Optimal Power Consumption during the Charging of Superconducting Cavities using Drain Voltage Modulation of Solid State Power Amplifiers

Long Hoang Duc, Anirban Bhattacharyya, Jorgen Olsson and Dragos Dancila
FREIA Laboratory - Uppsala University - Sweden
long.hoang@angstrom.uu.se and dragos.dancila@angstrom.uu.se

I. INTRODUCTION

The radio frequency cavities, used to accelerate charged particle beams, need to be charged to a nomial voltage after which the beam can be injected into them [1]. The nomial voltage is provided by means of RF power sources considering such as: Klystrons, Tetrodes, Inductive Output Tubes, and Solid State Amplifiers (SSAs). A step charging profile is used as a conventional procedure in order to fill such cavities to the nomial voltage. During the initial time of such filling process using the step input, a large amount of RF power fed into the cavity is reflected as can be seen in the below figure. A novel strategy was proposed for cavity filling by shaping the temporal profile of the RF signal applied to a cavity in order to significantly minimize such reflection energy [1]. In this paper, we introduce the solid state developement at FREIA laboratory [2] using the optimal charging scheme. The theoretical results are also presented.

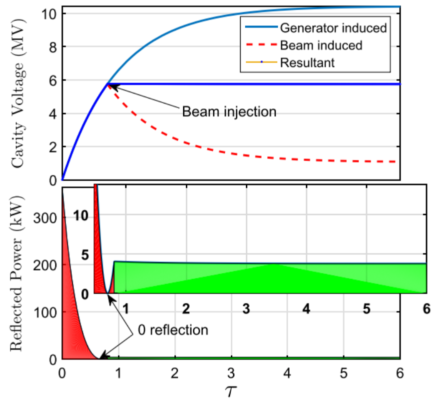

Fig. 1: The reflected power during the step filling, before beam injection is given by the red region, and the power falls exponentially as filling continues. The aim of the proposed scheme is to minimize the region shaded in red.

II. RESULTS

The proposed scheme is demonstrated for particular parameters of the superconducting spoke cavities of European Spallation Source (ESS) [3]. For such cavities the power required from the RF power sources is calculated to be 400 kW with 4% duty cycle (3.5 ms at a rate of 14 Hz) [2]. In order to deliver 400 kW output power, the solid-state based RF source is combined using several hundreds of SSPA (solid state power amplifier) modules, as publised in [4]. Applying the optimal scheme for such RF power source, the RF power profile and the reflected power are obtained as in Fig. 2. The reflected power is as small as about 8 kW at start, compared to approximate 400 kW in step filling, and then descreases exponentially as filling continues. The SSPA module achieves

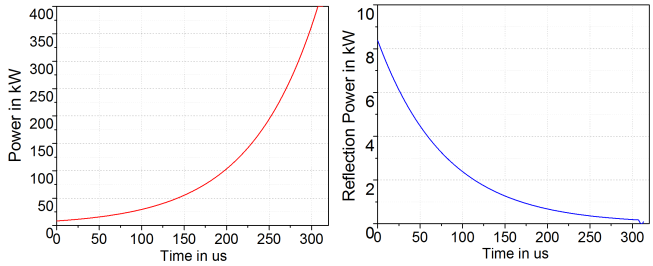

Fig. 2: The power from generator starts filling with very low power, then increases exponentially. Consequently, the reflection power is much smaller compared to step filling in Fig.1.

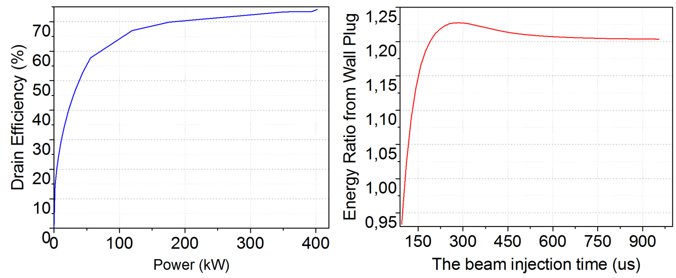

Fig. 3: (a) The solid state based RF power source efficiency versus power using the SSPA modules [4]. (b) The ratio between energy drawn from wall plug by the step filling and the optimal filling.

optimum efficiency when it is operated in compression. The dynaic effiency of the 400kW solid-state based RF source can be improved by using drain voltage modulation, in which the drain voltage of each module is controlled following an optimal shape. The presented system exhibits as high as 70% in efficiency, and about 24% of energy from wall plug can be saved using the optimal scheme with the beam injection time of approximate 300 us.

REFERENCES

[1] A. K. B. et al, "Minimization of power consumption during charging of superconducting accelerating cavities," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 801, no. Supplement C, pp. 78 – 85, 2015. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0168900215008852

[2] D. D. et al, "A compact 10 kw solid-state rf power amplifier at 352 mhz," *Journal of Physics: Conference Series*, vol. 874, no. 1, p. 012093, 2017. [Online]. Available: http://stacks.iop.org/1742-6596/874/i=1/a=012093

[3] S. Peggs, European Spallation Source, Tech. Rep. ESS-2013-001, April, 2007.

[4] L. Haapala, A. Eriksson, L. H. Duc, and D. Dancila, "Kilowatt-level power amplifier in a single-ended architecture at 352 mhz," *Electronics Letters*, vol. 52, no. 18, pp. 1552–1554, 2016.