LLRF Parameters Tuning for the 972-MHz System at the J-PARC Linac

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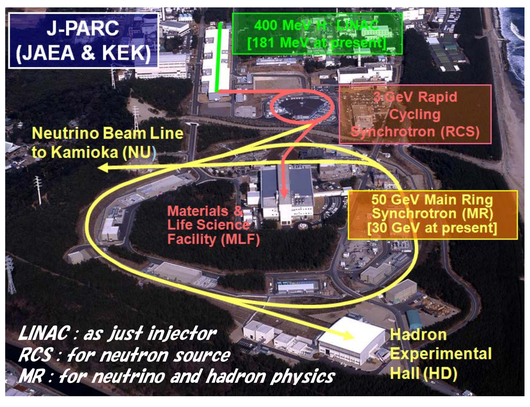
Introduction

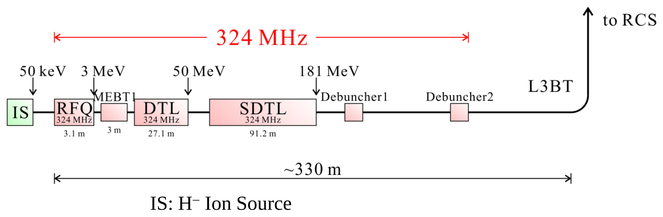


J-PARC is Japan Proton Accelerator Research Complex. J-PARC consist of 400-MeV linac, 3-GeV Rapid Cycle Ring (RCS), 50-GeV Main Ring (MR). It is one of the highest power proton accelerators in the world. We provide the beam as the neutron source with high intensity from RCS. Moreover it is used to investigate the neutrino physics and the hadron physics from MR.

In the J-PARC linac. Its length is about 300 m. The linac accelerate the negative hydrogen. The negative hydrogen by the ion source goes through RFQ. Then, in the out of RFQ, the energy of the negative hydrogen becomes 3 MeV. After that, the particles are accelerated by three DTL and fifty SDTL. The energy of the particle injected to RCS becomes 181 MeV. The maximum current is 30 mA. The acceleration frequency of these cavities is 324-MHz.

We are planning to the upgrade of the linac at the shutdown of this year by the installation of fifteen Annual Coupled Structure (ACS). After the upgrade of the linac, the energy is from 181 MeV to 400 MeV and the peak current is 50 mA. We will be able to provide the higher intensity beam. Here, the acceleration frequency for ACS is 972 MHz. For the ACS cavity modules, the LLRF system for 972 MHz was developed and RF reference distribution system was improved.

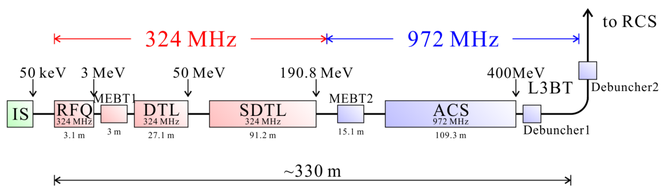
~ May 2013



IS: H⁻ Ion Source
RFQ: Radio Frequency Quadrupole Linac
DTL: Drift Tube Linac (3 cavity modules)
SDTL: Separate-type Drift Tube Linac (15 cavity modules)

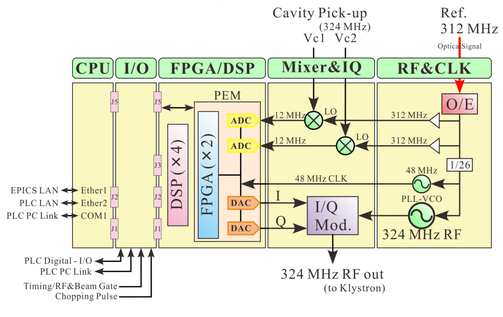
Energy Upgrade to 400 MeV from 181 MeV

2014 ~



IS: H⁻ Ion Source
RFQ: Radio Frequency Quadrupole Linac
DTL: Drift Tube Linac (3 cavity modules)
SDTL: Separate-type Drift Tube Linac (15 cavity modules)
ACS: Annual Coupled Structure Linac (21+4 cavity modules)

324MHz LLRF System (cPCI)

