DEVELOPMENT OF A RESONATOR TUNING SYSTEM USING AN INDUCED SIGNAL PICKUP*

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Abstract

Heavy-ion linacs are optimally designed using independently-phased resonant cavities which must be empirically tuned for the correct beam radio frequency (RF) phase relationship for a variety of beams with different charge-to-mass ratios. Superconducting resonators at the Argonne Tandem Linear Accelerator System (ATLAS) have traditionally been tuned by adjusting the resonator's phase and amplitude while using a surface barrier detector to measure the energy gain. For resonators at the beginning of the linac where small changes in phase result in large changes in beam steering properties, this method of tuning resonators is difficult and time consuming. A new Vsystem-based [1] process has been developed to automatically tune resonators by using the RF signal induced by the beam in a nearby downstream resonator. This new method for determining the correct accelerating phase of a resonator is accomplished by varying its phase and observing the resulting changes in the induced signal. The beam-induced phase can be accurately measured by a lock-in amplifier that filters noise and harmonic signals. A General Purpose Interface Bus (GPIB) module is used to retrieve data from the lock-in amplifier. The Vsystem process provides tabular and graphical displays of the induced-field amplitude and phase as a function of the accelerating resonator's phase. The process also reports lock-in amplifier error status messages, and determines the optimal phase setting for the accelerating resonator. The new method for tuning resonators with an induced signal pickup in a secondary resonator is a prototype diagnostic method for the proposed Rare Isotope Accelerator (RIA) facility.

INTRODUCTION

ATLAS is a linear accelerator system containing 2 separate ion source injectors and 64 superconducting resonators. This facility accelerates low-energy, heavy-ion beams ranging from isotopes of hydrogen to uranium. These ions are accelerated up to a maximum of 20% the speed of light mostly for the purpose of nuclear physics research. Typical operation at ATLAS is to start a new experiment every three to seven days, with beam being delivered to one of 3 target areas 24 hours a day. A crucial part of ATLAS operations is to quickly and accurately tune resonators, i.e., determine the beam-resonator phase relationship for ions of varying charge-to-mass ratios (q/m). These tunes are then used to configure the accelerator at the start of a new experiment.

An improved method for tuning superconducting resonators that accelerate heavy-ions at low velocities has been developed at ATLAS. The motivation for developing the new method was to reduce the amount of time it took to tune resonators that operate at the lowest energies of the accelerator (the first cryostat in ATLAS), and to tune with greater accuracy for achieving the maximum energy gain possible in each resonator. The criteria for the new method was to use existing equipment since drift spaces between resonators and interdispersed focusing devices are required to be at a minimum to preserve optimum beam optics. Therefore, excess beam line is not available for new diagnostic devices. The traditional method for tuning resonators at ATLAS is to use a scatter foil and a surface barrier detector to measure the beam energy as the phase of the resonator being tuned is adjusted, while searching for the phase angle that produces the maximum energy gain. For resonators operated at very low energies at the beginning of the linac, the above tuning method often requires careful and time consuming manual steering of the beam back onto the scatter foil as the phase is adjusted. The new method for tuning uses resonators that are normally used for acceleration purposes as 'beam phase detectors' in an 'autoscan' process.

ELECTRONICS SETUP

In the new method, the resonator to be tuned is paired up with a nearby downstream resonator that has been set to a reference RF field level. An induced beam phase signal is produced in the 'detector' resonator when the beam accelerated from the upstream resonator passes through the detector resonator. The beam-induced phase signal is measured by first applying a linear circular phase rotation to the reference RF field of the detector resonator, and then measuring the phase shift of the resonator's resultant signal. A synchronous detection method is used for extracting the beam phase information as it provides high accuracy phase measurements in a noisy environment (which is typically the case for superconducting resonators due to the high level of microphonic fluctuations of the resonator's resonant frequency caused by the mechanical vibration of superconducting components). A Stanford Research Lab SR830 lock-in amplifier [2] is used as the synchronous detector.

A typical diagram that demonstrates the relationship between the resultant induced phase signals in the detector resonator as a function of the phase of the resonator being tuned follows.

