ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-TUPLE16

RFA MEASUREMENT OF E-CLOUD GENERATION PROCESS AT FERMILAB MAIN INJECTOR

Y. Ji*, L. Spentzouris, Illinois Institute of Technology, Chicago,IL,USA
R. M. Zwaska, Fermilab, Batavia, IL,USA

Abstract

Electron cloud (E-cloud) refers to generation of unwanted electrons inside the beam pipe of a high intensity accelerator. The E-cloud could cause degradation of vacuum, beam pipe heating and beam instabilities [1]. The E-cloud generation mechanism consists of three steps: 1) passing beam bunches accelerate existing electrons, 2) accelerated electrons hit the beam pipe and knock out more electrons and 3) generated electrons are accelerated by the next bunch and the process is repeated. The mechanism generates the electron population exponentially and this eventually saturates when the space charge forces of the E-cloud cancel the beam kicks.

For accelerators that may be affected by E-cloud, it is important to monitor the E-cloud generation to study and possibly mitigate E-cloud related problems. In case of the Fermilab Main Injector (MI), while E-cloud is not causing instabilities or other operational problems at this time, E-cloud is observed in the MI, and may be a problem in the future due to planned increases in beam intensity. Since E-cloud is already present in the MI, there is an opportunity to study the build-up process of the E-cloud.

A Retarding Field Analyzer (RFA) is a device that collects electrons incident on a portion of the vacuum chamber wall of an accelerator [2, 3]. The RFA will generate a signal that measures the E-cloud bombardment rate at the collector. Systematic studies of the E-cloud generation process in the Fermilab Main Injector (MI) are presented.

THE RETARDING FIELD ANALYSER

Table 1: MI Parameters

Beam energy [GeV]	8-120
Intensity [protons]	50×10^{12}
revolution frequency [kHz]	90
Harmonic number	588
RF frequency [Mhz]	53
Total RF bucket filled	492
SEY	1.2-1.4
Bunch length [ns]	0.5-4

The MI RFA is located at the MI-10 area because the area's E-cloud generation parameters are well known [4, 5]. There is Secondary Electron Yield (SEY) measurement capability there, and E-cloud generation is sensitive to this parameter. Table 1 shows the general MI parameters. The RFA used is a copper collector cup with a metal grid on top. As electrons enter the collector cup a current signal proportional to the E-cloud bombardment rate is generated. Figure 1 shows the RFA, and a schematic of the RFA. There is a screen electrically isolated from the collector cup. By applying a negative bias voltage on the screen, electrons that pass the screen will be forced into the collector and all secondary electrons that are generated inside the collector cup will be recaptured. The screen also stops electrons with energy below the screen bias voltage from entering the collector. By controlling the screen bias voltage, the RFA can be used to measure the E-cloud wall collision energy distribution.

* yji11@hawk.iit.edu

The Equipment

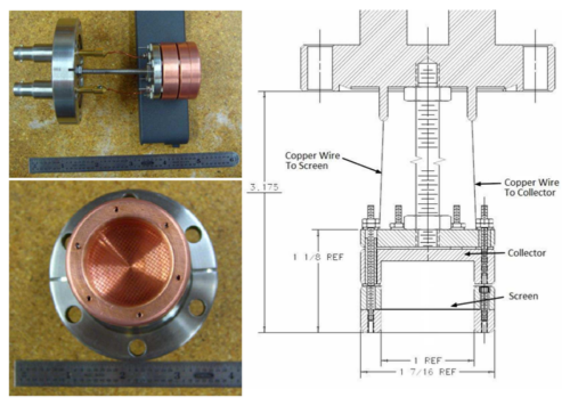

Figure 1: The Retarded Field Analyzer.

