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BEAM LOSS SUPPRESSION BY BEAM MATCHING IN KLYSTRONS

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Abstract

High power klystrons usually employ large cathodes to generate high currents which are compressed inside the gun to provide optimum beam sizes at the cavity section. We compress the beam by using electrostatic and magnetostatic focusing fields which are established by gun electrodes and external magnets respectively. The geometry of the gun electrodes and the external magnet is carefully designed to meet the matching condition which results in scalloping-free beam. We have established a systematic design procedures to achieve the beam matching condition at arbitrary beam sizes. In this article we report on the beam-matching design and simulation results with an example case of the 80-MW S-band klystron in the Pohang Accelerator Laboratory.

INTRODUCTION

If the beam in a high-power klystron (which requires beam current of several hundreds of amperes) is non-matched the beam envelope oscillates transversely as it propagates downstream. Electrons near the crests of the oscillation can, combined with the space-charge forces enhanced by the strong longitudinal bunching, be radially pushed to hit cavity gaps or drift-tube wall at the output cavity region. Furthermore strongly decelerated electrons at the output cavity gap are reflected back to the cathode which is most pronounced at the core of the beam waist where the potential depression is at maximum.

The problem is alleviated by making the beam envelope flat which is obtained by a carefully matching the beam from the gun to the downstream magnetic focusing system in a klystron. With insights gained from simple analysis based on the envelope equation [1] we have developed a systematic design procedure for the beam matching procedure [2]. The procedure is being used for designing matched beam for the 80-MW S-band klystrons in the Pohang Accelerator Laboratory (PAL). We utilize many commercial computer codes for the klystron design. Among them the CST TRK and PIC solvers are flexible and have proved useful in designing the PAL klystrons (with microperveance as high as 2) after cross-checking with the EGUN and the FCI codes.

COMPUTER SIMULATIONS

Figure 2 shows the setup for computer simulations with the TRK and PIC solvers. With the TRK we can simulate space-charge dominant beams from the gun to the collector (G2C) region. And the beam dynamics including the beam-to-cavity interaction is simulated by using the PIC solver but unfortunately it can't afford the G2C simulations and an initial particle distribution (PD) has to be prepared *a priori* and imported into it. We utilize the TRK to generate the PD and import it to the leftmost boundary of the PIC simulation setup as shown in Fig. 1.

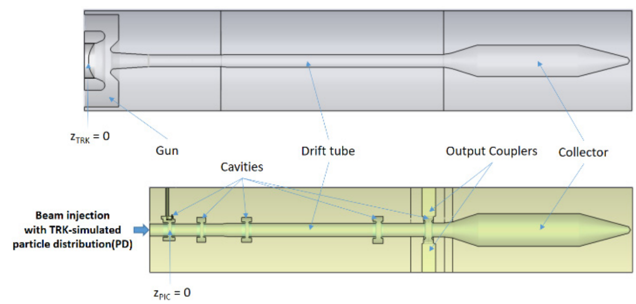

Figure 1: Setups for TRK(up) and PIC(bottom) simulations. Unlike the TRK the PIC does not include the gun into the simulation setup which results in significant errors in beam optics.

Figure 2 shows matched beams at various sizes together with the non-matched one for a comparison. G2C simulation with the EGUN yields similar result.

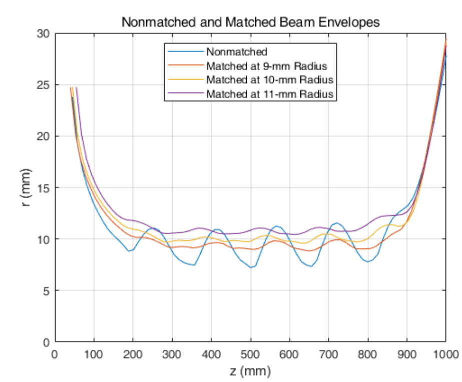

Figure 2: Non-matched and matched beam envelopes simulated by the CST-TRK.

We sample particle information at z_{TRK} = 150 mm in the TRK and transfer it to the beam-injection plane (z_{PIC} = 0 mm) of the PIC simulation setup. Beam profiles simulated by the PIC are shown in Fig. 3. Envelope oscillation in the non-matched beam (top figure) is suppressed in the matched one (middle figure). Bottom figure is slightly mismatched case at larger beam size.

One of the difficulties with the CST PIC is that, since it can't afford the G2C simulation, the beam should be injected to the leftmost boundary and some errors in the beam optics are inevitable. Moreover additional potential depression follows just after the beam is injected of which

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magnitude is significant (several tens of keV for a 400-keV, 500-A beam). We overcome the problem by additional optics tuning to yield beam profile similar to the TRK simulation. Example result is shown in Fig. 4.

