BLIP Scanning System Power Supply Control

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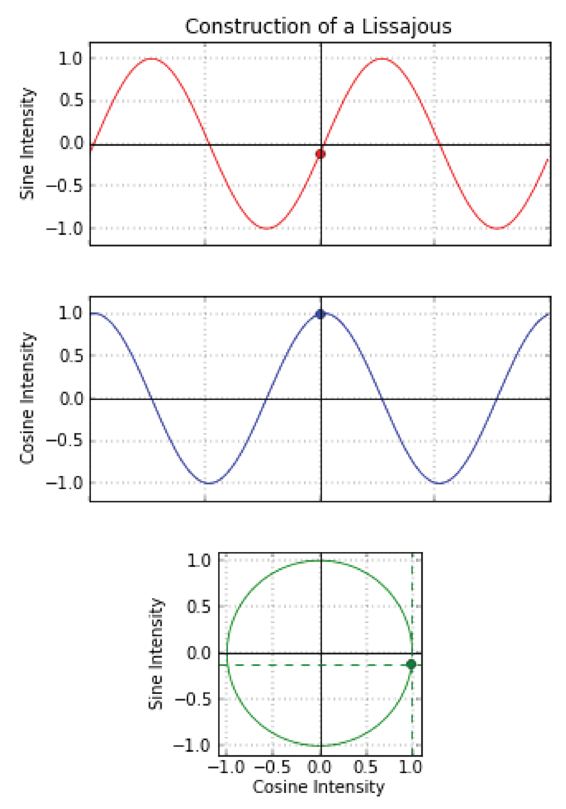
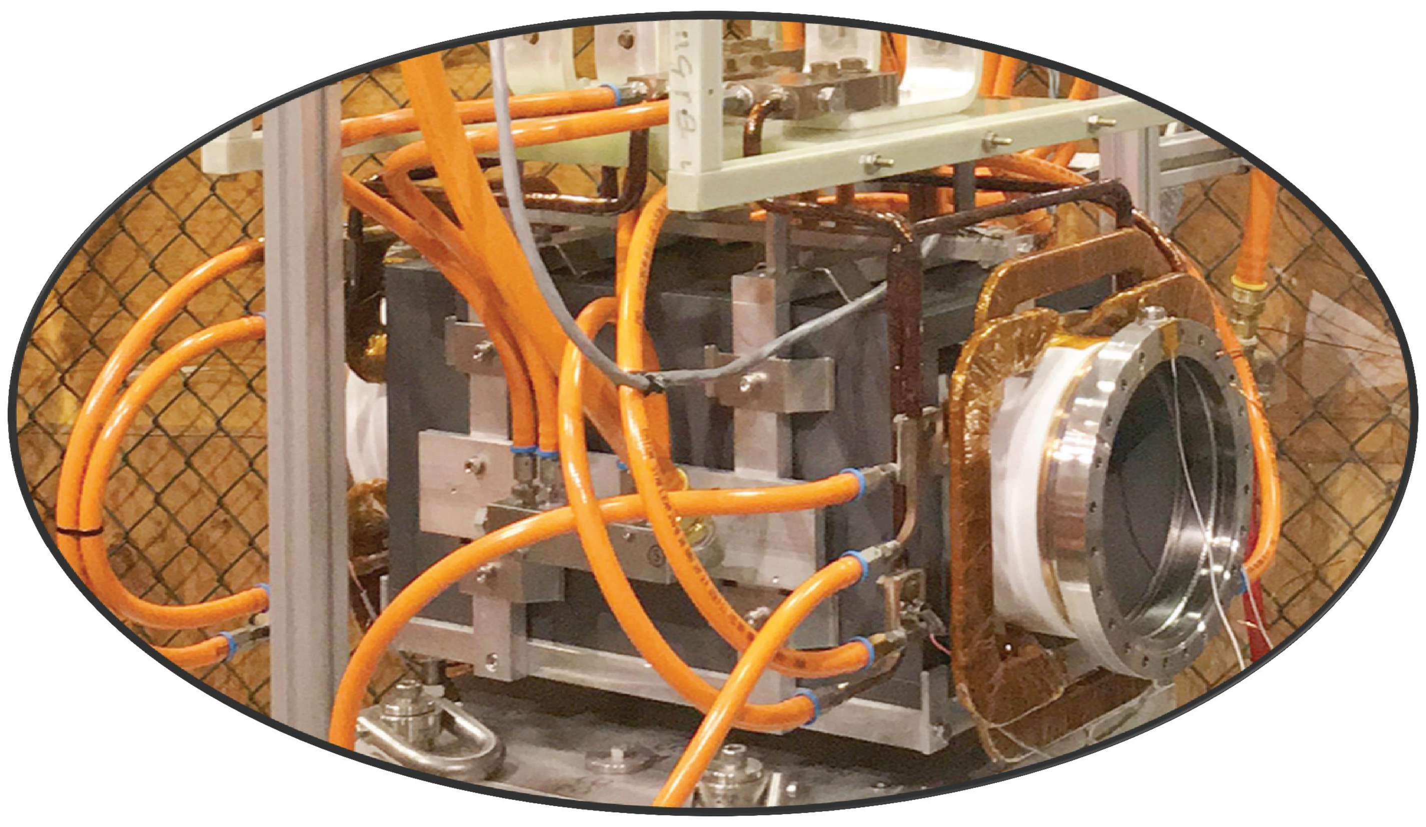
Abstract