The RFA is connected to a SONOMA 310b Broadband Amplifier. The amplifier has a 30dB gain or 31 fold increase in the output signal ($\frac{V_{out}}{V_{in}}$). The bandwidth is 9 kHz to 1 GHz and the input impedance is 50 Ω (Z_{in}). The signal is monitored directly a TBS2000 oscilloscope. A grid of 0.04 diameter holes are drilled above the RFA. Based on the design of the RFA system, the total surface area exposed to the RFA is roughly 0.82 cm^2 (A_{RFA}) and about 50% of the electrons pass through the holes based on POSINST simulation ($P(\theta)$). The RFA capture efficiency was measured to be around 90% (P_C) [6]. Based on this information the RFA signal to E-cloud bombardment rate conversion factor can be calculated by the following equation

$$V_{RFA} = eR_{Brate}P_C P(\theta)A_{RFA}Z_{in}(\frac{V_{out}}{V_{in}}) \tag{1}$$

Where V_{RFA} is the measured RFA voltage, R_{Brate} is the E-cloud bombardment rate and e is electron charge. Plugging in the numbers, the conversion factor is calculated to be

$$R_{Brate}\left[\frac{N_e}{\text{s cm}^2}\right] = V_{RFA}[\text{volts}] \times 1.128 \times 10^{16}\left[\frac{N_e}{\text{s cm}^2}\right]$$

ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-TUPLE16

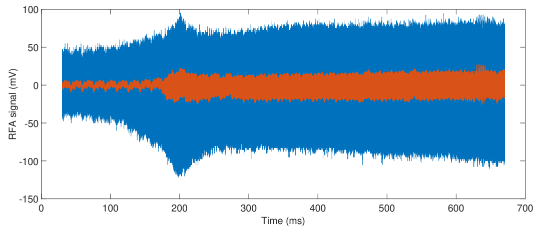

Figure 2: The RFA signal over a full acceleration cycle for Main Injector. The blue trace is the raw data, and the orange trace is filtered data. The beam intensity was 50×10^{12} protons.

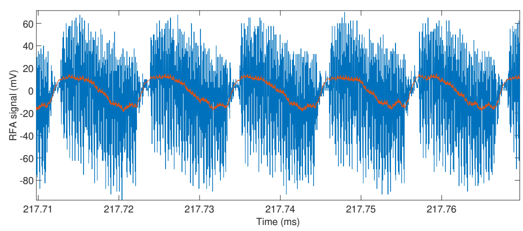

Figure 3: The RFA signal zoomed in for 5 turns. The blue trace is the raw data, and the orange trace is filtered data. The beam intensity was 50×10^{12} protons./

Signal Processing

The beam induces an image current in the conducting beam pipe walls that has nothing to do with the electron cloud density in the vacuum chamber; yet it can add to the RFA signal. It is necessary to filter out the image current to clearly identify the electron cloud signal. Figure 2 shows a typical RFA signal over the acceleration cycle. During the data acquisition, the beam intensity was 50×10^{12} protons, and the Secondary Electron yield (SEY) was measured to be 1.3 ± 0.05. Figure 3 shows the zoomed in RFA signal, 5 turns (revolutions) were included. As shown in the figures, the RFA signal not only contains the E-cloud build up information, the image current from the beam was picked up by the RFA too. In order to measure the E-cloud generation signal, the image current induced noise has to be removed.

A numerical low-pass filter with a 0.5 MHz cut off frequency is introduced. In Figs. 2 and 3, the blue line is the original signal, and the orange line is the filtered data. In Figure 3 the image current noise was clearly observable and largely shadowed the electron cloud build-up signal. After filtering, a clear build-up signature is observed.

The image current signal can be used to determine when the beam passes the RFA detector. Then, the RFA signal can be separated into each turn. The Figure 3 zoomed in 5 turn signal shows how each turn is separated. There is a clear gap between each turn, this is due to the MI filling pattern. The image current that shows up on the unprocessed RFA signal (blue trace in Fig. 3) shows whether there is beam or not. The full acceleration cycle signal may therefore be separated into each turn. Figure 3 shows that the E-cloud builds up when beam is present, and goes away during the gap in the bunch pattern left for the abort kicker rise time.

