Università degli studi di Torino

SCUOLA DI SCIENZE DELLA NATURA

Corso di Laurea Magistrale in Fisica

Tesi di Laurea Magistrale

TESTING OF THE TD26 TYPE CAVITY UNDER BEAM LOADING FOR THE CLIC PROJECT

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Considerate la vostra semenza:
fatti non foste a viver come bruti,
ma per seguir virtute e canoscenza

Dante, *La Divina Commedia*
Canto XXVI

Abstract

A new generation of colliders capable of reaching TeV energies is under development nowadays, and to succede in this task is necessary to show that the technology for such machine is available. The CLIC project is one of the most advanced design among the possible lepton colliders, and is formed by two normal conducting LINACs. To reach such high energies are necessary accelerating structures carrying gradient beyond 100MV/m and one of the biggest limitations is developing accelerating structures that present a sufficient low occurrence of vacuum arcs. This is pursued both with the design and the *conditioning*, which is the process of increasing the resilience to vacuum arcs of a structure using repetitive RF pulsing sessions.

The focus of this work is on the breakdown rate testing of the TD26 type cavity with and without beam presence inside. At CERN this test has been carried out on the cavity installed in the *dogleg* line in the CLIC-test-facility 3 (CTF3), and connected on the RF side to the X-band test stand 1 (Xbox1).

Other peculiar properties of the operation have been studied also, such has beam-induced RF generation into the cavity after the breakdowns, breakdown migration, ...

Italian abstract

(Translate once you have the ok to the english one)

Contents

Chapter 1

Introduction

Particle accelerators occupy a key role both in fundamental research and in all the applications and industrial processes that uses technology and processes developed initially for the physical research. E.g. at the moment there is a huge demand of high brilliance light sources, that are fundamental to inquire all the phenomena which take place at the nanoscale. In this perspective keep developing the accelerators for the physical research is a fundamental requirement to assure that the cutting-edge technology of today turns into the labware of tomorrow for all the other sciences, in addition of the contribution that pursuing the fundamental research can give to our understanding of the microscopic world.

On the particle physics side the observation of the Higgs Boson represents one of the milestones in the achievement of a fully predictive theory of the behaviour of the fundamental constituents of the matter, and was made possible by the construction of the *Large Hadron Collider* at CERN[1, 2, 3]. However the full understanding of the physics at the particle scale still needs to be achieved. Partially this will be realised with the increase of the collision energy of the LHC, but also the International Committee for Future Accelerators (ICFA) consider that the results of LHC needs to be complemented by the results of a lepton collider in the TeV-range[4].

The reason of this decision is that according to the standard model the hadrons are particles composed by quarks, that are continously interacting exchanging gluons. This peculiarity cause the collision at high energy not to be between the hadrons themselves, but within the quarks that are composing them. In addition, there energy of the quarks are distributed statistically, so it's not possible to know in advance which will be the energy of the collision. On the other hand, the leptons are punctual particles, so the interaction is directly involving the two bullets themselves, and the number of possible processes that can take place is definitely smaller. This behaviour of particles of different kinds makes hadron colliders *machines for discovery*, because involve all the possible processes that can take place, and the lepton machines *machines for precision*, because the reduced number of possible processes guarantees the observation of the events of interest much easier.

In a collider the probability of observe a particular interaction process is given by

$$P = \mathscr{L}\sigma$$

where σ is the process cross-section, which depends by the physics, and $\mathscr{L}$ is the luminosity, which depends entirely by the machine. Therefore the figure of merit when it comes to talk about accelerators is the luminosity, which is given by

$$\mathscr{L} = H_d \frac{N^2}{\sigma_x \sigma_y} n_b f_r$$

where H_d is a correction factor, N is the number of particles per bunch, σ_x and σ_y are the beam dimensions in the horizontal and vertical plane, n_b is the number of particle per bunch and f_r is the collision frequency of the bunches.

Then becomes obvious try to reach the highest luminosity possible since the events that are going to be studied are rare. This is realised using two kinds of machines:

- linear accelerators (LINACs): present a low repetition frequency, typically lower than hundred of Hz and the beam is passing just once to be accelerated through the machine.
- circular accelerators (typically synchrotrons): have a higher repetition frequency, up to tenth of KHz, and are keeping the particle beam in orbit for many turns, so can accelerate it over a long period of time

The key issue in the realisation of a lepton circular collider is the emission of synchrotron radiation, and is known that the power irradiated by a single particle in a circular machine scales according to the law

$$P \propto \frac{1}{\rho^2} \frac{E^4}{m_0^4}$$

where ρ is the bending radius of the machine, E is the particle energy and m_0 is its rest mass. As can be noted in the table 1.1, the energy loss per turn is a relevant fraction of the beam energy, e.g for the LEP machine over than 3 GeV were lost per turn, while the record energy per beam was 104.5 GeV.

