COLLIMATORS AND MATERIALS FOR HIGH INTENSITY HEAVY ION SYNCHROTRONS*

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Abstract

The operation of high power high brightness accelerators requires huge efforts for beam cleaning and machine protection. Within the WP 8 (ColMat) of the EU research framework EuCARD[1] we investigate new materials and methods for beam collimation and machine protection. We present an overview of these activities at the GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt.

Simulations of accidental beam losses in LHC and SIS100 have been performed. Scenarios for halo collimation of heavy ions and protons in SIS100 routine operation have been investigated. A prototype of a cryogenic collimator for charge exchange losses during intermediate charge state heavy ion operation in SIS100 has been build and tested with beam. Several candidates of advanced composite materials for collimation system upgrades of present and future high power accelerators have been irradiated and their properties are being characterized.

Most deliverables and milestones of the R&D programme were already reached before the end of the funding period.

COLMAT ACTIVITIES AT GSI

Collimator Prototype

A major part of the joined effort in the frame of ColMat aims at construction of actual prototypes of collimators for FAIR [2] and LHC phase II. Both prototypes have been successfully designed, constructed and tested. The prototype of the FAIR cryocatcher (see Fig. 1) was tested with beam from SIS18 (see [3] for results). The catcher is needed to prevent dynamic vacuum effects and allows the operation with heavy ion beams of highest intensity and intermediate charge state [4]. The design of this successful cryocatcher will be adopted for SIS100 and leads to the series production.

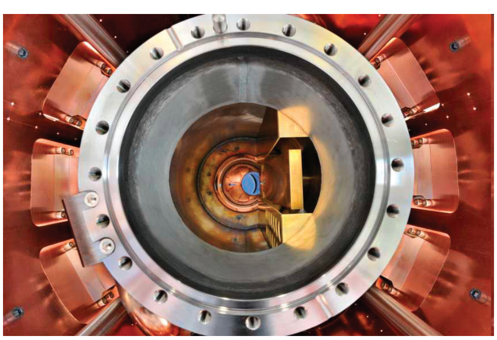

Figure 1: Picture of the cryocatcher prototype for FAIR's synchrotron SIS100. The catcher is needed to prevent dynamic vacuum effects and thus allows stable operation with heavy ions of intermediate charge-state like U^{28+}. (Picture: G. Otto)

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Simulation of Accidental Beam Losses

Modern high energy high brightness accelerators provide particle beams which are able to cause severe damage to experimental and accelerator components by accidental beam losses. The machine protection system should prevent such accidents but catastrophic scenarios might still occur and realistic simulations of such scenarios have to be performed. Within ColMat GSI contributed to a better understanding of possible LHC and SPS loss scenarios. Mainly the full loss of an entire full energy LHC beam on a single point and a full SPS bunch train injection has been studied.

The simulations is performed using a combination of the codes `BIG2` and `FLUKA`. First the energy deposition into the target is simulated with `FLUKA` then the response of the target is calculated with `BIG2` which is able to include thermodynamic and hydrodynamic effects. This is repeated for every time step in the simulation. The results suggest that the range of a full LHC proton beam is up to 25 m in solid carbon due to hydrodynamic tunnelling. The full simulations have been published in [5]. To benchmark the calculation's results, experiments with SPS beams at the HighRadMat facility are planned.

Simulations of intense beam losses are valuable for many modern accelerators. The use of "standard" tools like finite element codes might produce misleading results by neglecting the hydrodynamic effects in the target.

Halo Collimation for SIS100

SIS100 is the planned main synchrotron for the FAIR project. It will accelerate intense proton and heavy ion beams for external fixed target experiments and secondary beam generation. To provide "clean" beams for future experiments dedicated collimation systems for ions and protons are foreseen. The protons will be collimated in a multistage system depicted in Fig. 2. First the particles which are to be collimated are scattered within a thin foil. The now statistically disturbed trajectories lead to a two-stage collimation system which will be placed in the transfer section of SIS100. EuCARD is co-funding the R&D on layout

