EMITTANCE MEASUREMENT WIZARD AT PITZ, RELEASE 2

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Abstract

The Photo Injector Test Facility at DESY, Zeuthen site (PITZ) develops electron sources of high brightness electron beams, required for linac based Free Electron Lasers (FELs) like FLASH or the European XFEL. The goal of electron source optimization at PITZ is to minimize the transverse projected emittance. The facility is upgraded continuously to reach this goal. Recent updates of the PITZ control system resulted in significant improvements of emittance measurement algorithms. The standard method to measure transverse projected emittance at PITZ is a single slit scan technique. The local beam divergence is measured downstream of a narrow slit, which converts a space charge dominated beam into an emittance dominated beamlet. The program tool "Emittance Measurement Wizard" (EMWiz) is used by PITZ for automated emittance measurements. The second release of the EMWiz was developed from scratch and now consists of separated sub-programs which communicate via shared memory. This tool provides the possibility to execute complicated emittance measurements in an automatic mode and to analyze the measured transverse phase space. A new modification of the method was made called "fast scan" for its short measurement time while keeping excellent precision. The new release makes emittance measurement procedure at PITZ significantly faster. It has a friendly user interface which simplifies the tasks of operators. Now the program architecture yields more flexibility in its operation and provides a wide variety of options.

INTRODUCTION

At the PITZ facility, the electron source optimization process is continuously ongoing. The goal is to reach the XFEL specifications for beam quality – projected transverse emittance less than 0.9 mm mrad at a bunch charge of 1 nC. The speed of an individual emittance measurement, its reliability and reproducibility are the key issues for the electron source optimization. That is why an automatization of emittance measurement at PITZ is of great importance. The nominal method to measure the transverse projected emittance is a slit mask technique. Many machine parameters have to be tuned simultaneously in order to achieve high performance of the photo injector. This task is organized at PITZ through the emittance measurement wizard (EMWiz) software [1]. This advanced high-level software application interacts through a Qt [2] graphical user interface with the DOOCS [3] and TINE [4] systems for machine control and ROOT [5] for data analysis, visualization and reports. For communication with the video system and acquiring images from cameras at several screen stations, a set of video kernel libraries have been created [6]. During the past years some measurement hardware was replaced with faster and more precise devices. Accordingly, new methods and algorithms have been implemented by the emittance measurement procedures. It increases measurement accuracy and reduces measurement time. In this paper, details about the new Emittance Measurement System for both hardware and software parts are described.

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EMITTANCE MEASUREMENT HARDWARE

The transverse emittance and phase space distribution are measured at PITZ using the single slit scan technique [7, 8]. The Emittance Measurement SYstem (EMSY) contains horizontal and vertical actuators with 10 and 50 μm slit masks and a YAG screen for the beam size measurement. The slit mask angle can be precisely adjusted for the optimum angular acceptance of the system (Figure 2). Three EMSY stations are located in the current setup as shown in Figure 1. The first EMSY station (EMSY1) behind the exit of the booster cavity is used in the standard emittance measurement procedure. It is at 5.74 m downstream of the photocathode corresponding to the expected minimum emittance location. For this single slit scan technique, the local divergence is estimated by transversely cutting the electron beam into thin slices. Then, the size of the beamlets created by the slits is measured at the YAG screen at some distance downstream the EMSY station. The 10 μm slit and a distance between the slit mask and the beamlet observation screen of 2.64 m are used in the standard emittance measurement. Stepper motors are applied to move each one of the four axes separately. They give the precise spatial positioning and orientation of the components.

