manufacturing capability. This company can build to a performance specification as well as build to print. The Accel plant is very clean. It is clear that the company pays attention to detail to avoid some of the problems that come from a dirty work environment. Accel has built all of the LHC ring quadrupoles and is assembling the quadrupoles into cold mass assemblies that contain both quadrupoles and various types of correction elements. Some of these assemblies are up to 9 meters long (the quadrupoles themselves are about 5 meters long).

In my opinion, Accel is a qualified magnet vendor for the MICE solenoids. The contact information for the company is:

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Visit to Babcock Noell Nuclear GmbH, Wurtzburg Germany

I visited Babcock Noell on January 11, 2006. My contacts were Michael Gehring Dipl-Phys, Dr. rer. Nat. Wolfgang Walter Dipl-Phys, and Markus Borlein Dipl-Ing (FH) Electrical Engineering. It takes about an hour and a half by ICE train to get to Wurtzburg from the Fernbahnhof at Frankfurt airport. I stayed at the Hotel Amberger in downtown Wurtzburg. The Hotel Amberger offers very comfortable room with a good German breakfast for €67.00 per night. The Hotel Amberger is about a ten-minute walk from the railway station and about a ten-minute taxi ride from the Babcock Noell factory on the edge of town near the vineyards.

Babcock Noell Nuclear is part of a bunch of Babcock companies that are all over Europe. I suspect that the plant in Wurtzburg is part of a much larger company. Babcock Noell Nuclear has been in the superconducting magnet business for at least 20 years. Babcock Noell had the contract to manufacture one third of the dipoles for LHC. The other two companies that have the LHC dipoles are Alstom in France and Ansaldo in Italy. Babcock Noell is also manufacturing half of the Wendelstein X7 stellerator magnet coils (27 out of 54), which are solenoidal coils with a weird shape. The other half of these coils is being fabricated by Ansaldo. Babcock Noell Nuclers is fabricating some solenoids as well. In recent years Babcock Noell has built magnets that are cooled using 4.2 K GM and pulse tube coolers. It appears that Babcock Noell can fabricate magnets on a build to print basis or using performance specification similar to that used for the MICE tracker magnets. Babcock Noell has a full engineering department that can do a full range of calculations using FEA programs. The design of magnet cold mass assemblies and vacuum vessels to the pressure vessel code will not be a problem.

In my opinion, Babcock Noell Nuclear is a qualified magnet vendor for the MICE solenoids. The contact information for the company is:

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**Visit to Scientific Magnetics Ltd. (formerly Space Cryogenics Ltd.),
Abingdon, United Kingdom**

I visited Scientific Magnetics Ltd. (formerly known as Space Cryogenics Ltd.) on January 16, 2006. My contacts were: Dr. Peter Penfold (Sales and Marketing Director), Stephan Harrison (director), and Dr. Steve Milward (director). Scientific Magnetic Ltd. is company that was spawned when Oxford Instruments disbanded its specialty magnet division and laid off the engineering staff. This left one important customer in the lurch. The customer urged the former engineers who were on the AMS magnet (Sam Ting's magnet for the US Space Station) to form their own company to complete construction and testing of the AMS magnet. Thus Space Cryogenics Ltd was born. As of the beginning of 2006, Space Cryogenics changed its name to Scientific Magnetics Ltd. The new name reflects the broader mission of the company. Scientific Magnetics is a company with 17 employees. It is located at the Culham Science Centre in Abingdon.

Scientific Magnetics has had a number of projection since its founding in the year 2000. The largest magnet in the AMS magnet. This magnet consists of a pair of superconducting coil spaced about 1 meter apart. The flux from these coils is returned by twelve coils that are located between and beside the two larger coils. The AMS magnet has a net magnetic moment of zero and a low stray field. The coils are conduction cooled from tubes containing 1 atm superfluid helium, which are in turned cooled from a 2500 liter torroidal superfluid helium tank that is filled with helium at a pressure of 12 torr. The AMS magnet cryostat has four gas-cooled shields cooled with helium gas boil off from the superfluid helium tank. The heat leak into the magnet and its helium tank (which are about 2 meters in diameter and 1.2 meters is extremely low.

