HYDROGEN AND CESIUM MONITOR FOR H- MAGNETRON SOURCES

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Abstract

The relative concentration of cesium to hydrogen in the plasma of a H- magnetron source is an important parameter for reliable operations. If there is too much cesium, the surfaces of the source become contaminated with it and sparking occurs. If there is too little cesium then the plasma cannot be sustained. In order to monitor these two elements, a spectrometer has been built and installed on a test and operating source that looks at the plasma. It is hypothesized that the concentration of each element in the plasma is proportional to the intensity of their spectral lines.

INTRODUCTION

At the end of 2012, Fermilab upgraded its H- injector from the Cockcroft-Walton accelerator to an RFQ (radio frequency quadrupole) accelerator. [1] As part of the upgrade, the original slit magnetron source [2] was replaced with a dimpled magnetron source. [3] Fig. 1 shows the different cathodes used by these two sources. The slit source extracted beam at 20 kV while the dimpled source extracts beam at 35 kV. The other performance parameters are also quite different and are summarized in Table 1. It is clear from this table that the dimpled magnetron source not only dramatically improves the output beam current by 2×, but it is also a lot more efficient because the power efficiency goes from 6 mA/kW to 67 mA/kW. Furthermore, the dimpled magnetron source produces beam that is almost round compared to the flat ribbon like beam produced by the slit magnetron source. "Round" beam is required because of the RFQ acceptance.

Unfortunately, despite the dimpled source having much better performance when compared to the slit source on paper, one major problem that it suffered from is sparking during commissioning and in operations. Sparking can occur as often as once a minute and when this happens, not only does it detrimentally affect the physics experiments, it also trips off the high voltage supplies that have to be repeatedly reset. It took a long time to solve this sparking problem: it included change of materials in the source [4], better understanding of how the hydrogen gas pressure affects spark rates, as well as, finding out how to set the required cesium flow rate.

It is obvious that the amount of cesium in the source is a major parameter that requires careful monitoring to prevent sparking. A simple back of the envelope calculation of the cesium flow rate shows that it is about 20 nm/s! This tiny number makes it impossible to use traditional flow rate monitors like magnetic or piezo flowmeters. The only method that is obvious to the authors is the monitoring of the intensity of the cesium spectral lines of the plasma. This method can be, at best, an indirect measurement of the amount of cesium in the source that is available for replenishing the cesium layer on the cathode surface that was desorbed by plasma bombardment and thermal emission.

Figure 1: A slit cathode (top) and a dimpled cathode (bottom).

Table 1: Some Parameters of Slit and Dimpled H- Sources

Parameter	slit	dimpled
Arc current	50 A	15 A
Arc voltage	160 V	150 V
Beam current	50 mA	100 mA
Power efficiency	6 mA/kW	67 mA/kW
Source lifetime	3 months	9 months

SPECTROMETER

A simple home made spectrometer was constructed and mounted at the window on the source cube. See Fig. 2. It points directly at the plasma that is visible through that window. In order to make the spectrometer small and compact, a mirror is used to bend the light from the plasma to a 600 lines/mm grating to produce a spectrum. The spec-

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trum is captured with an astronomy CCD (charged coupled device) camera (SBIG ST402ME [5]) that is Peltier cooled. An integration time of 60 s is used because the intensity of the spectrum is quite low, and the CCD requires cooling because of the long integration time. The Peltier cooler also keeps the CCD at a constant temperature so that any temperature effects on the collection of photons by the CCD is minimized. The spectrum is grabbed by a program running on a PC and the peaks of the hydrogen and cesium lines are sent back to the control system for datalogging. An example of a spectrum that is captured by the camera is shown in Fig. 3.

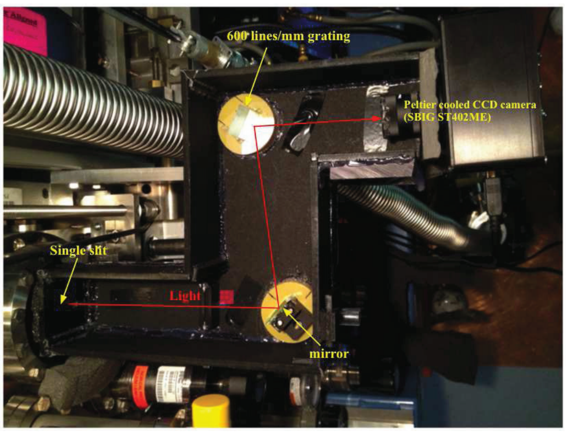

Figure 2: The spectrometer points directly at the plasma. In order to keep fit the spectrometer in the confined space of the injector, the light from the plasma is bent once by a mirror.

The strongest line in the spectrum is the hydrogen Balmer line at 658 nm. There are a cluster of lines that belong to cesium between 546 nm to 635 nm. The famous cesium blue lines at 456 nm and 459 nm are not seen. The hydrogen peak and three cesium peaks in the cluster are tracked over time. The time evolution of these peaks are discussed in the next section.

And it is important to note that since the camera is installed in an electrically noisy environment, ferrites are added to filter out any power supply transients that can destroy the CCD.