In the Brookhaven LINAC Isotope Producer (BLIP) facility, a fixed target is bombarded by proton beam to produce isotopes for medical research and cancer treatment. This bombardment process causes spot heating on the target and reduces its lifetime. To mitigate this problem, an upgrade to the beamline has been made by spreading the beam on the target in a circular pattern, which allows the target to heat more uniformly. The beam is steered in a circular pattern by a magnet with orthogonal (X and Y) windings. Each of these two windings is independently powered as part of a resonant circuit driven by a power amplifier. This paper describes the hardware platform used as well as the software implementation of the resonant circuit design and its feedback loop.



Courtesy of Wikipedia



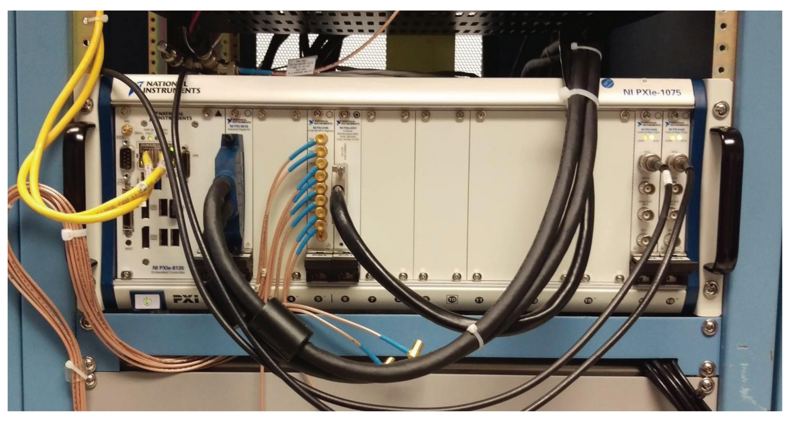
The Magnet Assembly

National Instruments' PXIe platform controls both power amplifiers (PAs); X & Y. The two 90° out-of-phase sine waves are generated within the platform that monitors PA current & voltage; magnet current & voltage

The system also checks if:

- 2 PAs are exactly 90° out of phase
- PA amplitudes have 0° phase error
- Magnet impedances are within range (+/- 5%)
- Amplitude is within +/- 2% of setpoint.

