The Design of a Resonance Control System for the IOTA RF Cavity

Gerrit Bruhaug

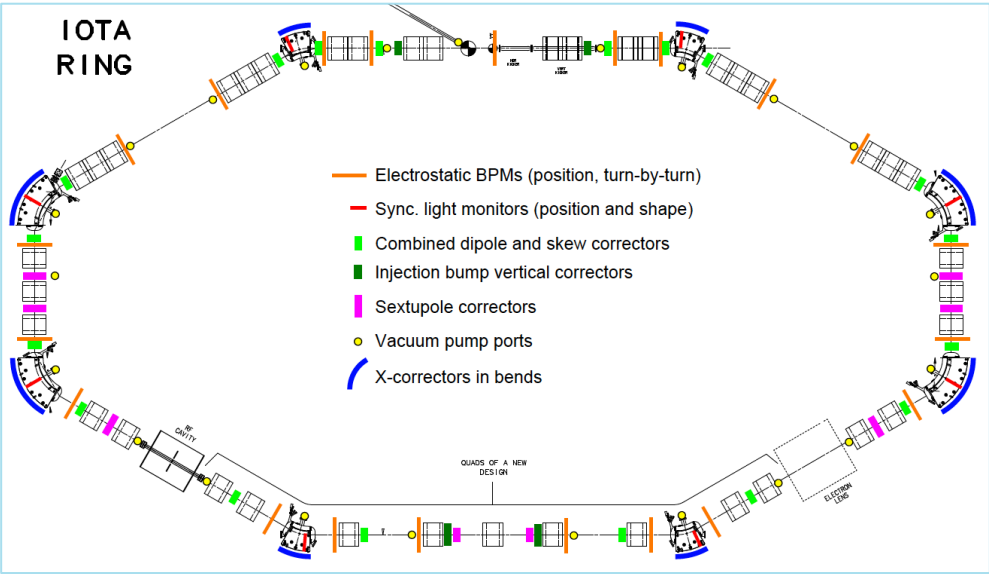
Lee Teng Internship Presentations

08/10/2016

Presentation Content

- Overview of IOTA
- Specifics of RF Cavity
- Controls System Design and Theory
- System Implementation and Results
- Thanks and References

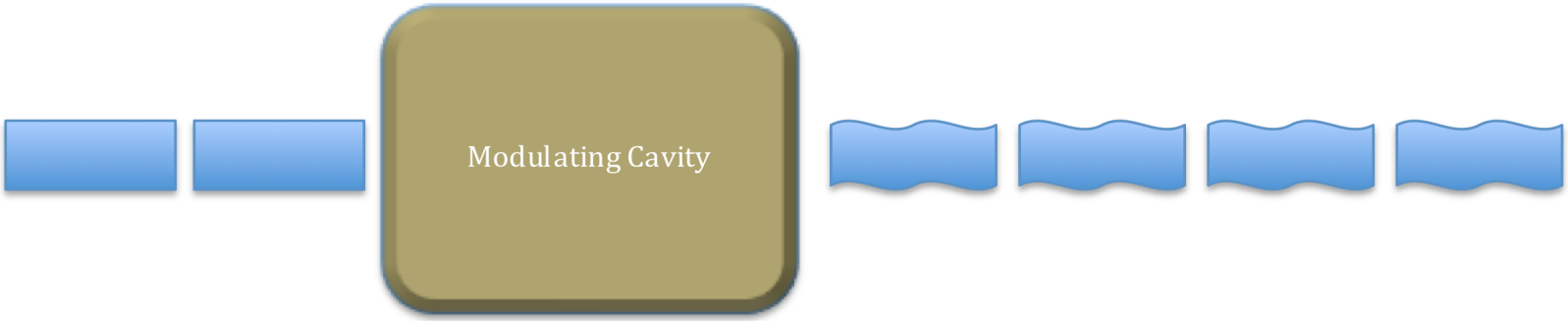
Integral Optics Test Accelerator (IOTA)



