RF Power Predictor for SPS 200MHz Cavities

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Introduction and Motivation

To achieve the higher luminosity of future high intensity beams desired in the High Luminosity Large Hadron Collider (HL-LHC), the LHC injector upgrade (LIU) project involved upgrading the configuration of the SPS main accelerating 200MHz travelling-wave structures (TWS) (see Fig 0) and replacing the analog cavity controllers that drive amplifiers to a fully digital system. The new SPS 200MHz TWS consists of 4 3-section structures driven by existing Philips and Siemens tube amplifiers, as well as 2 4-section structures driven by new solid-state amplifiers with much higher power. This new configuration should provide higher total voltages for the same power while having a lower total impedance, thus allowing to have higher available voltages with increasing intensity (i.e. higher number of protons per bunch, ppb), as shown in Fig 1. To reach LIU goals, the performance of the SPS RF system needs to be pushed to the limit. To that end, a tool for the calculation of the RF power required for acceleration of different beams in the SPS, before extraction into the LHC, is being developed. Once comparisons of the calculated data with measurements are found to be successful, the tool will be used in machine operation and machine development studies to better understand RF system capabilities, as well as optimize equipment protection & beam operation. [1]

Fig 0. The SPS accelerating structure. [2]

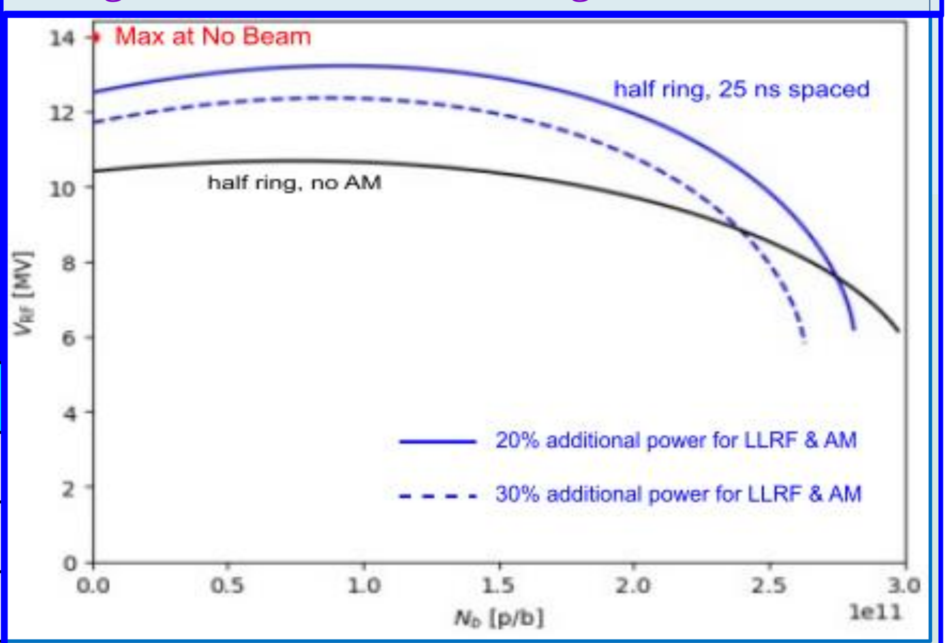

Fig 1. Available total voltage with increasing number intensity (protons per bunch).

Fig 2. A 11-cell, parallel stem, accelerating section. [2]

System	Peak (with AM)	CW (<10 s)	Coast (> 20 s)
3-sec structures (Siemens)	800 kW	600 kW	300 kW (400 kW)
3-sec structures (Philips)	1.0 MW (1.05 MW)	600 kW	300 kW (400 kW)
4-sec structures (Thales)	1.6 MW	800 kW	500 kW
Transmission lines	1.6 MW	750 kW	500 kW

Table 1. Power limits in different systems after LS2.

Voltage to Power Conversion & Power Balancing

To ensure the SPS becomes capable of delivering the high intensity beams in the future HL-LHC, during the long shutdown 2 (LS2) the SPS main 200 MHz cavity structures were reconfigured from 2 4-section and 2 5-section structures into 4 3-section structures and 2 4-section structures. Each section consists of 11 parallel stem style cells (see Fig 2) and n numbers of them are joined to form a n-section structure. The Power P_n required to have a voltage V_n available in one of these TWS is given by [3]

$$P_n = \frac{1}{Re\,(\alpha_n)}\left[\frac{V_n}{RL_n^2} + \frac{RL_n^2 I_{RF}^2 |\alpha_n|^2}{64} + \frac{V_n I_{RF} |\alpha_n| \sin(\varphi_s - \arg\alpha)}{4}\right],$$

where L_n is the length of a n-section structure, α_n is a parameter related to the phase slip τ_n and relativistic β:

$$\alpha_n = \left[\frac{\sin(\tau_n/2)}{\tau_n/2}\right]^2 - j\,\frac{2(\tau_n - \sin(\tau_n))}{\tau_n^2}, \quad \tau_n = \frac{2\pi L_n}{|v_g|}(f_{RF} - f_{0,n})(1 - \frac{v_g}{\beta c}).$$