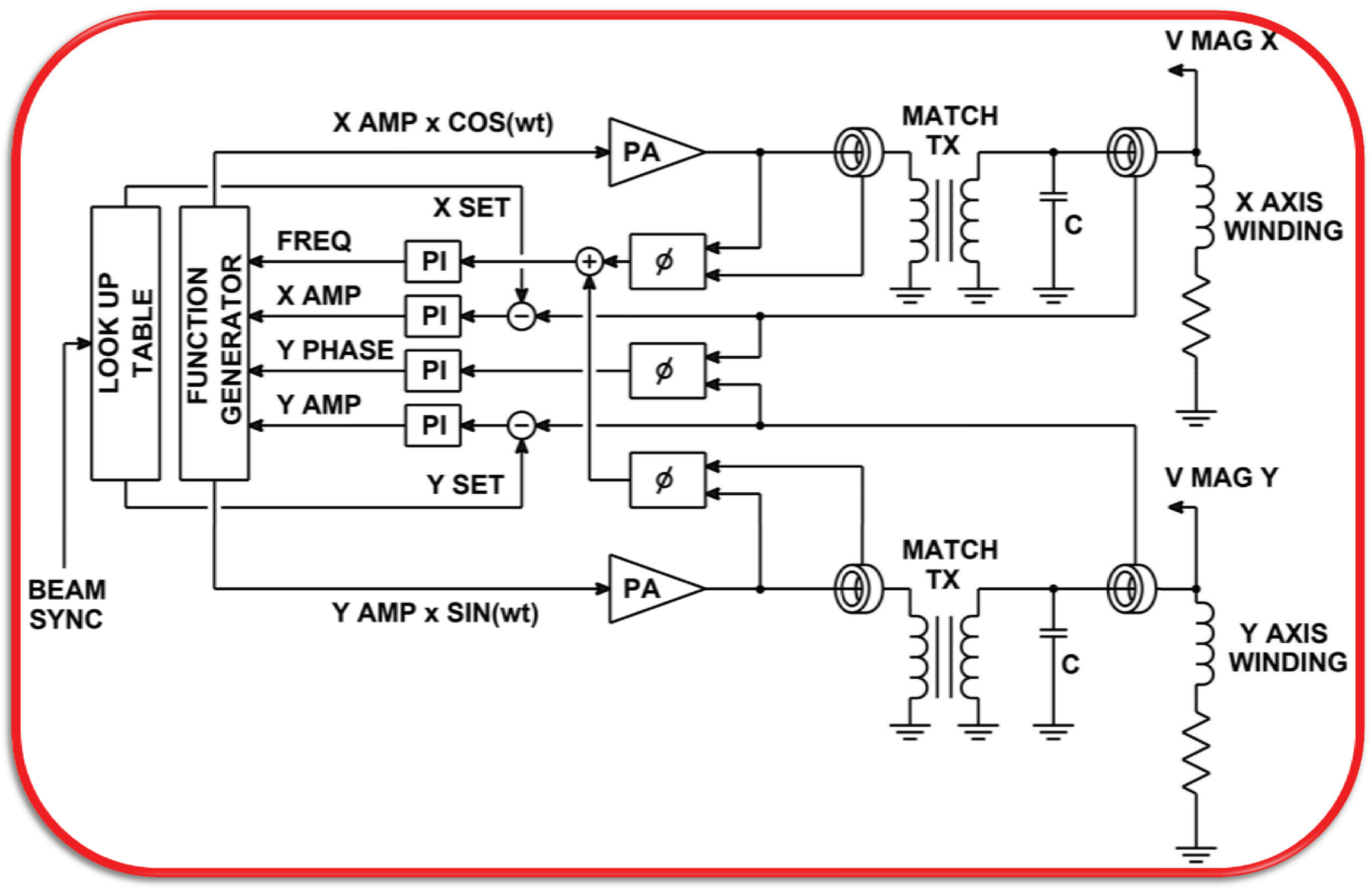
PAs are interlocked and beam is inhibited immediately, in case of a failure.



Two windings that are physically perpendicular to each other are powered independently via two power amplifiers that generate two separate sine waves which are 90° out of phase at 4.8 kHz.
These two sine waves create the circular lissajous pattern when plotted with respect to each other.

