

Introduction of ITER CODAC relevant technologies on JET and MAST

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ABSTRACT

The JET control and data acquisition system (CODAS) is an integrated system that provides all the pulse based and continuous data acquisition, real time and slow control and control room interfaces for JET. It has a long history, dating back to the beginning of JET in 1980. It utilises both commercially available hardware along with many in-house modules. The software has grown up and evolved largely independently of other developments in big science. Similarly, the data acquisition system on MAST has a long history of evolution from previous facilities at Culham (COMPASS). It utilises commercially available and in-house hardware (some shared with JET CODAS) and software that has developed largely independently of JET and other external developments. More recently, we have begun to adopt some ITER CODAC relevant technologies on both JET and MAST, in part, to also introduce some standardisation between the two facilities. This started with a pilot project to create a cubicle and environment monitoring system using commercial hardware and EPICS monitoring and HMI. We have since gone on to implement several camera and spectrometer filter controllers, several types of turbo-molecular pump controller, and various radiation protection monitors in EPICS on JET. We are also implementing a central information display system for MAST that links the OPC interface on the machine control through to several display screens showing the machine state using EPICS. We have several MARTe based real time applications on JET and are now developing an application to provide real time processing of high-resolution Thomson scattering data using MARTe V2 (an ITER/F4E initiative to improve the robustness of this real-time framework). We are also considering upgrading the existing MARTe applications to this version. On JET we have also started to use another ITER CODAC technology – SDN to supplement the ATM based real time control network on JET. Initially, as a proof of principle, a real time plasma profile display was implemented. This system is now being extended to include several real time data sources which will feed their data back into the ATM network and on to the real time controllers. Looking forward, we anticipate extending the JET real time network with a purely ITER CODAC/SDN connected real time control system and provide a richer ITER CODAC interface to the JET CODAS to accommodate the possibility of ITER diagnostics testing and provide a real stress test for ITER archiving technologies.

1. Introduction

Maintaining the control and data acquisition infrastructures for large fusion devices such as JET and MAST poses several challenges driven by evolving requirements. Both machines have had successful periods of development and stable operation based on the original and primarily bespoke architectures that were designed during construction. They have also generally proven sufficiently extensible and maintainable over a long period of operations. In recent years, new requirements have stimulated a program that is incrementally updating the systems to be compatible with modern approaches such as those selected for ITER. From a technical perspective there has been a requirement on JET to address hardware obsolescence, both at the

SCADA level for slow control and in the real-time network that interconnects the plasma control systems.

From a management perspective there are requirements to improve efficiency and to be able to maintain the technical team of staff with the right skills to operate and adapt the complex systems. However, the opportunities to adopt up to date open software stacks which bring with them quality advantages due to a large community support base, and which are well understood by a broad pool of technical experts have to be balanced against the need to continue to deliver high availability and high reliability operations to the research teams who exploit the machines. Best tools and practice have been adopted where practical on a case by case basis. This has been supported by extending the legacy core frameworks to permit interoperability with the new front end

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systems.

One of the efficiency gains that this makes possible is that new team members bringing translatable skills from other high energy physics machines can be immediately productive. Equally, enabling existing staff to become familiar with solutions that are relevant in other sectors and diverse organisations is beneficial for staff retention. Where possible, unifying on a common, modern toolkit across different business units has benefits for economy of scale and to maximise consistency and repeatability of operation. The planning and implementation of this work is partly driven by bottom up short term opportunities which enable medium term infrastructure evolution that in turn supports successful long term success. Senior strategic thinking is aligned with this pragmatic approach at regular intervals.

Driven by these principles, adoption of ITER relevant CODAC technologies is advancing in three domains: general SCADA, data acquisition and real-time control. This paper gives a status report that surveys some of the progress illustrated with case studies in these areas.

2. EPICS on MAST

MAST has a long history of evolution from previous facilities at Culham in particular its predecessor COMPASS. MAST utilises commercially available and in-house hardware, some shared with JET CODAS, and software that has developed largely independently of JET and other external developments. MAST does not have a single standard slow monitoring and control infrastructure. For historical reasons several separate control domains have made independent choices.

We have begun to adopt ITER CODAC relevant technologies on both JET and MAST, in part, to introduce some standardization between the two facilities.