The 4 3-section structures are driven by 2 Siemens and 2 Philips power plants, while the 2 4-section structures are driven by the 2 new Thales ones. The different power plants are able to provide different maximum power, while longer cavities produce more voltage proportional to their length. Power balancing should be done to exploit the power plants by requesting amounts of power proportional to their respective maximum. This is simply solving a system of simultaneous equations: $\frac{P_{n,i}}{P_{n,i,max}} = \frac{P_{n,j}}{P_{n,j,max}};\ i \neq j,\ \&\ \sum_{n,i} V = V_{tot}$, where $P_{n,i,max}$ is the max possible power from the plant. The LS2 upgrades also enables amplitude modulation (AM) for any SPS cycle meaning the power is modulated such that the higher power is provided for the turn length where there is beam and very little power otherwise; this is relevant and necessary for LHC and AWAKE type beams to reach higher ppb (while not so much for proton fixed target (PFT) beams where almost whole ring filled).

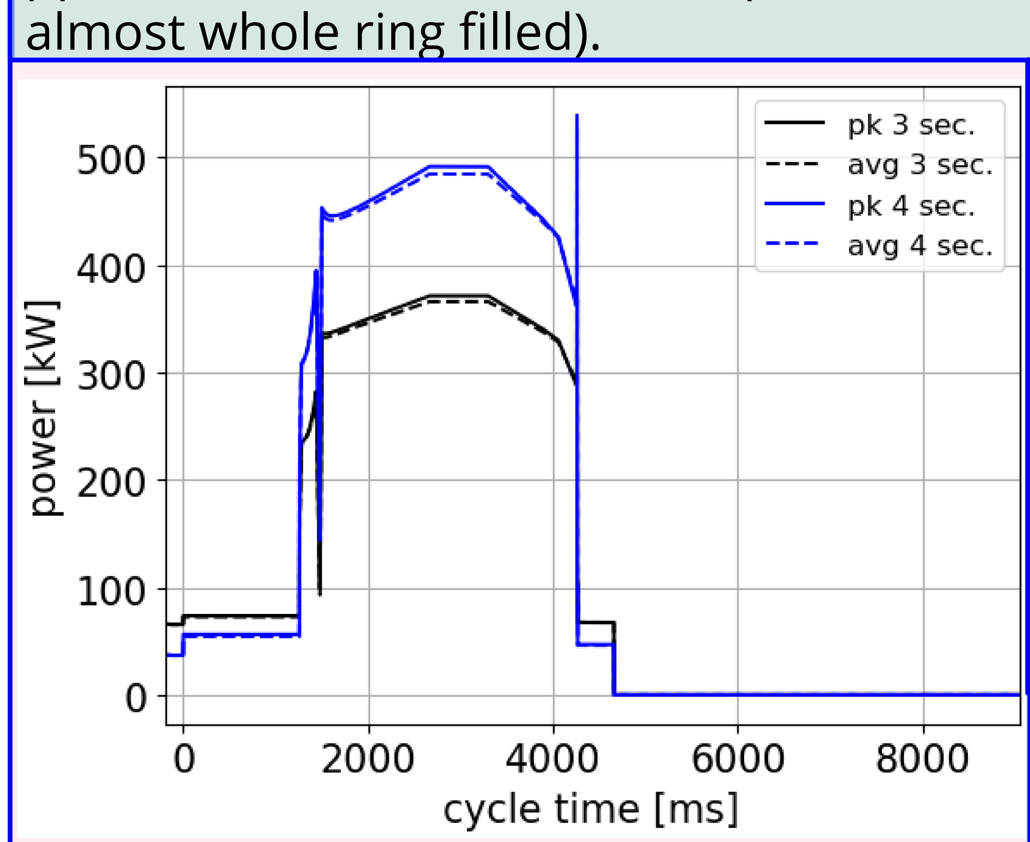

Fig 5. Peak & Max Powers computed using the SFTPRO momentum & voltage programs

Present Calculations & Preliminary Results

A script to calculate peak and average power for the different beams in the SPS (such as PFT, LHC, AWAKE types) has been written following the power dependence on voltage, impedance, beam current, RF frequency as related by the equations presented. Power balancing through optimum voltage partitions has also been considered in the calculations. The momentum, stable phase and voltage programs for SPS cycles are retrieved from LSA application software that communicates directly with the machines and input into the script along with other necessary parameters. Example plots of the momentum and voltage programs along with the resulting power calculations for the SPS PFT beam (SFTPRO) are presented in Figs. 3, 4 & 5. Similar calculations have been carried out for single bunch (SB) AWAKE beams and LHC (both SB and multi-bunch) beams.

