Software feedback for DESY HERA-e RF power control

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Abstract

To maintain the stable operation of RF system of DESY HERA electron ring a software feedback system has been implemented. It controls the power and phase of RF transmitters with total power up to 12 MW. Data coming from 7 FECs are processed by second level FEC. It calculates the optimal values of power and phase for the transmitters, taking into account beam load and power limits. The physical model, implementation and critical points of operation are described in the paper.

1 Introduction

HERA electron ring is operated as a part of p-e+ collider. Seven RF stations supply the energy to the positron beam with total power up to 12 MW. There are six conventional and one superconducting assembly of RF cavities, 14 to 16 cavities in each. Two parameters define how beam sees the cavities. First is voltage amplitude and second is voltage phase. In colliding mode stations are running just below their critical limits and should deliver power to the beam during continuous run up to 12 hours.

Stations have local electronic feedbacks keeping all cavities of one station in phase. Stations are distributed around the HERA ring uniformly in quadrants (fig.1). Total voltage and phase of each station was controlled by computer system based on NORD computers and SEDAC fieldbus. The global voltage feedback was already implemented and significantly simplified the operation. The goal of replacement of the obsolete control chain was to implement a global software feedbacks for voltage amplitude and phase simultaneously on the base of modern hardware and software. The standard set of equipment for DESY HERA control system is:

- PC based workstation with WindowsNT as a console
- PC based FrontEnd (FEC) running MS DOS.
- PKTR RPC [1] running over TCP/IP equipment access is used for communication between consoles and FECs.

2 Problem formulation

Existing control system (NORD+SEDAC) is almost obsolete. As a part of HERA Control renovation project the control for RF of the electron ring should be implemented on new hardware/software basis and perform a global feedback loops for total RF voltage and phase. Without feedback the parameters of individual station could slowly drift far from optimal values thus require permanent operator assistance. Feedbacks should provide a stable programmed level of RF voltage for injection, ramping and colliding mode of operation. RF parameters are critical for beam life time and wrong setting even on few percents can lead to beam loss.

3 Solution

To implement the feedback system we used in addition to seven primary FEC (PrFec) one more, so called second level FEC. Primary FECs are dedicated to perform a routine I/O and control local parameters of individual RF station. Second level FEC (SlFec further in this report) is responsible for the global RF parameters of RF system: amplitude and phase of RF voltage. It collects the information from PrFecs and global beam parameters (current and energy) and calculate the optimal load for each station. Compare this with real parameters SlFec determine detuning of individual station in amplitude and phase and correct the settings for this station.

The functional diagram of hardware is shown on fig1. All FECs and operator console are integrated in PKTR [1] control network (Ethernet).

SlFec software consists of two feedback loops: voltage feedback loop and phase feedback loop. Two feedback loops are independent, and can be switched ON/OFF from console. Operator can exclude any RF station from feedback loop (independently for voltage and loop feedback). By default, The station with superconducting cavities does not participates in both feedback loops. SlFec performs periodical (with period specified by operator) data acquisition from all PrFecs, calculates global parameters (like total RF voltage, average synchronous phase, etc.), and executes feedback algorithm if corresponding feedback is ON and data acquisition from PrFecs was successful. Maximal operational frequency of the feedback is up to 1 Hz.

Voltage feedback loop can work in two main modes:

1) keep total RF voltage of all stations constant at value specified from console;
2) keep total RF voltage according to the table specifying dependency of total RF voltage from beam energy.

The second mode is the most often used. If after calculation of total RF voltage it is found that difference between desired and real values exceed some predefined threshold (usually 0.5 MV) - feedback will try to increase (or decrease) voltages on all stations participating in this feedback to achieve required total value. At first, the required step voltage change is divided equally to all stations participating in feedback. Then algorithm for voltage feedback takes into account the following limitations:

1) Check status information (first of all different warnings, like overheating), decide (depending on warning) whether it is just not allowed to increase