2.1. MAST Cubicle Environment Monitoring

As a simple proof of principle, we used EPICS [1] and CS-Studio [2] to prototype a cubicle and environment monitoring system and operator interfaces for MAST. We used standard COTS SNMP manageable environment monitors with one of them also providing contacts for door monitoring. We implemented the IOC using the SNMP device driver [3], the operator interfaces using CS-Studio BOY [4], the logging system using CS-Studio BEAUTY [5] and the alarm system using CS-Studio BEAST [6]. We developed a python script to update EPICS database and BOY screens when new monitors are added to the monitoring system.

2.2. MAST Central Information Display

The MAST Central Information Display (CID) provides MAST high level summary information such as machine area state, shot number and vacuum conditions. The data is managed in a proprietary SCADA system called iFix. The EPICS IOC uses the OPC device support module [7] to implement an OPC connection to the iFix server and maps OPC tags into EPICS Process Variables (PVs). We created the Control

Information Display in CS-Studio and we used Tomcat as the webserver to deploy WebOPI (Fig. 1.) [8]. Web output can be proxied through MAST firewall giving read only access to external collaborators. The CID development opens up the possibilities to replace some or all of the iFix systems with EPICS/CS-Studio and to manage data acquisition systems through EPICS.

2.3. Conceptual data acquisition design for fusion facilities at Culham using EPICS

The use of EPICS for control is well-established. Its use for data-acquisition is less well developed. However, with the introduction of modules such as areaDetector [9] and the advent of structured data-types for process variables, EPICS becomes more functional in this regard. The fusion experiments at the CCFE have a requirement to perform shot-based data-acquisition. Fig. 2. presents one possible high level design for how shot-based data-acquisition could be achieved on MAST. An EPICS IOC, the Shot Info Service in Fig. 2., shall get shot number, shot mode (real shot or test shot) and shot state from the Machine Control System and publish them as PVs which can be read from the device IOC, XYZ IOC in Fig. 2. The device IOC shall then send an arm command to the device which shall start the acquisition when triggered from the hardware trigger line. A data client, XYZ Data Client in Fig. 2., shall be able to read the data when the data is valid and ready to be read according to the value of XYZ:valid PV.

2.4. MAST data acquisition for spectroscopic CCD cameras

The MAST spectroscopy team has nine spectroscopy experiments that use eight models of camera from four camera manufacturers. The team aims to develop data-acquisition programs for all the different spectroscopy experiments using EPICS. One solution which is being explored is the use of EPICS to control the spectroscopy cameras and collect data from them using areaDetector.

3. EPICS on JET

JET CODAS have an extensive, integrated, well established slow control and monitoring infrastructure with Plant Status Image points (150000), alarms (12000), trends (7000), logic and sequences, mimics (3000), control panels and role based security read only access over the online firewall. Although well established, JET CODAS was developed a very long time ago for Norsk Data systems and ported to Oracle Solaris and it is now becoming increasingly difficult to migrate to new hardware and operating systems and to support current deployed systems.

Introduction of EPICS provides JET CODAS with access to a vast body of well supported open source software and cross platform support and contributes to build a one team approach on JET and MAST.

3.1. JET CODAS – EPICS integration

Due to long history of JET CODAS and CODAS operators' experience

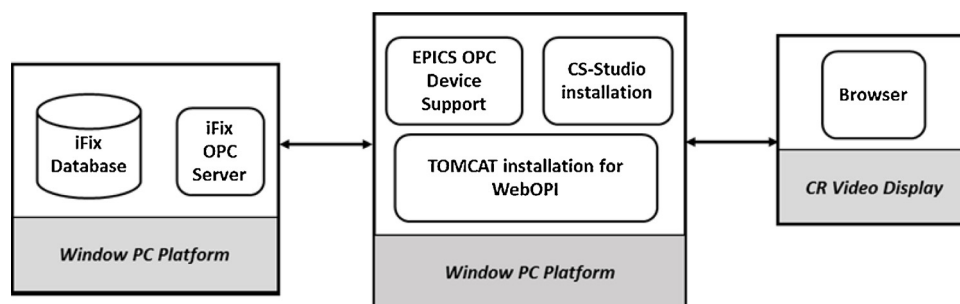


Fig. 1. MAST Central Information Display block diagram.

