SINGLE BUNCH TRANSIENT DETECTION FOR THE BEAM PHASE MEASUREMENT IN SUPERCONDUCTING ACCELERATORS*

P. Pawlik, M. Grecki, DMCS, Technical University, Lodz, Poland
S. Simrock Deutsches Elektronen-Synchrotron, Hamburg, Germany

Abstract

During commissioning and operation of linear accelerators the beam phase must be determined with respect to the accelerating rf fields. It is desirable to perform these measurements at low beam current and with a short beam pulse duration to avoid unnecessary beam loss during start-up when the correct beam phase is not guaranteed. In the case of the European X-FEL and the International Linear Collider the requirements are to measure single bunch transients at a bunch charge of 1nC to 8nC with an accuracy of a few degrees in phase and a few percent in amplitude in presence of accelerating fields up to 35 MV/m. This implies that transients of the order of 1e-3 must be measured with a few percent resolution resulting in a relative resolution of the order of 1e-5. The concept of the transient detector for the X-FEL is based on nulling method, where the cavity probe signal is split into two branches, one delayed by a up to 100 ns and phase shifted by 180 degrees before adding the two signals. The nulled signal is amplified by 60-80 dB with an rf amplifier and the transient induced by a single bunch is detected by a schottky diode based rf vector detector to achieve the required low noise performance. The principle of rf transient detection, the electronics design and measurements at the VUV-FEL at DESY will be presented.

INTRODUCTION

The measurement and adjustment of the phase of the accelerating field with respect to the beam phase is essential for the operation of any accelerator. In the case of vector-sum control of many cavities driven by one klystron it is even more important to guarantee the stability of the vector-sum [1]. For this purpose each individually measured cavity field vector is multiplied by a rotation matrix before adding the vectors to the calibrated vector-sum.

The measurement of the relative phase between accelerating field and beam can be based on the beam induced voltage. The measurement can be realized as a transient measurement or as a steady state measurement. In both cases the beam must be turned on and off to detect the change.

*We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 „Structuring the European Research Area" program (CARE, contract number RII3-CT-2003-506395), and Polish National Science Council Grant "138/E-370/SPB/6.PR UE/DIE 354/2004-2007"

PRINCIPLE OF TRANSIENT DETECTION

Single bunch running through the cavity induces RF field vector change called transient (Fig. 1) [2]. This transient is very small and for X-FEL and 3nC bunch at gradient 25MV/m is about 3 orders of magnitude smaller then the RF field. The vector model of the RF field without and with beam presence is shown in Fig. 1. The RF field change induced by the beam is subtracted from the vector of accelerating RF field. For maximum acceleration (on crest acceleration) the beam phase is 0° and the transient vector has opposite direction to the accelerating RF field resulting in a maximum decay in the RF field. For other beam phase the transient adds to the accelerating RF field geometrically. Knowing the phase of accelerating RF field and beam induced transient one can calculate the beam phase.

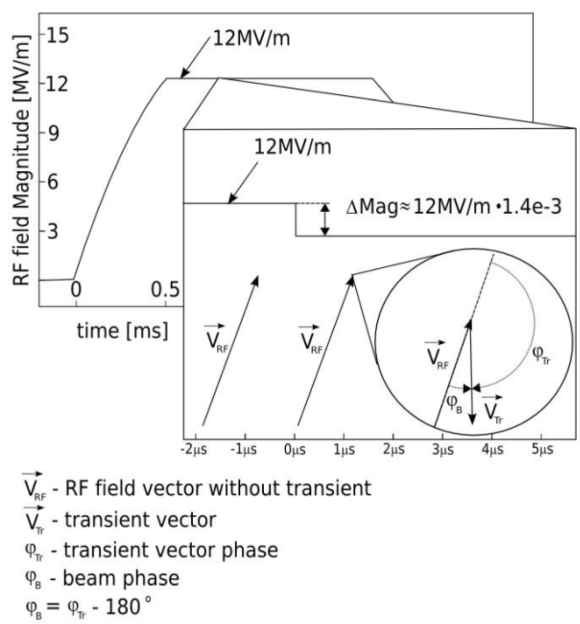

Fig. 1 Single 3nC bunch induced transients

To measure phase of these very small transients it is necessary to reduce carrier 1.3GHz frequency while leaving transients not attenuated. Method that is suitable for this purpose is based on subtracting actual signal from cavity probe from delayed one (Fig. 2) [3]. Short pulse with a width of a time delay is a subtraction result. This pulse carries information about transient.

