PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Francesco Giordano

XXXIII Cycle

Training and Research Activities Report – Second Year

Tutor: Prof. Pasquale Arpaia – co-Tutor: Dr. Benoit Salvant (CERN)

1. Information

a. Francesco Giordano, Master degree in Electronic Engineering – Università di Napoli Federico II, Impact of filling scheme on beam induced RF heating in CERN LHC and HL-LHC.
b. XXXIII Cycle- ITEE – Università di Napoli Federico II
c. PhD student enrolled at the PhD student programme at CERN
d. Tutor: Prof. Pasquale Arpaia co-Tutor: Dr. Benoit Salvant

2. Study and training activities

a. Courses (credits in brackets)
   - “Introduction to RF”, provided by Prof. A. Mostacci (0.5)
   - “Vacuum systems”, provided by Prof. V. Baglin (1)
   - “RF Engineering”, provided by Dr. F. Caspers and M.Wendt (2).
   - “Beam instrumentation”, provided by Prof. P. Forck (2).
   - “Superconducting RF cavities”, provided Dr. F. Caspers and M.Wendt (1.5).
   - “Accelerator controls”, provided by Dr. E. Zimoch (0.5).
   - “Introduction to magnets”, provided by Dr. Gijs De Rijk (0.5).
   - “Normal conducting magnets and mini-workshop”, provided by Dr. T. Zickler (1).
   - “Superconducting magnets and mini-workshop”, provided by Prof. P. Ferracin (1).
   - “Cryogenics for superconducting devices”, provided by Prof. P. Lebrun (0.5).
   - “Particle sources”, provided by Dr. T. Thuillier (1).
   - “Low-energy electron accelerators”, provided by Dr. W. Mondelaers (0.5).
   - “Accelerator for medical & industrial applications”, provided by Dr. W. Kleeven (0.5).
   - “Life-cycle and reliability of particle accelerators”, provided by Dr. S.Meyroneinc (0.5).
   - “Survey and Alignment of Accelerators”, provided by Dr. H. Mainaud Durand (0.5).
   - “Radiation safety”, provided by Prof. Prof. X. Queralt (0.5).

b. Seminars
   - “Accelerator Driven Systems”, Maud Baylac (0,4).
   - “CERN: AD, ELENA, LINAC4”, Philippe Lebrun (0,4).
   - “Accelerators for hadron therapy,” Marco Schippers (0,4).
   - “Energy recovery linacs”, Dr Michaela Arnold (0,4).
   - “Particle accelerators, instruments of discovery in physics”, Philippe Lebrun (1).
   - “Radiation Oncology Biology and Physics Clinical Applications”, Raymond Miralbell (0,4).
   - “ACHIP”, Benedikt Hermann (0,4).
   - “SwissFEL”, Dr Florian Löhl (1).
   - “Building large particle accelerators”, Philippe Lebrun (0,6).

3. Credits summary

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Cycle XXXIII

	Credits year 1								Credits year 2								Credits year 3									
		1	2	3	4	5	6			1	2	3	4	5	6			1	2	3	4	5	6			
	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	Summary	Total	Check
Modules	24	14	6			4		24	34	0	14					14								0	38	30-70
Seminars	5,5	5	0	0,5		0		5,5	5	0	5	0	0	0	0	5								0	11	10-30
Research	32	0	2	10	7	4	10	33	21	10	0	10	7	6	8	41								0	74	80-140
	62	19	8	11	7	8	10	63	60	10	19	10	7	6	8	60	0	0	0	0	0	0	0	0	123	180

4. Research activity

Title: Beam induced RF heating with Machine Learning application

The High-Luminosity Large Hadron Collider (HL-LHC) project aims at improving the performance of the LHC in order to increase the potential for particle physics discoveries after 2025 [1]. The target is a factor of 10 in luminosity beyond the LHC's design value [1]. In order to increase the luminosity also the particle intensity has to increase leading to strong electromagnetic (EM) fields generated by the beam [2].

The interaction of EM fields generated by a beam made of high energy particles with the surrounding accelerator devices causes the beam to lose energy, which is dissipated in the surrounding devices: this can be referred to as beam induced RF heating. Since the beam induced RF heating goes quadratically with the bunch intensity [3], it is one of the major limitations to increase ng the performance of the machine.

The major sources of heating in an high energy accelerator are: the particles lost on the wall [4], the electron cloud [5] and the beam--induced heating due to impedance [3]. In several scenarios the amount of power loss due to beam--induced heating is the major contribution to the total power loss. Because in the machine there are other sources accounting for the total power loss, from now on, unless clearly specified, the word power loss will be referred to the power loss due to beam induced heating.