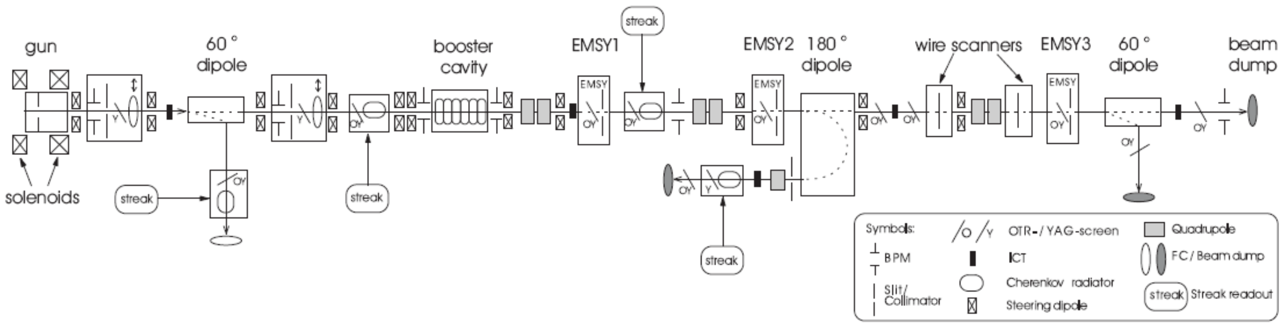


Figure 1: Layout of the Photo Injector Test facility at DESY, Zeuthen site (PITZ).

Every EMSY has four stepper motors which are controlled by the new XPS-C8 (Newport) controller, that were mounted in the beginning of 2011. This new controller type gives the possibility to read all hardware values during movement. The average value read time is about 5 msec which is a big improvement compared to the old controller which has a read time about 50 msec. With the new possibility, the EMSY software was redeveloped and in turn opened new horizons for improving quality and speed of emittance measurement processes. On each of the actuators besides slit mask in both x- and y- planes, a YAG screen is mounted to observe the beam distribution.

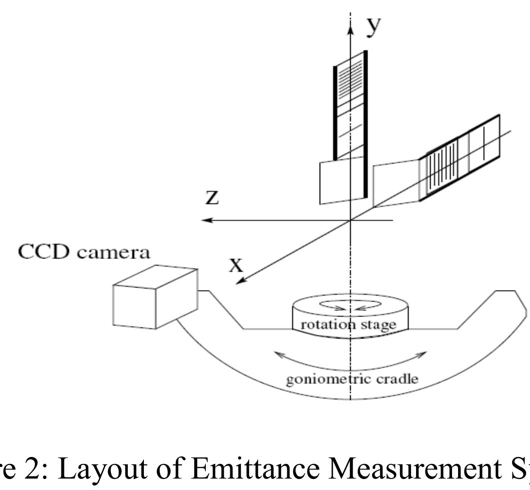


Figure 2: Layout of Emittance Measurement System.

A CCD camera is used to observe the images on the screens (see Figure 2). During the past years the PITZ video system was also under continuous improvement. Hardware and software parts were updated by the third release [9]. The most important for emittance measurement was that the problem of missed and unsynchronized frames is now solved due to new hardware and improved software. Earlier a considerable part of beam and beamlet measurements was rejected, because a lot of frames were missed or frame grabbing was not synchronized with the actuator movement. Sometime operators lost up to 50% of operating time because of these problems.

EMITTANCE MEASUREMENT ANALYSIS

A schematic representation of the single slit technique is shown in Figure 3. For this technique the local divergence is estimated by transversely cutting the electron beam into thin slices and measuring their size on a screen after propagation in a drift space. The so called 2D-scaled emittance is then calculated using the following definition [1]:

$$\varepsilon_n = \beta\gamma \frac{\sigma_x}{\sqrt{\langle x^2 \rangle}} \sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle - \langle xx' \rangle^2} \qquad (1)$$

Here $\langle x^2 \rangle$ and $\langle x'^2 \rangle$ are the second central moments of the electron beam distribution in the trace phase space obtained from the slit scan, where $x' = p_x / p_z$ represents the angle of a single electron trajectory with respect to the whole beam trajectory. The Lorentz factor $\beta\gamma$ is measured using a dispersive section downstream of EMSY.

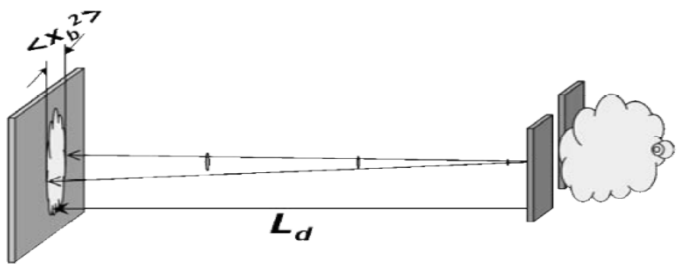


Figure 3: Schematic representation of the single slit scan technique.