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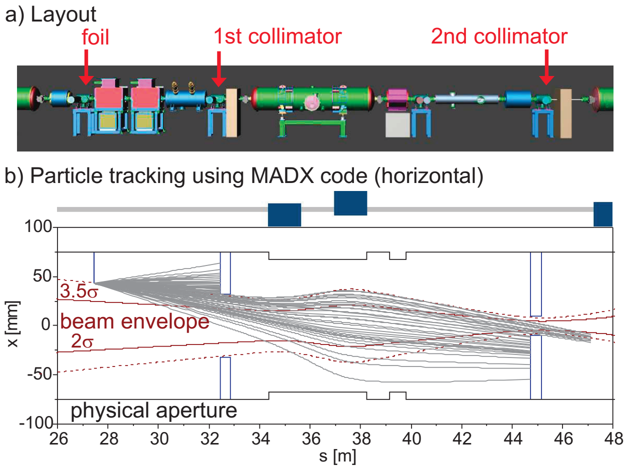

Figure 2: Layout of the SIS100 halo collimation system. It has to be inserted into the restricted space at SIS100. Without further fine tuning simulations yield a high efficiency of 80%.

and optimization of the proton collimation system. Ongoing work shows that the present layout has a cleaning efficiency of about 80% and fits well within the constrained space in the SIS100 layout. Further fine-tuning is expected to increase the performance beyond that value.

In addition to the collimation studies, irradiation experiments and simulations are being performed to investigate long term radiation damage and estimate activation levels of collimators, beam stops and other irradiated accelerator components. Results obtained have a direct implication on technical decisions for the FAIR project.

SEARCH FOR NEW MATERIALS FOR ACCELERATORS

Introduction

Another main focus of the ColMat activities is the identification and characterization of new high performance materials for machine protection and collimation devices.

The need of placing collimators close to the beam requires materials of high electrical conductivity to avoid huge impact on impedance budgets. In addition the collimators have to withstand the exposure to intense beams at least partially. Also efficient cooling should be possible. This requires high mechanical stability as well as good thermal conductivity. Some of this requirements are contrary and the selection of an ideal uniform material is not straight forward. Furthermore additional requirements like vacuum properties, price and ability to machine the materials lead to further constraints which can be different for different accelerators and applications.

The search for optimal solutions leads in many cases to composite materials providing beneficial positive qualities while ideally suppressing the detrimental features. At the beginning of the ColMat activities industrial and scientific partners presented metal-diamond composite materials as

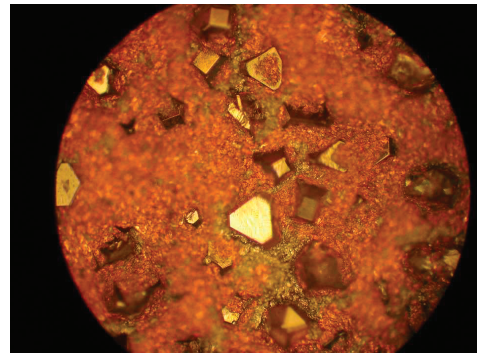

Figure 3: Low resolution optical microscopy image of Cu-diamond compound. Exotic metal-diamond composite materials provide high thermal and electrical conductivity while combined with high mechanical stability. In this project silver, copper or molybdenum matrix was combined with rather large mono-crystalline diamonds (> 100 μm). Beside measurements of their basic properties the materials were irradiated with proton and ion beams and degradation effects are being investigated.

an exotic solution which has the potential of combining the properties of diamond and the used metal matrix. The R&D project included the development of specific manufacturing methods which are able to produce samples of sufficient size for accelerator applications. Two different production methods were tested by two different partners.

The samples where successively irradiated and are under investigation to characterize their basic properties and radiation induced degradation before and after exposure to protons and heavy ions.

Theoretical studies have started within the ColMat workpackage to introduce these composite materials into existing simulation codes and allow predictions of their performance for future applications. The non-uniformity being the key characteristic of composite materials, makes the theoretical treatment very complicated. New approaches and solutions found here will be beneficial for many other applications of composite materials.

The joined effort of many partner institutes allowed us to identify Cu-diamond and Mo-diamond as promising candidates for collimators. These materials are to be tested in a future LHC phase II collimator (see [6]).