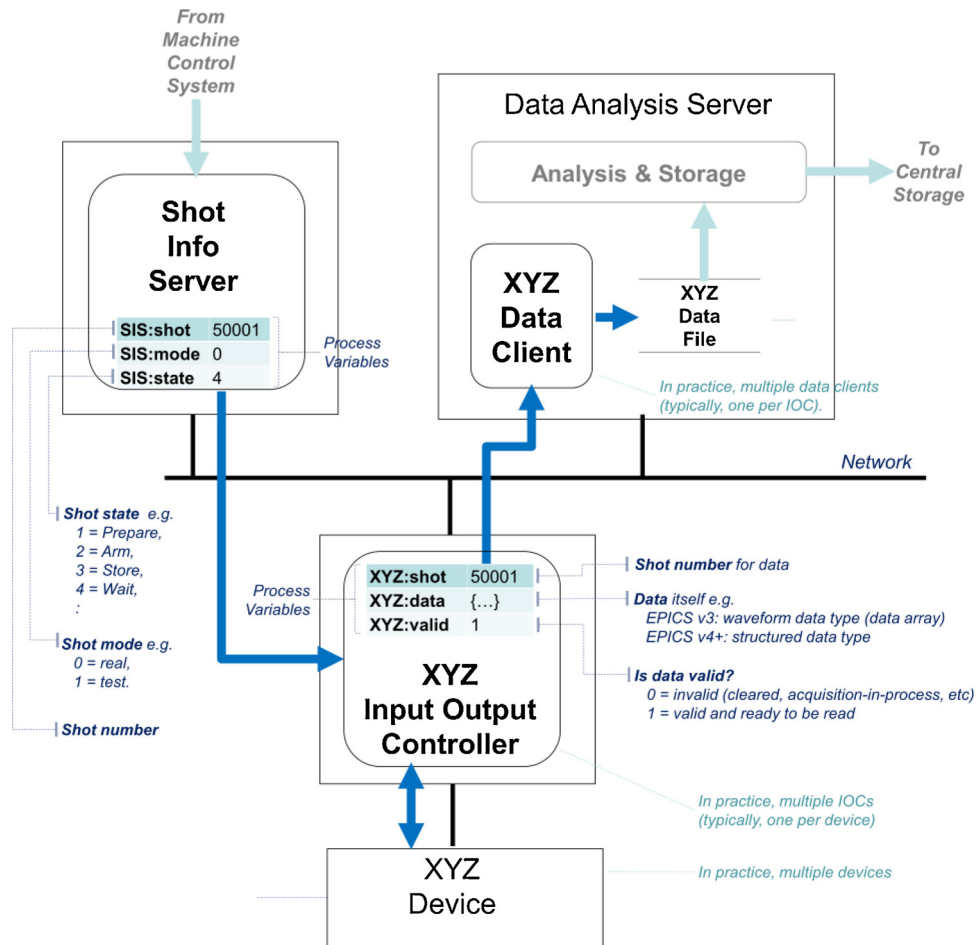


Fig. 2. Conceptual data acquisition design for MAST using EPICS.

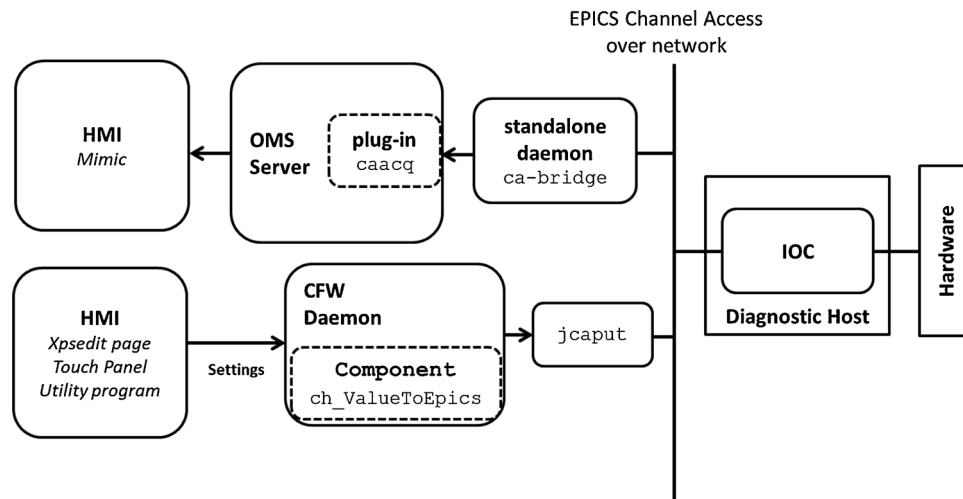


Fig. 3. System architecture to integrate EPICS systems in JET CODAS.

The CODAS Object Monitoring Service (OMS) is used within JET CODAS to provide reliable and efficient monitoring of dynamic data. The CODAS component Framework (CFW) [17] is a framework for writing control and diagnostics applications.

and expectations, an instant transition to pure EPICS/CS-Studio system was not possible, therefore we developed a Channel Access bridge (ca-bridge) to integrate new native EPICS systems in the current JET CODAS (Fig. 3.).