The factor $\sigma_x / \sqrt{\langle x^2 \rangle}$ is applied to correct for possible sensitivity limitation of low intensity beamlets, where σ_x is the rms whole beam size measured at the slit location. In the emittance measurement setup and procedure, intrinsic cuts have been minimized by e.g. using high sensitive screens, a 12 bit signal resolution CCD-camera and a large area of interest to cover the whole beam distribution. Therefore, emittance value is called 100% rms emittance. The measurement system was optimized to measure emittance lower than 1 mm mrad for 1 nC charge per bunch with precision of about 10 % [1].

EMITTANCE MEASUREMENT WIZARD

Since December 2010 a new release of EmWiz is available at PITZ. This second release has replaced the previous version [1] completely. All modern features of the Qt framework software and new hardware possibilities of the PITZ control system were implemented in this new wizard. It has a flexible design by being developed as a module set when each module has a specific task. A basic idea for this version was to simplify EmWiz GUI by decreasing the number of buttons, user readable information, number of windows and operator actions which are needed for a measurement process. Further on the goal was to give an interface for easy further development and for easy adding of new tools to the current work version. It is written for 64 bit Scientific Linux CERN version 5.0, but can be recompiled for other platforms.

EMITTANCE MEASUREMENT PROCEDURE USING EMWIZ

The first unit is named “Fast emittance scanner” (FES). This program (see Figure 4) provides measurement processes and hardware control. It can be started only by shift operators in the control room, because solely one program instance can be in the online mode with measurement hardware.

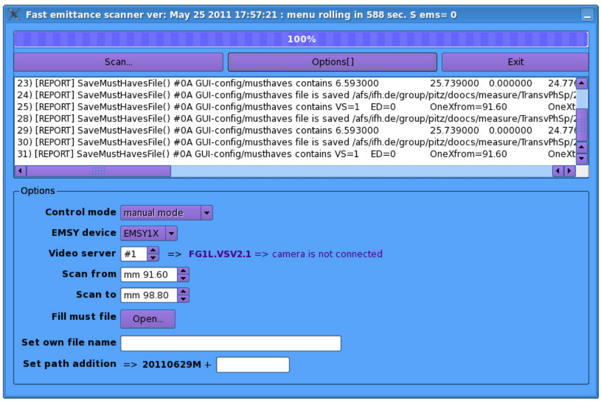


Figure 4: Fast emittance scanner, options. (FES)

The upper part of the GUI frame has a list box, which contains two types of messages: [REPORT] and [ERROR] (see Figure 4). All actions of the operator to the program and machine, system status, error events and alarms with time-stamp are stored to a separate own log-file (black box). Utilizing this file an expert can support the shift crew remotely to fix a problem and it is useful to explain some unusual results. In the list box error messages are marked by red color and content information about an error and an instruction “how to fix it”. This feature is common for all programs of EmWiz. Before using the program for a measurement, the machine parameters have to be adjusted. Some necessary values, e.g. gun and booster energy, laser beam rms size are measured by other tools and put in the corresponding field (see Figure 5). An operator can set the actuator speed. The measurement precision gets better with less speed, but the measurement time is increased.

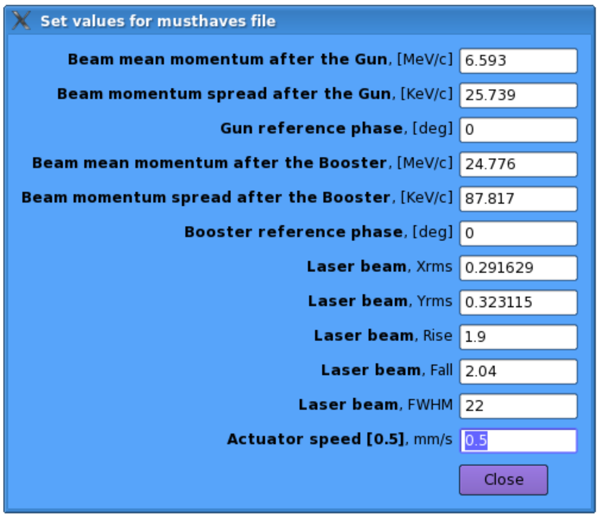


Figure 5: “Set values” dialog. (FES)

The typical emittance measurement time for a selected current value with the default speed (0.5 mm/s) is about 3 minutes (selected scan region = 4 mm). The time is about 5 minutes if the speed equals 0.2 mm/s.

