DESIGN OF THE NEW TRIM COILS AT THE KARLSRUHE ISOCHRONOUS CYCLOTRON

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Summary

After the decision in 1975 to build a new set of trim coils, the conception for designing the coils was that they should permit acceleration of $^3He^{2+}$-ions and protons in addition to the e/m = 1/2-particles already available. Numerical calculations were done and led to a trim coil configuration consisting of six coils per plate with summing fields. The desired field strength (1.2 KG) and a small installation height (13.5 mm) led to a high current density (12 A/mm^2). The coil conductor is indirectly cooled by 3 mm copper plates which are pasted on each side of the coil, after which the coil is completely filled with special epoxy resin. To get a high accuracy in the overall height, the coil was pressed during the hardening process in a special set-up which can be heated up to 90°C. The basic design of the coil and first results will be reported.

Introduction

The trim coils for the Karlsruhe cyclotron must be replaced because the coils used until now are partially damaged by radiation. The new coils should not only replace the old ones but also permit acceleration of $^3He^{2+}$-ions and protons in addition to the e/m = 1/2 particles. The acceleration of protons instead of H_2^+-molecules will result in a higher internal and external beam current for isotope production and will make possible injection of polarized protons from the external Lambshift-source. The acceleration of these additional ions as above mentioned, can be done in principle with the Karlsruhe fixed frequency machine by reducing the isochronous field to 3/4 or to 1/2 respectively of the magnetic field value for e/m = 1/2 particles.

The diminution of the main field, however, leads to a change in the radial magnetic field distribution Fig. 1. Curve 1 shows the measured field distribution for e/m = 1/2 particles while isochronous condition is fulfilled. Reducing the excitation current to 3/4 of the magnetic value shown in curve 1 the plot No. 3 is achieved. This measured field distribution for e/m =2/3 particles fulfills fairly well the resonance condition in the central zone. But in the extraction region the deviation from the nominal value for $^3He^{2+}$-ions (plot 5) is about 2 KG.

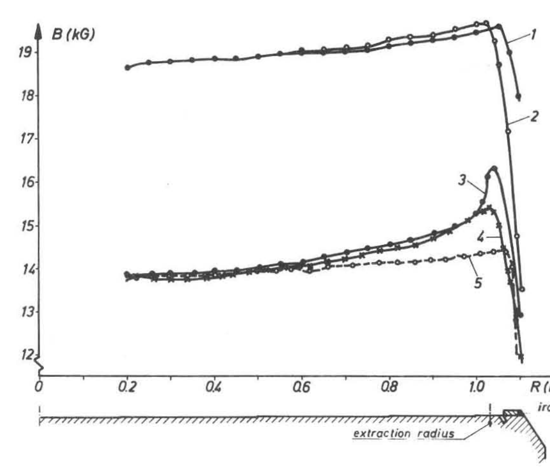

Fig. 1: Radial magnetic field distribution measured in the central plane of a strong sector. 1: Field plot for e/m = 1/2 particle; 2: Field plot for e/m = 1/2 particle without iron shim; 3: Field plot for e/m = 2/3 particle; 4: Field plot for e/m = 2/3 particle without iron shim; 5: Nominal field for e/m = 2/3 particle.

By removing the outer shim at the pole plate the maximum field correction can be reduced from 2 KG to 1.2 KG. Curve 4 shows the measured field distribution for e/m = 2/3 particles without shim. Now numerical calculations were done to investigate whether a suitable new configuration of trim coils is able to produce the appropriate field correction for $^3He^{2+}$ particles 1). These calculations led to a new trim coil set consisting of six coils per plate with summing fields Fig. 2. According to these calculations the trim coils were designed and a prototype coil finished in March 1978.

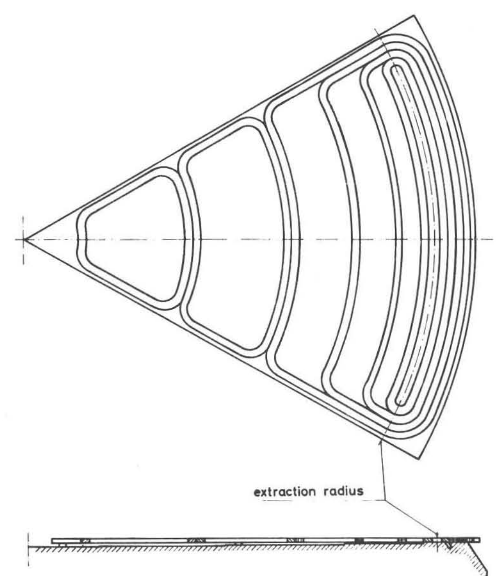

Fig. 2: New correction coil configuration allowing magnetic field shaping for $^3He^{2+}$-ions. The number of turns of the four outer summing coils is about 20 for excitation currents up to 40 A. The location of the individual coils and the necessary field strength for compensation were determined with a fitting program.

