Stefano Redaelli, 26-02-2007

82nd Meeting of the LHC Collimation Working Group, February 19th, 2007

Present: Ralph Assmann (chairman), Giulia Bellodi, Chiara Bracco, Markus Brugger, Francesco Cerutti, Bernd Dehning, Barbara Eva Holzer, Daniel Kramer, Laurette Ponce, Valentina Previtali, Stefano Redaelli (scientific secretary), Stefen Rösler, Alexander Ryazanov, George Smirnov, Rüdiger Schmidt, Joachim Vollaire, Thomas Weiler.

1 A.O.B.

A CARE-HHH workshop on crystal channeling for large colliders will be held at CERN on March 22nd and 23rd, 2007. Details can be found on the following web page:
`http://care-hhh.web.cern.ch/CARE-HHH/CrystalCollimation2007/default.html`
People that are interested in participating to this workshop should send an invitation request to Valentina Previtali.

2 Studies of Radiation Damage in Irradiated Graphite Collimator Materials for LHC (A. Ryazanov)

Alexander Ryazanov from the Kurchatov Institute in Moscow presented preliminary results of measurements carried out on irradiated samples of LHC collimator materials. Originally it was foreseen to send samples of the collimator jaws irradiated during the 2004 TT40 tests. However, this turned out to be too complicated due to the bureaucracy procedures to transport radioactive samples to Russia. Alternatively, it was decided to send non-irradiated samples that were irradiated at the Kurchatov Institute with the facilities of the Russian Research Center (RRC). A cyclotron and a Van Der Graaf accelerator can provide a wide variety of proton and ion beams (see details in Alexander's slides, page 17).

Oliver Aberle provided various samples of **three different types of Carbon-based materials** that were analyzed before and after irradiation. This set of samples include (1) the Japanese CFC used for the ring collimator series production; (2) the German Graphite used for the transfer line collimators and (3) another type of CFC from France. These samples arrived at the Kurchatov Institute at the end of October 2006 and hence A. Ryazanov's team could not yet perform measurements with all the required details. Today Alexander presented preliminary results of various tests and discussed the planning for future work.

An **extensive measurement program** has been carried out to determine the physical and thermo-dynamical properties of the samples before irradiation. A comprehensive summary of this measurements is given in the table at page 6 of Alexander's slides. These measurements confirm the results of measurements previously performed at CERN, which determined the choice of CFC jaws for the ring collimators. Notably, the recent measurements at the Kurchatov institute confirmed that the CFC resistivity is two to three times smaller than the Graphite's. A. Ryazanov's team also measured the effect of temperature on various material properties up to approximately 700 degrees. As expected, it is found that in the operational LHC range (below 100 degrees) the CFC has a negative thermal expansion coefficient. R. Assmann reminded that this feature has been used in the collimator jaw design to compensate the expansion of Copper in case of jaw heating ("sandwich" design).

Irradiation tests have been performed with 5 MeV C^{12} ion beams from the cyclotron at the Russian Research Center. The experimental setup works as it follow: a grid is put between the incoming ion beam and the sample to be irradiated. Some regions of the sample are in the "shade" of the grid and thus are not irradiated. The deformation of the irradiated zones is measured with respect to the zones that are not exposed to the beams.

These measurements can be used to calculate the percent deformation for a given DPA ("displacement per atom") produced by the incoming beam (see formula at page 14). In addition, visual inspections of the surface after irradiation are used to estimate the effect of erosion.

A. Ryazanov showed some examples of the measurement results. The preliminary analysis of measurement data shows that the deformation due to about 3×10^{17} p/cm^2 is approximately 2 μm for some CFC samples. This seems small however Alexander warned that this number has to be compared to the penetration 5 μm depth of the C^{12} ions and therefore the deformation is above the 20 % level. Next Alexander showed photographs of the CERN sample surface after irradiation. It is found that craters and caves are induced, which were not present before beam exposure. In some cases, the fibres of the CFC look "broken" or "cut". See Alexander's slides for detailed pictures. These results cannot be easily scaled to the LHC case. The real implications for the LHC collimators remain to be understood.

In conclusion, A. Ryazanov stated that, after having discussed with R. Assmann, they agreed that future irradiation tests should be done by using **proton beams** instead than ions. Energies up to **35 MeV** can be achieved with the present accelerator complex at the Kurchatov Institute. Alexander believes that with these beams one can get representative results for the LHC case. For 35 MeV protons the penetration length in Carbon is 7.7 mm and this ensures a uniform irradiation on the volume of the 4 mm long samples provided by CERN. These irradiation conditions are ideal to study the dependence on physical and mechanical properties as a function of the DPA. Notably, thermal conductivity, electrical resistivity, thermal expansion and mechanical properties will be measured before and after irradiation.

R. Assmann stressed that it is important to understand how the experimental results with low-energy and high-fluence beams can be **scaled to the LHC case**. The LHC will operate in a rather different radiation environment because we will have a smaller proton fluence but much larger induced energies, which will be concentrated in a relatively small fraction of the jaw volume (due to the small size of the shower induced by high energy beams). The issue has to be addressed with high priority and R. Assmann encouraged the experts to think of possible idea to sort this out. R. Schmidt agrees that the scaling of the experimental results to the LHC is an issue and thinks that, at this stage, scaling can only be done through appropriated simultions. Inputs from the FLUKA team was welcomed.

R. Assmann also commented that the tests performed at the Kurchatov Institute show again indications of material surface damage. Also the results obtained at the collimator material tests at RHIC suggested that pieces of material can be removed from the jaw surface. The implications for the vacuum remain to be understood. In addition, we must also (1) find - if possible - operational procedures to reduce this effect (for example, R. Assmann suggested to use the transverse collimator tank movement to "dilute" the doses on the jaw material) and (2) understand as soon as possible the implications for the material choice for the Phase II collimator.

Bernd Dehning commented that the high radiation environment will also change the material damage levels and the BLM thresholds will need to be changed accordingly. R. Schmidt replies that this issue is probably not the highest priority for the moment.

R. Assmann and R. Schmidt announced that together with Nikolai Mokhov from Fermilab they are organizing a **workshop on damage material from radiation**. The workshop will probably take place in September 2007 and will address, amongst other, the issue of the material survival in high radiation environment, which is of primary importance for the LHC.

The next meeting will be March 5th, 2007 at 15:30 (note the UNUSUAL TIME).