An operator's next step is set an EMSY device. 6 EMSY devices are available for emittance measurement: 3 EMSY x 2 axes. The video system at PITZ has more than 20 digital cameras with 8 and 12 effective bits per pixel and >7 video servers [6]. The video part, which can control the cameras, changing settings and connecting to a video server, is excluded from EmWiz. Currently it is realized via a set of programs which are written by Java, yet FES makes it possible to get the video image, to apply filters, to grab and to save video images and read camera's properties. An operator has to set a proper video server, check the camera status and set a scan region. All last used values are stored in the EmWiz. If it is necessary an operator can set an own file name or use a predefined unique file name and set a path addition for a predefined path name. It is done for flexibility, because this program is used for other (not only for emittance) measurements.

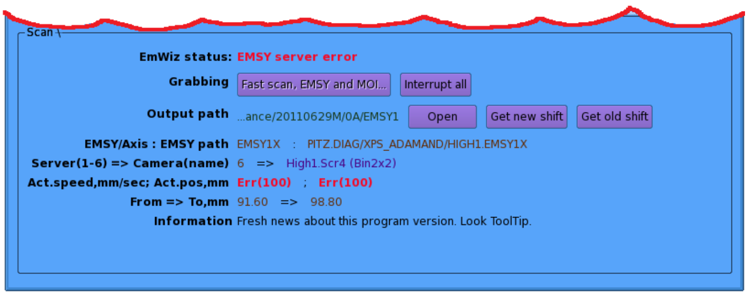
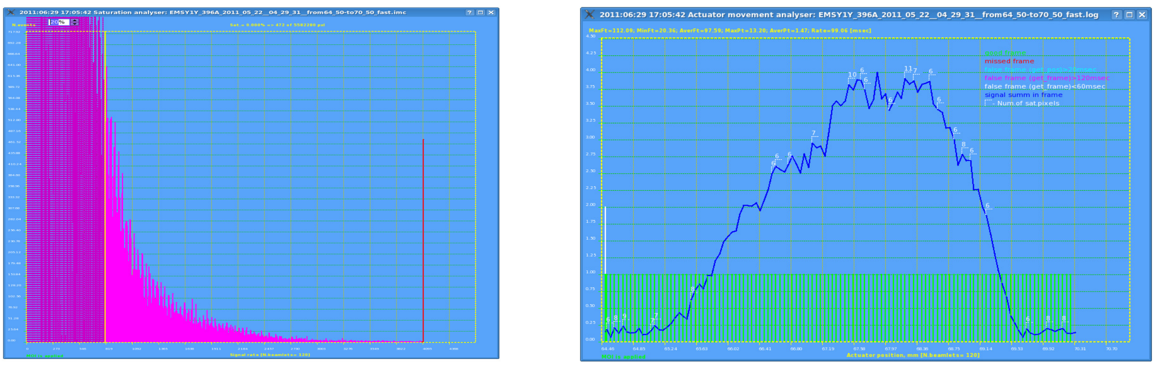


Figure 6: Scan panel, bottom part of FES. (FES)

The scan frame of FES shows appointed hardware parameters, hardware status, gives a set of measurement and control buttons when a measurement is possible for a current hardware status (see Figure 6).

For checking quality of an emittance measurement two report diagrams are available (see Figure 7). They appear during the measurement procedure. Absence of dramatic saturation level is one important criteria for obtaining good data quality. The major part of signal image



(a) Spectrum plot (b) Qualitative plot

Figure 7: Spectrum and qualitative plots. (FES)

(a) X-axis – signal rate of a video matrix pixel; Y-axis – number of pixels with the signal rate; the red line in the right part of the plot indicates saturated pixels.
(b) X-axis – position of beamlet, mm. Y-axis - reference unit; the colors means: green – "good" frame, red – missed frame, sky – inaccurate frame position, violet – late frame, white - early frame, blue – signal sum of beamlet, white numbers – number of saturated points.

pixels should have an intensity between 50% and 70% of maximum intensity. For example, the signal rate should be less than 3000 units (X-axis) for 12bpp camera. It is a criterion for a measurement without saturation.