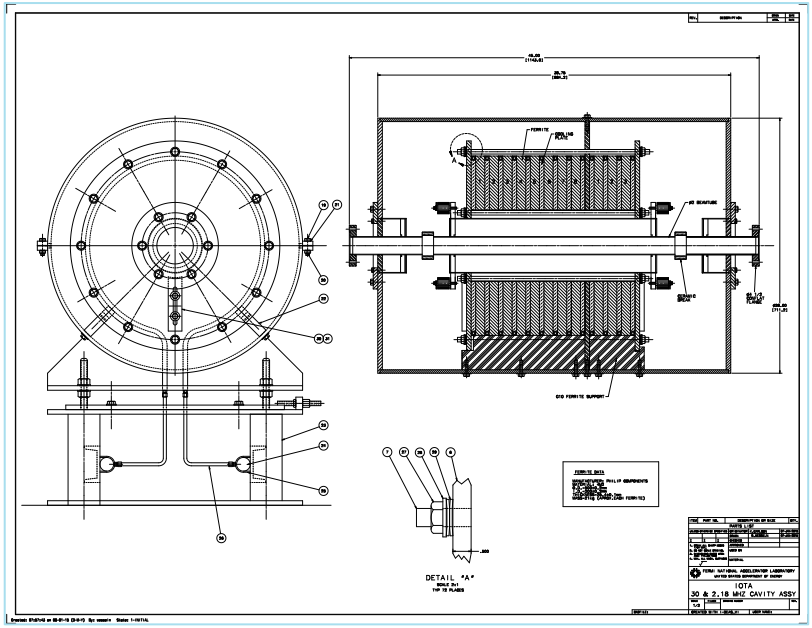
IOTA Proton/Electron Ring	
Nominal p^+ beam kinetic energy	2.5 MeV (70 MeV/c mom.)
Nominal p^+ beam intensity	8×10^{10}
Transverse p^+ emittance r.m.s.	1-2 μm
Nominal e^- beam energy	150 MeV(g=295) or lower
Nominal e^- beam intensity	1×10^9
Transverse e^- emittance r.m.s.	0.1 μm (~2 μm at inj.)
Circumference	40 m
Bending field	0.7 T
Beam pipe aperture	50 mm dia.
Maximum b-function (x,y)	12, 5 m
Momentum compaction	0.02 ÷ 0.1
Betatron tune	3 ÷ 5
Natural chromaticity	-5 ÷ -10
e^- SR damping time	0.6s (5×10^6 turns)
RF V,f,q	10 kV, 30 MHz, 4
e^- Synchrotron tune	0.002 ÷ 0.005
e^- Bunch length, momentum spread	2 cm, 1.4×10^{-4}

All pictures are provided by NML at Fermilab[1]

Bunching and Modulation



The IOTA Bunching Cavity



Drawing of IOTA Buncher[1]

- Cavity has two sections
- 2 MHz section bunches protons
- 30 MHz section bunches electrons and modulates protons[4]