In addition to the AMS magnet, Scientific Magnetics has built superconducting magnets for Zeus an x-ray experiment that has an ADR to cool the sensors into the mK temperature range. Scientific Magnetics has also built some HTS solenoids for application in an ion source. Scientific Magnetics has experience in using small cooler (both at 4 K and 20 K) to cool their magnets. The company has a background in superconducting magnet and low heat leak cryogenic systems. It appears that Scientific Magnetics has the engineering capability to design and build the superconducting solenoids needed for MICE. The quality of the workmanship I saw at their plant was excellent (the aluminum welding especially).

In my opinion, Scientific Magnetics (formerly Space Cryogenics) Ltd. is a qualified magnet vendor for the MICE solenoids. The contact information for the company is:

Scientific Magnetics Ltd. (formerly Space Cryogenics Ltd.)

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Visit to Cryogenic Ltd, London United Kingdom

I visited Cryogenic Ltd. on January 18, 2006. My contacts at the company were Dr. Jeremy A. Good (company founder) and Dr. Renny Hall (Director). Cryogenic Limited was founded over 25 years ago by Jeremy Good who got his degree in engineering physics at Oxford University in 1963. Jeremy Good was a student of Martin Wood (the founder of Oxford Instruments). Cryogenic Limited was the first company that I can remember that produced magnets that were run on 4 K coolers. The early coolers were two stage GM coolers with an added J-T circuit to produce cooling at 4 K. Among the early magnets built by Cryogenic Ltd, were ore separator magnets that ran in Africa. Since liquid helium was unavailable in Africa, all of these ore separation magnets were cooled using coolers. These magnets all ran in the persistent mode.

Today Cryogenic Ltd. is a company with about forty employees. The company produces superconducting solenoids with fields in the bore up to 20 T. The company also produces superconducting magnets of other types. Cryogenic Ltd. magnets are all housed in low heat leak cryostats. As an offshoot of the magnet business are low heat leak low temperature cryostats, dilution refrigeration systems, and power supplies for superconducting magnet. Over half of the magnet built by Cryogenic Ltd are cryogen free magnets. Of those magnets that are not cryogen free, but use coolers, most use some sort of the two phase helium pipe to distribute the cold in the magnet. Virtually all of the magnets that are cooled using coolers are also cooled down with the same cooler. More recent magnets are built to be continuously powered. These magnets have HTS leads between to magnet and the first stage of the cooler. Cryogenic Ltd makes their own HTS lead for their magnet.

The workmanship I saw at Cryogenic Ltd was excellent. They have excellent aluminum welder as well as good stainless steel welders. If Cryogenic Ltd were to propose to build MICE magnets, they would propose that the magnet cryostat vacuum vessel be made from aluminum. Cryogenic Ltd. would also propose that the helium used to cool the outside of the surface of the magnet be in a pipes. The pipes can be pre-charged with helium gas. The helium gas is cooled down with the magnet by the cooler. Cryogenic Ltd. does most of their machining in house. The company prefers to pot their magnets using vacuum impregnation. The type of conductor used by cryogenic Ltd tends to be a conductor with 50 or 60 filaments with a low copper to superconductor ratio (1.3). Despite the low copper to superconductor ratio their magnet train very little.

Cryogenic Ltd. builds smaller magnets than are needed for MICE. They can easily wind coils that are 500 to 600 mm in diameter and up to 1500 mm long. Cryogenic Ltd can definitely wind the focusing magnets. Since the cryostat is 1404 mm in diameter, the cryostat parts must be fabricated outside. (Many other companies would do the same.) It is probable that Cryogenic Ltd can wind the tracker magnet. The tracker magnet is longer than their normal lot of magnets, but the company has and can wind a magnet the size of the tracker magnet. There is a slight question mark on the coupling magnet. This magnet is bigger than anything I saw in their shops or in their promotional literature. Knowing Jeremy Good and his can do attitude, he would figure a way to fabricate the coupling coils even if it is larger than his normal sized product.