Behavior of the spectrum

The whole point of the exercise is to see whether the behavior of the source can be characterized by looking at the strengths of the hydrogen and cesium lines. For this purpose, a test source is used in these experiments. The results of one of these experiments are shown in Fig. 4 where the cesium valve and its heaters that control its flow are turned off. Here are the observations:

- There is a very fast ∼ 30 min increase in the intensity of both the hydrogen and cesium lines. One possible explanation is that the source is cooling off and this causes the intensity to increase. Therefore, this effect

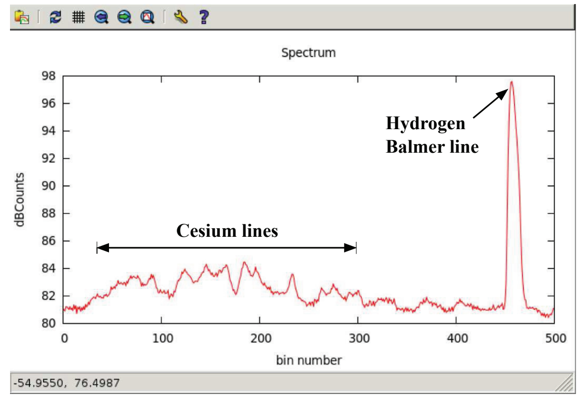

Figure 3: An example of a spectrum that is captured by the CCD camera. The strongest line is from hydrogen at 658 nm and there are a whole range of peaks between 546 nm to 635 nm that come from cesium. Unfortunately, the famous blue cesium doublet at 456 nm and 459 nm are not seen.

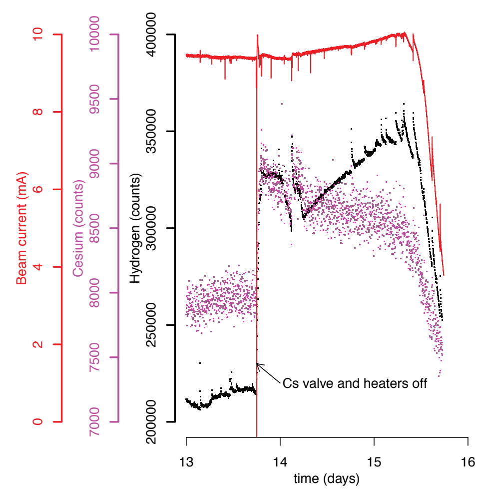

Figure 4: This experiment shows the behavior of the spectral lines after both the cesium valve and the heaters that control its flow are turned off. See text for the analysis.

shows that the spectral intensity is a function of both hydrogen gas pressure and source temperature.

- Both the cesium (magenta dots) and hydrogen (black dots) lines increase but the beam current is unaffected because there is an excess of cesium on the cathode surfaces. However, after about half a day, the hydrogen line starts to intensify while the cesium line starts to fade. The reason is because there is insufficient cesium to maintain the original plasma density and thus there is an excess of hydrogen. Meanwhile, the beam current starts to increase because the cesium layer on the cathode has decreased in thickness to give the lowest work function, i.e. this is the most efficient thickness for plasma production. [6] This result shows that there was too much cesium that maintained the original plasma!

- However, after two days, all the cesium is consumed and there is insufficient ions and electrons to excite the hydrogen and cesium vapor and all the spectral lines start to grow faint and the beam current also declines.

Sparking

The spectral lines of the operating source is shown in Fig. 5 during a period where there was sparking.

- The first set of sparks (A) is cured by decreasing the hydrogen gas pressure. This decrease in gas pressure does not intensify the hydrogen line but increases the intensity of the cesium spectrum. This shows that gas pressure has a complex effect on the spectrum.
- The second set of sparks (B) causes the source body to cool and despite the decrease in gas pressure both the hydrogen and cesium lines intensify, but clearly, the increase in the cesium line intensity is minimal. This behavior is not quite like that of the test source discussed above because the spectra of both the hydrogen and cesium intensities increase dramatically in that case.
- After the source recovers from sparking, the intensity of the hydrogen line decreases back to the level before the sparking period (B) before another deliberate change in gas pressure.
- All the while, starting from the set of sparks (A), the strength of the cesium spectrum is slowly increasing over time while the hydrogen line is decreasing until 20 April. This may indicate that too much cesium is in the source and the flow rate needs to be adjusted because this is the opposite behavior when there is less cesium in the source. See discussion above.

It is clear from this plot that the intensity of the spectrum is a complex function of gas pressure and source temperature. The disentangling of these observations in order to find stable operating points in parameter space is still an ongoing exercise. However, despite these complexities, the simplest notion is to ignore these complexities for now — if a "normal" intensity of the cesium that is good for operations can be identified, then when its spectrum is brighter, it indicates that there is too much cesium in the source. The key, then, is to identify what "normal" means. This notion is currently being tested.

CONCLUSION

The spectrometer has performed very well in a very harsh electrical environment where sparks can easily destroy the CCD camera electronics. Data has been successfully collected over the past few months and are continually being analyzed to discover whether there are any clear relationships between the strength of the spectral lines and stable points for running the source. Preliminary studies indicate that the cesium spectrum can be used to measure the level of cesium in the source in the simplest sense discussed in the previous section, but in reality, care has to be taken to disentangle it from the complex relationship between the hydrogen gas pressure and source temperature.

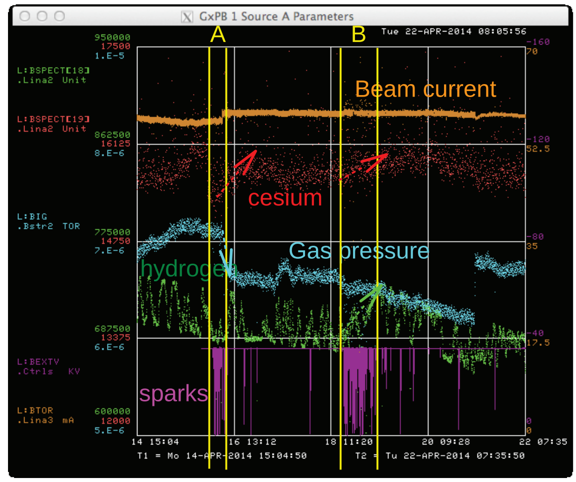

Figure 5: This data is collected over 8 days of running from the operating source for high energy physics. See text for details of the analysis.

ACKNOWLEDGMENTS

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