Subtraction can be realized as a sum of two 1.3GHz signals, where one is shifted by 180 degree with respect to the other one and where magnitudes are the same. Since the exact 180-degree phase shift cannot be achieved one observe also other component between pulses, which is a phase and magnitude adjustment error. To reduce adjustment error to the relevant level one need to attenuate carrier vector below the level of transients, i.e. the attenuation of 100dB is needed since the transients can be 10-4 smaller then the carrier. The phase has to be adjusted with a precision of 0.1° and magnitude 10-5 respectively.

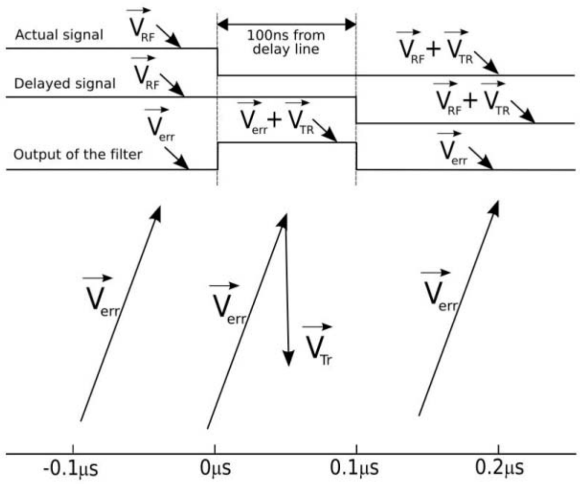

Fig. 2 Subtraction of delayed signal from actual signal

SYSTEM FOR TRANSIENT DETECTION

The block diagram of the system is presented in Fig. 3.

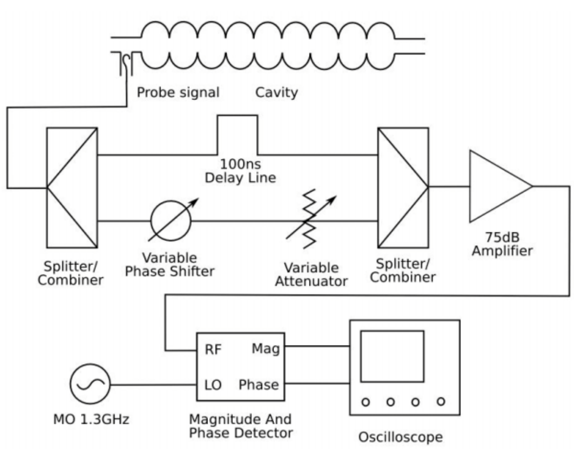

Fig. 3 Block diagram of measurement system.

It consists of cavity probe, nulling circuit, vector detector and digital scope. The probe signal is filtered in a nulling circuit, amplified and detected in vector detector allowing calculation of the real and imaginary part of the signals from the waveforms observed at the scope.

MEASUREMENT OF SINGLE BUNCH TRANSIENTS

The measurements were performed in the VUV-FEL accelerator in DESY. Signals were taken from cavity 3 in module ACC1 that requires phase -10º (that is essential for bunch compression). Gradient was at the level of 12MV/m and measured charges were 1nC, 2nC, 3nC.

Below there are presented measurement results for various beam charges. The beam phase was calculated from phase of transient obtained from change in real and imaginary part values measured on output of the vector detector.

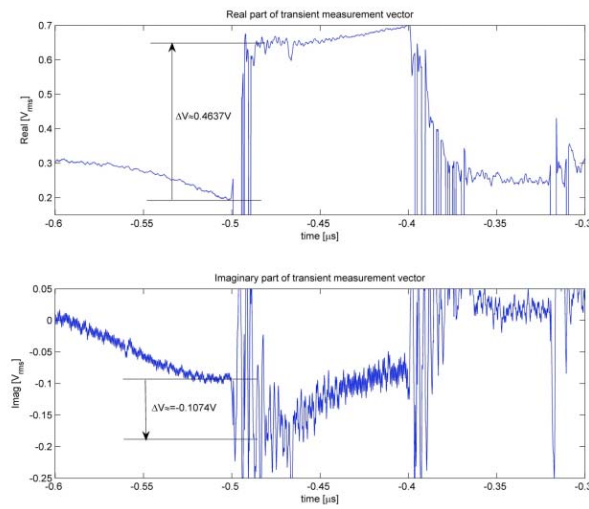

Fig. 4 Measurement of 3nC single bunch transient

Charge [nC]	I [V]	Q [V]	Phase [°]	M.Error [°]
1	0,18	-0,04	-12,33	-2,33
2	0,32	-0,05	-8,53	1,47
3	0,48	-0,11	-12,51	-2,52

Table 1. Results of measurements

Where:

M.Error (measured error): difference between expected and measured values

The differences between expected and measured values do not exceed 2.5°.

