Low Level Radio Frequency Controller by Developed for Superconducting Third Harmonic Cavity at SSRF

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Abstract: The independently developed passive superconducting third harmonic cavity at the Shanghai Synchrotron Radiation Facility has passed beam tests. Precise control of the induced cavity field is required during normal operation to achieve goals such as beam stretching and improving beam lifetime. A digital low-level control system which based on FPGA boards, up-down-conversion boards and utilizes I/Q demodulation technology has been developed. It includes a coordinated control algorithm for slow-stepping motors and fast piezoelectric ceramics. Under accelerator operation in the top-up mode with beam currents at 200 mA, the stability of the induced cavity field in the third harmonic cavity improved from ±5% in open-loop mode to within ±1% in closed-loop status, meeting design specifications. The voltage fluctuations in the piezoelectric ceramics remained within a range of ±45 V, achieving a smooth and stable output voltage. Beam lifetime increased by more than twice under these conditions.

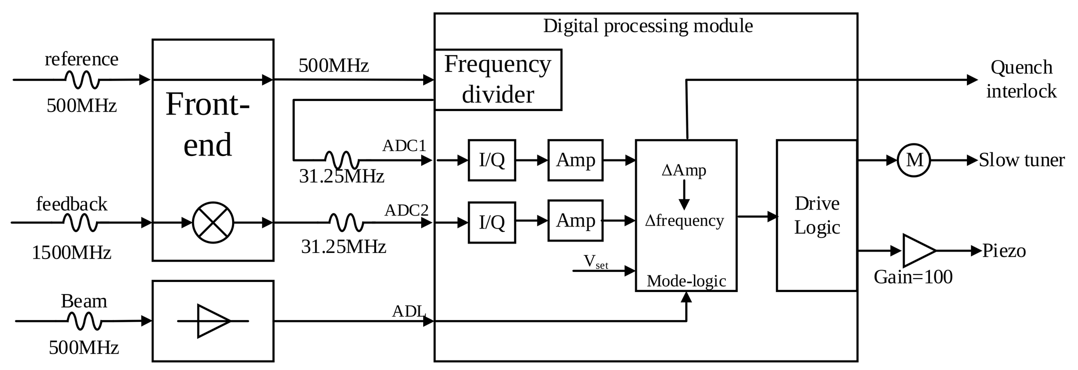
Introduction

Beam lifetime is one of the most critical design parameters for synchrotron radiation light sources, with Touschek scattering being a primary factor influencing beam lifetime. As more insertion devices are installed and tuned at the Shanghai Synchrotron Radiation Facility (SSRF), improving beam lifetime becomes a significant challenge. In the second-phase upgrade construction, the independently developed passive superconducting third harmonic cavity at SSRF has been successfully installed and subjected to beam tests, achieving the goal of stretching beam bunches to enhance beam lifetime.

DLLRF

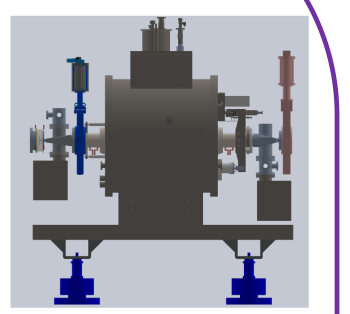
Parameters of SSRF harmonic cavity

Parameters	Value
Beam current (mA)	200~300
Harmonic number	720
Main RF voltage (MV)	4.5~5.4
RF frequency (MHz)	500
Revolution frequency (kHz)	~694.4
Main RF cavity R/Q (Ω)	44.5
Harmonic RF voltage (MV)	1.4~1.8
Harmonic cavity R/Q (Ω)	88
Harmonic cavity operating Temperature (K)	4
Quality factor(2K)	~1e10
Amplititude Stability(%)	≤±1



