

OPERATIONAL APPLICATIONS - A SOFTWARE FRAMEWORK USED FOR THE COMMISSIONING OF THE MedAustron ACCELERATOR

A. Wastl*, M. Hager, M. Regodic, EBG MedAustron, Wiener Neustadt, Austria

Abstract

MedAustron is a synchrotron-based cancer therapy and non-clinical research center located in Austria. Its accelerator is currently being commissioned prior to first medical treatment. During the tuning of the machine, many iterations of measurements involving several parameter changes are performed in order to optimize the accelerator's performance. An operation and measurement software framework called 'Operational Application Framework' (OpApp) has been developed for this purpose. It follows a modular approach and provides basic methods like 'write to file' or 'measure beam position monitor'. By appropriately combining modules, *OpApps* performing automatized measurements and complex procedures can be created. A detailed description of the setup as well as examples of use are provided here.

INTRODUCTION

The MedAustron accelerator complex includes up to four ion sources, a linear accelerator, a synchrotron and beam transfer lines guiding the beam to four irradiation rooms. Currently the accelerator commissioning is focusing on proton beams for two clinical horizontal irradiation rooms (energy range : 60 -250 MeV). For patient treatment clinical cycles of protons and carbon ion beams of 255 different energies have to be provided to three irradiation rooms.

OPERATING ENVIRONMENT

Accelerator commissioning, hardware installation and software development are processes performed in parallel leading to a very dynamic working environment. Commissioning requires repetitive measurements based on complex measurement procedures to be performed in order to verify several beam and accelerator parameters. To automatize this work the MedAustron Accelerator Control System (MACS) has constantly being extended with dedicated software tools. These tools interact with the Accelerator Control System and its sub-systems like the timing system, power converter controllers, RF systems or beams diagnostic devices.

MedAustron and CERN have developed a software infrastructure that communicates with the different systems. However, even with this infrastructure the development of commissioning tools face very specific challenges: the tools have to be flexible enough to adapt to new operation modalities of the accelerator components. Furthermore, in the course of commissioning the quantity of tools provided in different programming language increase causing the duplication of code and additional effort of maintenance.

A NEW FRAMEWORK

During the commissioning phase, flexible software applications are required that can quickly be adjusted to the changing environment, new features requested by users or to work around problems. To address these requirements an own software architecture, called 'Operational Applications' (OpApps) has been developed at MedAustron. The OpApp architecture enforces the use of small re-usable modules like setting of a control values or acquiring a beam diagnostic measurement. The basic modules can be combined to bigger modules and eventually to powerful applications.

The main domain of OpApps is the provision of configuration data and the measurement of the resulting beam. The according functionality is:

- Generate cycle dependent settings like current setpoints and waveforms from optical settings such as the magnet strength
- Deploy settings to accelerator devices
- Request the generation of beam
- Acquire beam diagnostic measurements
- Store data as files or a database entry

Optical computations and advanced analysis functionality are currently not part of the OpApps. In order to close the beam commissioning cycle (Fig. 1) a thought-through concept for the storage of measurement data has been developed. The concept defines a schema for file names, folder structures and the meta-data to be included. Sophisticated analysis modules such as the CERN ALOHA [1] program or in-house Python tools access the stored data and process it. The outcome of analysis and optical computations is fed back into Operational Applications via input files.

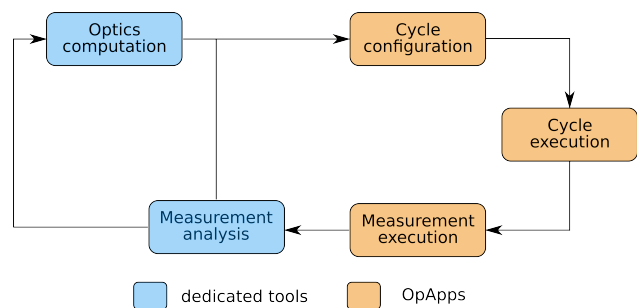


Figure 1: Commissioning tools cycle.

* alexander.wastl@medausttron.at

EXAMPLES

The OpApp architecture is programmed in C# which allows the use of an object-oriented programming style and modern programming techniques to sequence the modules. Code prepared in other languages can be used via the Microsoft .NET Framework. Furthermore, all modules can be called with a fluent syntax which even enforces the creation of modular components and enables unexperienced programmers to read OpApp code or even develop new OpApps.

The basic modules of the framework called *tasks* provide simple functionality like moving a beam monitor to the 'in'-position or setting the current of a power converter. As they still deeply interact with the hardware and the ACS, they are provided and maintained by control system (CO) experts only. *Tasks* hide these interfaces from higher level framework modules which may only interact with the accelerator components via *tasks*. Therefore these modules create a safe and flexible connection layer.