Samples of metal-diamond composites have been prepared and will be irradiated with CERN's SPS at the HighRadMat facility for future investigation. The samples which have already been irradiated at GSI and Kurchatov Institute will be tested in more detail as soon as the radiation levels decrease to an acceptable level.

GSI Material Research Experiments

Different materials for FAIR and LHC collimators were irradiated and characterized at GSI. The research programme includes conventional carbon-carbon composites as well as uniform materials and metal-diamond compos-

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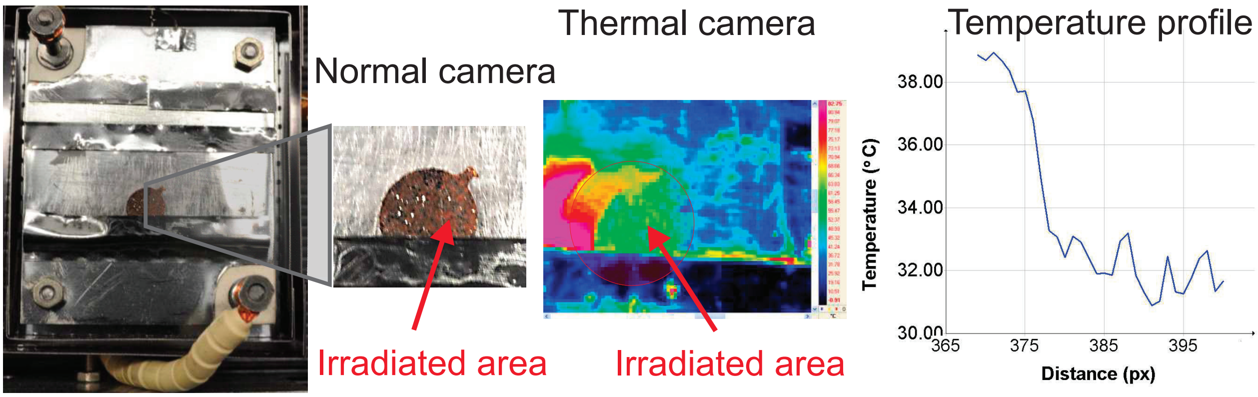

Figure 4: Image of the experimental setup for ion irradiation of copper-ciamond composites at GSI. The sample has been irradiated with $1{\cdot}10^{13}$, 1.14 GeV Uranium ions/cm^2. The temperature in the back has been increased to 100°C and the radiometric thermal image of the front side recorded. A slight decrease of thermal conductivity can be observed(see text).

ites [7, 8, 9].

Heavy ion induced degradation of the thermal conductivity of the copper-diamond composite was investigated using thermal imaging of samples that have been half exposed to the beam through a mask. Samples exposed to 1.14 GeV, $1{\cdot}10^{13}$ ^{238}U ions/cm^2 were mounted on a button heater. During irradiation the temperature on the back of the sample increased to 100°C and the radiometric thermal image of the front side of the irradiated sample was recorded with a FLIR SC7000 high-sensitivity thermal camera. The temperature profiles across the diameter of the samples show a slight decrease of the temperature signal on the irradiated half opposed to the heated side. The spikes in the temperature profile (Fig. 4 right) correspond to the diamond crystals embedded in the metallic matrix which habe a higher thermal conductivity. Further investigations are needed to check if the only cause of the reduced signal corresponding to the irradiated half is a slight thermal conductivity degradation, or a combined effect with the emissivity reduction by ion beam-induced sputtering of graphite present on the diamond's surface.

CONCLUSION AND OUTLOOK

The EuCARD WP8 ColMat is an successful interdisciplinary collaboration performing R&D on very different topics aiming to improve particle accelerator collimators and machine protection. Beside the individual research results achieved by the different subgroups many new collaborations were established in the frame of ColMat. Especially the investigations on metal-diamond composite materials lead to a vital interdisciplinary network. The collaboration of theoretical and experimental researchers in material science, plasma physics, mechanical engineering and accelerator science clearly shows that R&D frameworks can can tackle specific problems beyond projects typically addressed by national funding agencies. Joint expertise and forces of different basic research groups successfully demonstrated important contributions to applied topics and supporting the accelerator development towards the FAIR project. We hope to be able to continue this successful work within the EuCARD^2 framework starting 2013.

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