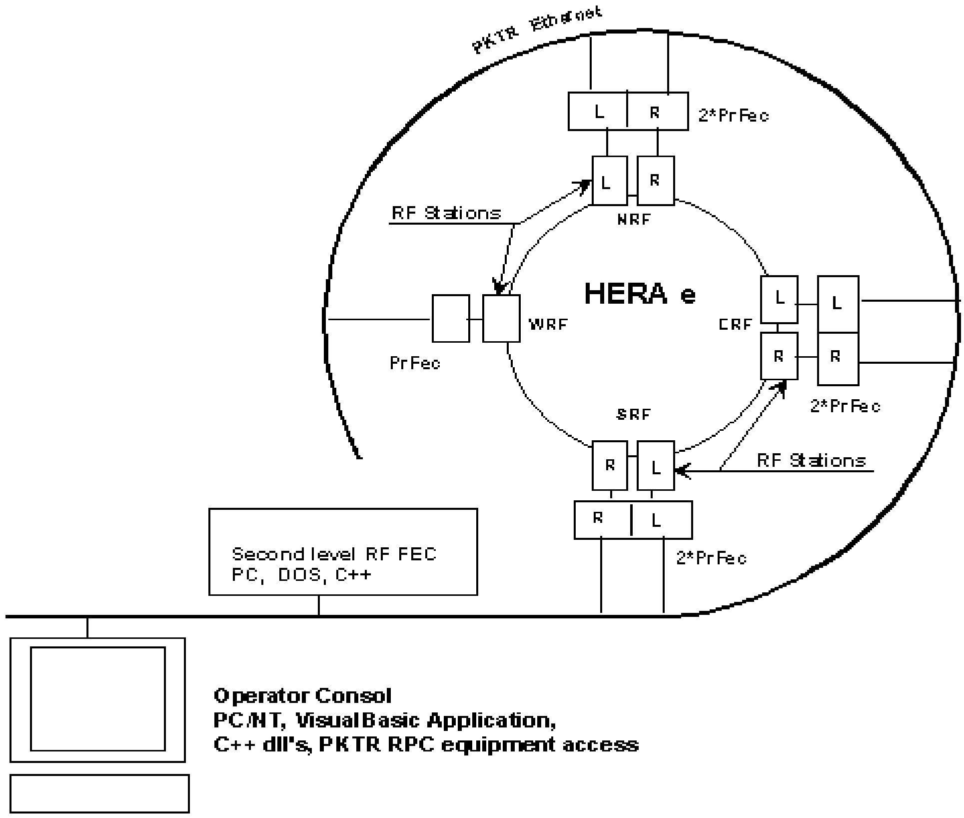

Fig.1 RF control schema

voltage on this station, or one need to decrease voltage for station where warning occurred and try to redistribute required changes to other stations.

2) Try (if possible) not to allow station to go very close to limits (voltage limit, klystron power limit, absorbers power limits, etc.) If this happens - feedback tries to redistribute required changes to other stations to achieve required result.

After new values for all stations have been calculated - new values are sent to PrFecs for writing to equipment. Because RF generators have quite slow voltage change rate - feedback algorithm has to remember when and which value change was written to every station and not try to write new values before one can expect that the previous setting was processed by hardware feedbacks. Loop gain for voltage feedback can be set by operator from console.

The purpose of phase feedback loop is to keep the value synchronous phase the same for all RF stations.

To determine the proper setting SlFec reads the following parameters from PrFecs:

- U_{ci} (MV) - total cavity voltage per station, calculated as sum of scalar voltages on each cavities.
- P_{fw} (kW) - power coming from klystron
- $P_{\lim}$ (kW) - power limits for klystron.
- beam current and energy which are global control system parameters.

SlFec perform a calculation of the following parameters:

- P_{def} (kW) - so called defect power (suppose comes to-the-beam):

$$P_{def} = 0.92P_{fw} - 1.08P_{absorb} - \sum \frac{U_{c,i}^2}{R_{Shunt,i}} - \sum P_{absorb\_ring}$$

φ_S (deg) - synchronous phase, calculated as:

$$Sin(\varphi_{Si}) = P_{def,i} / 2 \cdot U_{c,i} \cdot I_{beam}$$

Errors in calculation of synchronous phase can be very large due to measurement errors (especially at low beam current and energy). To avoid using erroneous results in feedback algorithm the following limitations are used:

1) If calculated $abs(Sin(\varphi_S)) \geq 1$ for at least one RF station - measurement result is considered to be invalid and phase feedback does not make corrections.

2) If power dissipated by beam does not exceed some limit (can be set from console in the range 0 ..100% of RF generator power) - measurements are considered to be invalid and phase feedback does not

