MEBT-BI-EMU82-04

EMU Development Document

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Change History

Rev.	Date	Author(s)	Description
0.1	2016-07-18	I. Mazkiaran	First version.
0.2	2016-11-21	I. Mazkiaran	Revised version
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EMU Development Document

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1 Introduction

In this document it is going to be described the implementation of the SW of the EMU.

For low energy linear accelerators, a typical method for measuring the transverse emittance consists in a slit and grid system.

As shown in Figure 1, for each slit position, the narrow aperture allows the passage of a beamlet populated by particles that have an almost equal position x and a certain angular distribution. Due to the phase space rotation in the following drift space, the beamlet angular distribution is transformed into a position distribution and sampled using a profile monitor, in our case a wire grid. Therefore, the profile measurement gives the angle x' (y') for a certain position x (y) and by scanning the slit across the beam, the whole phase-space can be reconstructed.

Transverse phase space measurements shall be done in the two transverse planes; horizontal and vertical.

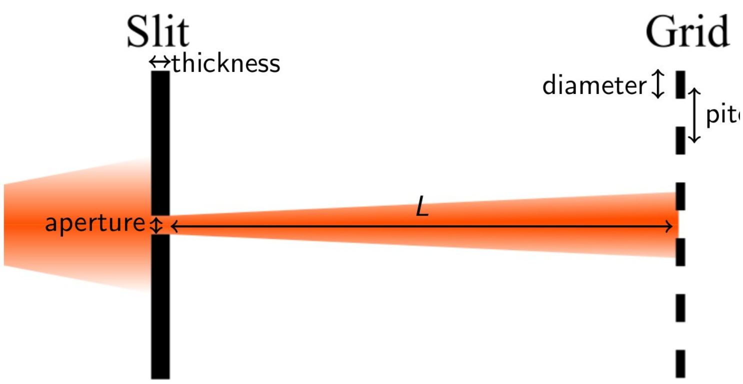

Fig. 1 EMU operation principle.

2 EMU system description

In this section the different subsystems involved in the EMU are going to be explained.

Main systems in the EMU are controlled by a µTCA chassis:

- Motion Control: System based on a bus ethercat.
- Lineal motion and incremental encoders, two limit switches (two more limit switches for MPS).
- Power supply control for motion control feeding
- Analog front-end interrelation for signal conditioning: amplify the signal before being digitized. Also a front-end feeding power supply is controlled. A bias voltage is applied to the grid.
- An Event Receiver Timing board and Analog to Digital Sample Acquisition board are in the crate.
- Beam Interlock System will be also considered, mainly for EMU power supplies, two extra limit switches, slit over temperature...