Contruction

The coil conductor is a copper band of 7 x 0.56 mm^2 in cross-section which is wound tightly around kidney-shaped aluminum forms. Fig 3 shows a photograph of the prototype trim coil set consisting of six separate coils.

The power dissipated in the coil windings is transported through a thin insulation layer on the copper band, a thin glass silk and a thin layer of epoxy resin with quartz to a copper plate on each side of the coil. These plates are cooled by water flowing through a rectangular cooling canal inserted into the plates. Fig. 4 shows a top view of the copper plate and the layout of the cooling canal. The copper plate is only

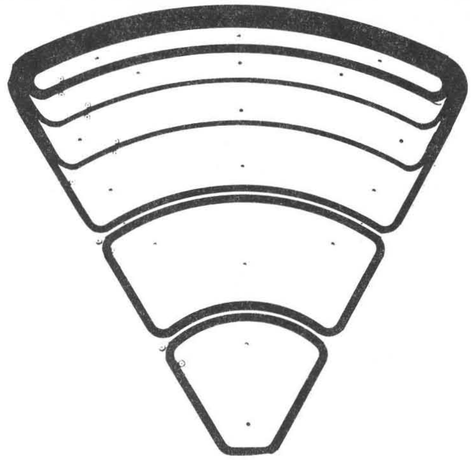

Fig. 3: Top view of the prototype coil with layout of the coil windings. The coil conductor for the six coils is a copper band 7 x 0.56 mm^2 wound tightly around kidney-shaped aluminium forms.

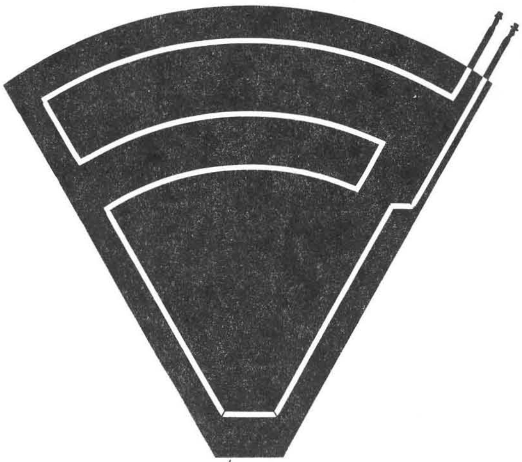

Fig. 4: Top view of the copper plate with layout of the cooling canal. The plate is 3 mm thick and the inner cross-section of the cooling canal is 14 x 1.5 mm^2.

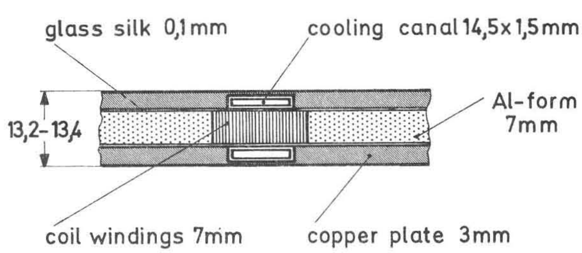

Fig. 5: Cross-section of a trim coil with cooling plates on each side.

3 mm thick and the cooling canal is 15 x 2.5 mm^2 with 14 x 1.5 mm^2 inner cross-section.

The overall height of the trim coil is 13.4 mm. Fig. 5 shows a schematic cross-section of the coil with cooling plates on each side.

Currents up to 50 A for each coil are necessary to get the calculated field corrections. These high currents produce a heat flux density of 1 W/cm^2. To get a quick heat transfer to the cooling plates, good thermal conductivity is necessary. The thermal conductivity depends on the distance and the medium between windings and cooling plate.

The distance between the windings and cooling plate is minimized by pressing the whole winding of the coils. The trim coil set is then completely embedded in epoxy resin and the cooling plates are pasted on each side. This leads on one hand to a good mechanical stability of the coil, on the other hand to an improvement of the thermal conductivity between windings and plates by appropriate selection of the epoxy resin. We used an epoxy resin loaded with quartz powder because of its relative high thermal conductivity $\lambda = 1.75 \times 10^{-3}$ cal/cm$\cdot$sec ^{o}C. In a preliminary test it was checked in what way the epoxy resin could be manipulated and how thin the layer between windings and cooling plate could be made. The thickness of the epoxy layer was not more than 0.15 mm.