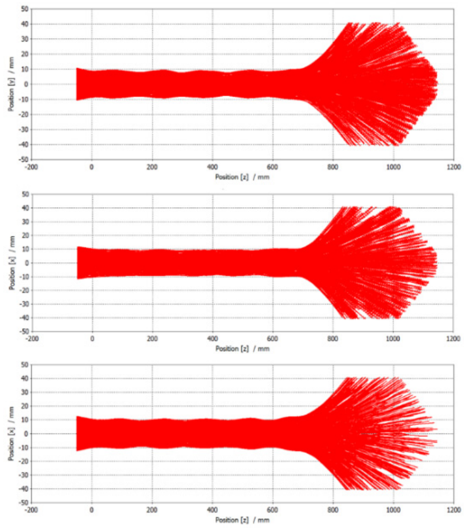

Figure 3: Non-matched (top) and matched (middle) beam profiles simulated by the CST-PIC. Bottom figure shows slightly mismatched beam at larger beam size.

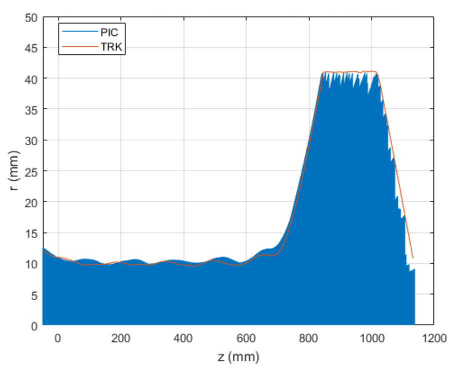

Figure 4: TRK-simulated beam envelope and PIC-simulated beam profile. In the PIC simulation, the injection boundary is at z = -50 mm which is 150-mm downstream from the cathode.

Figure 5 shows the longitudinal momentum profiles simulated by the TRK and PIC solvers. Due to the unrealistic potential depression occurring just after the beam injection, the PIC profile shows significantly lower momentum than the TRK. It is corrected by comparing the PIC momentum profiles with the TRK at a z position where the additional potential depression following the beam injection disappears. We scale up the initial momentum distribution according the TRK-PIC momentum differences. Since it depend on the radial coordinate we fit the differences to a polynomial function. The top trace in Fig. 6 shows the scaled momentum distribution to be imported into the injection boundary.

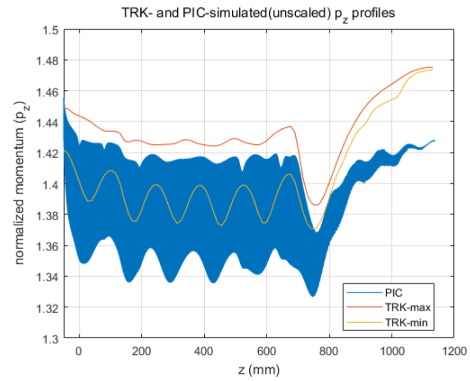

Figure 5: Longitudinal momentum profiles simulated by the TRK and PIC. The PIC profile shows unrealistic potential depression.

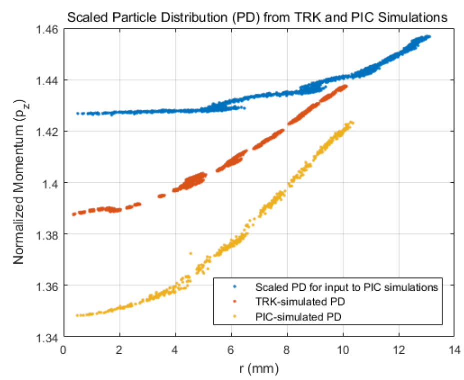

Figure 6: Scaled (top) particle distribution(PD) for input to PIC simulation. It is obtained from the PDs in downstream plane of the TRK (middle) and PIC (bottom) simulations. PIC-simulated PD has larger potential depression than TRK-simulated PD due to unrealistic.

With the new PD with the scaled momentum distribution we could obtain PIC momentum distribution roughly matching to that of the TRK (Fig. 7 and Fig. 8).

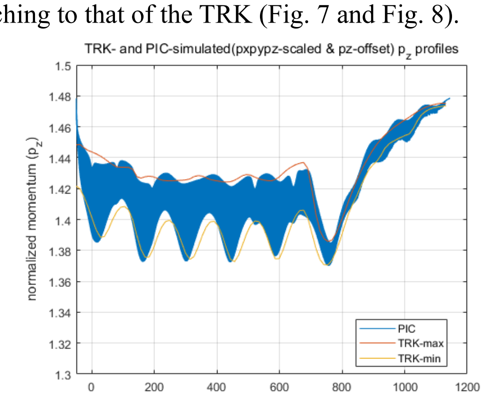

Figure 7: PIC-simulated longitudinal momentum profile with scaled initial PD to match to the TRK-simulated profile.

