

BEAM FAST RECOVERY STUDY AND APPLICATION FOR CAFe

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Abstract

Based on the MASAR (MACHine Snapshot, Archiving, and Retrieve) system [1], a beam fast recovery system was designed and tested in CAFe (Chinese ADS Front-end Demo Superconducting Linac) at IMP/CAS for high current CW (Continuous Wave) beam. The proton beam was accelerated to about 20 MeV with 23 SC (Superconducting) cavities, and the maximum current reaches about 10 mA. The fast-recovery system plays a major role in the 100-hours-100-kW long-term test, during which the average time of the beam recovery is 7 seconds, achieving the availability higher than 90%. The system verifies the possibility for high current beam fast recovery in CiADS (China initiative Accelerator Driven sub-critical System).

INTRODUCTION

The ADS superconducting proton linac prototype (CAFe) led by the Institute of Modern Physics, Chinese Academy of Sciences has continuously improved technology and achieved remarkable innovation in commissioning and operation in recent years: 15~16 MeV@2mA CW proton beam stable operation up to 100 hours in the early of 2019 [2], 100 kW proton beam stable operation at 10 mA in CW mode at the beginning of 2021 [3]. The control system provides an important safeguard for CAFe linac during

the stable operation. This paper introduces MASAR and its application in CAFe linac, mainly concerning beam fast re-tuning.

MASAR

MASAR is an epics V4 service, which is developed based on C++ and python. It was originally proposed and developed by Brookhaven National Laboratory in the United States, and then applied to the second generation synchrotron radiation light source (NSLS-II). The function is just like its name, including the archiving, comparison and restoration of machine snapshots, data archiving and data retrieval [1].

The MASAR consists of client and server: the client has a client Python API library, which can be used by both Python scripting and the GUI. A default PyQt4 GUI is developed for data viewing, snapshot taking, comparing a snapshot with a live machine, and restoring the machine to a particular status using a snapshot. The server has 4 layers: Service communication control; Service: parses a command from the client, implements the desired action, and returns the result to the client; Channel Access Client; DSL (data source layer) and Data layer [3][4]. Figure 1 shows the MASAR Architecture.