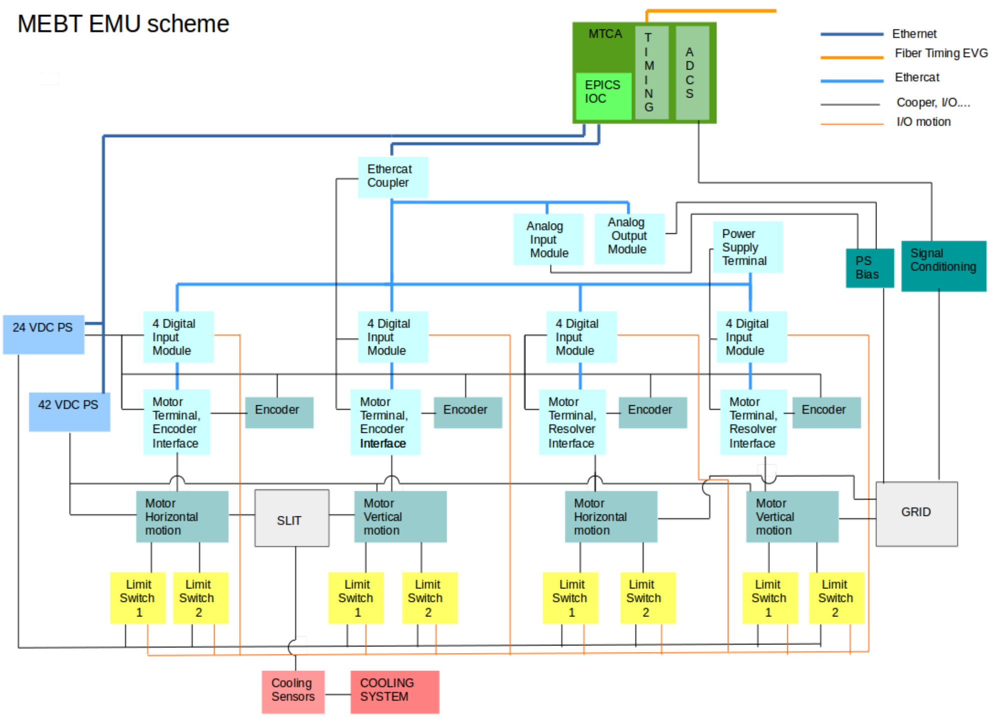

Fig. 2. EMU interfaces schematic

The schematics of this system can be shown in the Figure 2 based in the EMU Control Design document[1].

2.1 Future EMU solution

Actual developments on this HW based on VME platform.

The boards that are inserted in a VME crate: ELMA Type 39 Horizontal, 4U, 84HP should be:

- CPU: IOxOS IFC 1210
- Digitizer board: D-Tacq ACQ420FMC-4-2000-16: 4 analog channels, 2 MSPS, 16 bits.
- Event Receiver Board PMC-EVR-230

And the external integrated systems to control should be:

- Motion Control: Bus ethercat, lineal motion.
- Power supply control for motion control feeding, BIAS voltage supplying, front-end gain.
- Analogue front-end interrelation for signal conditioning.
- Inserted in the crate are Event Receiver Timing board and Analog to Digital Sample Acquisition board.

When all HW boards will be available, the actual developments based on VME are going to be migrated to µTCA platform by ICS.

The HW used in that case should be:

- µTCA crate: including power supply and cooling unit.
- MCH: µTCA Carrier HUB
- CPU: IOxOS IFC 1410 VITA based system, under development.
- Digitizer board: The idea should be having at least 24 analog channels shared in 2 FMC boards and rate > 500KSPS, 16 bits.
- Event Receiver Board from MicroResearch Finland: mTCA-EVR-300
- Event Generator Board from external subsystem

3 Software

This section describes the SW of the EMU.

3.1 EPICS modules

The main EPICS modules and HW drivers to be used are described below:
The control will be based on the EEE's recommendation.

Drivers needed for HW and VME standardization:

- IOxOS VME drivers
- MRF (Timing) drivers.

Those are the EPICS modules that take part in the SW solution:

- System and device support related modules: environment, pevdrv, nds3epics, nds3, asyn
- Specific digitizer hardware related modules: mrfioc2, ifcdaq, ifcdaqdrv
- Specific application related module: EMU_daq, where EMU functionality is implemented, and its IOC will be feeding the EMU GUI.
- Motion Control module eemcu also will be needed.
- mrfioc2: MRF timing module.
- pevdrv: Reading and writing to different areas of memory, different buses and doing DMA transfers.
- Ifcdaqdrv: Abstracts away differences between the FMC modules. Provides a generic data acquisition interface.
- Ifcdaq: EPICS device support.

3.2 Design Tasks

Software design divided in separated tasks :

- sscan control for motion and integrated acquisition.
- Emittance algorithms and Twiss parameters.
  EPICS data base are distributed in those conceptual files:
- General records declaration
- State Machine declaration and inputs / outputs flow, settings initialization...
- Motion Interface
- Channel features

The GUI for configuration and control in .opi files will be also developed.

3.3 IOC development

The EMU, FC, Scrapers, EVR and EtherCAT run over the same IOC. All these modules should still be separate in EEE and they should be assembled together using IOC Factory.

3.3.1 Program control

The software flow is based in sscan recursive records for Slit and Grid.

For data acquisition there is the D-Tacq ACQ420FMC-4-2000-16 board that has 4 analog channels. The measures will be done on those 4 channels, but the code as well as the GUI is programmed for 24 channels.