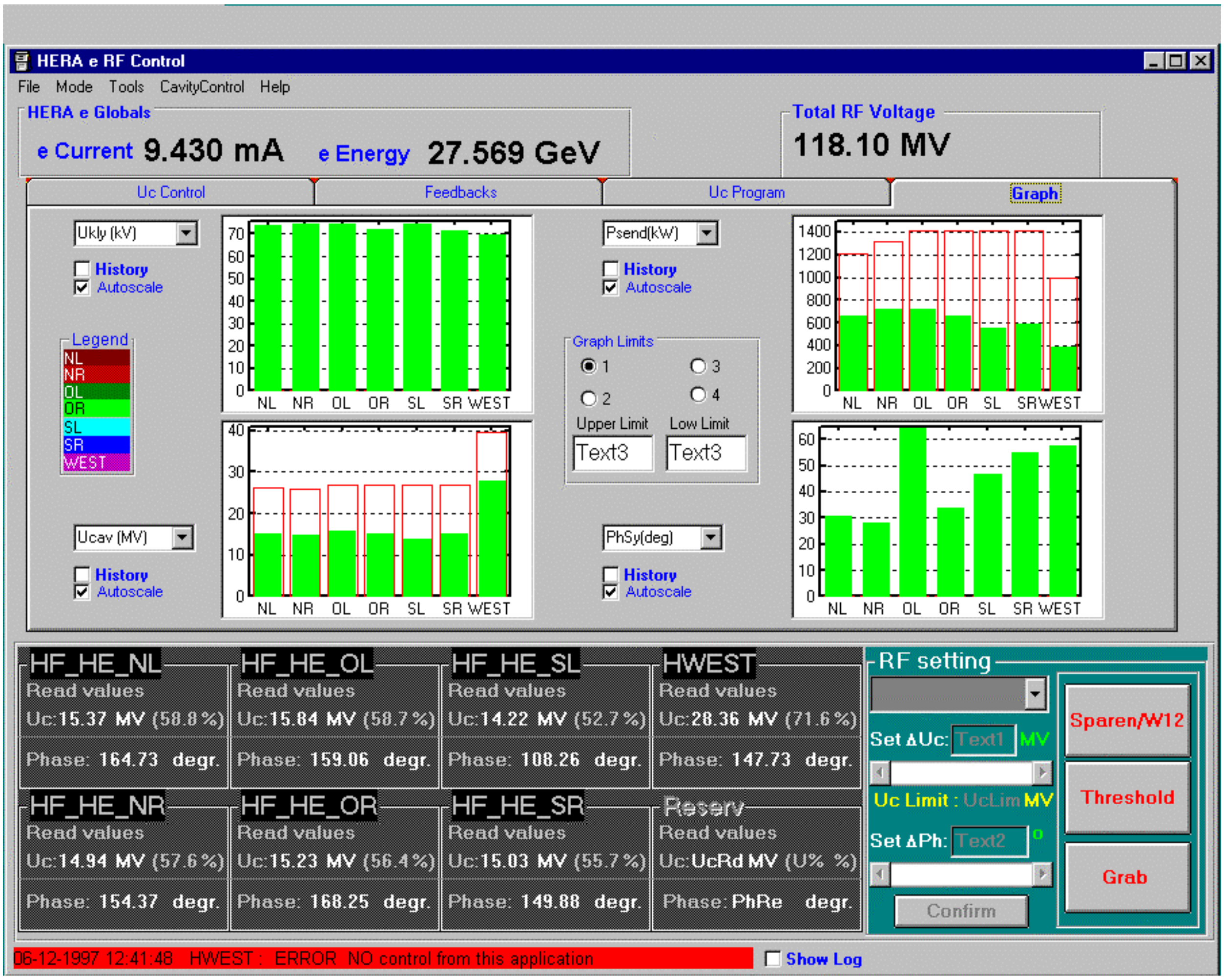

Fig. 2. Example of console screen during energy ramp.

make corrections. Usually when set this limit to 3 ..5% phase feedback works stable.

If measurement result is valid - feedback calculates the average synchronous phase for all RF stations and compares phase of every station with average. If synchronous phase calculated for RF station is different from average phase by more than predefined limit (usually 1 degree) and this station is not excluded from phase feedback loop by operator - new phase shifter setting is sent to corresponding Prfec. Loop gain for phase feedback can be set by operator from console.

5 Console application.

A console application is dedicated for the presenting operator the current parameters of RF system. Different levels of view, down to the physical parameters measured on each individual cavity and power absorber, and up to global parameters like total accelerating voltage and synchronous phase (fig.2). It provides the facility of program "voltage vs. energy" preparation to be download to SlFec.

The application is implemented with MS Visual Basic and few dll's written in c. It operate on NT workstation.

6 Conclusion.

System is now in daily operation but two points still restrict the performance:

1) Historical co-existance with old control chain (NORD, SEDAC) often lead to clashes and misfunction.
2) PrFec does not have the functionality to read back cu-rrent settings. As a result we are using a very complex and not 100% reliable algorithm to overcome the prob-lem.

Reference

[1] Philip Duval , The Use of PCs in Controlling DESY Accelerators, This conference