COMPENSATION OF LORENTZ FORCE DETUNING FOR SC LINACS (WITH PIEZO TUNERS) *

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Abstract

The superconducting linacs use niobium cavities working with extremely high quality factor. Therefore the bandwidth of the cavity is very narrow and even subtle deformation caused by Lorentz force detunes the cavity a lot. For high gradient operation (over 15MV/m) the mechanical deformation of the cavity during the RF pulse should be compensated by piezo tuner. The paper presents design of a piezo control system and the results of measurements of its efficiency. It was demonstrated in FLASH accelerator that an initial detuning of 300Hz can be compensated by single pulse excitation of the piezo. The described system consist of multichannel programmable pulse generator driving a 8 channel piezo amplifiers capable to supply piezos with pulses up to 1A and up to 80V. It can compensate for Lorentz force detuning in all three equipped with piezos FLASH cryhomodules (ACC3,5,6).

INTRODUCTION

The currently beeing designed (XFEL, ILC) and already operated superconducting linacs (FLASH) use niobium superconducting cavities working in cryho temperature (2K) [1]. These cavities are operated in pulse regime due to several reasons (most important one is limitation of power losses for high gradient). The pulsing RF (Radio Frequency) power causes pulsing mechanical stress in the cavity (due to Lorentz force) that deforms slightly the cavity. The resonance frequency of the cavity is modulated during the RF pulse due to changes of the geometrical dimensions of the cavity. Since the quality factor of the superconducting cavity is very high the bandwidth of the cavity is very narrow (in case of TESLA type cavities typical value for loaded Q is 10^6 and for half bandwidth is 230Hz). The operation with high gradient may easily lead to the deformation of the cavity by micrometer or so due to the Lorentz force that cause detuning of the cavity by several hundreds of Hz. That induces worsening of the RF energy transfer to the cavity due to reflection. In order to tune the cavities to the operating frequency (in case of TESLA typ cavities it is 1.3GHz) it is necessary to use step motors (slow tuners) and piezos (fast tuners) (Fig. 1). The slow tuners are used to tune cavities to the resonance frequency in steady-state conditions while the piezo tuners are used to compensate the dynamic deformation due to Lorenz force and microphonics. The fast tuner use piezo component that is able to elongate in cryho temperature [2]. In order to provide enough stroke and stiffness the piezos must be quite huge that means high electrical capacitance. The fast tuners require special control system able to drive capacity of piezo (of order of few μF) with high current and voltage pulses (up to 1A and 100V). The parameters of the compensating pulse must be calculated for each cavity separately basing on detuning curve during RF pulse.

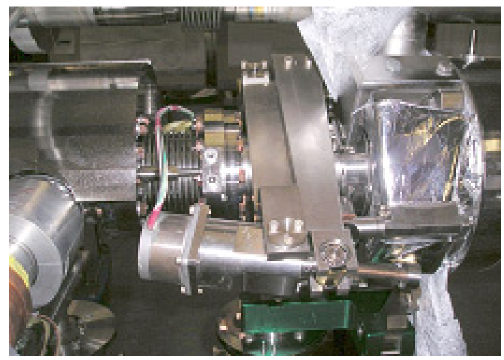

Figure 1: Cavity tuners (slow and fast).

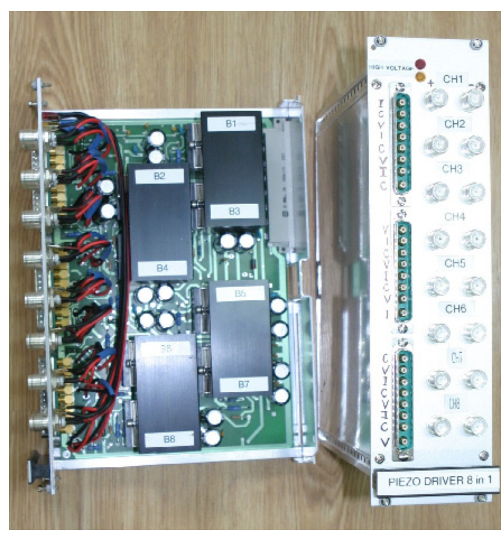

Figure 2: Piezo driver.