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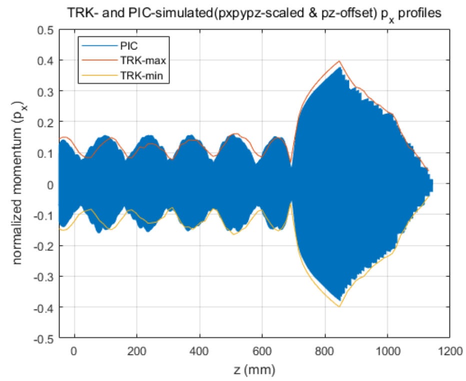

Figure 8: PIC-simulated transverse momentum profile with scaled initial PD to match to the TRK-simulated profile.

From a serious of PIC simulations with the matched beam and the PDs with scaled longitudinal and transverse momentum distributions we could obtain loss-free beam profiles even at 80-MW output power for the PAL klystron. Fig. 9 shows PIC-simulated beam energy profiles for non-matched (top) and matched (bottom) beams. The beam losses and reflections associated with the non-matched beam are successfully suppressed with the matched one.

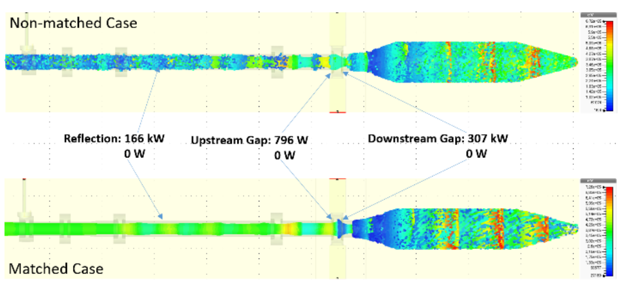

Figure 9: PIC-simulated beam-energy profiles for non-matched(top) and matched(bottom) beams. With the non-matched beam there are significant beam losses which are successfully suppressed by the matched beam. Simulation condition: Beam voltage = 400 keV, Beam current = 500 A, RF output power = 80 MW, Drive powers are 300 W for the non-matched beam and 75 W for the matched beam. An efficiency improvement of several percent as well as ~6- dB gain increase are attained.

EXPERIMENT PLAN

We will validate the suppression scheme by building and testing a klystron and solenoid magnet with a new beam optics. Planned experimental setup is shown in Fig. 10. Pancake coils in the solenoid will be independently powered to determine an optimum set of turn numbers after which a new magnet design is fixed. Beam matching at various beam sizes will be achieved by inserting an iron shim in the magnet aperture, z-translating the klystron body, and adjusting the current to the bucking coil. A relative measurement of the beam losses is done by using several radiation detectors. Target is to obtain the optimum set of MPSs currents to achieve high efficiency at low beam loss simultaneously.

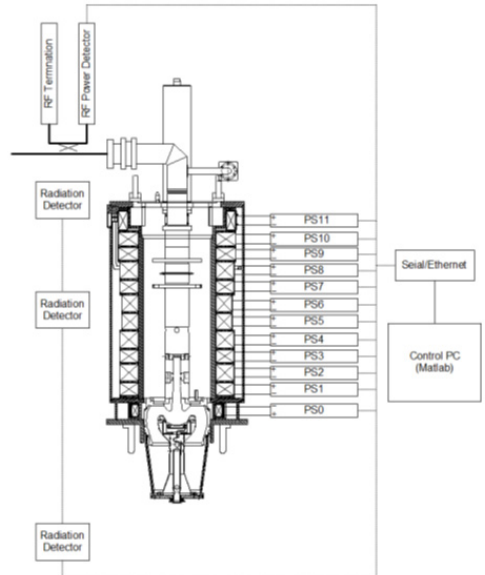

Figure 10: Setup plan for the experimental validation of the beam-loss suppression by optical matching in klystron. The optical matching at various beam sizes is achieved by inserting an iron shim between the gun and the magnet aperture, z-translating the gun, and independently powering the pancake coils of the solenoid magnet.

CONCLUSION

We have shown that by carefully matching the gun to downstream focusing magnetic system "scalloping-free" beam is obtained and beam losses and reflections present in the output sections in klystrons are successfully suppressed. The result is obtained with a series of the CST-TRK and PIC simulations and need to be validated by experiments.

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