COMPENSATION OF FAILURE OF RF CAVITY IN CW SUPERCONDUCTING LINAC*

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Abstract

Project-X is the proposed high intensity proton facility to be built at Fermilab, US. Project-X facility consists of superconducting (SC) Linac which will be operated for 1mA average current with a pulse current of 5mA in continuous wave (CW) mode. The operation at CW mode puts high tolerances on the beam line components, particularly on radiofrequency (RF) cavity. The failure of RF cavity is very critical especially at low energy where space charge effect is dominant. It results in mis-match of the longitudinal dynamics of beam with the following sections due to different transition energy which causes emittance dilution, and ultimately results in beam losses. Thus, it is necessary to retune the beam dynamics in particular section by varying the field amplitude of following cavities and focusing elements to achieve the smooth beam propagation in Linac. This paper describes the results of study performed for the failure of RF cavity & its compensation.

INTRODUCTION

Project-X is a high intensity multi megawatt (MW) facility (Fig .1) to be built at Fermilab [1].

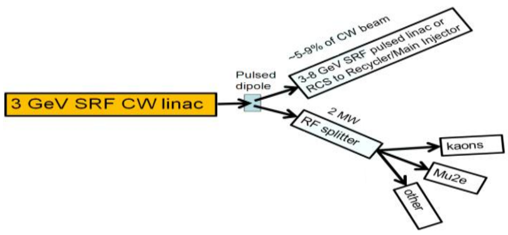

Figure 1: Project-X configuration

The proposed facility is based on 3 GeV, 1mA CW SC linac. The schematic of baseline configuration of the linac is shown in Fig. 2. It includes an ion source which provides 5 mA pulsed beam of H^- ions. The beam is accelerated through the RFQ which is operated at room temperature at 325 MHz frequency. The RFQ is followed by Medium Energy Beam Transport (MEBT) section which is used to chop the beam in order to get the time structure which is necessary to operate the different experiments simultaneously. The MEBT is followed by SC linac, which is segmented into two sections: low energy part and high energy part. The low energy section (2.5-160 MeV) uses three families of SC single spoke resonators i.e. SSR0, SSR1 & SSR2 which are operated at 325 MHz. The high energy section of the SC linac (160 MeV-3.0 GeV) uses two families of 5 cell SC elliptical shape cavities i.e. β=0.61 and β=0.9 which are operated at 650 MHz.

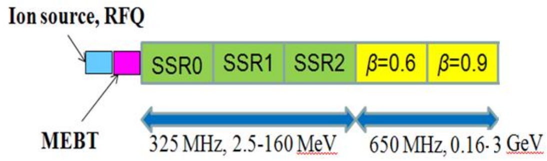

Figure 2: Acceleration scheme

Operation of the SC linac at CW mode puts high tolerances on beam transport elements, particularly on RF cavities. Failure of the beam transport elements like cavity, solenoid and quadrupole alters the focusing period of the beam, resulting in a mis-match of the beam with the subsequent sections. This, in turn, causes beam losses. In some cases, failure of the beam transport element results in complete beam loss and it becomes necessary to replace this element for nominal operation of the machine. These beam interruptions reduce the beam availability for the different experiments. To achieve high performance and hence reliability of the machine, it is necessary to include this scenario during the design of the SC linac lattice. It should have a capability that RF cavity or magnet failure could be compensated by using the neighbouring elements.

FAILURE OF RF CAVITY

Various reasons affect the nominal operation of a RF cavity like failure of a tuner, mechanical damage of RF cavity during installation etc. Calculations have been performed to study the effects of failure of RF cavities, especially in the low energy section of the SC linac where beam is non-relativistic and space charge effect dominates. Due to cavity failure, significant deformation in the longitudinal phase space takes place, which in turn induces strong envelope oscillations and halo formation. Through the coupling, a significant enhancement of halo formation in the transverse phase space is also introduced. Analysis is done to compensate the effects of failure of RF cavity with minimal user disruption. Neighbouring elements are retuned in order to achieve smooth beam propagation through the linac. In this paper, we demonstrate the compensation of failure of RF cavity. The most critical case of failure of first cavity in SSR0 section is considered.

Simulation is performed using multi-particle tracking code Tracewin (PARTRAN) [2]. Beam envelope and normalized r.m.s. emittance are shown in Fig.3 for tracking of 10000 macro particles through SC linac lattice up to the end of 325 MHz section without any failure.

*Work supported by IUSSTF and US DOE
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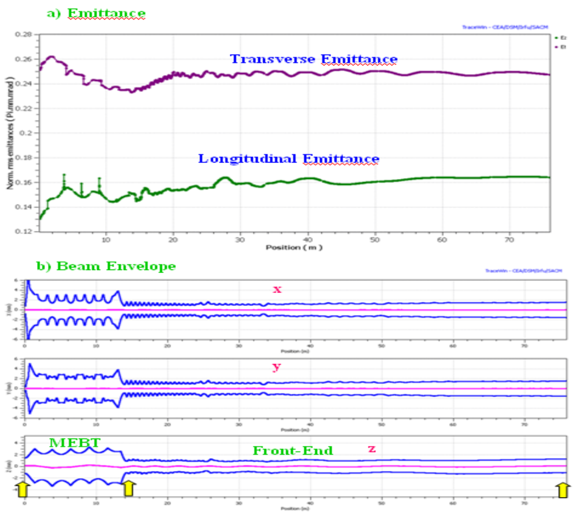

Figure 3: Longitudinal and Transverse (a) Emittance and (b) beam envelope for tracking through the SC linac lattice without any beam transport element failure.