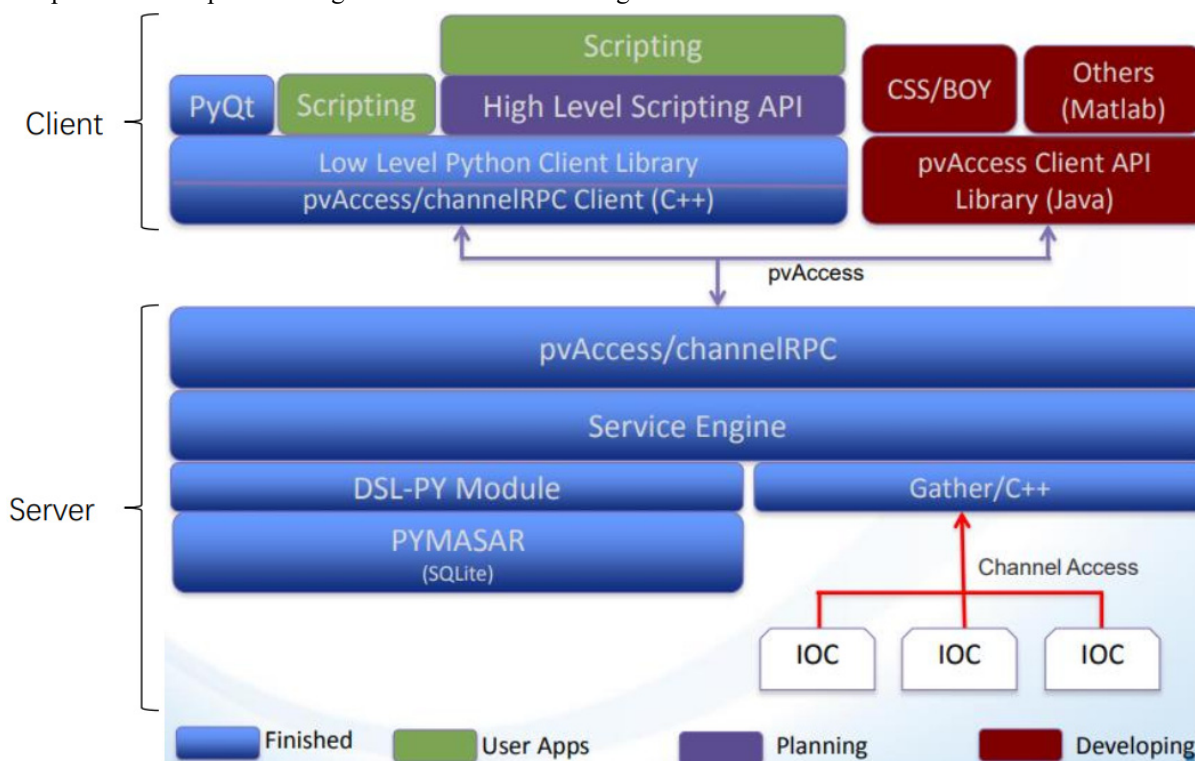


Figure 1: MASAR Architecture.

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BEAM FAST RECOVERY EXPERIMENT BASED ON MASAR

The purpose of beam fast recovery is, when faults occur to the machine, the beam is recovered in a short time. The machine faults should be judged before the recovery action by MPS: if the faults are serious, like severe LLRF (Low-Level Radio Frequency) failure, then the beam should be stopped before the RFQ (Radio Frequency Quadrupole); otherwise, the beam fast recovery system takes action. The beam fast recovery system helps improve the availability of the machine and ensures the stable operation of the beam for a long time.

Considering various recoverable faults, a series of orderly automatic recovery measures are taken. When BPMs (Beam Position Monitor) detect abnormal beam status, the beam will be stopped quickly; when all system returns to normal, the beam will be quickly restored.

The beam fast recovery system includes the operation, monitoring and judgment of MPS (Machine Protection System), BPS (Bypass Control System), timing and LLRF systems. The optimization of existing hardware improves the reliability and recovery speed, and main manual operation including pulling out the FC (Faraday Cup) before RFQ is replaced by the control system, without losing machine safety at the same time.

During beam recovery, it is necessary to judge the beam status (it is probe beam or continuous wave beam) and BPM status (the phase and position of the beam at all BPMs). Therefore, before the recovery, the machine

snapshot should be taken when the machine operates normally and stably (beam operation leader confirms that the beam reaches normal status), and the 81 BPMs snapshots (27 BPMs in total, each consists of Phase, X position and Y position) are saved, which is treated as the standard for BPM comparison and judgment. To ensure that the phase and position information of the beam at BPMs are saved at the same time, MASAR needs to be used for one-click operation.

When BPM judgment starts, the PV should be judged whether it is disconnecting. If so, set disconnect_Flag to true, otherwise false. The trigger number (trig_No.) is initialized to 0.

If $\text{trig_No.} < 3$, Count (the number of PVs' value satisfied the conditions) is initialized to 0. If BPM's PV is bypassed, Count plus 1; otherwise, the PVs' value is judged whether within the standard threshold. If within, Count plus 1 and Flag is set to true; if not within, F_Count (F_Count indicates the number of PVs' value not satisfied conditions) plus 1 and Flag is set to False. Then, judge $\text{F_Count} > 6$, if not, judge next PV is bypassed. If so, break off PV judgment.

Then judge whether $\text{count} \geq 76$: if so, return 1, indicating that the judgment passed; otherwise, Trig_No. plus 1.

If $\text{Trig_No.} \geq 3$, check disconnect_Flag is true or not. If true, return -1, the reason for not passing the judgment is that PV disconnect. If not, return 0, the reason for not passing the judgment is the number of PV's value satisfied conditions is less than required. Figure 2 shows the BPM judgment process.

