PHASE LAW OF A HIGH INTENSITY SUPERCONDUCTING LINAC*

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Abstract

The importance of a proper phase law is recognized to tune the synchronous phase of each superconducting cavities of a high intensity proton superconducting linac such as the SNS linac. The factors to be optimized are 1) maximizing the longitudinal acceptance 2) better matching throughout the linac and 3) achieving maximum beam energy. The driving force behind this study is how to effectively control the large voltage fluctuation from cavity to cavity, achieving low beam loss and high beam quality.

INTRODUCTION

Recently many high intensity linacs have been designed or constructed like the SNS (Spallation Neutron Source) [1], and J-PARC (Japan) [2]. Part of the SNS linac is a pulsed superconducting linac (SCL) accelerating from 186 MeV to 1 GeV. There is a significant spread of the cavity field from cavity to cavity as shown in Fig. 1. Besides, there are cavities turned off for various reasons. If the synchronous phase is set to design values which assumes uniform cavity voltage, cavity field variation and off cavities lead to significant perturbation to the beam, potentially leading to beam loss. So the goal is how to 1) preserve beam quality, 2) minimize beam loss and 3) get as high beam energy as possible. In this paper, we report the important factors to be considered in achieving the three goals.

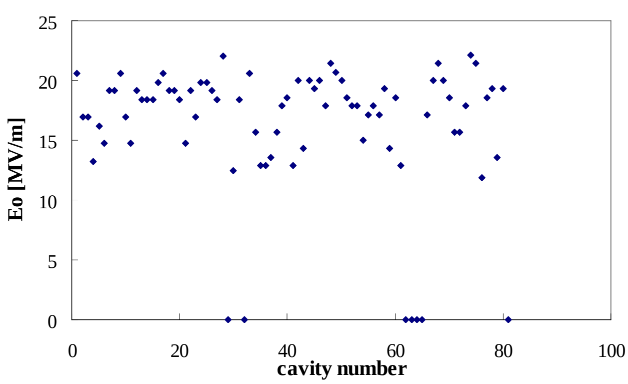

Figure 1: Plot of cavity field Eo vs. cavity number. Quite significant variation is observed besides that six cavities are off.

IT MATTERS HOW TO SET THE PHASE

Each superconducting cavity of the SNS linac is fed by individual klystron, leaving us a lot of freedom how to set the phase of each cavity. One approach is to vary the synchronous phase ϕ_s of each cavity to compensate the variation of Eo from cavity to cavity, hoping to provide smooth focusing across the superconducting linac. We call this method "Smooth Focusing Optics (SFO)" for the sake of convenience. The other approach is to fix the synchronous phase of most of the cavities to design values and vary the phase of a handful of carefully chosen cavities only. We call this method "Constant Phase Optics (CPO)". Figure 2 shows how the synchronous phase of each cavity is set for the two optics.

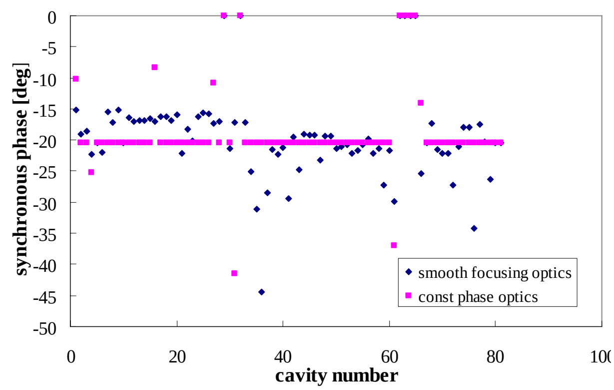

Figure 2: Plot of synchronous phase of the smooth focusing optics in blue and that of the constant phase optics in magenta. Phase of cavities that are off is set to zero in the plot.

Longitudinal Acceptance Matters

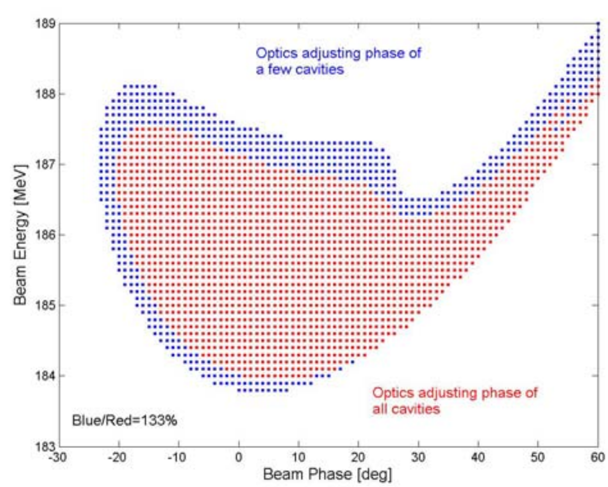

Figure 3: Longitudinal acceptance of the two optics. The constant phase optics in blue produces 33 % bigger acceptance than the smooth focusing optics in red.