Key Parameters	
Magnet Voltage (max.)	$655\ V_{PEAK}$ / $463\ V_{RMS}$
Magnet Current (max.)	$318\ A_{PEAK}$ / $225\ V_{RMS}$
Power Amplifier Voltage (rated)	$191\ V_{PEAK}$ / $135 V_{RMS}$
Power Amplifier Current (rated)	$68\ A_{PEAK}$ / $48\ A_{RMS}$
Power Amplifier voltage (operating point)	$131\ V_{PEAK}$ / $92.5\ V_{RMS}$
Power Amplifier Current (operating point)	$48.7\ A_{PEAK}$ / $34.4\ A_{RMS}$
Load Inductance	68 µH
Load Impedance	2.06 Ω
Resonance Frequency (nominal)	4.8 kHz
Power Amplifier Power (rated)	6 kVA
Magnet Power (apparent)	104.35 kVA

The important parameters of the entire system. Power amplifier operating points and the resonance frequency are set and controlled by the PXIe system, while the magnet voltage/current and impedance are continuously monitored to provide a closed loop system in the PXIe system.



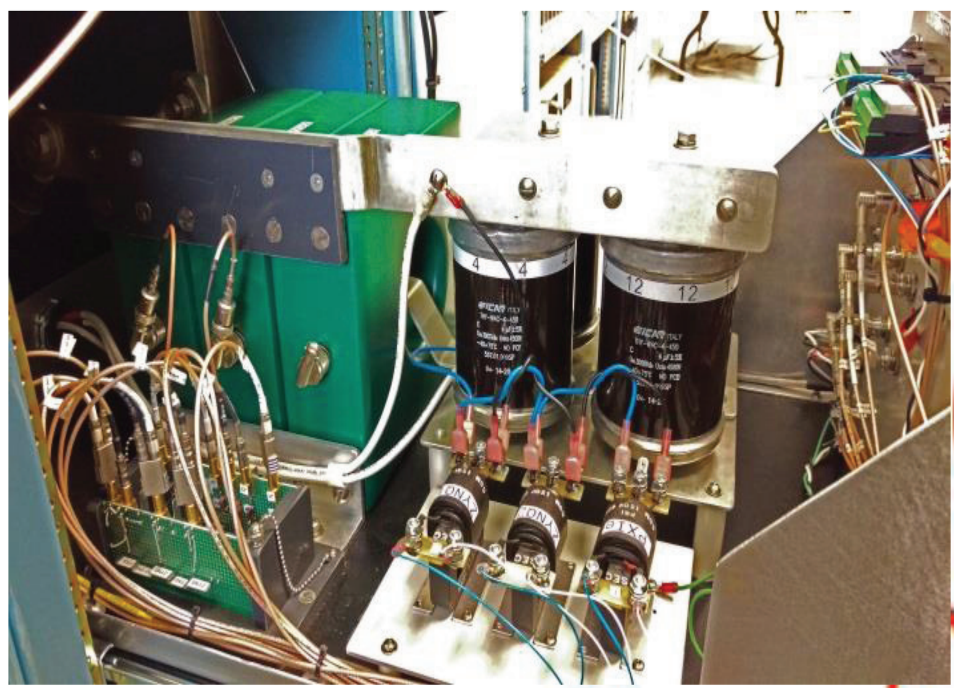
Hardware:

PXI Express (PXIe) Platform

- NI PXIe-1075: 18-slot 3U chassis
- NI PXIe-8135: 2.3 GHz quad-core i7 controller; running both Windows7 and LabVIEW RTOS simultaneously
- NI PXI-5402: 20 MHz arbitrary function generator
- NI PXIe-5105: 60 MS/s, 12-bit, 8-channel oscilloscope/digitizer
- NI PXI-6515: 30 V, bank-isolated, 32-channel I/O board
- NI PXIe-6341: 16 analog inputs, 2 analog outputs, 24 digital I/O board

Software:

LabVIEW 2013 SP1 Professional Development System and Real-Time Module

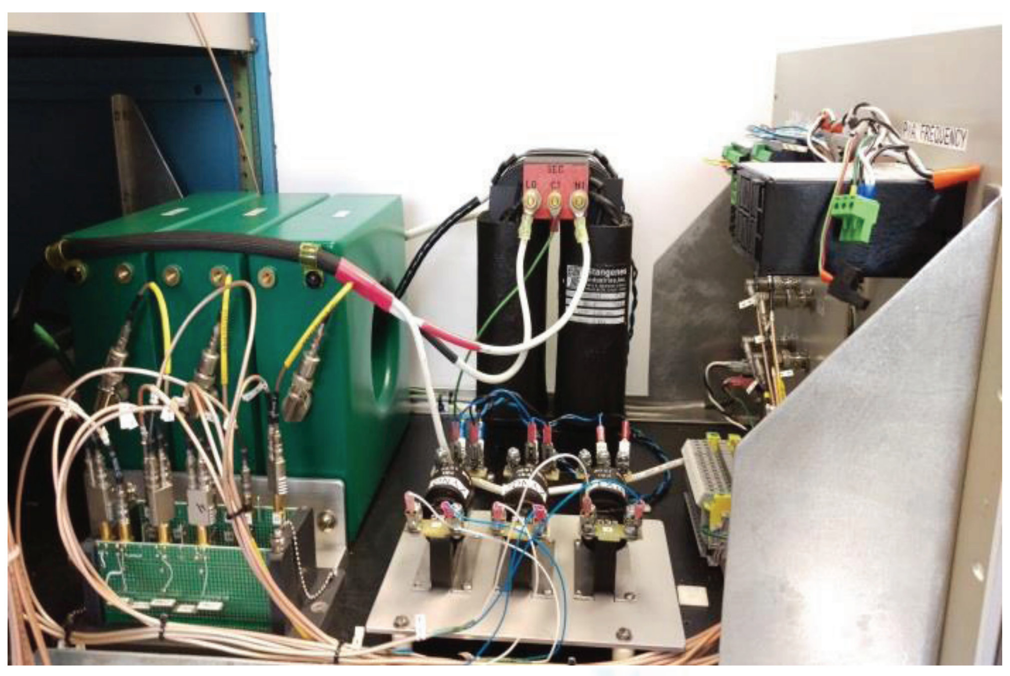


Interface chassis with the resonant capacitors, independent current transformers and independent voltage transformers. Both of these transformers are passive providing isolation between the measurements and the power circuit. This eliminates errors due to ground loops.

There are four main feedback loops: Two amplitude feedback loops, one frequency feedback loop, and one phase feedback loop. Each winding has its own amplitude feedback loop, but there is only one frequency feedback loop for both systems because the amplifiers are locked together in a master-slave configuration.

The amplitude feedback loops are software implemented PI loops with gains. The frequency feedback loop also utilizes a PI loop, and it operates on the phase sum of the power amplifier sine waves. Phase data of the voltage and current measurements for each amplifier is extracted and summed with the other amplifiers phase data. The frequency of the sine waves is adjusted with this phase sum to keep the systems frequency locked and on resonance. The amplitudes of the each sine wave are adjusted with the result of the amplitude feedback loops.

The phase feedback loop maintains the phase shift between the two sine waves (power amplifier outputs). This 90° phase shift determines the magnetic field pattern and subsequently, the path in which the beam is deposited on the target.



Interface chassis with the matching transformer and independent current transformers and independent voltage transformers. Both of these transformers are passive providing isolation between the measurements and the power circuit. This eliminates errors due to ground loops.

Each winding has two interface chassis. The first chassis provides access to the litz wire leads and includes the resonant capacitors, while the second chassis contains the impedance matching transformer and connection point to the power amplifier. Each chassis also includes a dedicated current transformer and a dedicated voltage sensor to measure the magnet current and voltage, and the power amplifier current and voltage, respectively. These measurements are acquired by the power supply control system to regulate the feedback loops.

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