Those are the states of the application:

INIT state: This is the beginning of the application. While being in this state, if beam permit is not allowed, the GUI is disabled.

SETTINGS state:

In idle mode, when no process has been began, settings can be changed.
The groups of settings are:
ADC settings as sample rate, trigger source, trigger threshold, number of samples...

Scan settings: There are different settings for slit and grid.
Scan mode: If scan mode is chosen as using precalculated positions, you can choose one of the files previously stored in the misc directory of the module.
BIAS settings: You can choose if activate it, and the voltage to be applied.
Gain of the ADC for each wire.
The plane horizontal or vertical where the results are taken.

This settings can be changed when the application is not running.

RUNNING state:

The software of the states are controlled from controls of the GUI
The reading of the current in the wires is read by pushing the START MEASUREMENT touch in the screen.

Before starting with the movement of the slit, it is checked if the BEAM is permitted, then there is a test of the power supplies. After that there is a checking of the wires and then depending of the option, the bias voltage is set.

PAUSE state: The EMU application is paused and the operator has the possibility to continue or just to restart it. While being in this state, if beam permit is removed, then the slit and grid are removed, the bias voltage has to shutdown, and the machine goes to INIT state, and the GUI is disabled.

3.3.2 Motion control

The motors are independently controlled.

There are four motors to be controlled:

Motor 1: Slit in horizontal plane.

Motor 2: Slit in vertical plane.

Motor 3: Grid in horizontal plane.

Motor 4: Grid in vertical plane.

The commands for the movement of the slit will be sent first, then the grid moves around the grid.

There are two modes of setting the movements of slit and grid: moving with equidistant intervals, and moving in precalculated positions of the slit and the grid.

Movement at equal intervals:

For calculating the movement of the slit, there are five settings (set by the operator) to be taken into account: start/end position and the step size of the slit and the desired resolution and amplification factor k.

For example, for a grid with wire ptch of 500 µm and a desried resolution of 100 µm, 5 microsteps (steps of the grid for each slit postion) of the grid will be calculated. The formula for calculating the grid movement, for each slit position, is the following [2]:

$$x_{grid_1} = kx_{slit_0} - 200\,\mu m$$
$$x_{grid_2} = kx_{slit_0} - 100\,\mu m$$
$$x_{grid_3} = kx_{slit_0}$$
$$x_{grid_4} = kx_{slit_0} + 100\,\mu m$$
$$x_{grid_5} = kx_{slit_0} + 200\,\mu m$$

On each movement of the grid, the program reads the value in volts that is proportional to the current induced by the beam protons hitting the wires.

Movement in precalculated positions of the slit and the grid:

In this case the positions of both the grid and the slit should be imported from a text file.

The format of the content of the file will include a head, and then the values of the positions of the slit and the grid, in order of the movement as well as the plane.

There will be independent files for horizontal or vertical movements. The format of the file are two columns separated by ','. The first column indicates the position for the slit and the second column, the position of the grid.

3.3.3 Acquisition

The acquisition of the voltage in the wires is done when the slit and the grid reach their position.

The operator shall set the number of consecutive reads in each position.

The sample rate will be configurable by the operator. Accordingly the pretrigger and number of pulse samples will be set.

The raw data composed of the slit position, angle of the grid wires and the value, in volts, of the current in the wires will be stored in a waveform to be archived.

3.3.4 Background substraction

The operator will set one or two time intervals (prepulse and postpulse) for the background estimation. The background value is calculated as an average of these intervals. This value is subtracted to the average of the samples in the ROI (region of interest).

3.3.5 Data analysis

For calculating those RMS emittance and Twiss parameter values a threshold will be setup by the operator. The threshold is chosen as a percent of the peak value. The emittance and Twiss parameters will be calculated with the ROI signal subtracted by the background of prepulse and postpulse windows, and according to the equations in appendices A and B.

3.3.6 Bias voltage

The operator will have a control to configure the bias voltage. This voltage will be configurable from the GUI.

There is a bias power supply status flag status that will give an alarm in case of malfunction of the power supply.