The ca-bridge allows to:

1. read or monitor an EPICS PV from JET CODAS HMIs,

2. write to an EPICS PV from JET CODAS HMIs,
3. read or monitor a CODAS resource from EPICS,
4. write to a CODAS resource from EPICS.

3.2. JET Filter Wheel Control

The JET Diverter Spectroscopy system uses Thorlabs FW102C

Motorized Filter Wheels. We developed an IOC to enable monitoring and control of the position of the Filter Wheel. The FW102C is a high-precision, motor-driven, six-position filter wheel with a text-based command line interface (CLI). The IOC uses the EPICS StreamDevice support module [10] to implement the communication with the FW102C via this CLI protocol. Although we developed the IOC to be used to control the FW102C Filter Wheel in the JET Diverter Spectroscopy system, the IOC is a general purpose controller, suitable for managing an FW102C Filter Wheel in a variety of applications. The IOC is fully integrated in the JET CODAS using the ca-bridge. The IOC shall also be deployed for JET experimental cameras.

3.3. JET Turbomolecular Pump control

JET has used and will use in the future different kinds of turbomolecular pumps. We developed EPICS IOCs to monitor engineering data for Oerlikon Leybold turbo pump MAG.Drive Digital controller, Agilent Tritium compatible turbopumps Turbo-V 550 Controller and Edwards STP-A2203 Series turbomolecular pump/SCU-1600 Control Unit. The IOCs can monitor signals such as pump rotation speed, motor current and pump temperature and, depending on the pump, other engineering data. LeyboldTurbo EPICS IOC also allows an authorised user group to turn the pump on or off or reset the pump if it has an error status. The IOCs use AsynDriver module [11] and streamDevice support module [10] to communicate to the pump controllers via their serial interface. The IOCs are fully integrated in the JET CODAS using the ca-bridge.

The software we developed for Oerlikon Leybold Turbo pump MAG.Drive Digital controller has been released to the EPICS community.

3.4. MRF Radiation Protection Instrumentation

The Culham MRF (Material Research Facility) Tritium Stack Monitoring system is implemented using DTionix Tritium online analyzers supplied by Premium Analyse. Two monitors are already deployed and we plan to expand the system to have 13 monitors. The monitors publish measured data via Modbus Protocol. We developed an EPICS IOC which periodically polls Premium Analyse Tritium Monitors' Modbus service using the EPICS modbus device support [12] and loads downloaded parameters into EPICS PVs. The EPICS monitoring system is fully integrated in the JET CODAS. The IOC is hosted on a Virtual Linux Server. PVs values are copied to PSI (Plant State Image) points and trends recorded in the JET CGRT (Continuous Recorded Data) system.

4. JET Real Time Network Extension using ITER CODAC SDN

ATM (Asynchronous Transfer Mode) is the current technology to transmit real time data on the JET Real Time Data Network (RTDN). ATM, though very reliable and well tested, is not widely used anymore and it is difficult to source ATM cards. Therefore the upgrade of the real time network to ITER CODAC Ethernet/SDN (Synchronous Databus Network) [13] is under development. We did some performance tests using Intel Pro1000 network interfaces card and Gigabit edge with 10 Gigabit interconnects Extreme switches. We tested UDP multicast with transmitter and receiver connected via a cross cable, connected via a switch and connected via two switches with a 10 Gigabit interconnect. We also tested performances with an aggressor injecting additional high network traffic. We used test techniques as for an ITER/F4E real time network qualification contract. We had good results (Fig. 4.), though we observed some features not seen with the ITER/F4E equipment.

4.1. JET architecture for ITER CODAC SDN

The JET real time data network support communications between

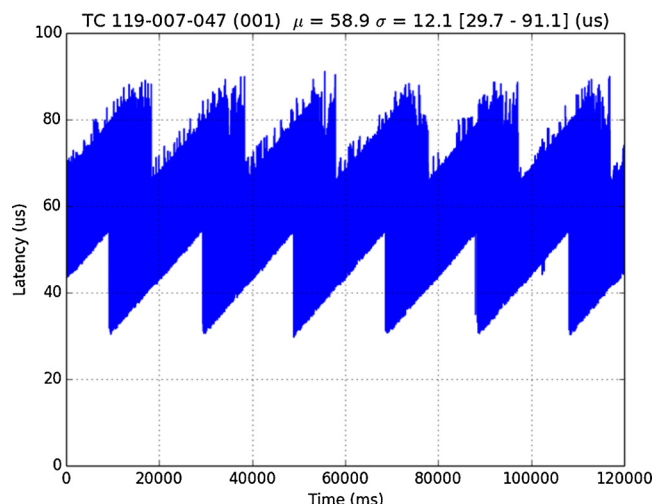


Fig. 4. Latency results for multicast UDP over two switches with TCP aggressor traffic over two switches. 10Gb link between switches. Packet size 149 bytes. The sawtooth modulation is attributed to a characteristic of the network switch.