The next higher level modules are called *procedures* and combine a sequence of *tasks* or other *procedures*. They create functional blocks like shown in the kick-response example below. *Procedures* may be implemented by CO experts, but also experts from other fields may develop *procedures*. They are checked and approved by the CO group, but because of this opportunity all tools are highly integrated and undergo extensive quality checks.

```
foreach (var corrector in listOfCorrectors)
{
    SetMagneticField.Of(corrector).To(0.001);
    var orbit = MeasureTrajectory
        .Of(accelerator)
        .ShowPlots()
        .SaveMeasurementsAt("C:...")
        .Measure();
    SaveInDB.From(orbit).ToMainStorage();
}
```

The third and highest layer of modules in the framework are called *Operational Applications (OpApps)* and represent the tools available for the users. *OpApps* combine *procedures* and *tasks* to more or less complex measurement sequences. Simple *OpApps* e.g perform reproducibility measurements with one monitor displaying mean and standard deviation while an automatized chromaticity measurement changes magnets strengths, triggers the tune kickers and records beam oscillations.

At MedAustron, two types of *OpApps* are available: a) *Complex OpApps* with certain settings to be changed by the user, data plotting and simple analysis functionality provided by CO experts b) *Atomic OpApps* executed from a common launcher via a generic interface with reduced options to be set and directly storing raw measurement data.

The most frequently used *Complex OpApp* is the 'Beam Scan OpApp' providing the functionality to combine a) the scan of a control value within a given range and b) a given measurement. Examples of these combinations are:

- magnetic injection kicker fall time vs. number of circulating particles
- synchrotron dipole magnet strength vs. position of circulating beam
- electrostatic extraction septum voltage vs. beam position in HEBT
- betatron core voltage vs. extracted beam intensity
- sRF injection voltage vs. number of captured particles

These tools have been used extensively during commissioning thus saving a lot of beam time compared to manual operation. Furthermore, the data acquisition is independent of the user's operation experience and technical knowledge. Figure 2 shows an example where the electrostatic injection septum voltage was scanned from 31.7 to 32.5 kV in steps of 100V while monitoring the current of the circulating beam in the synchrotron.

The most frequently used *Atomic OpApp* is the 'Loop file OpApp'. The user defines a sequence of settings of multiple components in a 'Loop file' which is loaded by the OpApp, applied to the components and the raw measurement data of a given beam monitor is stored. Usage examples are:

- tune map [2]: measuring the circulating beam current for different quadrupole strengths combinations
- tomoscope [3]: beam profile measurements for multiple phase-shifter-stepper settings [4]

An example of a loop file is shown below. The number in the first column defines the cycle number at which the settings of the according component are applied. In this example three different settings for two quadrupole magnet families are used. The number of components changed at each cycle as well as the number of cycles can be extended. The result of a 'loop file' tune scan is shown in Fig. 2.

```
1,MR-00-001-MQZ,Strength,0.41677870
1,MR-02-000-MQZ,Strength,0.36761078
2,MR-00-001-MQZ,Strength,0.41465342
2,MR-02-000-MQZ,Strength,0.36823729
3,MR-00-001-MQZ,Strength,0.41195782
3,MR-02-000-MQZ,Strength,0.36859163
```

Other *Atomic OpApps* perform kick-response-matrix measurements where the measurement data is passed on the ALOHA for analysis as well as dispersion, chromaticity or emittance measurements.