3.3.7 Wire integrity

Wire integrity will be doing at the beginning of each measurement. It should be disabled during measurement.

For this purposes some mVs are applied to the wires of the grid at the same time by shifting the signal from a controlled power supply.

As a result of reading the voltage in the wires, a wire integrity flag status is set. The values of the flag are: no integrity checking performed, some wire failed, all the wires are correct.

3.3.8 Calibration

The front-end for analog signal conditioning is fed by a fixed value power supply. Due to this signal stage, where signal amplification is the main task, a calibration is needed. The calibration is made at least once at manufacturer facilities and can be also done at commissioning, or in case of interest whenever the technical staff considers necessary. For that an external high accuracy and precision power supply calibrated by a certified entity has to be used. Then, a connector in the front end of the EMU is left for connecting the power supply.

3.4 Interlocks

The slit and grid movement and its functionality is controlled by a MicroTCA system. They are controlled within the same IOC.

The cooling and interlocks control will be on a single PLC: Interlocks PLC.

The EMU, FC, Scrapers, EVR and EtherCAT run over the same IOC. All these modules should still be separate in EEE and they should be assembled together using IOC Factory.

The inputs to the interlocks PLC in the control of the slit are:

- Water cooling temperature.
- Water pressure at input/output: pressure switch (digital input) that has a single normally closed contact that indicates the pressure is within normal operational range.

- Motion axes behaviour.

The Inputs to interlocks PLC in the control of the grid are:

- Power supplies behaviour.
- Motion axes behavior.

The interlocks PLC calculate the behaviour of those input parameters and then give these signals to the MPS.

- Temperature is within normal operational limits.
- Pressure within normal operational limits.
- Power supplies are healthy.
- Motion axes are not stuck.

The Output to MPS is:

- EMU status.

This output signal of the status of the EMU is given from the Interlocks PLC to the MPS.

If this signal is in low level (failure), the MPS takes the decision of interrupting the power of the motion controllers (whether that means that they interlock the power of the stepper motor or the beckhoff PLC and is not yet decided), and then MPS puts a signal in low level then the EMU control knows that is not permitted to run the EMU.

The input to EtherCAT system from MPS.

- EMU permitted to insert: BEAM PERMIT.

As it is supplied with a motion control, also two extra limit switches for each axis that are dedicated to MPS will be settled. The model of the switches is SPDT-NO/NC Roller Lever Microswitch, 100 mA @ 30 V dc from OMRON.
In case the BEAM PERMIT is not allowed, the control system doesn't perform the running of the application.

4 Display

Those are the main features that can be found in the control and displaying screen:

- The tests of wire integrity, calibration.
- The control of the flow of the EMU.
- The settings of motion control, data acquisition, bias voltage.
- The screen of wire average voltage.
- The screen of on time intensity measurement per wire.
- The screen of phase space surface.
- The status flags of beam permit, motion system status, acquisition system status, integrity wire test status, power supplies status.
- The control to calculate RMS Emittance and Twiss parameters.

In order to manage the software, we have designed a GUI (see figure 3), that is more a tool for development purposes as an engineering screen, based on the one from Linac4 Slit and grid engineering screen that comes with the specification document.