The processing of the epoxy resin at 70^{o}C was done in vacuum to ensure a proper outgassing. The cure was made at 90^{o}C while simultaneously pressing the whole trim coil set. This is done in vacuum, too. The arrangement for this procedure is shown in Fig. 6.

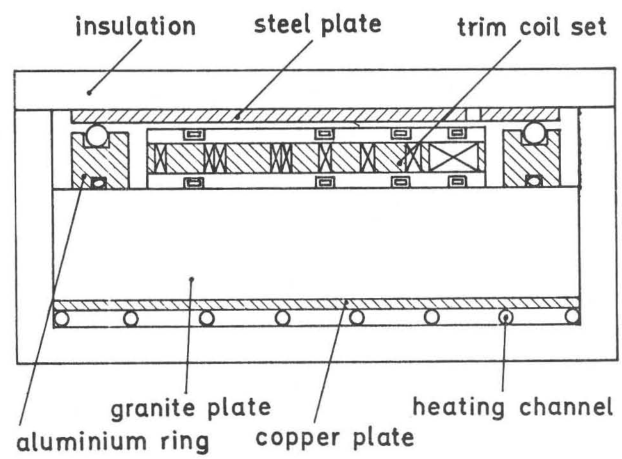

Fig. 6: The arrangement for pressing and outgassing the whole trim coil set during the cure of the epoxy resin by means of vacuum. The whole set-up can be heated to 90^{o}C.

The basis is a granite plate (150x150x20 cm) which can be heated up to 90^{o}C by means of heating channels at the bottom. The surface of the granite plate is manufactured with an accuracy of 1-5 µ and a parallelism of 1/10 mm. This surface quality does not change while heating up the plate to 90^{o}C. A vacuum chamber is built up with an aluminium ring on the surface of the plate. A steel flange will close this chamber. The whole trim coil set will be inserted into this chamber and can be heated. By properly dimensioning the height of the aluminium ring it is possible to press the trim coil set between the steel flange and the granite plate by evacuating the chamber. In this way the trim coil set is fixed during the cure time of the epoxy resin.

The connectors for each coil were designed such that they can be disconnected very easily, that they have small dimensions in height and diameter and a small voltage drop. A cross-section of such a connector for currents up to 50 A is shown in Fig. 7. This connector consists of a copper bolt where the end of the coil windings is soldered. The bolt is inserted insulated into the coil form and has on the top a countersink. In this hole a copper band will be pressed by means of a hollow screw and a serrated lock washer. The accessible voltage drop is only 2 mV at 50 A. Fig. 8 is a photograph of the 50 A connector.

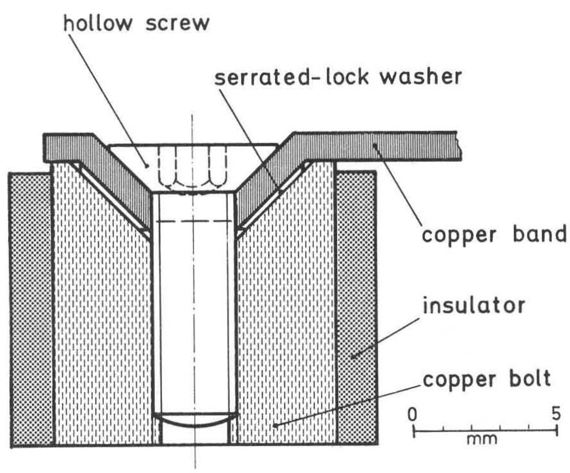

Fig. 7: A cross-section of the 50 A-connector. This connector is inserted into the coil form.

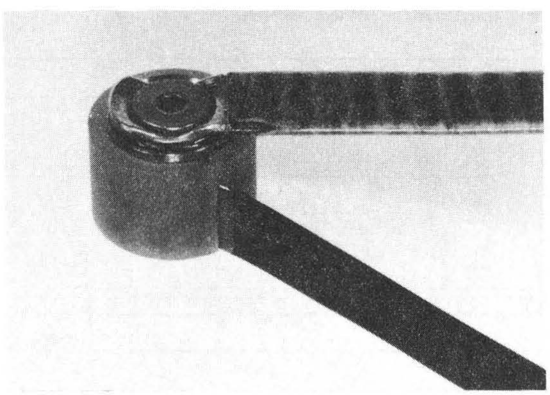

Fig. 8: The connector for 50 A is characterized by feasible disconnection, small dimensions and a small voltage drop.