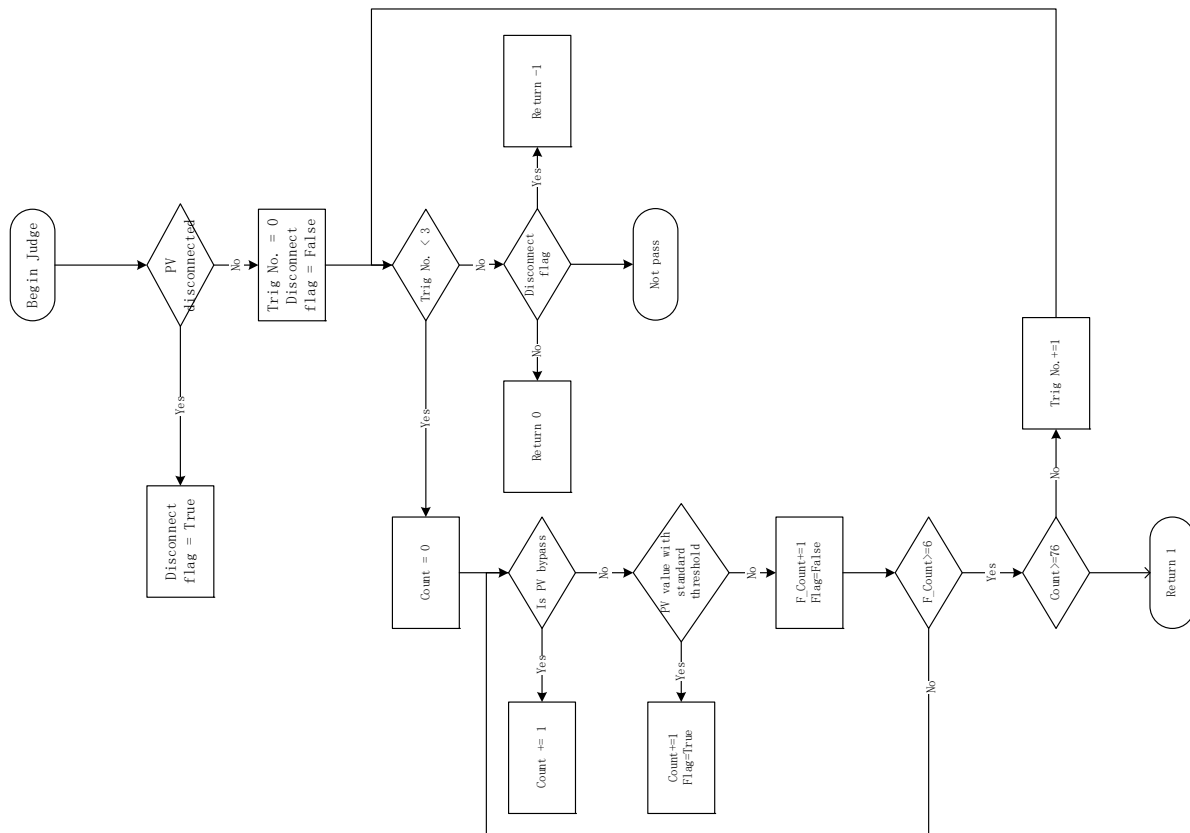


Figure 2: BPM judgment process.

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We use MASAR to save the relevant information of BPM beam: Firstly, save the PV list of 81 beam phase and position information of BPM in masarService/example/pvs/beam_auto_Re.txt text file; Secondly, configure the PV group of MASAR and establish a connection with

the PV related to publishing BPM, so that the PV value can be obtained through CA protocol when it is necessary. Edit the masarService/Python/pymasarsqlite/db/settings.py file and add the following content:

```
# pv group name: [pv list file, description]
pvgroups= {
    'BEAM_AUTO_RE': ['pvs/beam_auto_re.txt', 'beam auto recovery use snap give bpm']
}
# config name: [config desc, system]
configs= {
    'BEAM_AUTO_RE': ['beam auto recovery use snap give bpm', 'BM']
}
# config name: [pvgroup,]
pvgroup2config= {
    'BEAM_AUTO_RE': ['BEAM_AUTO_RE']
}
```

Finally, create the SQLite3 database: Python masarService/python/pymasarsqlite/db/configmasardb.py. So far, the

BPM snapshot of MASAR has been configured. Restart the MASAR server:

```
$ cd masarService/cpp
$ ./bin/linux-x86_64/masarServiceRun
```

The interface is shown in Figure 3.