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One of the primary advantages of setting the phase of each superconducting cavities according to the constant phase optics is that we can get bigger longitudinal acceptance, even though the output beam energy is the same (less than 0.5 MeV different). As shown in Fig. 3, the acceptance of the constant phase optics produces about 33 % bigger acceptance than the smooth focusing optics. The blue solid squares represent the acceptance of the constant phase optics and the red squares the smooth focusing optics.

At the end of each beam operations, survey of residual activation throughout the entire accelerator is routinely performed. Figure 4 shows the residual activation of the superconducting linac measured at 30 away. The 11/26/2007 120 kW run was performed with the "Constant Phase Optics (CPO)", while the 08/13/2007 run and 08/27/2007 run with 150 kW and 160 kW of beam power with the "Smooth Focusing Optics (SFO)". Radiation survey indicates that the residual activation of 340 kW run is comparable to that of 160 kW run.

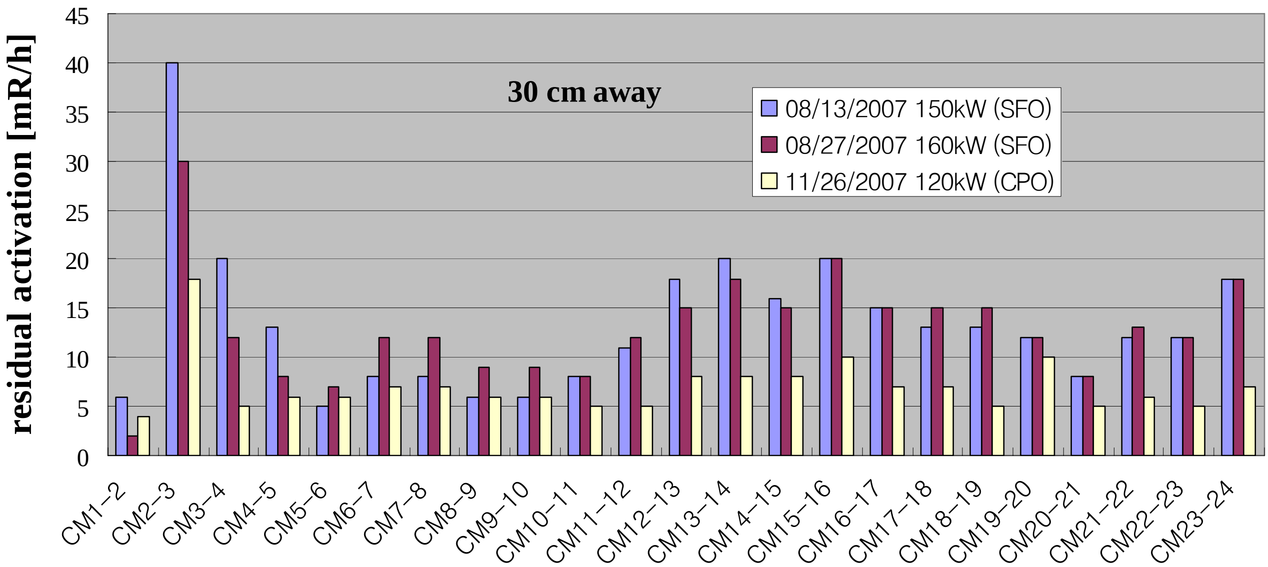

Figure 4: Plots of the residual machine activation 30 away after the beam operation for three different run periods. The 150 kW (08/13/2007) run and the 160 kW (08/27/2007) run used the "Smooth Focusing Optics (SFO)", while 120 kW (11/26/2007) run the "Constant Phase Optics (CPO)". CM1-2 means that between the cryo-module 1 and 2.