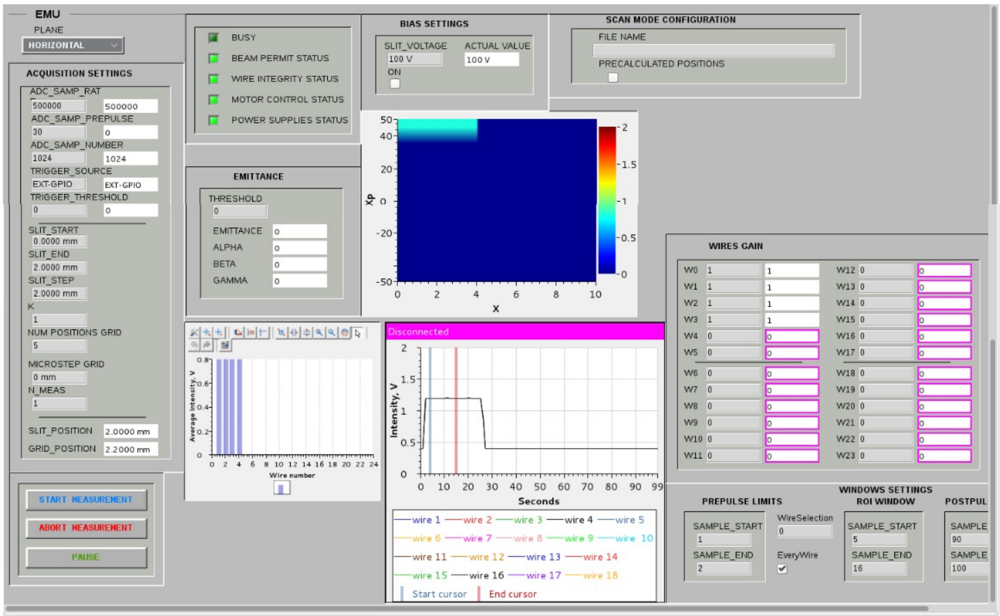

Fig. 3. EMU engineering screen.

The results have been made inserting a pulse of 50 microseconds with 0.8 Volts of Amplitude and 0.4 Volts of offset in the 4 channels that have our digitizer board.

Also here there is the scan mode selection, where the files for precalculated positions have to be stored in the misc directory of the module.

The gain of the ADC of each wire is presented in the GUI. We have to remark that these are not FE gains, because the dinamic range from 10 nA to 200 micro Ampers is covered by the amplification ethap of the FE electronic and due to simulations S/N has a good value.

5. EPICS Database

In this section will be a short description of the files and templates that constitute the development.

EMUFunctions.template

This template add the functionalities of checking if the BEAM is permitted, the status of the power supplies, the wire integrity and the configuration of the bias voltage. Also the flags status.

Those are the main Process Variables to control these functionalities.

Name	Type	Description
$(DEVICEEMU)(PLANEEMU):TST_BEAM_PERMIT	calc	Test Beam Permit from MPS.
$(DEVICEEMU)$(PLANEEMU):BEAM_PERMIT	longin	Beam permit status flag.
$(DEVICEEMU)$(PLANEEMU):BUSY_EMU	bo	Busy flag of EMU.
$(DEVICEEMU)$(PLANEEMU):WIRES_OK	longin	Check wires flag.
$(DEVICEEMU)$(PLANEEMU):POWERSUP_OK	longin	Power Supplies Status flag.
$(DEVICEEMU)$(PLANEEMU):BUSY_SCAN	calc	Busy flag of scanning.

EMUSlit.template

In this template there are PVs associated to the Slit.

Name	Type	Description
$(DEVICEEMU)$(PLANESLIT):DIST_SLIT_GRID	ai	Distance from SLIT to GRID.
$(DEVICEEMU)$(PLANESLIT):SLIT_POSITIONS	seq	Links to calculate the positions of the slit according to mode.

EMUGrid.template

In this template there are PVs associated in general GRID motion calculation.

Name	Type	Description
$(DEVICEEMU)$ (PLANEGRID):PRE_WIRE_CHECK	sseq	Integrity wires test.
$(DEVICEEMU)$(PLANEGRID):FACTOR	seq	Grid K Amplification Factor.
$(DEVICEEMU)$(PLANEGRID):uSTEP	ai	Grid MicroStep.
$(DEVICEEMU)$(PLANEGRID):NuSTEP	longin	Grid Number of Positions in scan.
$(DEVICEEMU)$(PLANEGRID):START_POSITION	calcout	Start init position for the grid.
$(DEVICEEMU)$(PLANEGRID):END_POSITION	calcout	Grid End Position

EMUGridProcess.template

In this template there are PVs associated to the acquisition in the wires.

Name	Type	Description
$(DEVICEEMU):GRIDSCAN_DATA	aSub	Grid scan configuration
$(DEVICEEMU$(PLANEGRID):CHANNEL010_DATA	aSub	x, x', current data of wire 1
$(DEVICEEMU$(PLANEGRID):CHANNEL021_DATA	aSub	x, x', current data of wire 2
$(DEVICEEMU$(PLANEGRID):CHANNEL0XY_DATA	aSub	x, x', current data of wire X

EMUMotionMode.template

In this template there are PVs associated related to the motion mode and the file process for precalculated positions mode. Some of these PVs are described.