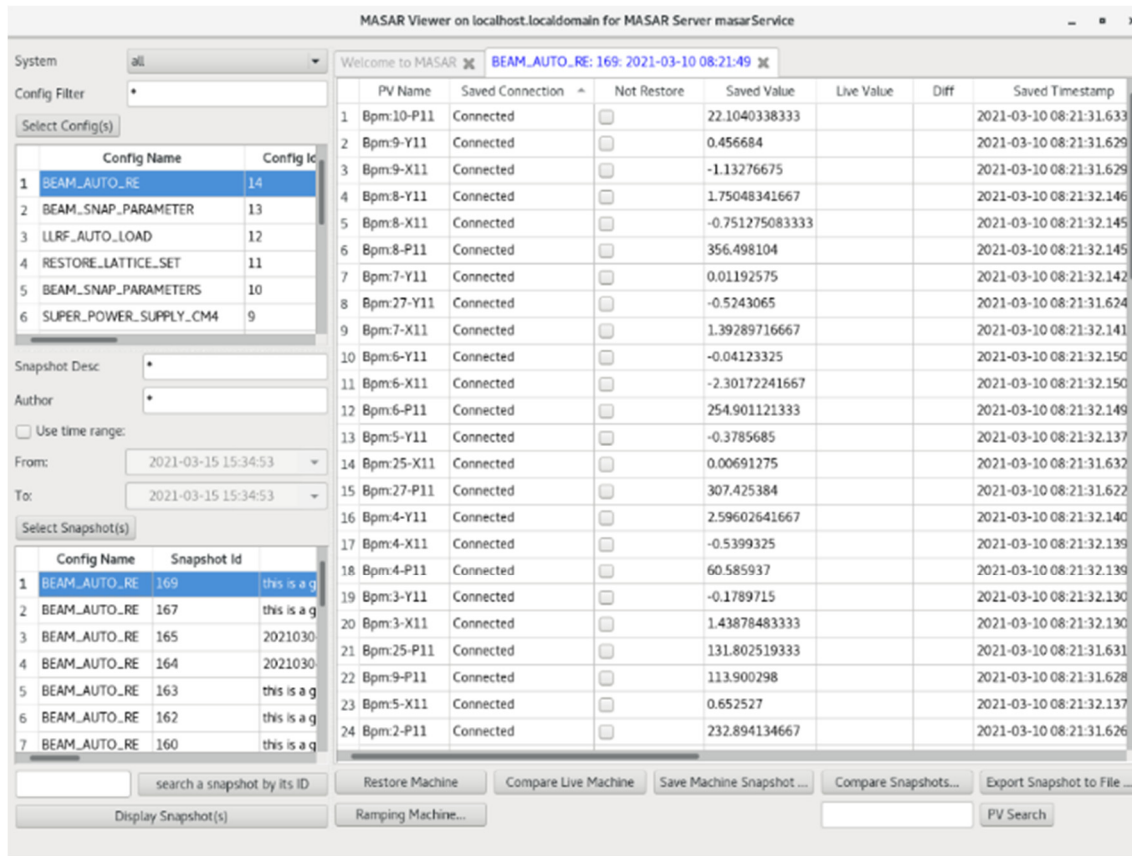


Figure 3: MASAR view

According to the operation status of the machine, the beam operation leader judges when the beam reaches a normal state, and the MASAR snapshot is saved with the beam phase and position information at all BPM. Call the saveSnapshot() function of MASAR, and use it as the judgment standard of BPM beam phase and position information during beam fast recovery. Before the subsequent machine operation, retrieve the beam phase and position information from the previously saved BPM data, then call the retrieveSnapshot() function, and assign the saved PV values of the BPM phase and position to the standard PV values of the corresponding BPM phase and position one by one, for the comparison in the beam fast recovery experiment.