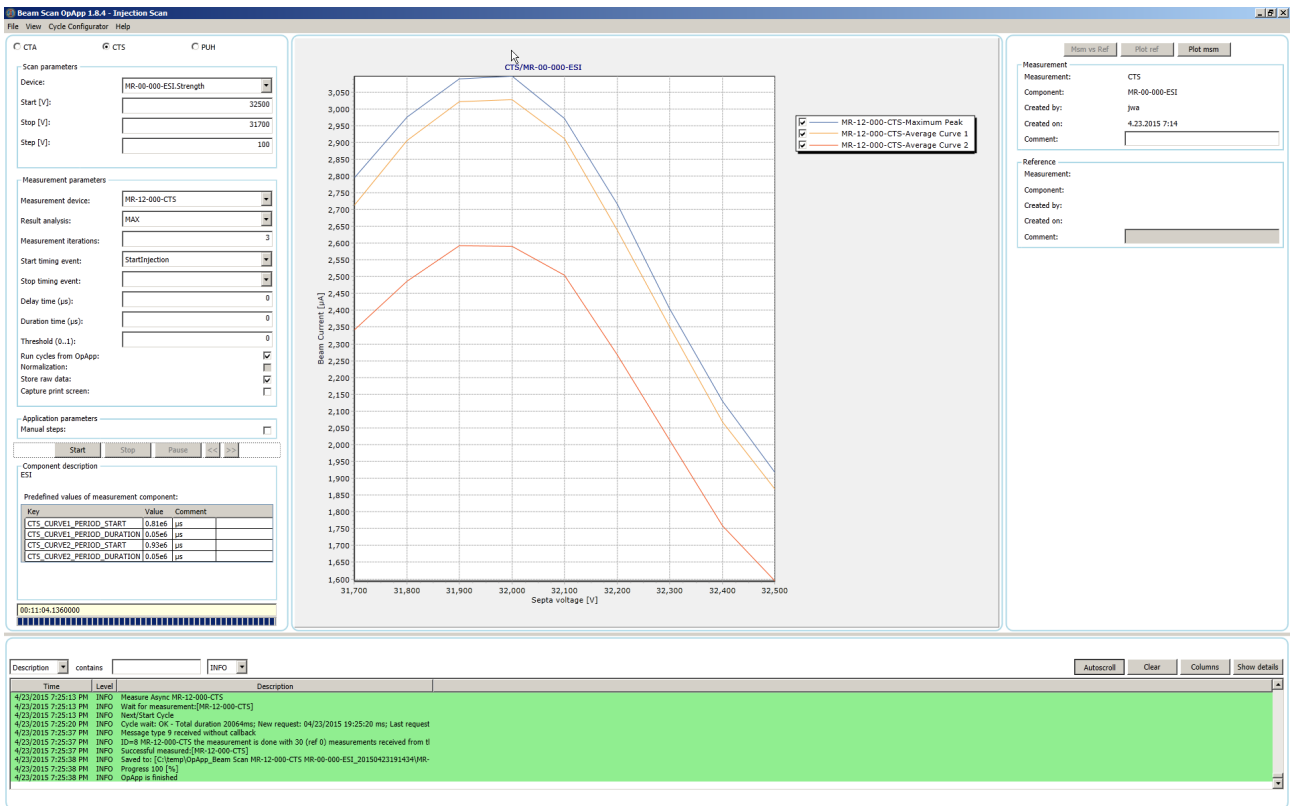


Figure 2: The 'Beam Scan OpApp' scanning the voltage of the electrostatic injection septum. The three different beam currents (maximum peak at injection, 10ms and 410ms after injection) are recorded and displayed.

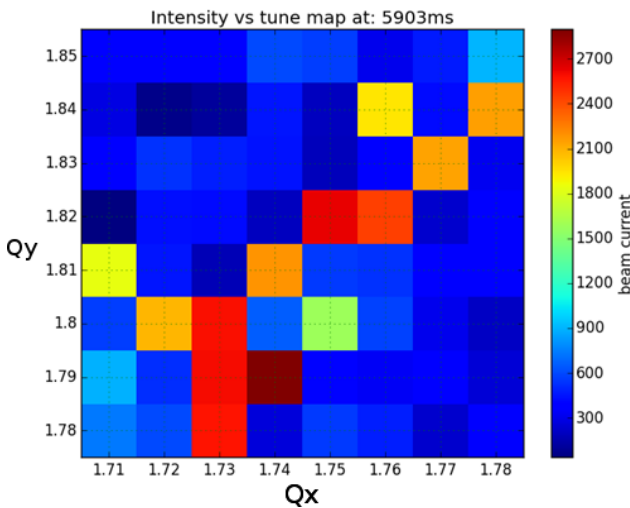


Figure 3: The measurement for a tune scan is being performed in approx. 30 minutes.

OUTLOOK

The use of OpApps is constantly being improved and extended. As most of them still base on the same set of core functionalities, new features can be developed quickly within the OpApp framework. A recent example is the creation of

a multiple dimensional scan OpApp scanning the strength and fall time of the magnetic injection kicker.

Furthermore, advanced analysis are not performed by *OpApps* currently but the measurement data files are loaded into a dedicated Python analysis framework providing this functionality. Additional Operation Applications are already foreseen for Quality assurance purposes and for a constant monitoring of the accelerator. A database dedicated to store the setup of the accelerator, the generated cycles and related measurements is already in development.

CONCLUSION

A measurement and operation framework for beam commissioning and quality assurance in the dynamic setup of an accelerator has been developed. Its simplicity of use and versatility makes it an indispensable tool for the commissioning of the MedAustron accelerator. Applications performing optical parameter scans or more complex procedures like kick-response or chromaticity measurements are already available while new tools are continuously being developed. The acquisition of measurement data is highly independent of user errors and a lot of beam time is saved because complex measurement procedures can be prepared off-line and then be executed rapidly by an OpApp.

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