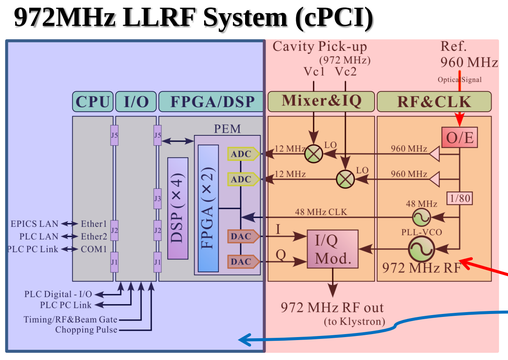


- ✓ The 312-MHz optical signal is received by the RF&CLK module as the phase reference.
- ✓ The 324-MHz RF signal is generated by a PLL-VCO.
- ✓ The cavity signals are down-converted to 12-MHz IF signals by mixers and sampled by 48-MHz ADCs.

RF : 324 MHz
LO : 312 MHz
IF : 12 MHz
CLK : 48 MHz

The 324-MHz system is working very well with a very good stability of ±0.2% in amplitude and ±0.2 deg. in phase including beam loading .

972MHz LLRF System (cPCI)



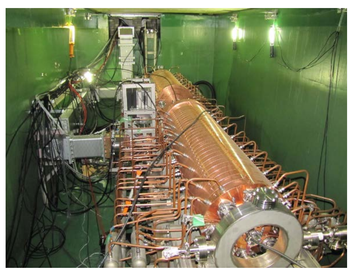
- ✓ The 960-MHz optical signal is received by the RF&CLK module as the phase reference.
- ✓ The 972-MHz RF signal is generated by a PLL-VCO.
- ✓ The cavity signals are down-converted to 12-MHz IF signals by mixers and sampled by 48-MHz ADCs.

RF : 972 MHz
LO : 960 MHz
IF : 12 MHz
CLK : 48 MHz
} same as the 324-MHz system

The analog modules was newly developed.
The digital modules are same as the 324-MHz system.

High-Power Test for ACS cavities

- Periods: June and July in this year
- Cavity ID: ACS01 (low-β section), ACS11 (medium-β section)



972-MHz LLRF system
Check and debug for the new LLRF system
Confirmation of the LLRF parameters tuning

Optimization of PI Gain

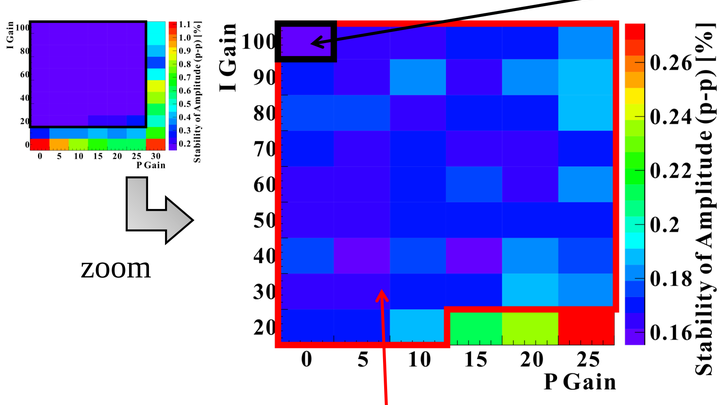
The feedback (FB) system on the PI control is used to keep the stability of amplitude and phase for the J-PARC linac. The required performance for the stability of the acceleration field and the phase in the linac RF are required to less than 1 % and 1 deg., respectively.

The 324-MHz system is working very well with a very good stability of ±0.2% (peak-to-peak: p-p) in amplitude and ±0.2 deg. (p-p) in phase including the beam loading.

When the high-power test for ACS cavities was performed, the PI gain was optimized for the 972-MHz system and check the stability of amplitude and phase.

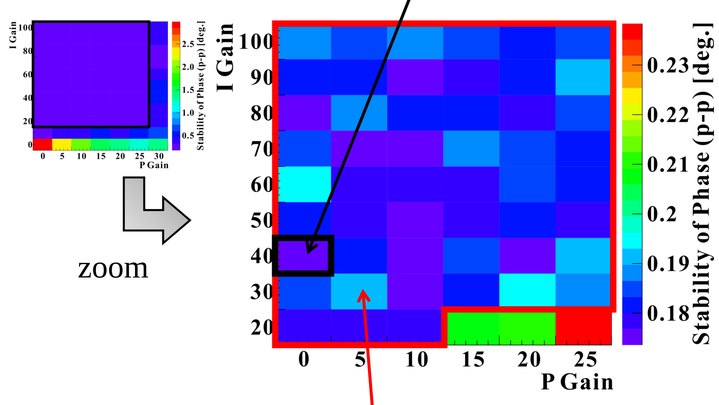
Best PI Gain:
Amplitude: ±0.16%
Phase: ±0.18 deg.