Each frame corresponds to a certain actuator position. Both video frame and actuator position recording times are controlled. If a frame comes too late or too early this frame is “bad” for emittance measurements. The qualitative plot gives information about missed and “bad” frames, local saturation, actuator movement and signal level. With the help of the report plots an operator can understand if this measurement is successful or not for sure and can interrupt unsatisfactory measurement procedure without saving data.

The transverse beam images and background frames at the slit location (EMSY) and at the beamlet screen (MOI) are recorded via “Fast Scan, EMSY and MOI” buttons (Figure 6). These images are required for the emittance calculation using formula (1). Then the beamlet scan procedure “Fast Scan” can be started via the same button. At first the background statistics is collected in the next step, the slit is moved continuously with a constant speed in the selected scan region. At the same time, the attached CCD camera to the selected video server grabs the image frames from the beamlet observation screen with fixed rate (10 Hz); measurement times and actuator positions for each image frame are recorded in parallel. The operator repeats the scan for all main solenoid current values of interest.

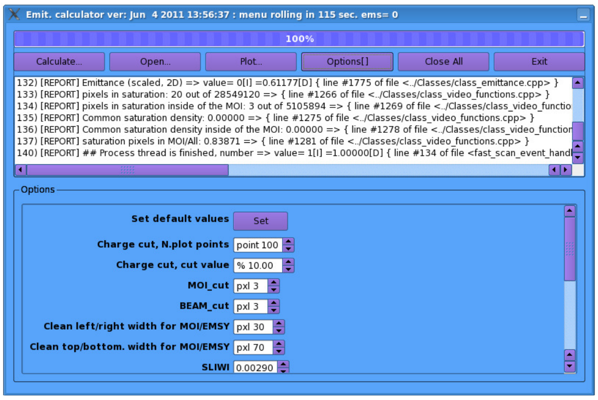


Figure 8: Emittance calculator, panel “Options” (EC).

The measurement time for one solenoid setting is about 3 minutes. This time includes all necessary procedures for the measurement. The process of data collection in FES stores all machine parameters continuously and informs the operator about critical fluctuations of controlled parameters, which can influence the measurement reliability. The data is recorded with cross-reference to the number of the grabbed frame. That means the actuator position, RF-

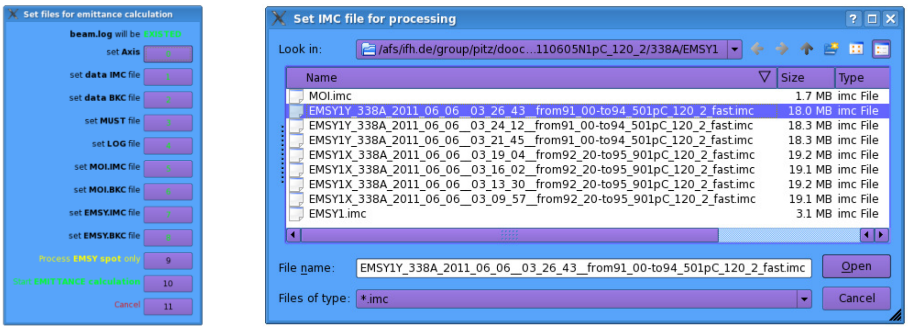


Figure 9: Dialog boxes for emittance calculation, manual mode (EC).

power and gun temperature are known for each video frame. This gives the possibility to process and explore data with more precision.

The last step in the measurement is to calculate the emittance using the “Emittance calculator” (EC) tool (see Figure 8). FES sends measurement data to EC with a request of an operator. If EC is not started yet FES starts EC. EC makes calculations and sends the plot data to a program “Root plotter” (RP). The task of RP is plotting diagrams and reports. This program RP is a symbiosis of the plot system ROOT and Qt. Also the operator can set a folder with saved data by hand (see Figure 9), and then EC calculates the data and plots results.

A lot of data processing is ongoing during calculation. Different filters, formulas etc. can be applied to the data. If necessary some parameters can be customized via options (see Figure 8). A user can select plotting options (see Figure 10) to plot all intermediate results after each complex process. At present time up to 27 different plots are available for using.