The quantity allowing to distinguish the beam induced heating from the other contributions to the total power loss is the longitudinal impedance [6] of the structure where the beam is traveling into.

The longitudinal impedance is a frequency--defined quantity that represents the interactions between the EM fields generated by the beam and the considered component of the accelerator. The impedance depends strongly on the material and on the geometry of the component of the machine. The beam induced heating team has to monitor that the temperature of each component inside the machine does not exceed dangerous values that could cause unexpected behaviour.

For each machine component such as collimators, kickers, magnets, etc, it is possible to measure the impedance with different tests on the component, based on Radio Frequency (RF) measurements, before installing them in the machine.

The main studies performed so far have focused on simulating the power loss from two beams, computing the power loss from transverse impedance and developing a classifier for vacuum gauge readings.

a. Vacuum gauge classifier

An analytical classifier has been developed in Python to identify vacuum gauge readings that would show signs of beam induced heating. The aim is to identify heating indication in the LHC. A machine learning classifier has been carried out that provides already meaningful results that are then processed both from the impedance team for heating understanding and also from the vacuum team to identify vacuum issues.

The work has been accepted at the AMLD international conference in Lausanne to be presented as a poster.

b. One-beam power loss

An effective versatile script was implemented and optimized in Python for power loss of a single beam of arbitrary filling scheme and parameters inside an element with arbitrary impedance.

c. Two-beam power loss

The power loss computed in time domain simulations by the CST software has been benchmarked against analytical formulae for the single bunch and multi-bunch case for 1 beam both for resistive wall impedance and cavity-like structures impedance.
Heavy computational studies with two beams inside a cavity were set up and are ongoing to understand how the power loss varies with the phase difference between the two beams and with the transverse offset. The results indicate interesting behavior of the power loss as a function of the phase between the two beams.

d. Transverse impedance power loss

A model implemented in Python was developed to compute the transverse impedance contribution to the power loss as a function of the transverse offset. The method has been applied to crab cavities in order to account for the offset of the beam in the computation of the worst-case scenario power loss.

e. PT100 temperature probes

RF measurements in collaboration with the TE-ABT and EN-STI groups have been performed on shielded and unshielded temperature probes and confirmed that the shielded probes available on the market effectively avoid electromagnetic coupling from the beam and should solve the problems identified in measuring the temperature in several LHC components.

f. Others studies and activities

Power loss computations for several devices (crystal goniometer, crab cavities, TCLD and TCL collimators) have been performed as applications of the scripts developed in the frame of this thesis.
Impedance bench measurements have been also performed on several LHC collimators, in particular the TCLD collimator.

The main external collaboration on this research are: CERN and INFN.

5. Products

Journal paper:
Arpaia, P., De Vito, L., Giordano, F., & Salvant, B. (2020). Estimating the impedance of a synchrotron component from beam-induced power loss. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 955, 163244.

Conference paper (peer reviewed):
Teofili, L., Marongiu, M., Migliorati, M., Giordano, F., Lamas, I., Nuiry, F. X., ... & Salvant, B. (2019, November). Analysis on the thermal response to beam impedance heating of the post LS2 proton synchrotron beam dump. In *Journal of Physics: Conference Series* (Vol. 1350, No. 1, p. 012169). IOP Publishing.

6. Conferences :

Presentations made:
Poster presentation at the: PhD school Italo Gorini.
Place: Napoli, Italia.
Dates: 3-6/09/2019
Number of posters: 1

Francesco Giordano

Prof. Pasquale Arpaia

[1] G. Apollinari, O. Brüning, T. Nakamoto, L. Rossi, High luminosity large hadron collider hl-lhc, Tech. rep., CERN (2017).
[2] W. Herr, B. Muratori, Concept of luminosity, Tech. rep., CERN (2006).
[3] C. Zannini, G. Rumolo, G. Iadarola, Power loss calculation in separated and common beam chambers of the lhc, Tech. rep., CERN (2014).
[4] A. Mostacci, Beam-wall interaction in the lhc liner, Ph.D. thesis, Rome U. (2001).
[5] G. Rumolo, A. Ghalam, T. Katsouleas, C. Huang, V. Decyk, C. Ren, W. Mori, F. Zimmermann, F. Ruggiero, Electron cloud effects on beam evolution in a circular accelerator, Physical Review Special Topics-Accelerators and Beams 6 (8) (2003) 08100.
[6] L. Palumbo, V. G. Vaccaro, Wake field: impedances and green's function, Tech. rep., CERN (1987).