Amplitude Stability Dependence on PI Gain



amplitude stability : <±0.2% (p-p) region

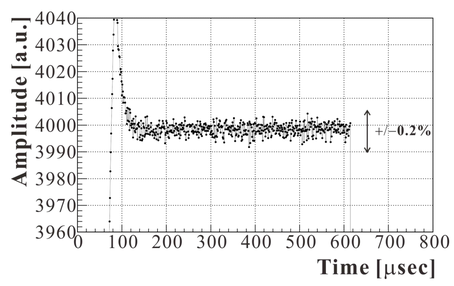
Phase Stability Dependence on PI Gain



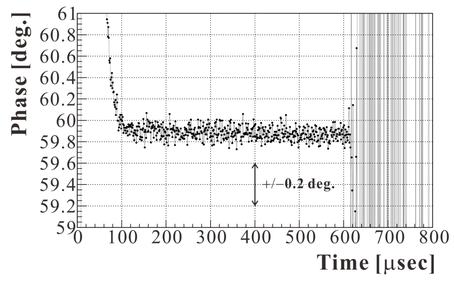
phase stability : <±0.2 deg. (p-p) region

Typical Stability (P=10, I=40)

Amplitude Stability



Phase Stability

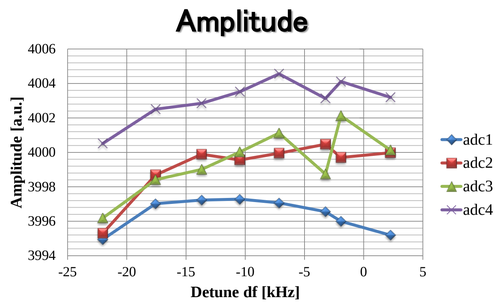


Pickup Dependence of Field

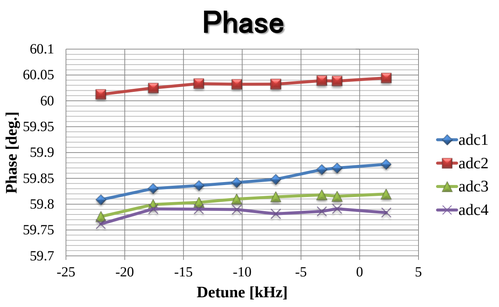
An ACS module has four antennas to confirm and control the cavity field. We are planning to control the cavity field of ACS, FB and FF, using the vector sum of two pickup signals. In the simulation, the flatness of the cavity field has the dependence of the detune factor.

Here, we checked the flatness of the field of the ACS cavity. We measured all pickup signals of an ACS module (ADC1-4), simultaneously. The field of ADC1 was controlled to the constant by FB. Then, we measured the detune dependence of the cavity fields from ADC2, ADC3, and ADC4.

Amplitude



Phase

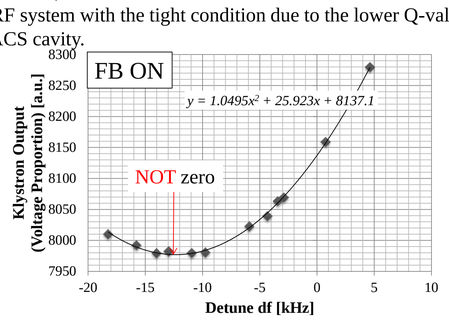


The pickup dependence cannot be confirmed for this measurement.
→ We will be able to use every pickups of an ACS module in order to control the cavity field.

Auto-Tuner Control

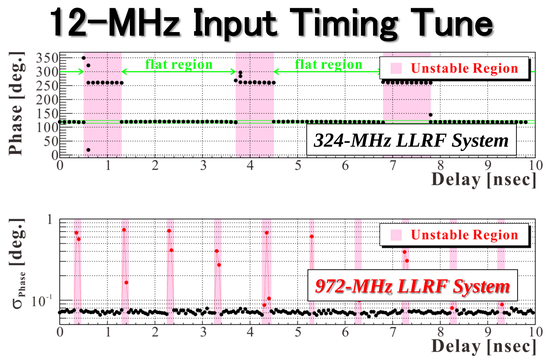
For the preset cavity with the 324-MHz LLRF system, the tuner position was controlled using the information of the damped free oscillation.