Schematic of the LLRF controller in 3rd harmonic cavity at SSRF

Control cabinet



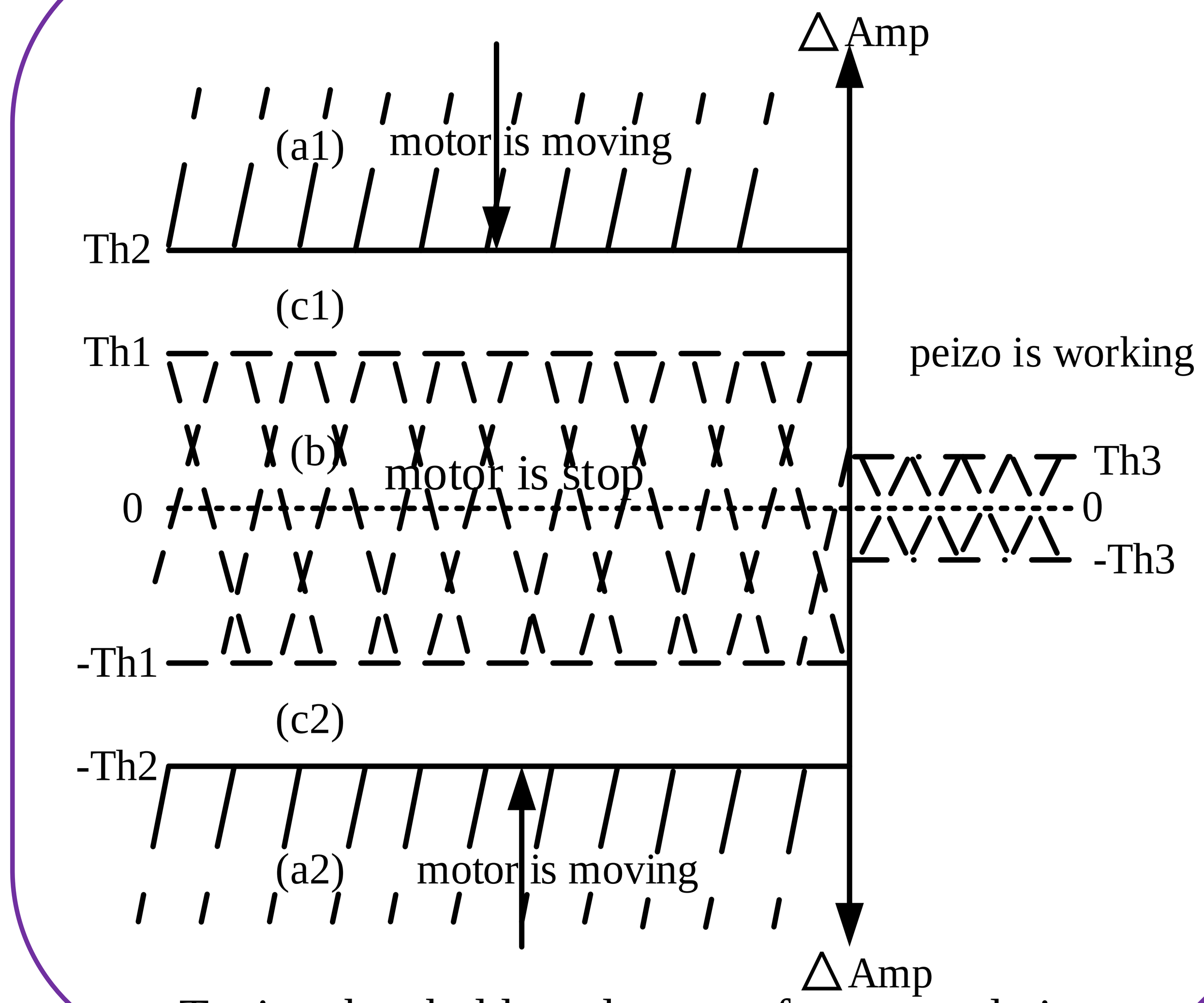
Hamonic Cavity

RK596ACE-H100

P235.40

The control mode for the low-level of the third harmonic has two operational mechanisms: automatic and manual operation mode .