Name	Type	Description
$(DEVICEEMU)$(PLANEEMU):MOTION_MODE	longin	Selection of scan mode.
$(DEVICEEMU)$(PLANEEMU):FILE_PREC	waveform	File in precalculated positions.
$(DEVICEEMU)$(PLANEEMU):INIT_LOADS	aSub	Read of Positions File.

EMUDAQConfigure.template

In this template there are PVs associated to the configuration of the samples acquisition that are not directly associated to PVs of the ifcdaq module.

Name	Type	Description
$(DEVICEEMU)$(PLANEGRID):ADC_PRETRGR	longin	Pretrigger from EMU Menu.
$(DEVICEEMU)$(PLANEGRID):PRETRGR	calcout	20 microsecs min pretrigger.
$(DEVICEEMU)$(PLANEGRID):N_WIRE	longin	Number of wire to visualize.
$(DEVICEEMU)$(PLANEGRID):ALL_WIRES	bi	Visualize all the wires.

EMUDAQWindows.template

In this template there are PVs associated to the windows on the raw data screen: pre pulse window, post pulse window and range of interest (ROI) on the signal flat top. Some of these PVs are described.

Name	Type	Description
$(DEVICEEMU)$(PLANEEMU):ROI_START	longin	Start of ROI.
$(DEVICEEMU)$(PLANEEMU):ROI_END	longin	End of ROI.
$(DEVICEEMU)$(PLANEEMU):PREPULSE_START	longin	Pre pulse window start.
$(DEVICEEMU)$(PLANEEMU):PREPULSE_END	longin	Pre pulse window end.
$(DEVICEEMU)$(PLANEEMU):POSTPULSE_START	longin	Post pulse window start.
$(DEVICEEMU)$(PLANEEMU):POSTPULSE_END	longin	Post pulse window end.
$(DEVICEEMU)$(PLANEEMU):ROIPULSE-$(CHANNEL)	waveform	ROI window.
$(DEVICEEMU)$(PLANEEMU):PREPULSE-$(CHANNEL)	waveform	Prepulse window.
$(DEVICEEMU)$(PLANEEMU):POSTPULSE-$(CHANNEL)	waveform	Postpulse window.
$(DEVICEEMU)$(PLANEEMU):BACKGROUND-$(CHANNEL)	calc	Avg of pre pulse and post pulse background.

EMUEmittance.template

In this template there are PVs associated to the calculation of the emittance and the TWISS parameters. Some of these PVs are described.

Name	Type	Description
$(DEVICEEMU)$(PLANEEMU):THRESHOLD	longin	Threshold.
$(DEVICEEMU)$(PLANEEMU):EMITTANCE	ai	Emittance
$(DEVICEEMU)$(PLANEEMU):ALPHATWISS	ai	Alpha twiss parameter.
$(DEVICEEMU)$(PLANEEMU):BETATWISS	ai	Beta twiss parameter.
$(DEVICEEMU)$(PLANEEMU):GAMMATWISS	ai	Gamma twiss parameter.
$(DEVICEEMU)$(PLANEEMU):EMITTANCE_CALC	aSub	Emittance Calculations.

slitGridScanner.substitutions

Compilations of components from scanning module.

The following macros must be defined when loading the templates:

Macro	Description
DEVICEEMU	Name of the isntanciated device: $(SECTION)-$(SUBSECTION):$(DISCIPLINE)-$(DEVICE)-$(INDEX): MEBT-010:PBI-EMU-001
PLANESLIT	Plane of the Slit, horizontal or vertical • SH • SV
PLANEGRID	Plane of the Grid, horizontal or vertical • GH • GV
PLANEEMU	Left in blank
CHANNEL	Number of wire: CH0..CH23

A RMS Emittance

As the number of particles in a beam is huge, it is not possible to measure the position and velocity coordinates of each of them. Instead the intensity is measured for different points in the vertical and horizontal two dimensional phase spaces. This gives a series of points c(x, x') of intensities. If these are distributed over the whole phase space where the beam is and a sufficient number of them fall within the beam itself, the statistical emittance can be calculated.