PROPOSAL FOR AUTOMATED OPERATION

Since the parameters of the notch filter drifts slowly in time and also depends on temperature the system requires special adjustment procedure before the measurements start. The amplifiers gain should be set to minimum value for the beginning of adjustment procedure. The signal 1.3GHz is connected to the input of the filter and at the output real and imaginary parts is observed (special Matlab script was designed for computation of complex signal in the real time). For adjustment procedure (input signal is constant) the complex signal should be observed in the complex coordinate system as a single point. By changing attenuation or phase shift the real and imaginary part of the signal changes and point representing signal moves at the screen. When the filter attenuation increases the magnitude of the signal drops down and this point moves towards the beginning of the complex coordinate system. After the point corresponding to the null amplitude is reached the gain of the amplifier should be increased to make higher precision adjustment. This procedure has to be continued until minimum magnitude is achieved with maximal gain (75dB).

This process is annoying and its automation is very useful. It will improve performance of the measurement system. The block diagram of the proposed automated measurement system is presented in Fig. 5

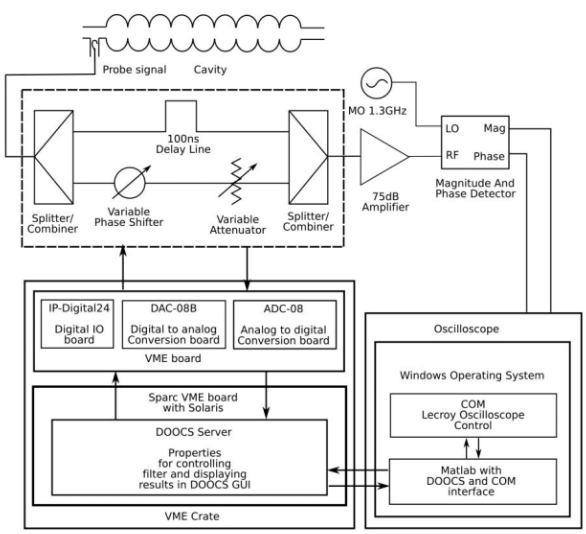

Fig. 5 Block diagram of automatic adjustment circuit

In order to control the adjustment circuit the computer system equipped by ADC, DAC and IO boards are required. For this purpose VME board with three modules is used: IP-Digital 24 module from SBS GreenSpring, DAC-08 and ADC-08 from ACTIS Computer.

The CPU is an embedded VME SPARC computer installed in the same VME crate. It runs under Solaris operating system and DOOCS [4] is used for remote access to the system.

For computation purpose the Matlab scripts running on DOOCS server are used. The scripts get measured waveforms from LeCroy WaveRunner 6100 oscilloscope, compute the required adjustment of the filter and drive DACs and switches that control system motors.

When filter is adjusted properly Matlab script records data with transients for further beam phase calculation. Measured beam phase is available as a DOOCS server property for beam diagnostics.

CONCLUSIONS AND OUTLOOK

From this paper one can figure out that presented method is very promising for amplitude and phase calibration. Filter used for carrier signal nulling achieved its requirements. Transients detected at its output were used to calculate beam phase. Results from this calculations were close to expected values.

Automation of the filter in the future will make measurements more convenient and less time consuming. It will make possible to see beam phase changes in a long term not only for short measurements.

In addition for more accurate and robust measurements filter is planned to be precisely thermally stabilized. Cable which is currently used will be replaced by a semi rigid version with a very high thermal stability. Currently used Amplifonix amplifiers with 1dB Noise Factor will be replaced with Amplitech amplifiers with 0.3dB NF which will further improve measurements accuracy.

REFERENCES

[1] Thomas Schilcher, DESY, “Vector sum Control of pulsed Accelerating Fields in Lorentz Force Detuned Superconducting Cavities” Phd Thesis 1998, TESLA Report 98-20

[2] S.N. Simrock, T. Schilcher DESY “Transient Beam Loading Based Calibration Of The Vector-Sum For The Tesla Test Facility”, DESY http://accelconf.web.cern.ch/AccelConf/e96/PAPERS/THPL/THP025L.PDF

[3] P. Pawlik, S. Simrock, H.C. Weddig “Simulation And Measurement Of An RF Notch Filter For An Electron Beam Single Bunch Detector”, MIXDES 2004, Szczecin 24-26 June 2004 Poland, pp. 430-434

[4] http://tesla.desy.de/doocs/doocs.html