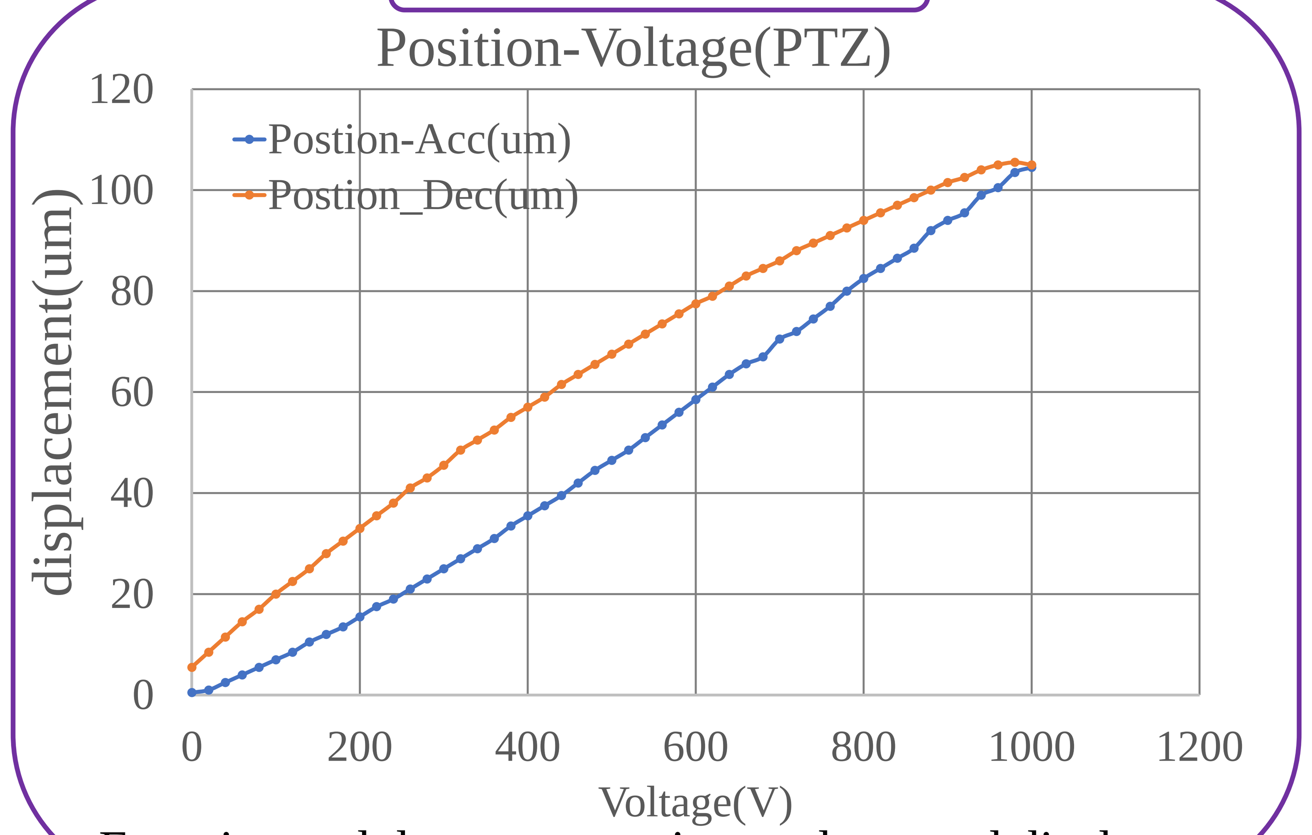
Thresholds and status



Tuning thresholds and status of motor and piezo

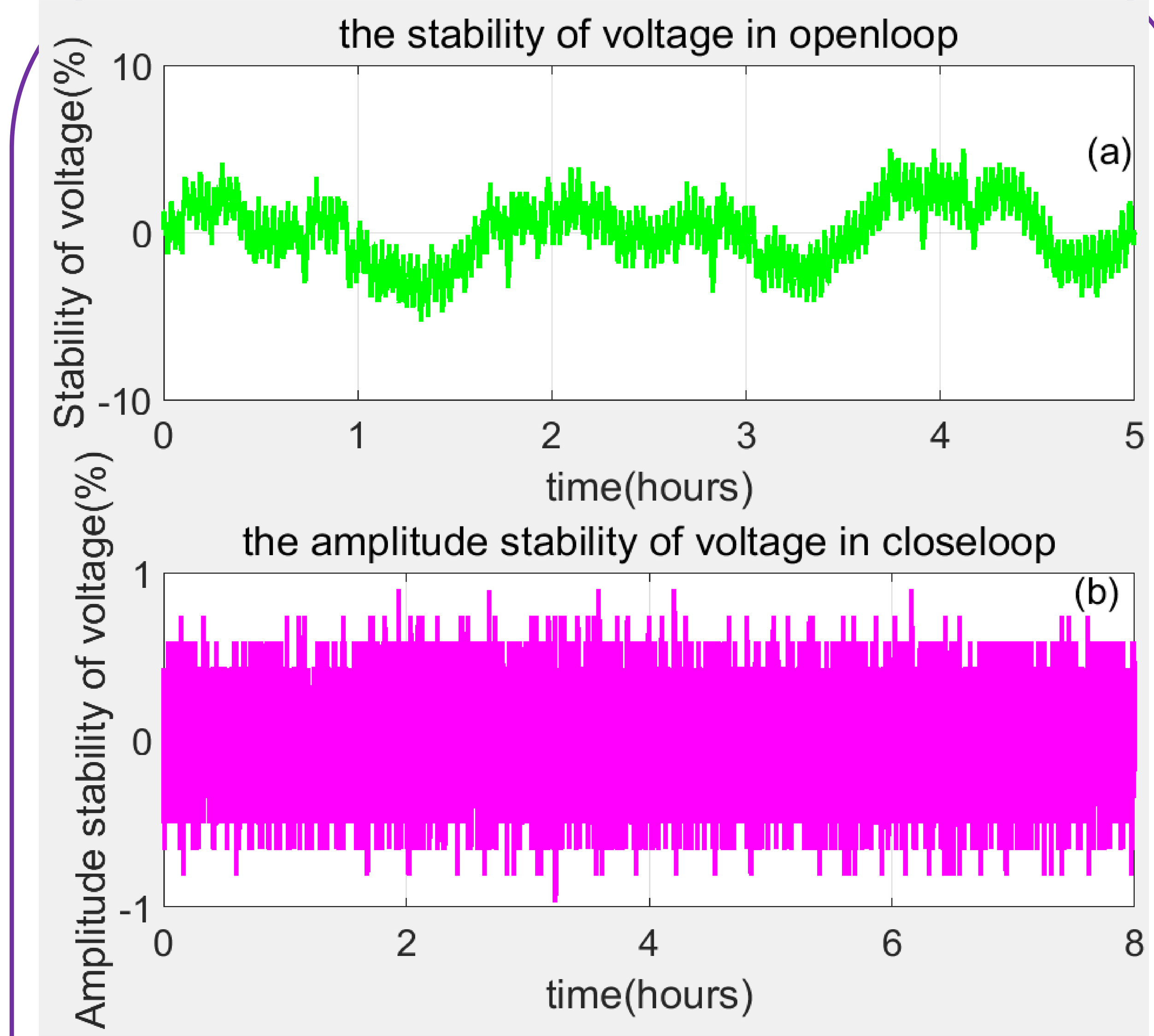
The structural characteristics of piezoelectric ceramics have hysteresis and nonlinearity. In the controller, the system's output at the next moment depends not only on the current input and output but also on whether it is in the voltage-up or voltage-down process.