As shown in Figure 2 there is also low frequency noise present in the RFA signal. Its source came from ramping up of magnets and other cycle dependent background. The peak-to-valley and mean-to-valley variation is extracted for each turn to remove the low frequency noise. Once this is done, the variation in the E-cloud signal can be plotted over the entire acceleration cycle, using either the peak-to-valley or the mean-to-valley number for each turn. Figure 4 shows the processed RFA data.

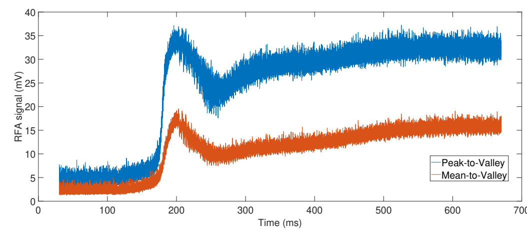

Figure 4: The RFA processed signal.

RFA MEASUREMENTS

Collision Energy Distribution

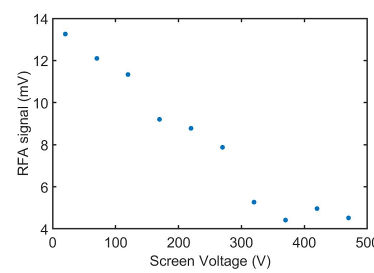

Figure 5: The RFA signal vs Screen voltage.

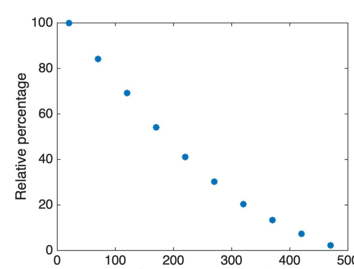

Figure 6: The simulated percentage of electron counts that hit the beam pipe above each collision energy.

The screen voltage of the RFA is an adjustable retarding voltage experienced by electrons before the RFA detector collects them. By changing the screen voltage, the RFA measures the E-cloud collision energy distribution. Figure 5 shows a measurement of the RFA signal vs screen voltage. The screen voltage measurement is directly comparable to the simulated collision energy distribution. The electrons that hit the beam pipe with collision energy higher the screen voltage will be collected by the RFA; electrons with collision energy lower than the screen voltage will be ignored by the RFA. Figure 6 shows a simulation of the percentage of electrons in the distribution above each electron collision energy.

This comparison shows the noise level of the RFA system. When the electron count is too low on the RFA, the noise will mask the E-cloud build up signal. The screen voltage measurement can be used to determine the ground level noise of the system. Figure 5 shows that at 20 V screen voltage, the RFA signal is around 13 mV. As the screen voltage increases, the RFA signal decreases and is flat after 300 V screen voltage. Figure 6 shows that simulation predicts the electron distribution should continue to decrease past 300 eV. The RFA ground level noise starts to mask the E-cloud signal after 300 V screen voltage. The ground level noise is determined to be around 5 mV.

Intensity Scan

The beam intensity is a major factor of the E-cloud build-up process. The RFA can be used to measure how the intensity affects the E-cloud build up process. Figure 7 and 8 show an intensity scan of E-cloud generation versus intensity over the MI acceleration cycle. Figure 7 shows how the peak-to-valley E-cloud generation changes for every turn over the acceleration cycle. Figure 8 shows the mean-to-valley E-cloud build up signal over every turn of the acceleration cycle. The beam crosses transition at about 0.2 seconds, where the RFA signal reaches it peak (see Fig. 7 and 8). The RFA measurements show that the E-cloud generation

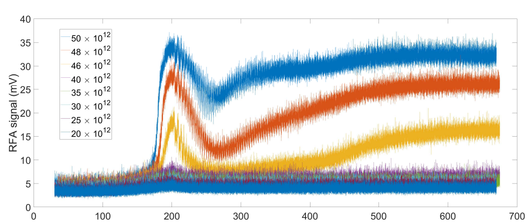

Figure 7: The Peak-to-Valley RFA signal of 8 different intensities.