The area where Cryogenic Ltd stars is in their power supplies. I was really impressed with the kind of power supplies they can fabricate and the capability of these power supplies. The Cryogenic Ltd. power supplies are the best I have ever seen, including those used on Superbend at LBNL. MICE requires a two quadrant power supply with very low ripple and very good filtration from the crap on the mains. The MICE power supplies need to regulate the magnet current to 0.01 percent (100 ppm). Cryogenic Ltd power supplies regulate to this level without a problem. In fact, some of the Cryogenic Ltd power supplies are capable of regulating the current to 1 ppm. The company fabricates power supplies from 10 A to 600 A. Two of their standard supplies fit the needs of MICE. One produces up to 360 A at +10 V/-8.2 V. Another produces up to 80 A at ± 5 V. The budgetary cost of these supplies is lower than what has been budgeted for MICE.

A characteristic of the Cryogenic Ltd. supply is an automatic disconnect when the magnet quenches or the power is cut off. Under the latter condition the magnet discharges at the same voltage as the charging voltage. Everything about the Cryogenic Ltd. power supply is first class. Their power supplies have features that I have never seen any place else. As a result of visiting this company's power supply manufacturing facility, I will visit other potential power supply vendors as well. After the experience with the Superbend power supplies (expensive with some problems), it is clear that having a vendor that understands the power supply requirements for superconducting magnets is essential.

In my opinion, Cryogenic Ltd. is a qualified magnet vendor for MICE focusing solenoids. I think that this company would do a good job on the tracker solenoids. They may also be able to fabricate the coupling magnets as well. The contact information for the company is:

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Visit to American Magnetism Incorporated (AMI), Oak Ridge TN, USA

I visited the facilities of American Magnetism Incorporated in Oak Ridge during the morning of March 13, 2006. My primary contact at American Magnetism was Paul Arakawa, a magnet engineer. I spoke to a couple of other people including the son of the company's founders Ken Efferson, who died last year.

American Magnetism Incorporated (AMI) was founded in 1968 as a spin-off from the Fusion Energy Division of the Oak Ridge National Laboratory. In 1982 or 1983, American Magnetism Incorporated was purchased as a wholly owned subsidiary by Dyasonics (a former Bay Area company interested in MRI and other medical imaging). This set the course of this company for a number of years. The company was bought back by some of its former owners in 1986 or 1987. The company is still involved in the full body MRI magnet business as well as a number of other lines. The company is building parts of MRI magnet system for a major supplier of MRI systems in the US.

Despite some difficulties that occurred when the founder of the company died, the company is very much in the business of selling superconducting magnets, magnet leads, power supplies, and instrumentation related to superconducting magnets. It appears that the company has weathered the transition of ownership reasonably well. Under the DOE definition of small business, AMI is definitely a small business with between forty and fifty employees. Many of these employees have been working for the company for a long time. AMI appears to have the capability of doing quality engineering on superconducting magnets and related magnet sub-systems.

American Magnetism has extensive experience in building high quality uniform field solenoids are cooled with one or more small 4.2 K coolers. They can build magnets that are cryogen free that are cooled down from room temperature using the coolers. The company also has experience with liquid interfaces between the cooler and the magnet coils. The company has experience with both GM and pulse tube coolers at 4.2 K. The company not only makes solenoids, but they make dipoles and other types of accelerator magnets as well. Many of their magnet system are delivered as turn-key systems to their customers. As a magnet manufacturer for MICE magnets, I consider this company to be a qualified vendor for engineering the magnets as well as fabricating the magnets.

In addition to the fabrication of superconducting magnets, AMI manufactures the following components that are used with superconducting magnets: 1) gas-cooled current leads, 2) HTS current leads (with both conduction cooled or gas-cooled upper lead stages), 3) superconducting magnet power supplies, both standard supplies and custom made power supplies at currents up to about 600 A, 4) superconducting level gauges (for liquid helium) and capacitive level gauges (for liquid nitrogen and possibly liquid hydrogen), 5) automated magnet system controllers.

