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LHC Note 342

Refurbishment of Slightly Radioactive Magnet Coils from a Big Proton Accelerator

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Refurbishment of Slightly Radioactive Magnet Coils from a Big Proton Accelerator

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Abstract—Using CERN's 450 GeV proton synchrotron as injector for LHC requires a rather flexible solution for spares, where the supply can be adjusted to the needs of the 20 years old main magnet system. Most magnet coils, especially those having suffered insulation damage, are slightly radioactive, with Co60 dominating in the copper windings and Na22 in the glass fibre reinforced epoxy insulation. Refurbishment of the damaged coils has several advantages and is worthwhile doing but depends strongly on the availability of a furnace meeting the constraints of modern legislation. Such a furnace is described in more detail. Questions concerning coil manufacture, burning of epoxy insulation, environmental protection and handling are discussed based on the experience with SPS-main dipole coils.

I. INTRODUCTION

There are about 800 MBA and MBB-type magnets in use at CERN's 450 GeV Proton Synchrotron (SPS). After 15 years of operation more than 50% of the spare coils of the MBBs had been used up, and one had to start thinking what would be a good and economic solution to fill up the stock again. Should one order a series of about 10 new coils or was it possible to refurbish defective coils, even when they were slightly radioactive?

II. MAIN FEATURES OF THE SPS MB-COILS

A. Geometry

Table I gives information on coils and conductors. Figure 1 represents a cross section through an MBB coil. There are 3 subassemblies which can be separated after burning off the epoxy insulation.

B. Materials

Interturn insulation and ground wrap on the existing coils are made with glass fibre tape of the E-type and the coil impregnation with epoxy resin from the Araldite F family. The following CIBA-GEIGY products were used:

Epoxy resin: MY 745 (modified bisphenol)
Hardener: HY 906 (methyl nadic anhydride)
Accelerator: XB 2687 (ammonium phenolate or amino substituted phenol)

These components contain, according to CIBA-GEIGY, only insignificant quantities of halogens and do not create special environmental risks if burned at a proper temperature.

TABLE I
COIL CHARACTERISTICS

		MBB	MBA
Copper mass	(ton)	1.88	1.38
Overall length	(m)	6.476	6.501
Number of turns		4 + 12	2 + 10
Conductor of inner coil	(mm ²)	32 x 22.5	24 x 33
Conductor of outer coil	(mm ²)	33.5 x 33.5	32 x 32
Number of subassemblies		3	3

All coils are built from certified OFHC grade 1 copper and all joints are made using silver brazing without flux (SILPHOS).

III. NEED AND AVAILABILITY OF SPARE MAGNET COILS

The rate of spares foreseen for the SPS main magnet system was about 5% spare magnet coils and 2.5% assembled spare magnets. This covered as estimated the first 20 to 25 years of operation. With the ageing of the system and the influence of ionising radiation things became less predictable.

There were strong indications that the insulation specified above, which is commonly used for conventional magnet coils in particle accelerators [1], is "ageing" even without radiation and this makes long term predictions again more difficult.

The fact that the SPS has been foreseen to serve as an injector for a future Large Hadron Collider (LHC) obliged us to look for an economic solution where also in difficult situations "enough" spares could be made available.

IV. PRICE COMPARISON - ADVANTAGES OF REFURBISHMENT

The supply of a series of new coils had to include new fabrication tools, since the original tools were worn out and had been scrapped.

A study made by one of the MBB - coil suppliers showed that a series of 10 new coils having twice as many brazed

Fig. 1. Cross-section of MBB-Coil.

joints as the original ones, and being therefore of a lower fabrication standard, would cost 2.5 times as much money as refurbishment of 10 non-radioactive coils. This big difference in price made it worthwhile to invest time, money, and energy to find also a solution for (slightly) radioactive coils.

Refurbishment is less work, and once the equipment and a suitable contract exist it certainly takes less time than making new coils. The solution is perfectly in line with modern ecological tendencies. It avoids accumulation and storage of bulky radioactive scrap.

V. TECHNICAL AND LEGAL CONSTRAINTS

Unfortunately it turned out that European coil makers had neither experience nor equipment for this particular task.

We therefore had to look ourselves into technical constraints and had to find standards and regulations dealing with environmental protection.

A. Temperature for incineration

The pyrolysis of the epoxy insulation has to be done at 450 ± 30 °C in order to avoid damage to the brazed joints.