PID Loops and Controls Theory

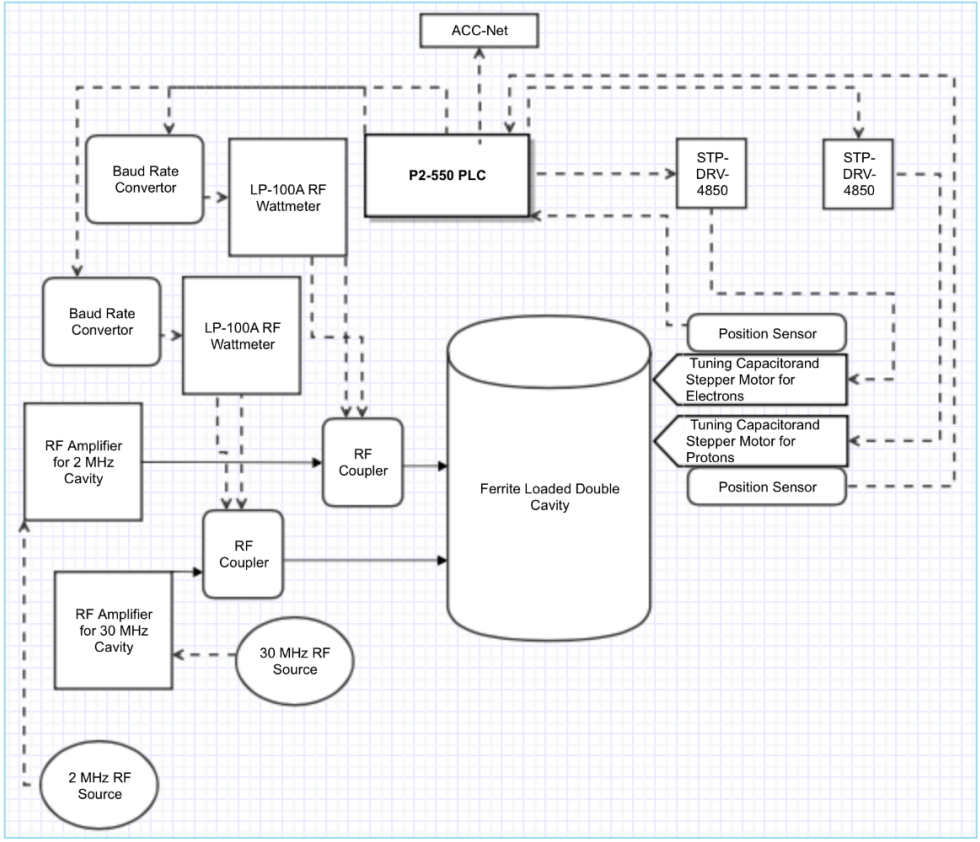
- Proportional, Integral, Derivative
- Used to prevent oscillations in controls systems
- Origin can be traced back to 19th Centaury steam ship controls[3]

$$\underbrace{M_n}_{\text{Control Output}} = \underbrace{K_c * e_n}_{\text{Proportional Term}} + \underbrace{Ki * \sum_{i=1}^{n} e_i}_{\text{Integral Term}} + \underbrace{Kr * (e_n - e_{n-1})}_{\text{Derivative Term}} + \underbrace{Mo}_{\text{Initial Output}}$$

Bias Term

PID Control Loop Equation[2]