Here, we checked the auto-tuner control of the 972-MHz LLRF system with the tight condition due to the lower Q-value of an ACS cavity.



The zero position of the detune by this control was not corresponded to the least output power point of the klystron.
→ We will make a continuing review for the cause.

12-MHz Input Timing Tune



The cycle of the unstable region of the 972-MHz LLRF system, about 1/960MHz ~1 nsec, was confirmed.
→ We should operate the 972-MHz LLRF system in the center of the stable region.
Preparing the 12-MHz delay module with the 0.05 nsec tune
Upgrading the 12-MHz distribution system with the better temperature property

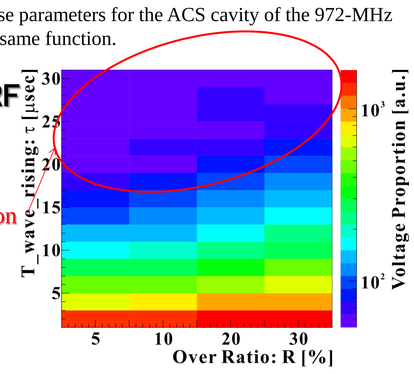
Optimization of Rising Parameter

For the 324-MHz LLRF system in the J-PARC linac, the rising function of the macro pulse was defined as two parameters (R, τ).
rising function A(t):
A(t) = (A'+R)*(1−exp(−t/τ)) if A(t)<A'
A(t) = A' else
A' : reference amplitude
t : time from RF on

We optimized these parameters for the ACS cavity of the 972-MHz LLRF system using the same function.

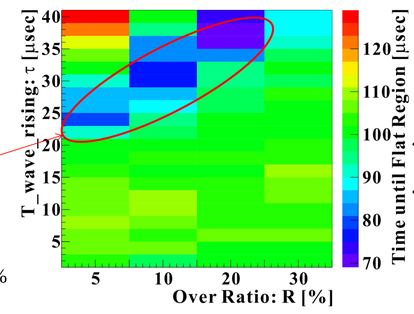
Peak of Reflected RF from Cavity

Small Reflected Wave Region



Time until Flat Field

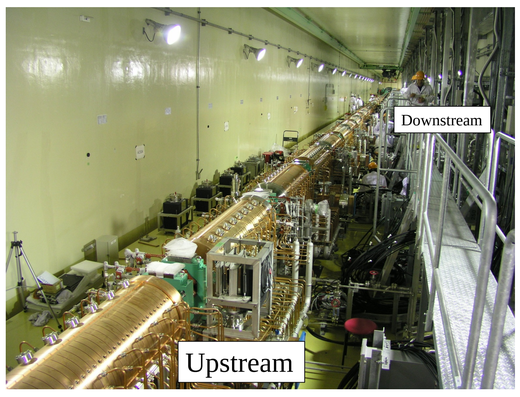
Quick Rising



Flat Field:
Amplitude: < ±0.5%
Phase: < ±0.5 deg.
(NOT definition, measured cavity pickup)

We should choice the region with the small reflected wave from a ACS cavity and with the quick rising until the flat field.

Present Status



Present Works:
Accelerator Tunnel: Installation, Alignment, Cable terminal processing
Gallery: Wiring works

Our Purpose: The cavities high-power conditioning will be started in November of this year

Summary

- ◆ We are planning the energy upgrade of the J-PARC linac by the installation of twenty-five ACS cavities in this year.
- ◆ When the high-power test of ACS modules,
  - we checked the PI-gain dependence on the stability of amplitude and phase
    -> large stable region against the PI-gain parameters
    Amplitude: < ±0.2%
    Phase: < ±0.2 deg.
  - we investigated the pickup dependence of the cavity field.
  - we confirmed the control system such as the auto-tuner.
  - we measured the cPCI behavior against the 12-MHz input timing.
  - we optimized the parameters in the rising function.
- ◆ We are installing the ACS cavities in the accelerator tunnel.
- ◆ We will start the high-power conditioning of all ACS cavities in November of this year