* This work is supported by the U.S. Department of Energy, Nuclear Physics Division, under contract W-31-109-Eng-38.
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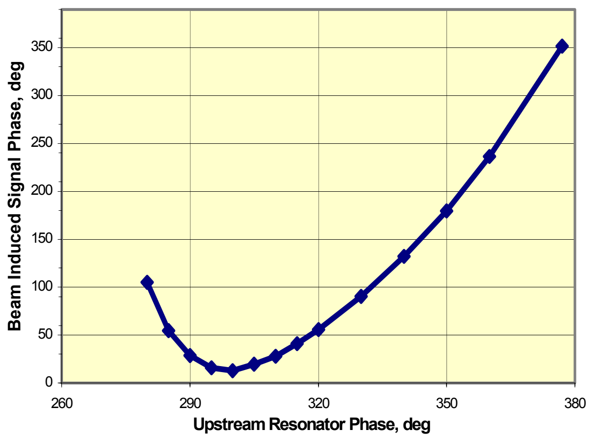

Figure 1: Phase of the Beam Induced Signal as a Function of the Upstream Resonator RF Phase.

A previous paper [3] provides a detailed technical explanation on the complete experimental setup for using a superconducting resonator as a beam phase detector at ATLAS. This particular setup establishes a relationship whereby the minimum value of the induced beam phase corresponds to the optimal phase angle of the resonator being tuned that produces maximum energy gain. What follows now is a description of the development of a software process that searches for the minimum beam induced phase, and automatically sets the resonator to its optimal phase angle.

PROCESS DEVELOPMENT

The primary goal was to produce a process that interacts with a lock-in amplifier as the tuning resonator's phase is cycled, while simultaneously providing real-time display of collected detector resonator data in an easily interpreted and interactive user interface. Another criterion of the new autoscan process was to effectively integrate with the already existing surface barrier detector autoscan process, and other control system processes so that either autoscan method could be selected by the operator. Communication with the lock-in amplifier and the ATLAS control system software (Vsystem) is accomplished with a GPIB module interfaced to an AlphaServer computer running the OpenVMS operating system [4].

Process Demands and Expectations

During the early stage of the development of the resonator autoscanning software process, the resonator electronics setup continued to undergo modifications and improvement as well. This type of software application development in parallel with electronics hardware development placed unexpected demands on the software. Due to the cycling nature of the output signal from the detector resonator to the lock-in amplifier and significant noise levels in the system, it was observed that the lock-in amplifier's output signal to the GPIB bus could inadvertently occur in the following unusual formats:

- the lock-in amplifier output amplitude signal could falsely be set to a negative value,
- the lock-in amplifier phase and/or amplitude signals could consist of a continuous stream of ASCII characters with no terminating character that normally is part of the communications I/O, or
- the lock-in amplifier does not send any output data characters at all.

Stanford Research Systems technical support was consulted to confirm the above data output cases. Off-line testing of the process, using a function generator to create a noisy input signal, was performed to substantiate the operating conditions that the process must be able to manage. The process code was then modified to take into account the above possible scenarios by:

- examining collected detector resonator data for the occurrence of a lock-in amplifier signal conversion problem,
- routinely checking to see if the lock-in amplifier has generated a GPIB service request (SRQ) as a result of error status bits getting set in the lock-in amplifier,
- posting error messages to the Vsystem display to aid the user in correcting parameter settings on the front panel of the lock-in amplifier, resonator control settings, or other electronics settings, and
- providing an interactive display feature for the user to clear the lock-in amplifier data buffer of invalid results.

User Interface

With these hurdles overcome, the user interface was further developed and fine-tuned to provide useful information on how well the detector resonator was doing its job of acting as a beam phase monitor. The basic premise of the new method for autoscanning resonators is to:

- step through setting the phase angle of the resonator being tuned,
- allow the user to observe the real-time signals of the detector resonator on a Vsystem display and decide if the results are valid,
- manually interact with the display to 'record' the data point for that particular resonator phase setting, and then
- repeat these steps until the occurrence of the resultant minimum detector phase signal is obtained.