Piezo Test

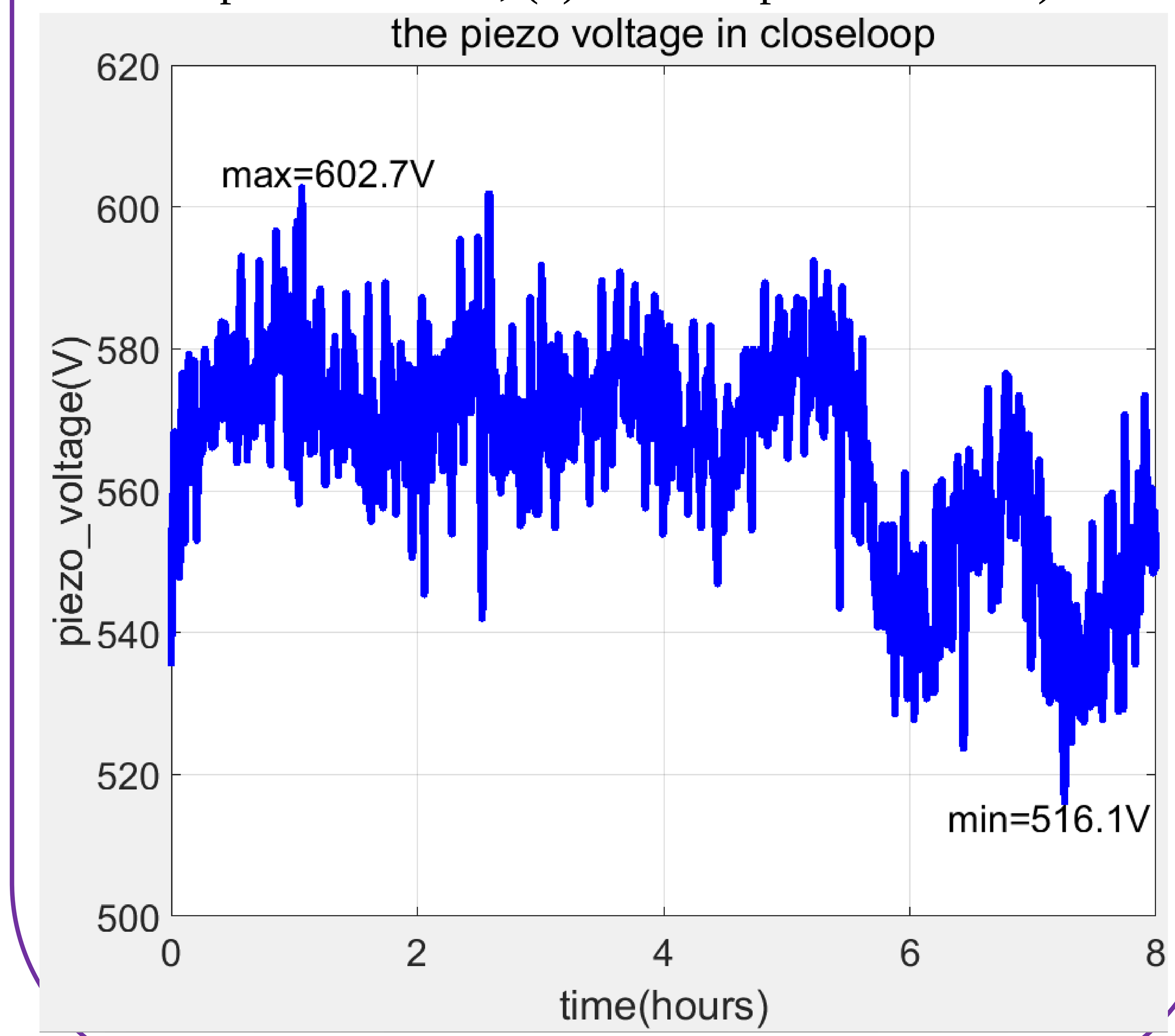


Experimental data tests on piezo voltage and displacement

Test:200mA top-up



Compare with amplitude stability of voltage ((a): open loop within ±5%; (b) close loop within ±1%)



Output of voltage by piezo

Inclusion

- The beam bunch length increases from 55ps to 116 ps.
- The voltage fluctuations in the piezoelectric ceramic is smooth and stable.
- The stability of the cavity voltage in the third harmonic improved from ±5% in open-loop to within ±1% in closed-loop (with 200mA top-up mode).
- The beam lifetime has been extended from 5.27 hours (the harmonic cavity is not in operation) to 11.7 hours(the harmonic cavity is active). (with 200mA top-up mode).