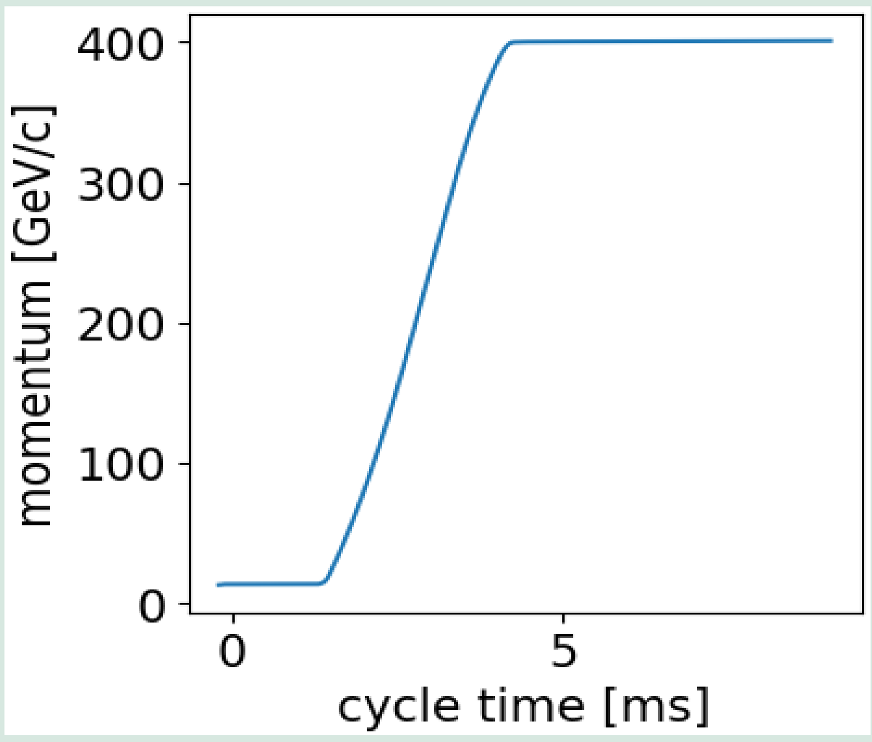

Fig 3. Momentum program for SFTPRO.

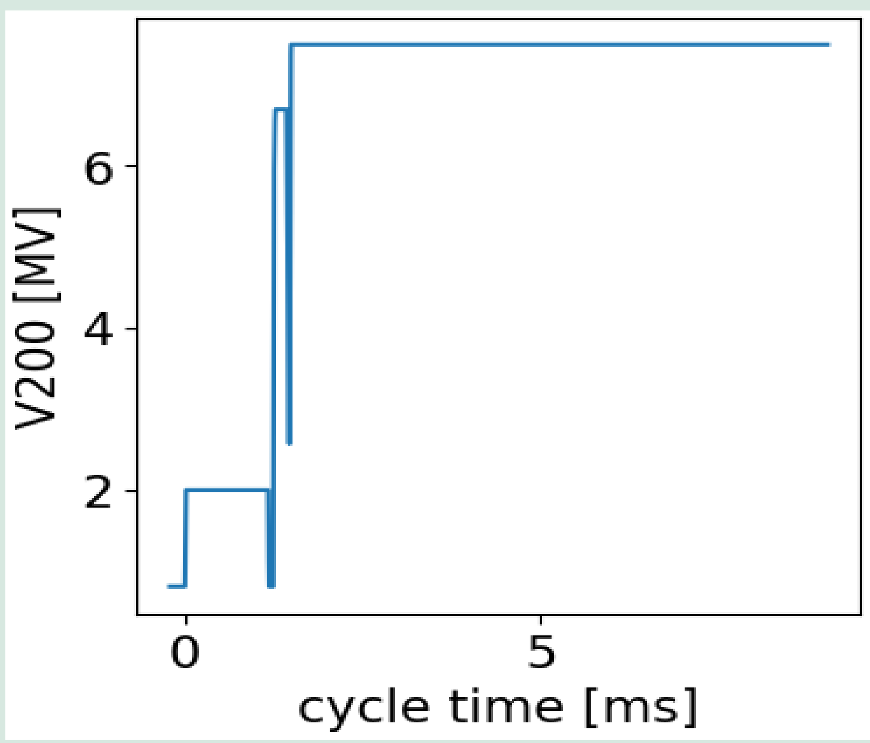

Fig 4. **Voltage** program for SFTPRO.

Concluding Remarks & Outlook

A script to compute the peak and average power required to have a available voltage for different beams in the SPS has been written and is being tested. To push the SPS to the limits while at the same time ensuring all constraints are considered and agree with reality, comparisons with real measurements will be done. The script will also be developed further to be more user friendly such as modified into a GUI such that machine operators along other MD scientists will be able to use the tool easily in their work if desired. The final developed tool will aim to be capable to communicate with LSA directly in real time such that the peak and average powers can be calculated instantly with changes with machine configuration when making MDs as well as for normal operations. These features shall allow to truly test the SPS performance in the limits in real time and ensure HL LHC goals are truly achievable.

References

[1] Operation and protection of the SPS RF power system for the various beams after the LIU upgrades; [2] Phys. Rev. Accel. Beams 22, 101002; [3] G. Dôme, "The SPS Acceleration System Travelling Wave Drift-tube Structure for the CERN SPS", 1977.

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