

Online Emittance Monitoring for the New Ion Source and RFQ at Fermilab

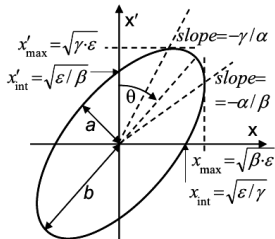
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Project background

- ▶ Cockcroft-Waltons - first stage of acceleration of protons (as H^- ions) for Fermilab (750 keV)
- ▶ installed in '68, becoming less reliable
- ▶ planned to be replaced by an RFQ during this shutdown
- ▶ energy, emittance, resonant frequency all have to be matched to design parameters before installation

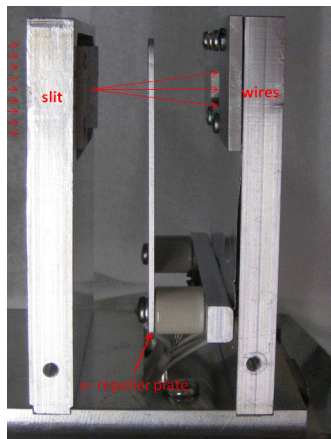
Emittance

- ▶ measure of size and spread of beam
- ▶ area/ π of ellipse in phase space (position x vs. angle x')
- ▶ $\epsilon_{rms} = \sqrt{\sigma_x^2 \sigma_{x'}^2 - \text{Cov}_{xx'}^2}$ ($\pi^* \text{mm}^* \text{mrad}$)
 - ▶ $\alpha = \frac{-\langle xx' \rangle}{\epsilon_{rms}}$, $\beta = \frac{-\langle x'^2 \rangle}{\epsilon_{rms}}$, $\gamma = \frac{-\langle x^2 \rangle}{\epsilon_{rms}}$
- ▶ $\epsilon = \gamma x^2 + 2\alpha x x' + \beta x'^2$
- ▶ normalization for energy
 - ▶ factor of $\gamma\beta$ (relativistic)



Emittance Probes

- ▶ slit to select position, wires at different angles (5 mrad resolution)
- ▶ ions hit wires, causing a voltage
- ▶ electrons can get knocked off the wire, so bias voltage of 70 V
- ▶ voltage read out proportional to number of ions, result in distribution of particles
- ▶ horizontal and vertical probes
- ▶ destructive scan, and wires are damaged by prolonged exposure to beam, faster scans are better



Current Measurement Method

- ▶ scans probe through beam
- ▶ records wire voltages, position, beam current
- ▶ outputs to excel file, placed online
- ▶ file imported into Mathematica notebook which calculates, plots emittance

L69 LINAC TEST STAND EMITTANCE MONITOR SCAN ◆Pgm_Tools◆

Setup		Plot Options	
DAQ Event	A1	Show Plot	FALSE
Start From	Given Start Position	Minimum	-10
Stop Mode	Go to Start Position	Maximum	10
Start Position	2.5 cm	Connect Points	TRUE
Step Algorithm	Via End Position	Grid	FALSE
Step Size	250 cm		
End Position	-2 cm		
Number of Positions	40		
Readings per Position	1		
Write Excel File?	FALSE		
File Name	EmitScan		
Automatic	TRUE		

Buttons: [START] [Display Data] [Graph] [Move to Out] [QUICK EMITTANCE SCAN]

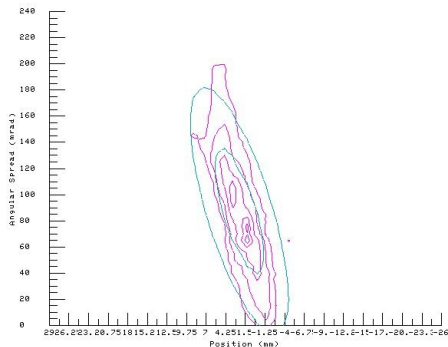
Messages

Modified Emittance Program

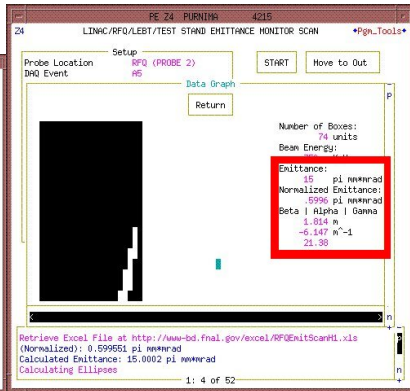
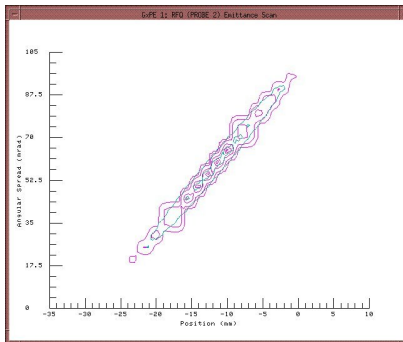
- ▶ cuts out voltages less than 10% (or other cutoff) of max to cut out noise
- ▶ calculates means, variances, covariances of x and x' using rectangular summation
 - ▶ does not assume that the position step size is constant
- ▶ calculates emittance, normalized emittance, and Twiss parameters
- ▶ calculates theoretical ellipses and overlays with contour plot of the real beam