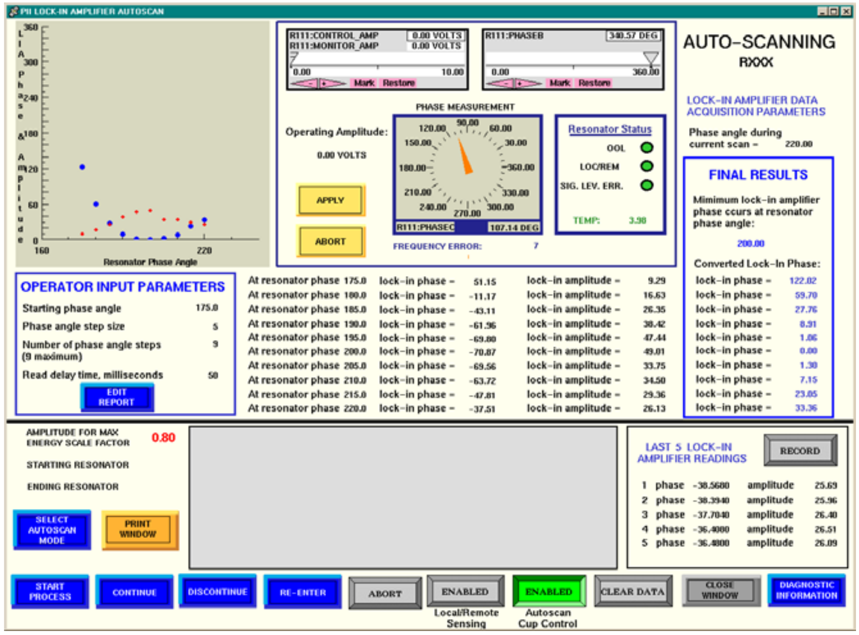

Figure 2: Resonator Autoscan Display.

At the current stage of the process development, the user enters a starting phase angle for the upstream resonator, the number of degrees for the phase angle step size, and the number of steps to use. After the requested number of phase setting data points have been collected, the process interprets the data and automatically sets the upstream resonator to its optimal phase. Figure 2 above shows the present status of the Vsystem resonator autoscan display.

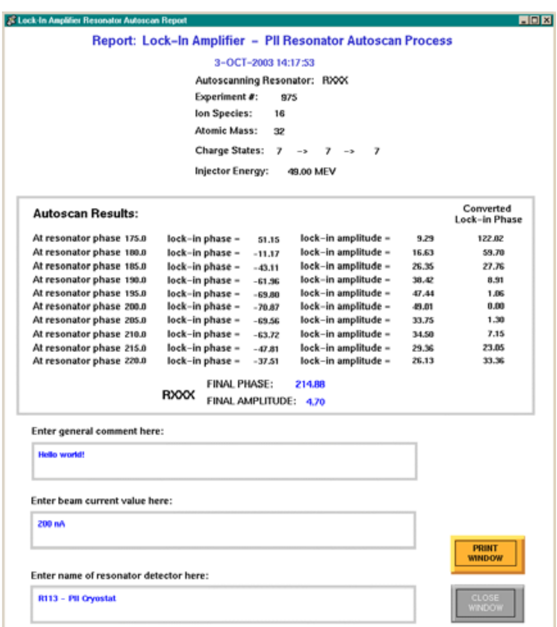

Figure 3: Interactive Resonator Report Feature.

Interactive Report

During the development of the new autoscan process, it became apparent that the printed report generated at the end of the process needed to be interactively modifiable by the user to indicate the type of accelerator beam and the success status of the current tuning procedure. As shown in Figure 3, text input boxes are provided on the Vsystem report display to provide the ability to modify the contents of the printed report of each resonator autoscan. This report aids in documenting research efforts that can later be used to improve the autoscan method, and serves as a guide for tuning future experiments.

CONCLUSION

A new process has been successfully tested for autoscanning resonators using a downstream resonator as the beam phase detector. Future work on this project includes collecting data on a variety of beams tuned with the new resonator autoscanning method. Based on this information, a fully automated tuning algorithm could be developed that quickly identifies the upstream resonator phase region that contains useable beam-induced detector resonator signals. Thus, the objective of creating a faster and more accurate resonator tuning method would be achieved in part by minimizing user intervention with the control system software. This new method has demonstrated the potential to be an effective means for tuning resonators in the future RIA Facility.

REFERENCES

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[4] Hewlett-Packard Corporation, Palo Alto, CA, USA