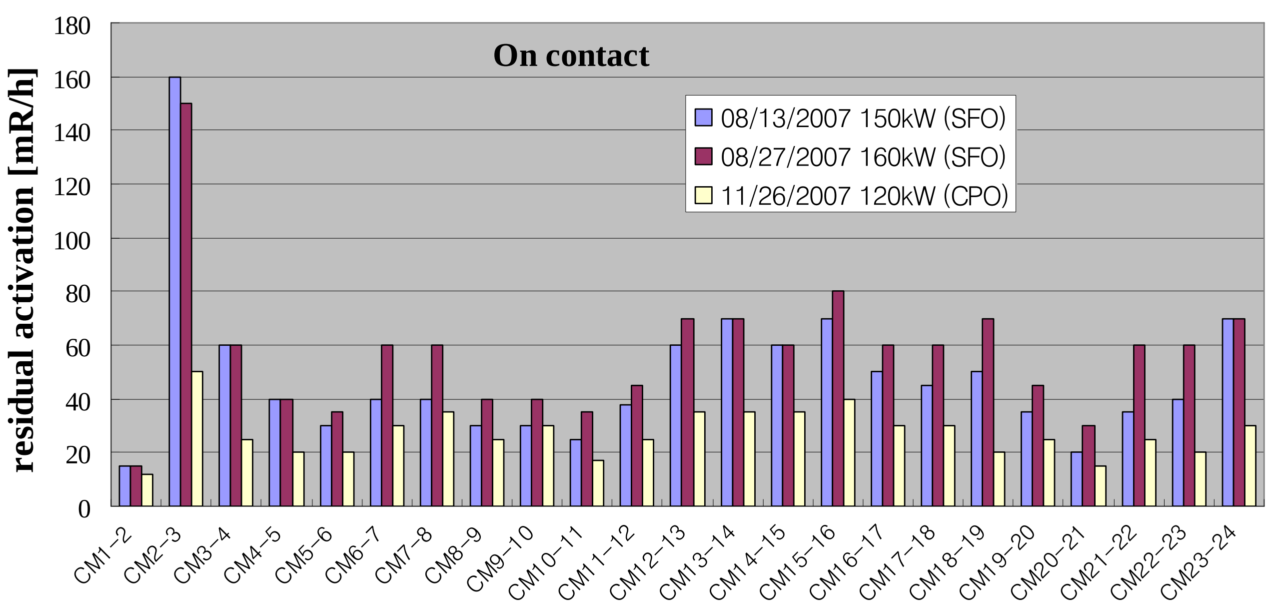

Figure 5: Plots of the residual machine activation on contact after the beam operation for four different run periods. The 150 kW (08/13/2007) run and the 160 kW (08/27/2007) run used the "Smooth Focusing Optics (SFO)", while 120 kW (11/26/2007) run the "Constant Phase Optics (CPO)".

Table 1: Cumulative Beam Power

	Cumulative beam power	Time lapsed for survey
08/13/2007	27970 kWh	40 hours
08/27/2007	25350 kWh	63 hours
11/26/2007	22450 kWh	49 hours

Table 1 lists the cumulative beam power delivered to the target in [kWh] and the time between the radiation survey and the production run for each period listed on the left.

Matching Matters

Matching is also an important factor as shown in Fig. 6. Without proper matching, the orientation of the acceptance may not line up with the beam distribution, more prone to spilling beam particles outside the rf bucket, even though the overall area of the acceptance may remain the same. The acceptance in Fig. 3 is for well matched case. It should be noted that the difference primarily in orientation and also in shape.

Figure 7 shows the Trace3D envelope profiles for the constant phase optics used in the November, 2007 run and for the smooth focusing optics used in the August, 2007 run. The cavity field and phase are shown in Figs 1 and 2. For these runs, six superconducting cavities were off. Judging from the longitudinal beam envelope, the longitudinal matching from the medium beta section to the high beta section is marginal for the smooth focusing optics used then.

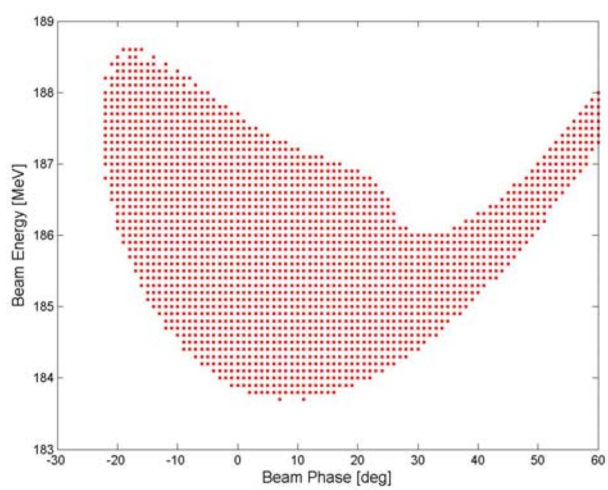

Figure 6: Plot of the longitudinal acceptance when the phase of all cavities are set to the design values without any matching.

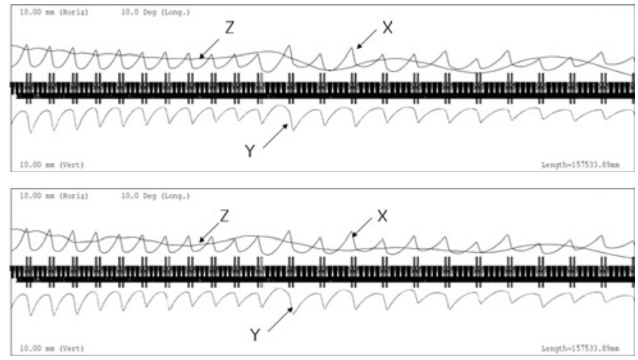

Figure 7: Trace3D envelope profiles for the smooth focusing optics (upper plot) and those for the constant phase optics (lower plot).

CONCLUSIONS

Study shows that it is important to get as big a longitudinal acceptance as possible while maintaining reasonable matching throughout the superconducting linac in order to minimize beam loss for the SNS superconducting linac.

REFERENCES

[1] J. Stovall et al., Proc. of 2001 Part. Accl. Conf., Chicago, USA, p. 446.
[2] Y. Yamazaki, Proc. of 2003 Part. Acc. Conf., Portland, USA, p.576.