B. Post Combustion

Pyrolysis of Epoxy based on Araldite MY 745 and Hardener H 906 gives according to CIBA - GEIGY for temperatures in the range of 350 to 500 °C the following types of products:

a) Gas like products

CO, Hydrocarbons and Hydrogen in small quantities

b) Very volatile products

H₂O, Acetone, Aldehydes, Methylcyclopentadiene

c) Products of average volatility

Phenol, Isomers of Cresoles, Isomers of Isopropylphenol, Xylenol, small quantities of Bisphenol A

d) Products of low volatility

Higher condensed Aromatics, also derivatives of Benzofurane and Benzopyrene

e) Coke-like residuals

The noxious products, which have to be decomposed before releasing the gases into the open air, are mostly those listed under c) and d). This can be achieved by post combustion in a second burning chamber working at least at 850 °C by keeping the gases 0.5 seconds or longer at this temperature. The oxygen inlet to the second chamber has to be monitored and regulated via a feed back loop. There must be at least 6% of oxygen in the gases entering the second chamber.

C. Legal frame work

We were prepared to include a customer tailored furnace in the tooling. It had to be good for use over many years in all Member states of CERN and had therefore to comply with the most severe national and the most recent International European Regulations, which were (in 1993):

- European standards [2]
- European Community Commission directives [3]
- Swiss regulations [4].

TABLE II
Na22 CONTENT OF MBA SAMPLE
a) before and b) after burning of the Epoxy
confirming that Na22 stays with the glass fibre

a) Spec. No-SL93054A	Total activity Na22	6496,5 ± 484 Bq
b) Spec No.SL93057A	Total activity Na22	6550 ± 480 Bq

VI. COMPLICATIONS ARISING FROM RADIOACTIVITY

Coils where the insulation has suffered radiation damage are slightly radioactive, which makes refurbishment much more complicated. There is very little risk, but most people are afraid and react highly emotionally. Laws and regulations are very strict. It takes a very long time to convince and to get authorisations. Protective steps have to be taken. Work has to be done in restricted controlled areas, and the staff involved has to be registered as radiation workers. There has to be close monitoring and filtering, especially for all processes dealing with the removal of the insulation. Samples have to be taken and analysed.

In our case all coils had been stored at least two years after removal from the accelerator and the radioactive elements predominating were Co60 in the copper windings and Na22 in the glass fibre reinforced epoxy insulation. Moreover, it was the capture of Na22 which was supposed to come off with the smoke where experts had diverging opinions.

VII. SAMPLE TESTS PROVE FEASIBILITY AND LEAD TO SIMPLE APPROACH

Na22 contained in the "hot smoke" seemed to be the biggest threat to the environment, and the advice from the experts was to install "absolute filters" in the chimney or to wash the smoke in scrubbers and to monitor the results. To do all this with gases, which have temperatures close to 1000 °C would have been complicated and expensive.

Finally we tried it out and proved by a series of tests that Na22 stays with the glass fibres and is not liberated by the incineration process.

CERN radioprotection services analysed a series of insulation samples. The quantity of Na22 before and after pyrolysis at 450 °C proved to be the same within the error rate of the spectrometer (see also Table II).

VIII. QUANTIFYING RADIOACTIVITY

It took a considerable effort to quantify what is commonly called: "slightly radioactive magnet coils". - The usual way to make safe estimates, namely, to determine the activity in the "hottest" place and to multiply by the total mass of the object, gave results which were orders of magnitude too high, since only a fraction of the 2 ton coil became radioactive, when it was hit locally by the particle beam. The following approach seemed to be more adequate:

A. Radioactivity derived from spot measurements

A grid was traced onto the coil and the activity in a representative number of positions measured. The instrument,

for massive copper in Bq/count. Reference were copper samples from one of the coils, which had been evaluated in a gamma spectrometer. An average specific radioactivity worked out from such spot measurements was finally used to calculate the total radioactivity of the coil.

We determined also an upper limit for the total activity of the insulation, since only radioactivity stemming from the insulation could lead to contamination.

Samples showed that the specific activity of the insulation was in all cases much smaller than the specific activity of the copper. What is measured on the surface is practically the activity of the conductor below the insulation. Taking the same value also for the insulation results in very safe estimates. Table III shows typical examples for the radioactivity in the MB - coils as presented in our specification.

IX. SOLUTIONS CHOSEN BY THE CONTRACTOR

A. Furnace

TESLA ENGINEERING (GB), being awarded our contract decided to invest in an oven, which can deal with even bigger magnet coils than CERN's MBBs. This furnace may be of interest for other Accelerator Labs and is therefore described briefly. Figure 2 shows schematically the lay-out.

The furnace consists of a 8,3 m long and 2,5 m wide refractory lined combustion chamber build up in 4 sections. Each section has a single pressure jet oil fired burner firing into the oven space. The oven roof, in 3 sections, is filled with explosion relief panels. The nominal process temperature is 450°C. - A high temperature exhaust fan suitable for temperatures up to 550°C takes the fumes from the oven to the separate secondary combustion chamber, where they are subjected during one second to 1000°C before leaving the chimney.