diagnostics and plasma control systems. Since it is critical for JET operations it was impractical and too risky to migrate all systems from ATM to Ethernet at once. To support an incremental migration we developed a bridge between the two technologies and we used MARTe1 [14] as the underlying real time framework to develop the SDN bridge (Fig. 5).

A first use case was to provide an updated display application for the session leader. The Mantid [16] visualization framework was selected to provide the UI.

The bridge reads the ATM packets coming in and passes the information over SDN and vice versa. We developed Mantid plugins to listen to SDN data and Mantid is now used to display real time flux surface reconstruction in the JET control room (Fig. 6.). We currently have two Ethernet switches and two native SDN diagnostics at JET, the High Resolution Thomson Scattering diagnostic, a MARTe2 application publishing SDN data over Ethernet, and the Electron Cyclotron Emission Michelson interferometer (KK1) diagnostic. We plan to enhance real time controllers, move local actuator managers onto Ethernet/SDN and release spares for real-time protection system.

5. Future work

We are planning to develop data acquisition systems managed via EPICS and to implement areaDetector based acquisition from spectroscopy cameras.

We completed the development of an EPICS interface for Granville-Phillips Ion Trap Vacuum mass spectrometer. It is not yet deployed but it is of interest to ITER via the US Domestic Agency.

We aim at implementing an EPICS archiver and CS-Studio based HMI's.

We are looking at the possibility of using the ITER CODAC DAN (Data Archiving Network) [15] and the ITER Real Time framework for the JET RTCC2 (Real Time Central Controller) and PCS (Plasma Control system).

6. Conclusions

Control and data acquisition systems provide the central integration without which no Tokamak system can operate. They are implemented with technologies which evolve at a very high rate. Evolution must be managed to avoid stagnation which brings risks that can eventually become unsupportable, but in a way that balances the need for update with the responsibility to deliver stable operational services.

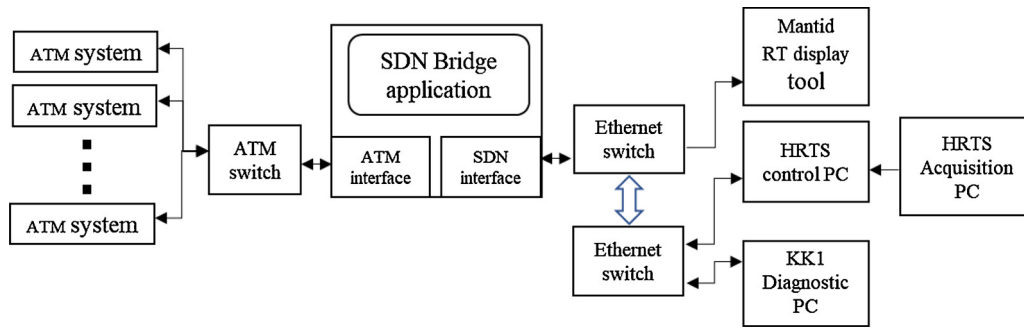


Fig. 5. JET architecture for extension of JET real time network using ITER CODAC SDN.

We are managing this requirement on JET and MAST by adopting EPICS solutions for SCADA projects where practical on a case by case basis. In so doing, we are contributing to the EPICS open source community and building new staff capability in this area. This is resulting in a virtuous spiral, since as our capability increases, the cost and risk of adopting the better technology on subsequent projects becomes easier to justify. It also enables recruitment of staff from outside the project who already have these skillsets and provides an environment in which they can become immediately productive. A similar approach is also paying dividends in respect of real-time control on JET, where new systems are being implemented using modern ethernet solutions. It should be noted that although this paper has focussed on the run time applications which implement the various required data flows, a critical complementary technology is powerful configuration management to link them consistently. On JET, this is driven by a very sophisticated “Level-1” software package. Providing equivalent functionality on other machines remains a topic of interest.