Test Stand Results

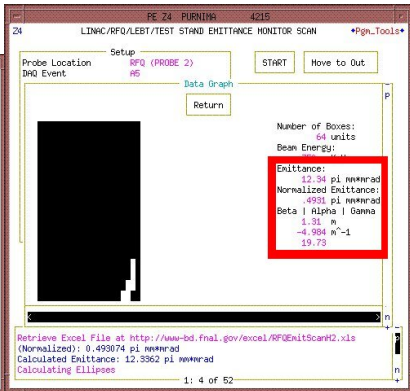
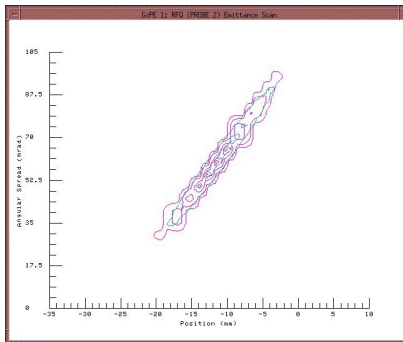
- ▶ source, extractor, one lens, toroid to measure current
- ▶ 35 keV beam (larger than 750 keV)



RFQ Measurements (horizontal, 38 mA, 208 kW)



RFQ Measurements (horizontal, 36 mA, 145 kW)



Other Features

24 LINAC/RFQ/LBET/TEST STAND EMISSIONS MONITOR SCAN ◆Pgm_Tools◆

Setup

Probe Location	Test Stand
DAQ Event	A1
Angular Resolution	5 mrad
Emission Cutoff	.9
Beam Energy	Extractor Voltage
Assumed Beam Energy	750 keV
Start From	Given S
Stop Mode	Move Ou
Start Position	2.5
Step Algorithm	Via End
End Position	-2
Number of Positions	45
Readings per Position	1
Write Excel File?	TRUE
Which Data Set?	Raw Dat
File Name	TestBen
Automatic	TRUE

Bad Wires

00	10	20	30	40
01	11	21	31	41
02	12	22	32	42
03	13	23	33	43
04	14	24	34	44
05	15	25	35	45
06	16	26	36	46
07	17	27	37	47
08	18	28	38	48
09	19	29	39	49

Messages

- ▶ allows user to mark bad wires (bad connections, burned out, etc.), linearly interpolates voltages
- ▶ can reanalyze data without needing to take another scan

Other Features

WB6 LINAC/RFQ/LEBT/TEST STAND EMITTANCE MONITOR SCAN ♦Pgm_Tools♦

Setup

Probe Location	RFQ (PROBE 2)
DAQ Event	A5
Angular Resolution	5 mrad
Emittance Cutoff	.9
Beam Energy	User Input
Assumed Beam Energy	750 keV
Start From	Given Start Position
Stop Mode	Move Out
Start Position	2.5 cm
Step Algorithm	Via End Position
End Position	-2 cm
Number of Positions	45
Readings per Position	1
Write Excel File?	TRUE
Which Data Set?	Raw Data Only
File Name	RFQEmitScan
Automatic	TRUE

START Move to Out

Quick Emittance Scan

Identify Bad Wires

Recalculate Emittance

Graph Display Data

Messages

- ▶ can switch between different probes
- ▶ allows user to input energy based on previous measurement
- ▶ can do a coarse scan to find beam position, and then a fine scan to collect voltage data

Other Features

24 LINAC/RFQ/LBET/TEST STAND EMITTANCE MONITOR SCAN ◆Pgm_Tools◆

Setup

Probe Location RFQ (PROBE 2) START Move to Out

DAQ Event A5

Raw Scan Data

Return Write to File

	L:PROBE2	Z:LTOR	Z:VEW00	Z:VEW01	Z:VEW02	Z:VEW03
Start	0	0	.0002	.0003	-.0002	0
Stop M	1	0	.0003	-.0001	.0004	.0003
Start	2	0	-.0002	.0002	.0002	.0012
Step A	3	0	.0001	.0005	.0006	.002
End Po	4	0	.0001	.0007	.002	.0047
Number	5	0	0	.0012	.0032	.008
Readin	6	0	.0002	.001	.0043	.0127
Write	7	0	.0005	.0012	.0051	.0155
Which	8	0	0	.0015	.0051	.0167
File N	9	0	.0005	.0009	.0045	.0151
Automa	10	0	.0001	.0005	.003	.0114
	11	0	.0002	.0004	.0017	.0069
	12	0	0	-.0001	.0007	.004
	13	0	-.0002	-.0002	.0004	.0015
	14	0	.0004	-.0002	-.0003	.0005
	15	0	-.0001	-.0002	-.0001	.0005

(Normalized): 0.938015 pi mm*mrad
Calculated Emittance: 23.4682 pi mm*mrad
Calculating Ellipses
alpha = -0.332850

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- ▶ allows user to inspect data (raw or interpolated/cutoff)
- ▶ is able to write out data even if the scan is aborted or user forgets to mark the option

Summary

- ▶ installation of the RFQ depends on beam meeting energy, power, efficiency, emittance requirements
- ▶ offline emittance analysis is inconvenient, not realtime
- ▶ heavily modified program to calculate emittance and make plots online
- ▶ easy to use for larger emittance studies or one time scans
- ▶ using these measurements, should hear a verdict on installation by the end of the week

Acknowledgements



- ▶ Dan Bollinger
- ▶ Cheng-Yang Tan
- ▶ Pat Karns