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 – Third 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)
   - "Machine Learning" provided by: Marco Aiello, Anna Corazza, Diego Gragnaniello, Francesco Isgrò, Roberto Prevete, Francesco Raimondi, Carlo Sansone. (5)

3. Credits summary

	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	14	0	14					14	5				5			5	43	30-70
Seminars	5.5	5	0	0.5		0		5.5	5	0	5	0	0	0	0	5	0							0	10.5	10-30
Research	30.5	0	2	7.5	7	4	10	30.5	41	10	0	10	7	6	8	41	55	10	10	10	5	10	10	55	126.5	80-140
	60	19	8	8	7	8	10	60	60	10	19	10	7	6	8	60	60	10	10	10	10	10	10	60	180	180

Credits adjustments.

4. Research activity

Title: Simulation Analysis and Machine Learning Based Detection of Beam-Induced Heating in Particle Accelerator at CERN

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 are:

a. Heating detection from pressure measurements

   Machine learning models were developed to detect heating from pressure measurements in synchrotron colliders. These results allow to analyse all the pressure measurements in the time available between two consecutive machine runs. Due to the prevalence of noise and the diversity of the behaviours, simple heuristic-based techniques do not achieve high performance. To overcome the limits of simple heuristic-based algorithms, several machine learning models have been trained, tested and compared with an heuristic-based approach which is used as base-line. In particular, it is shown for the case of the Large Hadron Collider (LHC) that machine learning models reached better performance both in precision and recall scores with respect to the baseline. The work has been published on NIMA journal.

b. Two-beam power loss

   Electromagnetic simulations were used to benchmark recent theoretical models and assess their possibility to compute the two beam power loss. It is shown how beam-induced power loss can largely differ from the single beam case when two beams are present in the same component. Simulation studies have been done in the case of a resonant pillbox cavity. This benchmark also allowed simulating cases, for which the lumped impedance assumption of the available analytical formula may not be valid anymore.

c. 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, Bregliozzi G, Giordano F, Prevete R, Salvant B, et al. Machine learning for beam dynamics studies at the CERN Large Hadron Collider, Nuclear Instruments and Methods in Physics Research, 2020. DOI:10.1016/j.nima.2020.164652.

Arpaia P, Giordano F, Prevete R, Salvant B. Machine Learning-based Heating Detection from Pressure Measurements in the CERN Large Hadron Collider, Nuclear Instruments and Methods in Physics Research, 2021. DOI: 10.1016/j.nima.2020.164995.

Teofili L, Arpaia P, Giordano F, Lamas I, Rumolo G, Salvant B, Zannini C, Migliorati M. Wakefunction and Impedance Determination For Two Counter-Moving Particle Beams, accepted for publication on Physical Review Accelerators and Beams, 2020.

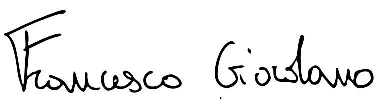
Quartullo D, Arpaia P, Biancacci N, Giordano F, Lamas Garcia I, Mostacci A, Palumbo L, Redaelli S, Salvant B, Teofili L, Migliorati M. Electromagnetic characterization of the crystal primary collimators for the HL-LHC, submitted to Nuclear Instruments and Methods in Physics Research, 2020.

6. Conferences :

Presentations made:
Poster presentation at the: AMLD conference.
Place: Losanna, Svizzera.
Dates: 25-29/01/2020
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).