PIEZO CONTROL SYSTEM

For controlling the piezos in FLASH the LLRF control system was supplied additionally with piezo controller (Fig. 3). It closely cooperates with RF controller and calculates detuning from RF signals [3]. It is assumed that detuning due to Lorentz force is repeatable in successive pulses. The compensating pulse is a single period of sinusoidal waveform with modulated amplitude and time be-

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fore RF pulse however also other pulse shapes can be applied. The frequency of the pulse is fitted to the mechanical resonance of the cavity (in case of TESLA cavities it is about 300Hz). Basing on the estimated detuning the parameters of compensating pulse are calculated for the next RF pulse. For signal processing and generation the SIMCON DSP board was used [4]. It is equipped with FPGA circuit and analogue inputs and outputs (14bit ADCs and DACs). The compensating pulses are generated in multichannel programmable generator and amplified in piezo driver (Fig. 2) [5].

The driver uses the PB51 from APEX as an power amplifier. It is equipped with overvoltage and overcurrent circuits (100V, max. 1A). The power supply rails are protected by high voltage suppressors. The board is equipped with embedded temperature monitoring circuits. Single PCB board carries 8-channel piezo driver.

RESULT OF MEASUREMENTS

The developed piezo control system was evaluated in FLASH accelerator during the study period (August 2007). The piezos are installed three of six accelerating modules (ACC3,5,6). Two different types of piezo elements were installed

- Physik Instrumente $C_{2K} = 4,4\mu F$
- NOLIAC $C_{2K} = 2,4\mu F$

The piezo control system was installed and connected to the piezos (Fig. 4). Before the measurements, the all piezos capacitance was measured and verified with nominal values. After that the detuning was measured for all cavities operating without any compensation while accelerator was operated with high gradient. During RF pulse the detuning was of order of 300Hz depending on the cavity (Fig 5). After measurements without piezo compensation the piezo control system was turned-on. Both type of piezos were successfully driven by the control system. After manually tuning the parameters the detuning during RF pulse was significantly reduced (below 10Hz - see Fig. 5). For the cavity no.5 there is no improvement. The reason for that is a well known problem with fixing of this cavity. The piezo tuner is lose and cannot stress mechanically the cavity. The parameters of the compensating pulses varied slightly depending on cavity (the pulse amplitude was about 35V and pulse was given to the piezo about 4ms in advance of RF pulse). Since the maximum pulse amplitude generated by the piezo driver is higher (it is about 70V) there is still place for higher gradients.

CONCLUSION

The described Lorentz force detuning compensation system was sucesfully design, manufactured and installed in FLASH. The performed tests have proven that using active compensation system the Lorentz force detuning can be reduced below 10Hz. In the near future the piezo control system will be permanently installed in FLASH and operated automatically. Basing on the detuning measurements the compensation system will calculate the pulse parameters and generate signals driving piezos.

Figure 4: Piezo control system installed in FLASH.

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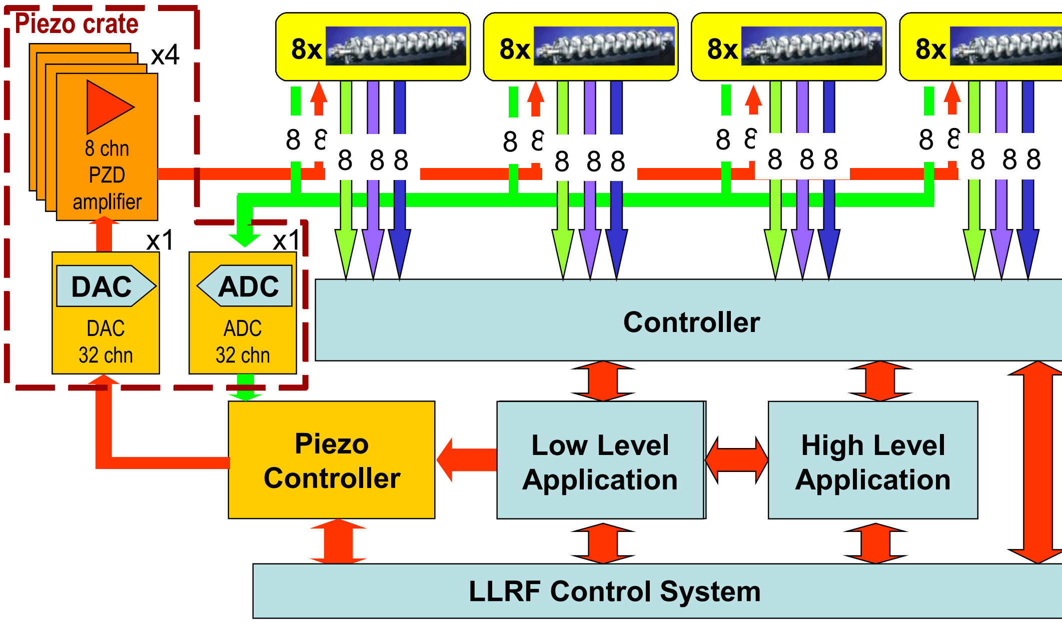

