Development and Test of a \( P_{kQ_L} \) Control Procedure at KEK STF

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Introduction

In order to operate the superconducting cavities at the International Linear Collider (ILC) [1] near their maximum gradients, cavity input \( P_k \) and cavity loaded Q \( Q_L \) have to be controlled individually \( \left( \text{P}_kQ_L \text{ control} \right) \) [2]. In this scope an automated beam compensation procedure and a fully automated \( P_{kQ_L} \) control were developed and demonstrated.

In preparation of ILC the Superconducting RF Test Facility (STF) is operated at the High Energy Accelerator Research Organization (KEK). In the configuration for the quantum beam project [3] the linear electron accelerator consists beside others of two super conducting 9-cell TESLA type L band cavities driven by a single klystron in the Distributed RF Scheme (DRFS) and operated using digital Low Level RF (LLRF) control techniques [5].

Beam Loading

Beam loading induces a drop \( \Delta V_{ind} \) in the cavity gradient, which can be derived from the cavity differential equation by considering only the beam contribution.

\[
\Delta V_{ind} = \frac{\pi}{Q} f_{0} I_{0} \Delta t
\]

Automated Beam Compensation

For stable beam acceleration flat gradients are required. These can be achieved by adding a beam feedforward (FF) table to the base FF table. By this additional driving power during beam transient is supplied. Since the beam current profile is not flat a automated beam FF shape generation was established.

Nominal Operation

Long term (1 hour) vector sum stabilities after nominal operation \( (V=16 \text{ MV/m}, V_{c}=24 \text{ MV/m}, Q_{L1}=9 \times 10^6, Q_{L2}=3 \times 10^6) \) with beam compensation.

\[
\Delta \Phi_{RMS} = 0.009^\circ, \quad \Delta A_{RMS} = 0.009\%
\]

Fully Automated \( P_{kQ_L} \) Control

The essentials for LLRF cavity control are to operate at flat gradients during beam transient with a constant RF output over filling and flattop time in order to operate the klystron near to saturation. Only in \( P_kQ_L \) operation both requirements can be fulfilled. In ILC the cavity gradient spread will be \( \pm 20\% \) around the average and all cavities will be operated 5% below their respective quench limits.

Conclusion

Digital LLRF control procedures for ILC-like operation covering beam loading compensation, nominal operation, and fully automated \( P_{kQ_L} \) operation have been developed and demonstrated at KEK STF. The vector sum long-time stabilities under \( P_kQ_L \) operation were comparable to those under nominal operation. All introduced ILC requirements were fulfilled.

References


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