Fig. 4 shows the beam profile (zoomed region around the failed cavity) through the SC linac lattice in case of the failure of first cavity in SSR0 section. It can be seen that longitudinal profile of the beam blows up which results in emittance dilution and increase in beam losses. However, transverse profile of the beam remains unchanged.

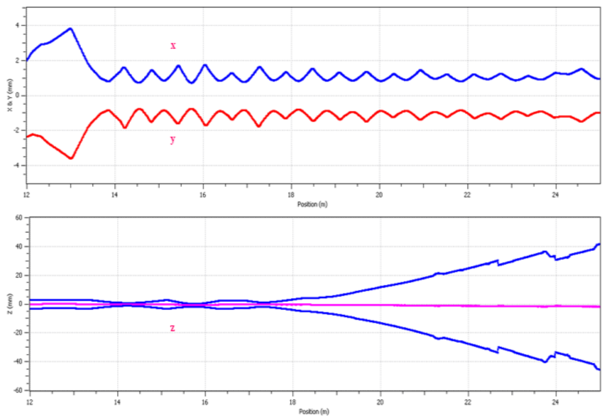

Figure 4: Beam profile in transverse plane (top) & longitudinal plane (bottom) in presence of a failed cavity before compensation.

Thus, in order to operate the SC linac with failed element (RF cavity in this case) it is necessary to compensate this effect. In the first order compensation scheme, adjacent elements in the vicinity of failed elements are re-adjusted (RF phase and field amplitude of RF cavity and field gradient of the solenoid and quad) to achieve smooth beam propagation through the SC linac. All the cavities in the SC linac are operated with independent RF sources, which provide the freedom of varying the RF phase and field amplitude of each cavity separately. Fig. 5 shows the beam profile after compensation of the failed cavity. Neighbouring beam transport elements are also highlighted which are re-adjusted to achieve smooth beam propagation. Two cavities (referred as Gaps), two solenoids and a quad triplet in the upstream MEBT section, one solenoid in the same period of the failed cavity, and one solenoid and one cavity in each of the two downstream periods (after the failed cavity) are used to re-tune the beam propagation. As shown in Fig. 6, emiitance dilution is minimized by this compensation .

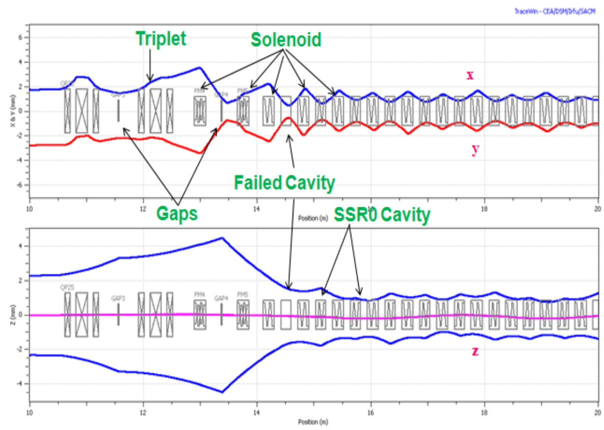

Figure 5: Beam profile in transverse plane (top) & longitudinal plane (bottom) in presence of a failed cavity after its compensation.

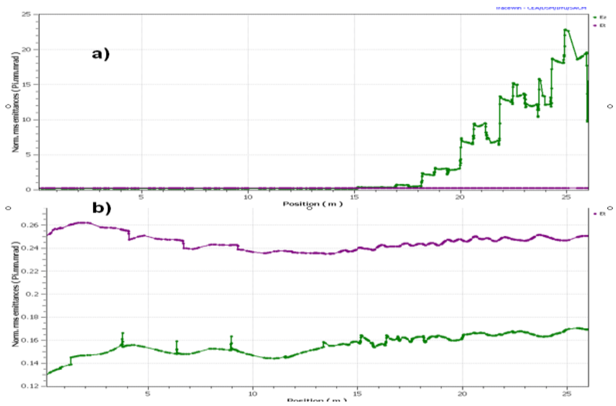

Figure 6: Longitudinal (green) and transverse (magenta) emittance dilution for two cases: (a) without compensation and (b) with compensation.

CONCLUSION

The method of compensation of failed RF cavity is demonstrated. It is shown that presented lattice can be operated even with the failure of first, most critical, RF cavity in SSR0 section after compensation.

REFERENCE

[1] S.D. Holmes "Project X: A Multi-MW Proton Source at Fermilab", IPAC 2010.
[2] R.Duperrier et al. "CEA Saclay codes review for high intensity linac", ICCS conference, Amesterdam, 2002.