This secondary combustion chamber is a large cylinder, 3 m in diameter and 4 m high. It is fitted with 3 pressure jet light oil burners, which are arranged in a way that hot gases are spiralling from the bottom to the top where they are leaving via the flue system and an induced draft cone at 8,8 m from the ground level.

The primary flue section incorporates the servicing heads for the flue gas monitoring of oxygen, carbon monoxide and smoke density.

TABLE III
DATA ON INDIVIDUAL COILS

Highest dose rate levels measured (μ Sv/h)		Complete coil Co 60 + Na 22		Coil insulation	
Contact	Distance 0.4 m	Total activity (10 ⁶ Bq)	Average spec. Activity (Bq/g)	Total activity (10 ⁶ Bq)	Average spec. Activity (Bq/g)
800	40	71.4	50	3.2	2.3
44	10	35.5	18.4	1.0	0.5

Fig. 2. Furnace layout.

B. Incineration and removal of residuals

The incineration cycle takes 9 hours. Figure 3 shows a coil leaving the oven after incineration. -The appearance of the insulation on the outside is remarkably clean and white.

The windings of the tape stay completely intact so that there is very little risk of contamination by loose fibres.

Fig. 3 MBB coil leaving furnace after incineration.

C. Removal of residuals, cleaning

The cutting and removal of the tapes takes place under special precautions. Hereafter the coils are dismantled into 3 subassemblies and the windings strung open on "Christmas tree" like support structures. Carbonised residuals and oxide layers are removed from the conductor surface by grit blasting.

D. Examinations

All brazed joints are He-leak checked and in case of defect unbrazed and repaired by insertion of new ferrules. This procedure is followed by dimensional checks and eventual corrections of the coil geometry. There should be no deformations due to the incineration process.

After a chemical wash the coil is ready to be reinsulated as defined in the specification for new coils.

X. RESULTS FROM SAMPLE ANALYSIS

We investigated mainly glassfiber reinforced epoxy insulation but analysed as well samples with additional Mica-layers in it.

One group of the Mica samples came from a septum magnet and had decayed over 4 years, while others were "freshly collected" from a steering dipole only 9 days after the magnet had been removed from the beam.

Results from "freshly collected" Mica-insulation samples (Table V) confirm what was measured on the cooled down sample (Table IV).

The short lived isotopes fade out, and what remains is Na22 localised in the glass fibres and traces of Mn54 and Cs134 in the Mica layers. The negligible amount of Co60 in Table V may come from impurities in the insulation or from copper particles which were possibly scratched off the conductor when cutting out the insulation samples.

There is a remarkable high amount of Be7 in the fresh samples. We analysed Araldite, glass fibre and Mica separately and found comparable amounts of Be7 in all 3 components.

It is therefore the decay of Be7 which determines the time a coil should be stored before one can burn the insulation without risks of pollution.

This is in fact only one parameter for the timing since the exposure to ionizing radiation of persons doing the refurbishment work will much more depend on the radioactivity of the conductor material.

TABLE IV
MICA REINFORCED INSULATION: 4 YEARS DECAY

Spec. No. SL95131B	Total activity = 5.471 E02 Bq/probe	
Nuclide	Half Life time	Proportion total activity
Na22	2.6 years	97.42%
Mn 54	312 days	0.72%
Cs 134	2.07 years	1.86%

TABLE V
MICA REINFORCED INSULATION: 9 DAYS DECAY TIME
SPEC. NO SL95143B: TOTAL ACTIVITY = 14616 BQ PROBE

Nuclide	Half life time	Proportion tot. Act.
Be7	53.2 days	55.06%
Na22	2.6 years	41.89%
Sc46	83.8 days	0.16%
Sc47	3.3 days	0.23%
V48	16 days	0.03%
Mn52	5.6 days	0.12%
Mn54	312 days	1.67%
Co56	77.1 days	0.06%
Co57	271.8 days	0.08%
Co60	5.27 years	0.37%
Cs134	2.07 years	0.37%

CONCLUSIONS

- It has been proved in the context of this work that radioactive Na22, contained in the coil insulation, does not come off with the smoke when burning the Epoxy. Cleaning and monitoring of the smoke is therefore less of a problem, and the process becomes simpler and much cheaper.

- Mica reinforced insulation contains in addition traces of Mn54 and Cs134. It is unlikely that heavy Mica particles leave via the chimney, but one should make controls by analysing smoke samples and adapt the incineration cycle.

- Coils should be stored at least 8 to 12 months after the magnets have been removed from the beam to let short lived isotopes and especially Be7 decay.

- The conductor cross-section of coils to be recycled must not be too small, it should, according to our experience, have at least 400 mm².

- Refurbishment of slightly radioactive magnet coils implies more preparatory and administrative work than recycling non-radioactive coils, but it is economic and worthwhile doing.

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