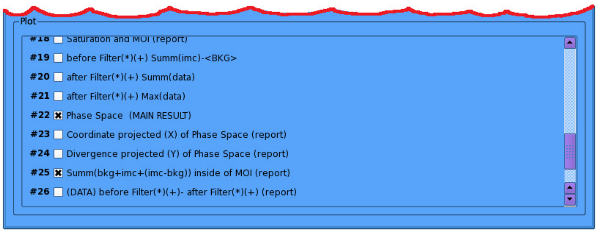


Figure 10: Bottom part of emittance calculator, panel “Plot” (EC).

At the end of the calculation the emittance plot is shown by default (see Figure 11). It is possible to transform the plot data into CSV/TXT formats.

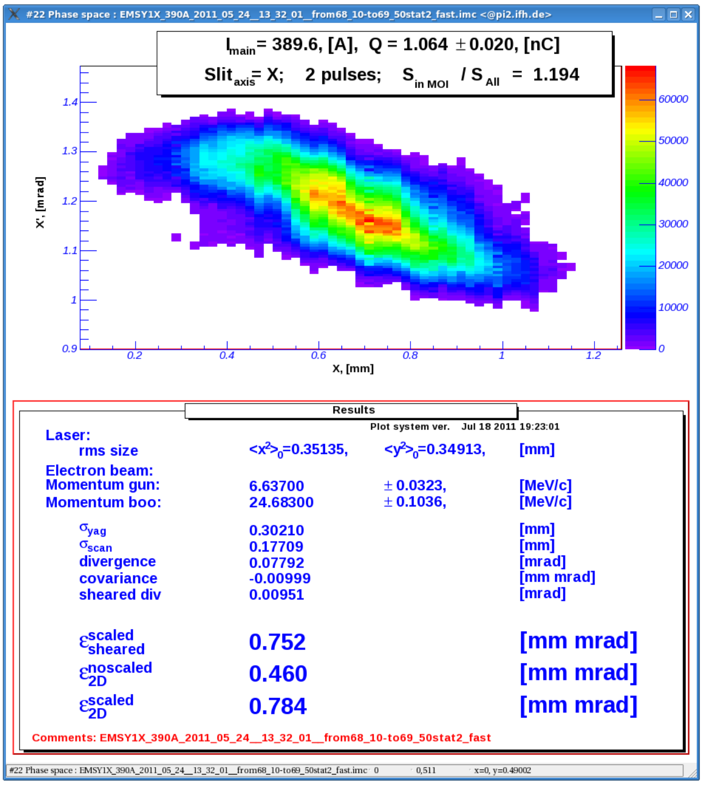


Figure 11: Phase Space plot, emittance report (RP).

Currently, the wizard consists of separated programs for each logical task. Communication between program components is realized by a shared memory. This approach gives the possibility to use EMWiz components on different user stations operating on one host. This increases graphics productivity and decreases the CPU loading. The disadvantage of using shared memory is that the operational system cannot realize the used shared memory without special actions.

An instance of the tool "Memory Watcher" (see Figure 12) is always started together with an instance of EMWiz. The tool is hidden to the user, only some useful information can be read. MW closes unused programs automatically after z predefined time, cleans probable lost shared memory, kills possible hanging components and informs about user conflict which blocks

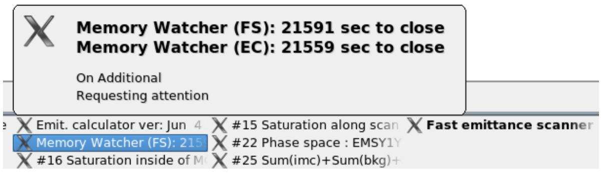


Figure 12: Memory watcher (MW).

starting of components of EMWiz. It is very useful at PITZ, because the computer system has a lot of computers and users. The system has to be continuously in operation (7/24).

CONCLUSIONS

The Emittance Measurement Wizard (EMWiz) is being one of the main measurement tools at PITZ, which consists of a set of applications. The new version of the EmWiz significantly decreased the measurement time while accuracy is being improved. The wizard strongly interfaces with the machine control and video system. Using this program, the transverse phase space and emittance value can be measured much faster and more reliable. A friendly GUI and a wide variety of options make the operator job more effective. The majority of wizard components are universal and can be used for others tasks. With the help of this tool operators can solve a wide of spectrum tasks. The PITZ facility is upgraded continuously and development of EMWiz is also ongoing. The work with EMWiz is going in the directions of complete automation of the measurement process, simplification of using, improving the quality of the experimental data and calculation algorithms.

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