As we grow and refresh our technical CODAS teams, use of state of the art approaches has benefits for being able to recruit and retain new staff. As we transition towards a future Fusion industry it is important that we leverage the opportunity to embed our junior engineers in teams where they can learn from colleagues with decades of experience in the challenges that delivering and operating integrated Tokamak control systems brings. We believe that this approach will continue to be important as UKAEA expand their portfolio of Fusion research and development facilities where finding ways to transfer knowledge from

Fusion operations to industry and ways to select and deploy the best industrial approaches in new devices are complementary and mutually beneficial.

CRedit authorship contribution statement

John Waterhouse: Conceptualization, Methodology, Project administration, Resources, Writing - review & editing, Writing - original draft. **Adam Stephen:** Conceptualization, Methodology, Project administration, Resources, Writing - original draft. **Nicoletta Petrella:** Conceptualization, Methodology, Project administration, Resources, Writing - original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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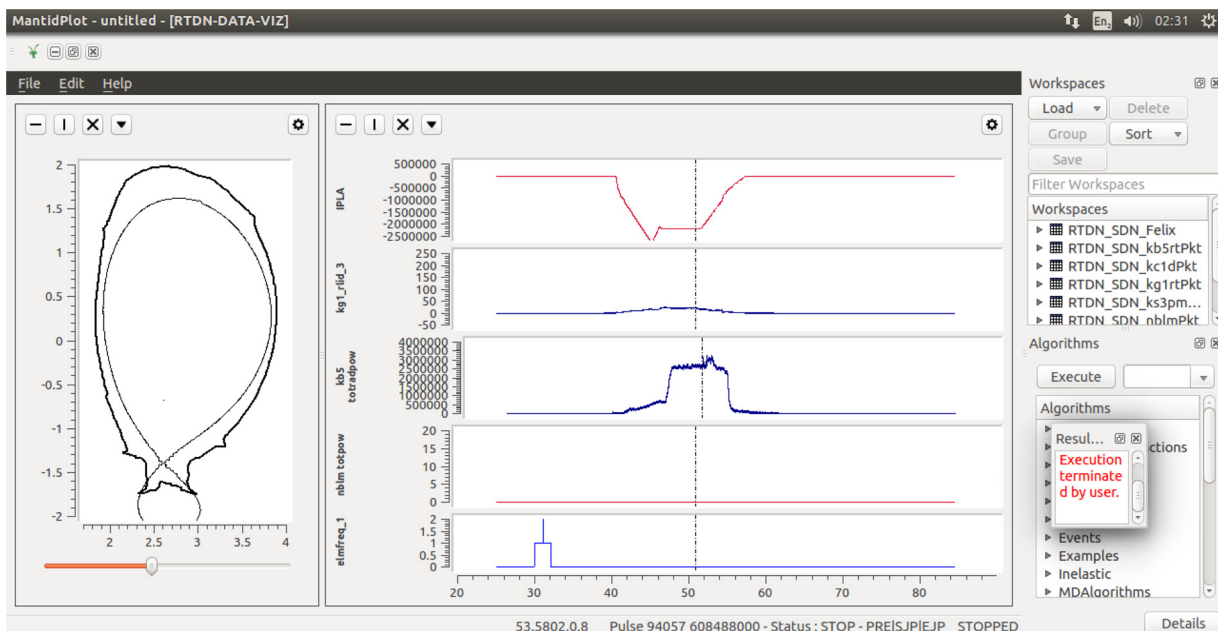


Fig. 6. A screenshot of Mantid for real time flux surface reconstruction in the JET control room for pulse number 94057.

which are not liable for any use that may be made of the information contained herein. This work has been carried out within the framework of the Contract for the Operation of the JET Facilities and has received funding from the European Union Horizon 2020 research and innovation programme. The views and opinions expressed herein do not necessarily reflect those of the European Commission. We thank JET CODAS Group and MAST DATAC Group at CCFE, Culham Science Centre, Abingdon, Oxfordshire, OX14 3DB, UK. We thank Tessella Ltd, 26 The Quadrant, Abingdon Science Park, Abingdon OX14 3YS, UK, and Cosylab, d. d., Control System Laboratory, Gerbičeva ulica 64, SI-1000 Ljubljana, Slovenia for providing training materials. Mark Clark, Peter Heesterman, Misha Beldishevski, Matthew Furseman, Colin Hogben (they are not authors but we would like to thank them for the work on the various projects we describe in this paper and for all their help in collecting all projects' information for this paper.)

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