International Muon Collider Design Study

Accelerator Design meeting

Monday 27/02/2023, 16:00 – 17:30

(https://indico.cern.ch/event/1254683/)

Chair:	Daniel Schulte
Speakers:	Daniel Schulte, Fabian Batsch
Participants (zoom): ??	*Incomplete list: Alexej Grudiev, Antoine Chancé, ..., Daniel Schulte, ..., Fabian Batsch, Rama Calaga, Heiko Damerau, Ivan Karpov, Donatella Lucchesi,..., Scott Berg, Ursula Van Rienen, Sosho-Abasi Udongwo...*

MEETING ACTIONS

1: Fabian Batsch	Check for consistency and comparison of longitudinal emittances in MuCol documents, MAP and studies presented today.

0. Comment on these minutes

These minutes are mainly reconstructed from memory as only few notes were taken during the meeting

1. NEWS (DANIEL SCHULTE)

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2. REPORT FROM WG ON RF (Fabian Batsch)

- Fabian reminds of the baseline scheme for his studies: a chain of three to four Rapid Cycling Synchrotrons (RCS) with 2 counter-rotating muon bunches (mu+ and mu-), similar to the MAP design.

- Fabian reports that the possibility of having a hybrid RCS in the LHC tunnel was studied by David Amorim and himself. The conclusion is that a 5 TeV machine does not fit because of the required amount of bending strength would fill the tunnel almost completely with magnets. A machine around 4 TeV would fit, but it is not studied further because it does not fulfill the baseline parameter of a 10 TeV collider.

- The presentation covers two main topics:

  1. Beam-induced power estimates for muon RCS RF systems

  2. Studies on synchronous phase and consequences on the acceleration.

- In the first part, a rough estimate for the HOM power, to be seen as upper limit is derived: 22 kW. Exact values are calculated in two ways:

  1. through approximated wake potentials in macro-particle tracking simulations (BLonD) and

  2. the output of ABCI code for detailed RF structure.

- Values for both methods and all 3 RCS are presented: both methods give values on the order of 10 kW per bunch and cavity (<11kW for RCS1, <15 kW for RCS2, <8.5 kW for RCS3).

- Bunch crossings inside the cavity may increase power up to 4 times, this case must be avoided.

- The present parameter tables are based on the ILC cavity (1.3 GHz), but a lower frequency, e.g. 800 MHz, might be required if the HOM power cannot be handled.

- Similar studies are presented for a 801.58 MHz cavity, together with studies from Sosoho-Abasi Udongwo -> with 800MHz, due to the larger apertures, the HOM power could be reduced by 40 to 50%.

- Fabian stops for questions on the first part. Scott Berg asks if the values for the power have to be understood as peak values or averaged over time. Fabian answers that the values are the average power during acceleration. He refers to the equation for the HOM power, which has a time term, the bunch spacing, which is the revolution period in the case of 1 bunch in the muon RCS. The value is therefore the power during approximately 1 ms. Somebody mentions that the repetition rate of the RCS will be 5 Hz, so one will 10 kW for 1 ms, and 199 ms no power. It is asked how this affects the maximum power the HOW couplers have to handle. It suggested that 1 ms is long with respect to 1.3 GHz RF frequency, and therefore should be considered similar to CW.

- In the second part of the presentation, Fabian presents results concerning the synchronous phase of the RF systems, which was raised during the 1st IMCC annual meeting. A larger synchronous phase might reduce the bucket area and therefore possibly decrease the over-voltage, which is 6 GV with 45° for the first RCS.

- Fabian shows the savings in voltage as a function of the synchronous phase, relative to a synchronous phase of 45°, both normalized to the RF voltage at 45°, and in absolute numbers, assuming a fixed energy gain per turn of the muons.

- Fabian presents studies of the bunch length, bucket area, beam losses, HOM power and shift of the potential well minima as function of the synchronous phase. The studies are for fixed and constant energy gain per turn, for a single bunch, and both cavity types (1.3 GHz and 800 MHz). The input emittance is 0.1 eVs (*comment: pi times 2 sigma length times 2 sigma energy, see discussion later*).

- The slides show plots of the bucket area which decrease with increasing phase, without and with distortion of the bucket area due to induced voltages / intensity effects. A larger synchronous phase leads to larger bunch length and smaller HOM power due to reduced high frequency content of the bunch spectrum. The bucket filling factors are also presented. When the bucket filling factor is between 70% and 100%, beam losses occur due to the bucket becoming too small. The asymmetry of the bucket also increases with increasing synchronous phase.

- The following slides 28-31 show equal studies for RCS 2 and 3, for 1.3 GHz. The same studies for a 800 MHz cavity are added to the appendix of the presentation.

- In summary, under the assumption of a longitudinal emittance of 0.1 eVs (4 sigma), the studies find that the synchronous phase can be increased up to 60° in RCS 1 and to around 65° in the other RCSs. Instabilities of the bunch do not seem to be an issue for the synchronous phase studies. The synchronous phase could be a mean to reduce the HOM power because of the increasing bunch lengths. Adjusting the synchronous phase allows for decreasing the over-voltage by >20%, and even more for a 800 MHz system. Beam-crossings must be avoided in cavities to keep the HOM powers small. This is assumed to be possible as bunch positions are already precisely controlled for existing colliders as the LHC.

- As future work, Fabian mentions similar studies for nonlinear ramping functions of the magnets / RF, full longitudinal tracking through all 3 RCS, and the inclusion of multi-turn effects in simulations (also for counter-rotating bunches).

Discussion:

- Scott Berg asks which intensity effects are used to calculate the bucket / potential well. Fabian replies that he included the fundamental long-range wakefields and short-range wakefields according to thew K. Bane theory.

- Scott has a question on the figures on slide 24, showing a simulation of the muon bunch during acceleration in RCS1 and a plot of the bucket filling factor (bunch emittance divided by bucket area). Scott asks which definition for the emittance was used: outer bound, 1 sigma, 4 sigma?

- Fabian replies that the bunch emittance is calculated as 99% encircling emittance, close to 4 sigma. Scott reminds that the MAP study assumed a 0.5 eVs (4 sigma) emittance, hence would need to be divided by 16 to get RMS number.

- It is discussed that by looking at the phase space plot of slide 24, the 4 sigma bunch length is 0.1 ns, the 1 sigma energy spread seems to be around 0.5eV. Daniel mentions that the baseline value is 7.5 MeVm. Heiko mentions that this corresponds to 0.025 eVs.

- It is agreed that these numbers must be crossed-checked as the individual definitions are not the same or clear how they are defined and that a factor of 3 to 4 might be different between the studies and the official tables.

- No further questions.

3. AOB (EVERYBODY)

- Next meeting next week: Current status of the 10 TeV collider, by Christian Carli, Kyriacos Skoufaris.

=> See https://indico.cern.ch/event/1260422/.

Reported by F. Batsch and H. Damerau