starts about 0.17 second into the acceleration cycle, is a maximum at transition, drops after transition and rises up slowly again. E-cloud generation over one machine cycle could be dependent on several factors. In this case, the E-cloud generation trend is mainly caused by bunch length changes over the acceleration cycle. Figure 9 shows the development of the peak-to-valley RFA signal and bunch length over the acceleration cycle. The bunch length was obtained by the Blond simulation code with inputs matched to MI conditions. The RFA trend is the inverse of the bunch length trend. E-cloud generation starts when the bunch length decreases enough to generate an observable E-cloud. At transition, the bunch length is minimized and the E-cloud generation is maximized. After transition, the bunch length increases and then decreases, while the RFA signal decreases and then increases. The major features of the bunch length are inversely matched on the RFA signal.

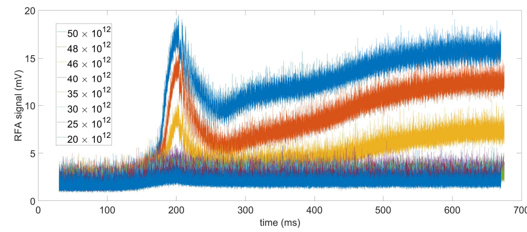

Figure 8: The Mean-to-Valley RFA signal of 8 different intensities.

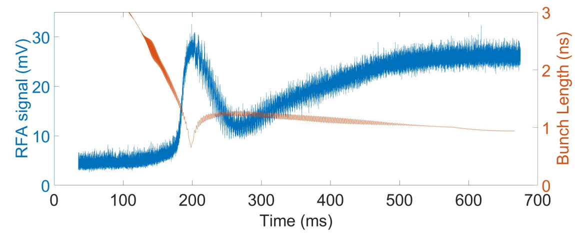

Figure 9: 50×10^{12} intensity RFA signal compared with bunch length over acceleration cycle.

CONCLUSION

An RFA system for measuring electron cloud is installed at the MI-10 area of the Fermilab. The RFA data includes two contributions from noise: 1) the high frequency image current from beam and 2) low frequency cycle dependent background. A filtering process is introduced to remove the high frequency noise and a turn-by-turn process is introduced to remove the low frequency noise. A collision energy distribution measurement shows that the RFA has a 5 mV noise threshold. The RFA system successfully measured the E-Cloud generation for different beam intensities over the MI acceleration cycle. By comparing the RFA signal and bunch length trends over the acceleration cycle, the bunch length dependence of E-cloud generation is observed.

ACKNOWLEDGMENT

This work was funded by the National Science Foundation under the grant no. PHY-1205811, and Joint University - Fermilab Doctoral Program in Accelerator Physics and Technology.

ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-TUPLE16

REFERENCES

[1] F. Zimmermann, "ECLOUD12: Joint INFN-CERN-EuCARD-AccNet Workshop on Electron-Cloud Effects," CERN, Geneva, Switzerland, CERN-2013-002, pp.9-17, Jun 2012.

[2] M. Backfish, J. Eldred, "Beam Tests of Beampipe Coatings for Electron Cloud Mitigation in Fermilab Main Injector," Fermilab, Batavia, IL, USA, FERMILAB-PUB-15-366-AD-APC, Jul. 2015.

[3] Ubaldo Iriso Ariz,"Electron Clouds In the Relativistic Heavy Ion Collider," DOI: 10.2172/1061819

[4] Y. Ji, L. K. Spentzouris, and R. M. Zwaska, "Secondary Electron Yield Measurement and Electron Cloud Simulation at Fermilab", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 629–632. doi:10.18429/JACoW-IPAC2015-MOPMA039

[5] Y. Ji, L. K. Spentzouris, and R. M. Zwaska, "Update of the SEY Measurement at Fermilab Main Injector", in *Proc. North American Particle Accelerator Conf. (NAPAC'16)*, Chicago, IL, USA, Oct. 2016, pp. 1190–1193. doi:10.18429/JACoW-NAPAC2016-THPOA45

[6] L. McCuller, "Simulations and testing of retarding field analyzers for electron cloud monitoring" presented as undergraduate project, 2009.