The company appears to make a number of power supplies built around a central controller. Details of currently available power supplies can be found on their web site. The power supplies are in the process of being reengineered to meet modern solid state electronic standards. It appears that the power supplies from this vendor and a number of other vendors are much better than they were just a few years ago.

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Visit to Cryomagnetics Incorporated (AMI), Oak Ridge TN, USA

I visited the facilities of Cryomagnetics Incorporated in Oak Ridge during the afternoon of March 13, 2006. My primary contact at Cryomagnetics was Mike Coffey, the son of the founder of this company. I have known Mike Coffey for a good many years because of his involvement in the Applied Superconductivity Conference board of directors. I know his father, who is still living, who founded the company.

Cryomagnetics Incorporated was founded in 1984, by one of the original owners of American Magnetics when that company was sold to Dyasonics. The founder of Cryomagnetics was from the Fusion Energy Division of the Oak Ridge National Laboratory. Cryomagnetics was founded because Dyasonics wanted American Magnetics to stop any work on custom physics magnet application and concentrate entirely on MRI. When the previous owners of American Magnetics bought the company back from Dyasonics, the owner of Cryomagnetics was not among the buyers. Cryomagnetics is run today by the son of its founder Mike Coffey.

Cryomagnetics, like its rival three miles away is a small business with about forty employees. Neither Cryomagnetics or its rival American Magnetics do much with SBIR's from DOE or any other government agency. Both companies have a list of loyal customers who buy from them. While the companies have very similar capabilities they tend to serve different niches of the superconducting magnet buying community. The two Oak Ridge companies rarely compete with each other head to head.

Cryomagnetics specializes in very uniform field magnets for NMR, ICR. These magnets operate in the field range from 7 to 12 T. Cryomagnetics has built at least one 20 T uniform magnet system. Many of the Cryomagnetic magnets are cooled with small coolers. The company has experience with both GM and pulsed tube coolers. This company may have as much experience in using Cryomech pulse tube coolers as any one in the magnet business. The cooler cooled magnets built by Cryomagnetics Inc. run in both the cryogen free mode or in a mode with a small amount of liquid helium in contact with the magnet coils. This company does both wet lay up wound magnets and vacuum impregnated magnets. I consider the company to be a qualified bidder for any of the superconducting solenoids for MICE.

Cryomagnetics appears to make excellent superconducting magnet supplies. The baseline supplies come in four unit sizes that produce ± 20 A at ± 5 V, ± 50 A at ± 5 V, ± 100 A at ± 5 V, and ± 100 A at ± 10 V. The building blocks can be combined to produce the power supply requirements for MICE ± 300 A at ± 10 V and ± 50 A at ± 5 V. The basic controllers are four quadrant controllers. It appears that all of the MICE power supplies can be produced for under the budgeted amount. Cryomagnetic power supplies offer excellent regulation and filtration from power sources with a lot of noise. The cryomagnetic's power supplies will run on power sources at 110 V, 60 Hz, 220 V 60 Hz and 220 V 50 Hz. The Cryomagnetic power supplies allow for quench detection and operation in the persistent mode. I consider Cryomagnetic to be a viable supplier of superconducting magnet power supplies for MICE. There are a number of added features that include being able to operate both 50 A supplies through a single controller.

In addition to magnets and power supplies, Cryomagnetics produces liquid level gauges for helium (a superconducting gauge), nitrogen (a capacitive gauge) and hydrogen (a capacitive gauge that is not as accurate as the gauge for liquid nitrogen). The liquid level gauges can be turned into controllers.

In addition Cryomagnetics builds HTS leads and gas-cooled lead. They also build temperature sensors that can be used for controlling the cool down of superconducting magnet systems. Cryomagnetics also builds and installs hall effect magnetic measurement devices that measure the magnetic field at 4 K and around the magnet cold mass. Cryomagnetics appears to have a good understanding of how to integrate its instrumentation to other parts of a system.

The following information is given so that one can contact Cryomagnetics for the purpose of soliciting proposal or bids to buy the products the company produces:

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