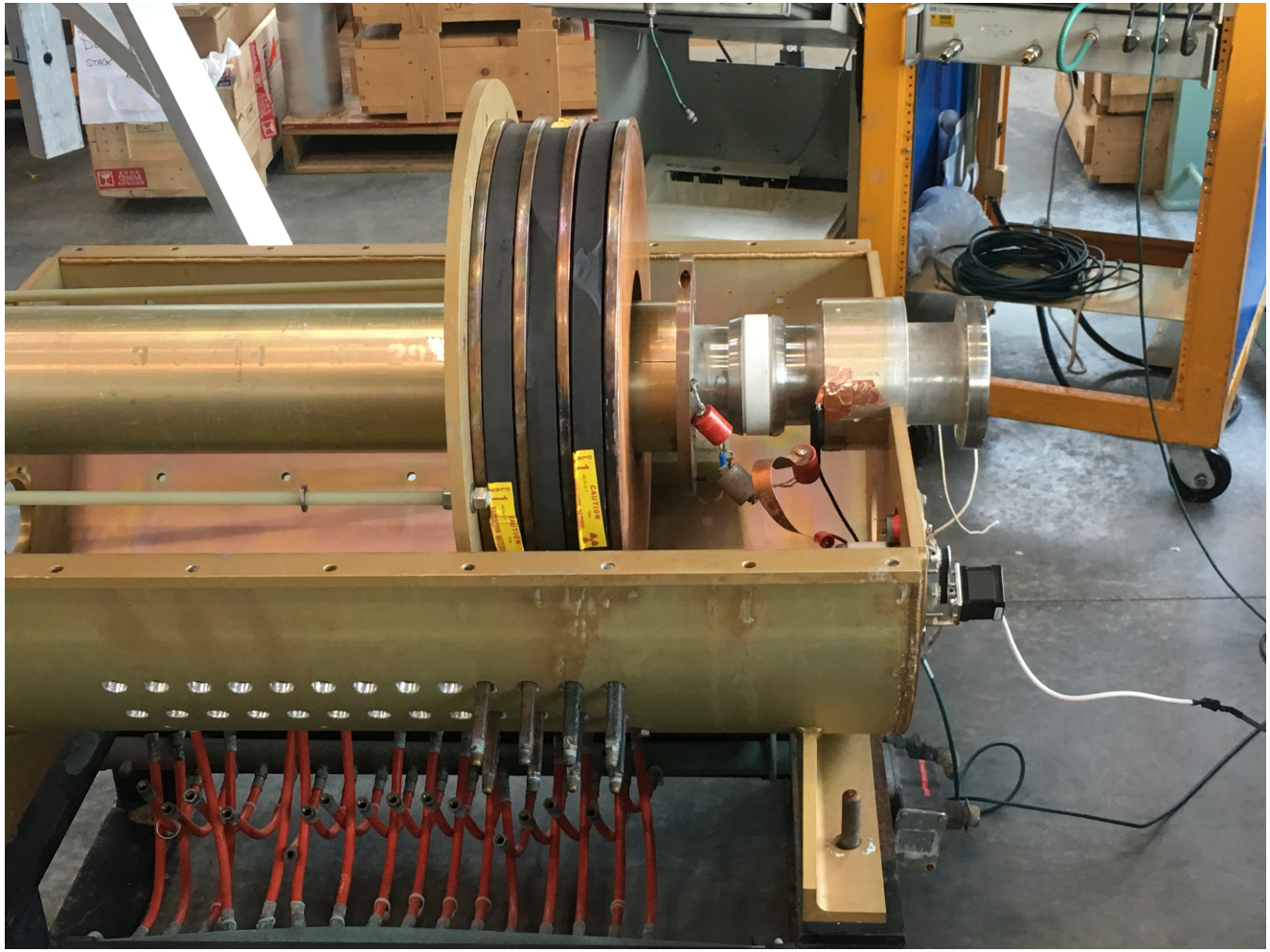
System Implementation



Overview of PLC based RF Control System

Diagram drawn with Gliffy graphics website

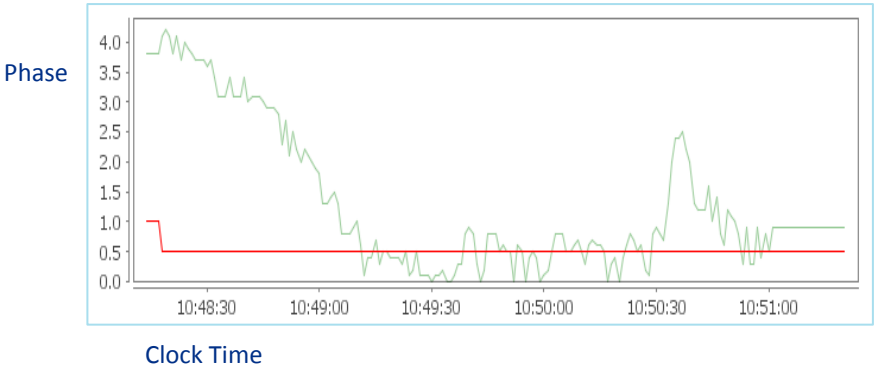
Mounting for Testing



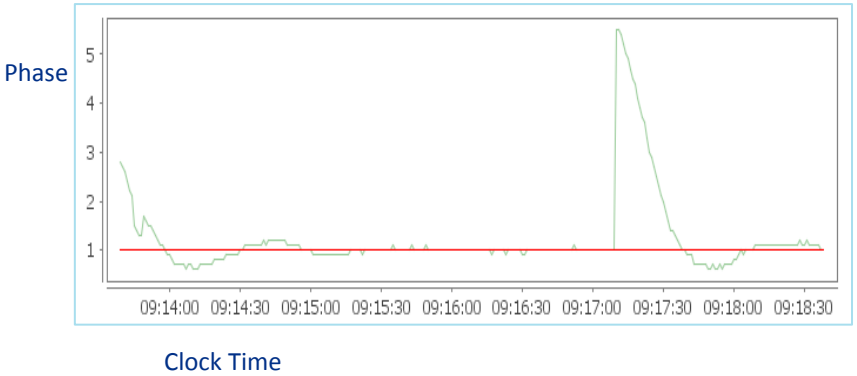
Old Single Ceramic Break with One Stepper for Testing

Live Test and Results

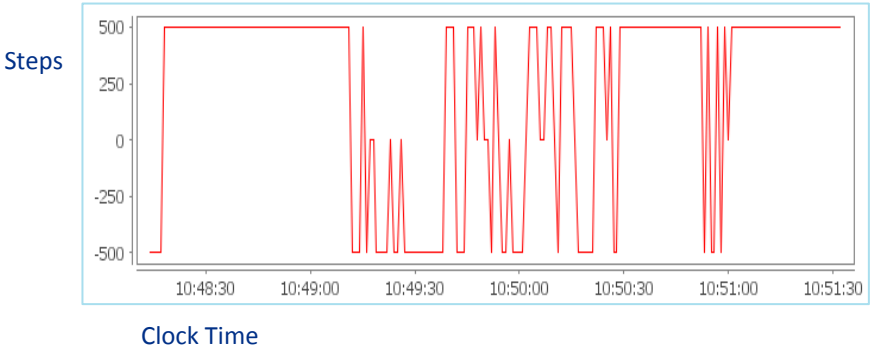
Phase of RF Cavity with Untuned PID



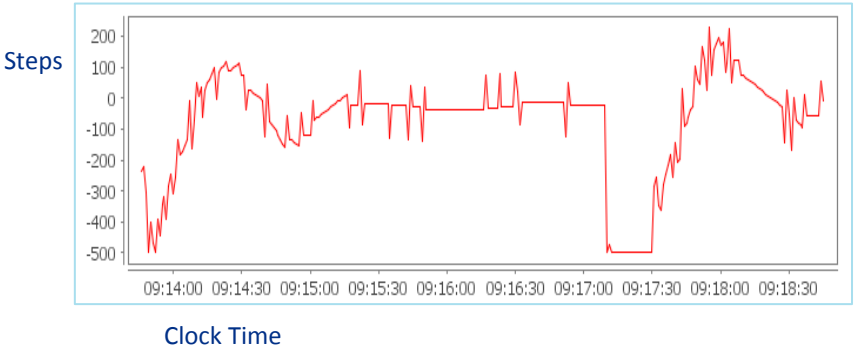
Phase of RF Cavity with Tuned PID



Untuned PID Output



Tuned PID Output



References and Acknowledgments

1. New Muon Lab, Fermilab, http://asta.fnal.gov/IOTA/IOTA_Parameters.pdf
2. Automation Direct, Introduction to PID Loops, https://www.automationdirect.com/resources/microsites/videos/take_aways/VID_L_PC_P3K_005-Programming.pdf
3. S. Bennet, “Historical Perspective”, 1993, http://www.ieeecss.org/CSM/library/1993/dec1993/w05-HistoricalPerspectives.pdf
4. E.~Prebys, "RF Capture of Protons the IOTA Ring at Fermilab", Batavia, Illinois, January 2015
5. G.~Kazakevich, K.~Carlson, "IOTA Cavities Engineering", Batavia, Illinois, December 2015