The formula of the RMS emittance is a root mean square value. For a collection of N points with intensity c(x, x') the emittance is given by those formulas attached from [3]:

$$\varepsilon_{RMS} = \sqrt{(\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2)}$$

where $\langle x^2 \rangle$, $\langle x'^2 \rangle$ and $\langle xx' \rangle$ is given by

$$\langle x^2 \rangle = \frac{\sum_1^N c(x, x') x^2}{\sum_1^N c(x, x')}$$

$$\langle x'^2 \rangle = \frac{\sum_1^N c(x, x') x'^2}{\sum_1^N c(x, x')}$$

$$\langle xx'^2 \rangle = \frac{\sum_1^N c(x, x') xx'}{\sum_1^N c(x, x')}$$

It is important that the data is centered before the RMS emittance is calculated. So, the values of x and x' will be centred for those calculations.

B The Twiss parameters:

The RMS Emittance is closely linked to the phase space ellipse. In particular the Twiss parameters alpha, beta and gamma describes the phase space ellipse though the equation:

$$\gamma x^2 + 2\alpha x x' + \beta x'^2 = \epsilon_{x,RMS}$$

In addition to the RMS Emittance there is the 4RMS Emittance that is simply:

$$\epsilon_{4RMS} = 4 \cdot \epsilon_{1RMS}$$

where the factor 4 is there to make the RMS Emittance more similar to the geometrical emittance. The ellipse of the equation encircles the core of the beam and the same ellipse with the 4RMS Emittance encircles the whole beam. The ellipse is therefore sometimes called the beam envelope ellipse. The Twiss parameters are defined as:

$$\alpha = \frac{-\langle xx' \rangle}{\epsilon_x} \quad , \quad \beta = \frac{\langle x^2 \rangle}{\epsilon_x} \quad \text{and} \quad \gamma = \frac{\langle x'^2 \rangle}{\epsilon_x}$$

The meaning of these parameters can be seen in the Figure 4

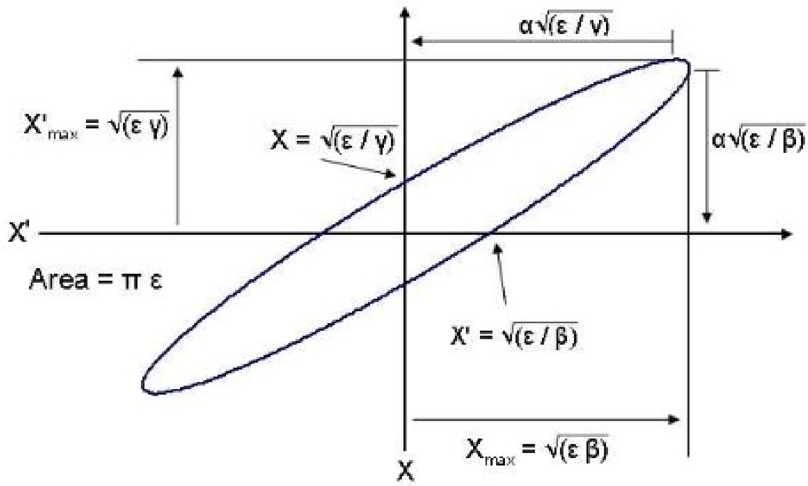

Fig. 4. Twiss parameters on the beam envelope ellipse.

5 References

[1] Idoia Mazkiaran, “EMU control design” document. ESS Bilbao, Design Document 2016.

[2] B. Cheymol and H. Kocevar, “Slit and grid system software functionalities”, Revision 1 (1). European Spallation Source, ERIC, 2016.

[3] Christian Andrè Andresen, “IONEKIKDER OG PARTIKKELSTRÅLE DINAMIKK”, Norges teknisk-naturvitenskapelige universitet- NTNU, 2004.