CONCLUSION AND PROSPECT

In the experiment, as a tool of EPICS, MASAR realized fast saving snapshot, retrieving snapshot data and assisting snapshot data value recovery in 1 s, which leaves enough time for the adjustment of the hardware system, shortened the beam recovery time and improved the availability of the machine. The results of the 100-hours-100-kW beam stability test are shown in Table 1, and the availability of the machine is up to 93.5% with beam fast recovery. The beam recovery time distribution is shown in Figure 4, and recovery issues within 6 s take higher than 80%. The frequency statistics for automatic recovery are shown in Figure 5, of which 90% have the condition for automatic recovery and 78% are successful. The system verifies the possibility for high current beam fast recovery in CiADS.

Table 1: Test Results

Parameters	Value	Unit
Beam energy	17.272±0.034	MeV
Average current intensity	7.2966±0.0244	mA
Beam power	126.0	kW
Total test time	108	h
RF superconducting system availability	98	%
Machine availability	93.5	%

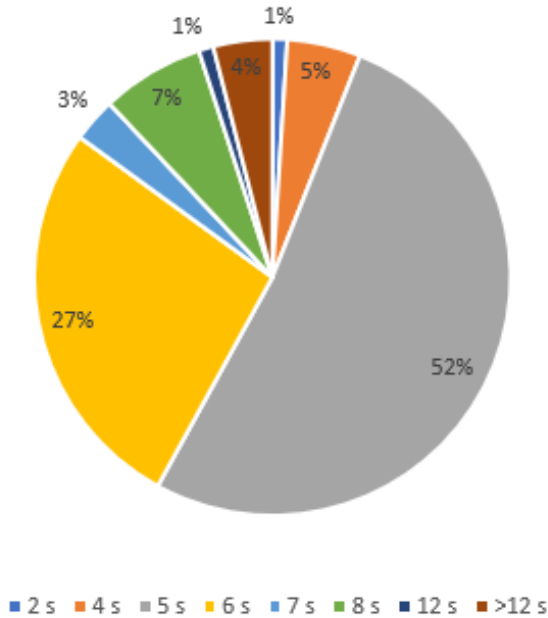


Figure 4: The time required for beam recovery.

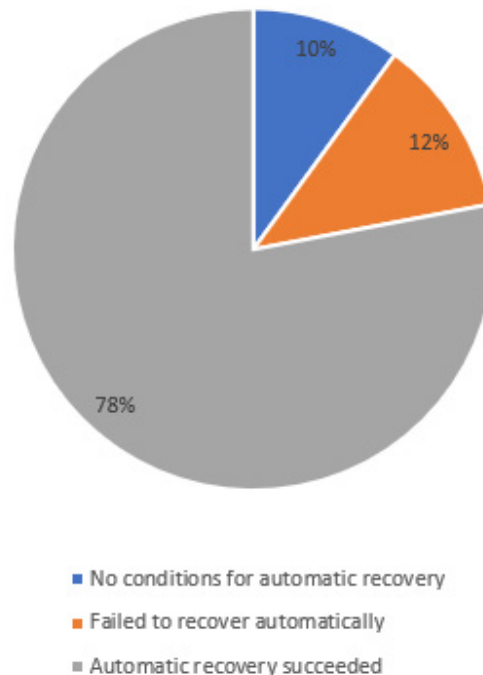


Figure 5: The automatic recovery times.

There are many advantages in beam fast recovery system: compared with manual recovery, the time is very short; automatically judge the beam status, which is more reliable; automatic execution, greatly reducing labor intensity and improving reaction speed; most trip situations could be judged and handled.

There are still some issues that need to be optimized in the beam fast recovery system. PV disconnection occasionally occurs during the experiment, and with the number of disconnection times increases, the time required for reconnection becomes longer, which is related to the reconnection mechanism of PV. In addition, the beam fast recovery system is not stable enough, and the stability of the program needs to be improved.

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