To solve the issue the development of new lepton colliders is so focusing on two different solutions:

1. Use muons instead of electrons: this approach has to deal with the short life of muons, which is roughly $2\mu s$ in the laboratory frame
2. Limit the losses caused by synchrotron radiation, or increasing the bending radius or abandon the circular topology for the linear one

Also has to be noted that the former technology is rather new and needs to still be fully developed, while the latter profits of the progresses achieved in the last half century mainly in SLAC and KEK on the LINAC technology.

Parameter	LEP2	FCC-ee	CLIC		ILC
Centre of mass energy $[GeV]$	209	350	500	3000	500
Peak luminosity $[10^{34}\,cm^{-2}\,s^{-1}]$	0.012	1.3	2.3	5.9	1.8
Total lenght $[km]$	26.7	100	13	48.4	31
Loaded acc. gradient $[MV/m]$			80	100	31.5
Bunch population $[10^9]$	105	170	6.8	3.72	500
Bunch spacing $[ns]$		4000	0.5	0.5	554
Number of bunches	4				1312
Collision rate $[Hz]$			50	50	5
$\epsilon_x^* \,/\, \epsilon_y^*\,[\mu m]/[nm]$			2.4/25	0.66/20	10/35
$\sigma_x^* \,/\, \sigma_y^*\,[nm]$		3600/70	202/2.3	40/1	474/5.9
Energy loss per turn $[GeV]$	3.34	7.55	-	-	-
Power consumption $[MW]$	3.34	7.55			163

Table 1.1: Comparison of two circular machines, LEP[5] and FCC-ee[5, 6] and the two projects for linear machines, the fist and last stage of the CLIC implementation [7] and the final stage of ILC[8]

In this perspective a number of project are under study at the moment, of wich the most ambitious are FCC-ee,*Future Circular Collider*, ILC, *International Linear Collider*, and CLIC, *Compact Linear Collider*. The first one consist in a circular collider which is supposed to be placed in a 80-100 km long tunnel before of the installation of the FCC-hh, the other are LINACs even if based on completely different technologies and solutions. A comparison of the features of these projects in the final stage is presented in the underlying table, and also precedent machines, LEP and SLAC, are presented for comparison

Furthermore a recent interest arose on more compact technologies, e.g. plasma acceleration techniques, but the reliability of such designs still need to be proven in the perspective of creating a fully functional machine that goes beyond the prototype.

1.1 The CLIC poject and the CTF3 facility

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1.1.1 The two beam acceleration concept

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1.1.2 Physics at CLIC

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Chapter 2

Theoretical background

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2.1 Vacuum arcs

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2.1.1 General background

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[1] first foot note
[2] another foot note

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2.1.2 Applications in particle accelerators

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2.2 Accelerating structures theory

2.3 Signal processing techniques

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2.3.1 Interaction with the RF

2.4 Signal processing techniques

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Chapter 3

Experimental setup

3.1 The TD26 accelerating structure

3.2 The LINAC and the Dogleg

Bullet list example

- first point
- second point
- third point

3.3 RF power generation

Enumeration example

1. first point
2. second point
3. third point

Description example

first descr first point

second descr second point

third descr third point

3.4 DAQ system

3.4.1 Hardware

3.4.2 Online selection of the events

describe the online, but then the offline is in the next chapter
. . . but you can also build nested lists

- first point
  - first point
  - second point
- second point
- third point

3.5 Other systems

mention here thermal systems for the structure and something else ???

Chapter 4

Data analysis tools

4.1 Offline selection of the events

A tabular example

Tit1	Tit2
el1	el2
el1	el2
el1	el2

but tabulars cannot be captioned ! (are in text elements)

Using the table environment, the caption works ! BUT BECOMES FLOATING OBJECTS (in fact is on the bottom of the page due to no more text inserted afterwards).

Same thing for the figure environment

4.2 Time and space positioning of the breakdowns

4.3 Migration of the breakdowns

4.4 Beam induced RF

4.5 Neural network based events selection

1	2	3
4	5	6
7	8	9

Table 4.1: A simple table

Chapter 5

Results and future developments

5.1 Results

A figure example, with text in line (NO CAPTION)

A figure example, with floating object and caption

5.2 Further developments

Figure 5.1: the logo of UniTo

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Bibliography

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