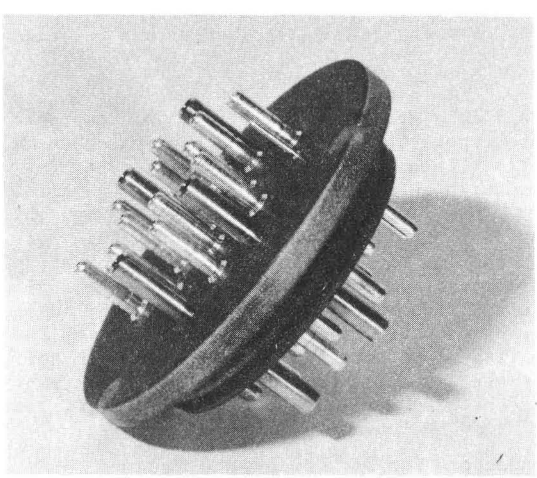

Fig. 9: The prototype flange with the special feed-through for 12 x 50 A and for 4 water connections. Such an epoxy flange supplies one trim coil plate.

For the high currents up to 50 A a special vacuum tight feed-through was designed. This feed-through consists of an epoxy flange into which hard silver plated copper plugs and copper pipes are cemented. The plugs mate with special sockets with automatic snap-in contacts. In this way the connections are protected against erroneous disconnecting. Each coil plate will be supplied separately with current and water so that six epoxy flanges are needed. The flange with the arrangement of the current and water connections is shown in the photograph of Fig. 9.

Results

For determination of the inner temperature of the coils the voltage drop of each coil was measured as a function of current. All six coils were in serial connection. The average temperature rise in the coils was 35°C at 50 A.

The temperature map at the surface of the cooling plate was measured while all coils were at 50 A. In Fig. 10 the radial temperature distribution in the middle of the coil is shown. The maximum temperature is about 65°C at the fringe of the coil. This value will be lowered by increasing the number of cooling canals in this region.

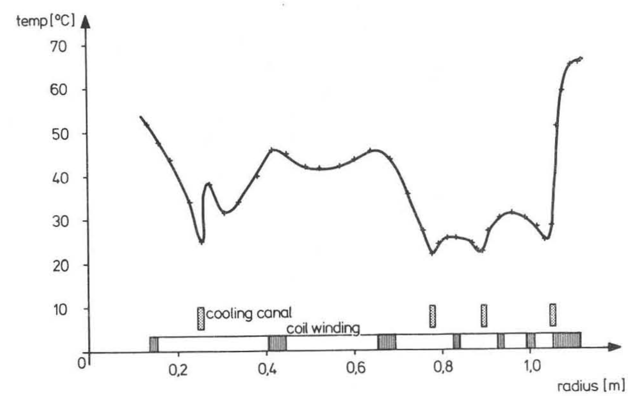

Fig. 10: The radial temperature distribution in the middle of the coil. The location of the cooling canals and the coils are drawn to scale in the same figure.

The magnetic field in radial direction and along the extraction radius was determined. The radial field distribution in the middle of the coil at a distance of 3 cm from the coil surface is plotted in Fig. 11. For comparison the calculated data from the TCOIL-Program 2) are also shown in the figure. There is a good agreement with the experimental data whereby the inner section of the coil is better reproduced than the fringing region. The summarized data of the prototype trim coil are given in Table 1.

Total power consumption	4 kW
Cooling water consumption	360 l/h
Resistance R_{max}	0.32 Ω
Current density	12 A/mm^2
Heat flux density	1 W/cm^2
Average inner temperature	35°C
Weight	35 KG
Overall Height	13.4 ± 0.15 mm

Table 1: Data for the prototype trim coil plate. All six coils are in serial operation at 50 A.

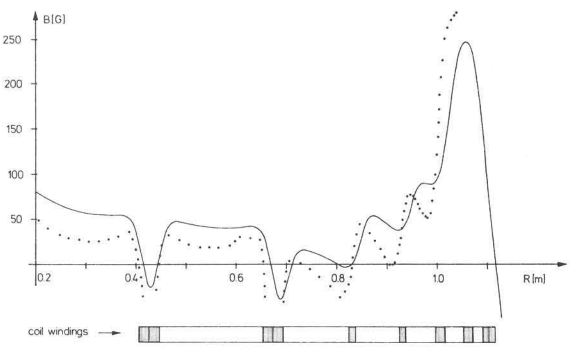

Fig. 11: The radial magnetic field distribution in the middle of the coil at a distance of 3 cm from the coil surface. The dotted line represents data calculated from the TCOIL-Program 2).

The production of the trim coils was started in the middle of this year so that in the early spring of 1979 the installation into the cyclotron can be done.

References

1) F. Schulz, H. Schweickert; Report KFK 2298 (1976) p. 15

2) H. Braun; Report SIN-TM-03-13 (1970)