Figure 3: The architecture of LLRF controller with implemented piezo control

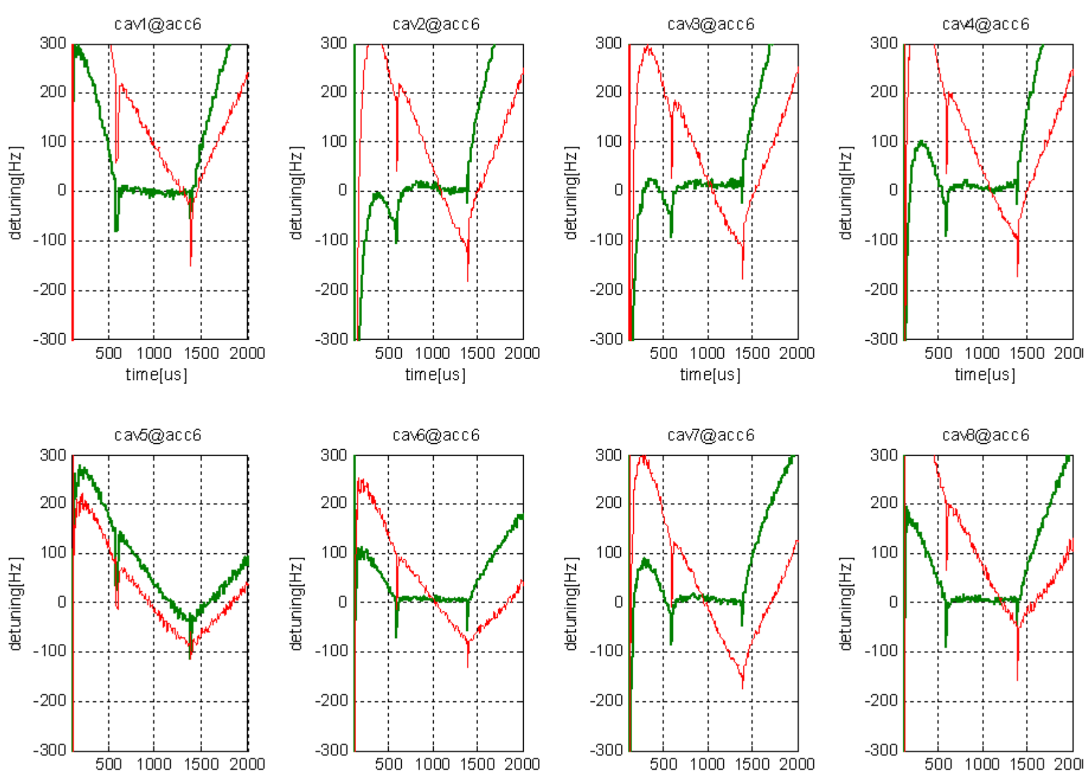

Figure 5: The detuning in ACC6 without compensation (red) and with compensation (green). Gradient SP = 15 MV/m, Pforw(C1) = 220kW, rep = 5 Hz, Parameters of compensating pulse: Cav.(1-3): Amp=34V, Dly=-4.1 ms, Cav.(4-8): Amp=23V, Dly=-4 ms. Cavity 5 is not compensated due to known problem with mechanical fixing.