A PID CONTROL ALGORITHM FOR FILAMENT POWERED VOLUME CUSP ION SOURCES

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Abstract

Volume-cusp ion sources require a fast and precise control algorithm to ensure the arc current, and thus the beam current is stable for high-power industrial DC operation. Using D-Pace's TRIUMF [1] licensed filament-powered H^- volume-cusp ion source, a proportional-integral-derivative (PID) control algorithm was implemented that provides a peak-to-peak beam current variation of ±0.45% and a root mean square error of 0.025mA for 10.16mA of beam current over 60 minutes. The PID parameters were tuned for different set points and the performance of the algorithm is compared for the different settings. Measured arc current stability, and measured beam current as a function of time are presented and the algorithm utilized is described in detail.

INTRODUCTION

Filament-powered volume-cusp ion sources require a high stability control algorithm to ensure stable beam operation. The plasma inside the source is generated by heating a tantalum filament assembly. A diagram of the wiring of a filament-powered volume-cusp ion source is presented in Figure 1.The filament is negatively biased so that the electrons emitted from the filament are accelerated to the wall of the source. The current to the wall, denoted as the arc current, is directly related to the power input into the plasma and therefore arc current stability is directly related to beam current stability. A PID control algorithm was implemented to keep the arc current stable and thus keep the beam current stable.

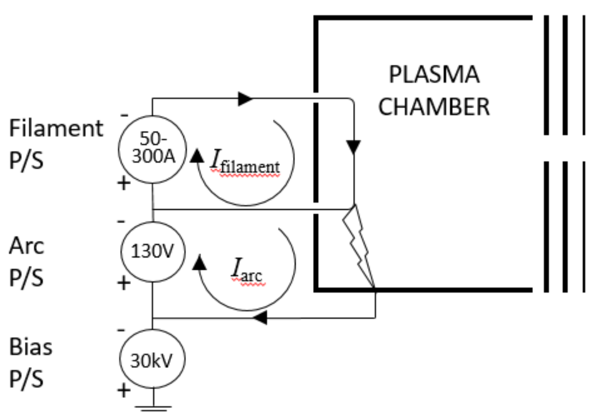

Figure 1: Schematic of the wiring of a filament-powered volume-cusp ion source. The arrows show the direction of the electron current.

The hydrogen plasma is generated by 4 half circle tantalum filaments. The plasma is confined by 10 rows of Sm_2Co_{17} magnets. Beam current is measured by a Faraday cup 50 cm downstream from the ion source extraction lenses.

PLASMA PROPERTIES

The plasma in a filament-powered volume-cusp negative ion source is generated by a glow discharge. Current is first measured when electrons begin to be emitted from the filament. Further raising the filament power supply current will increase the arc current until there is a Townsend discharge [2]. The electrons create an avalanche by collision with the gas particles inside the chamber thus igniting the plasma. At this point the current from the filament power supply needs to be lowered to keep the arc current constant. The arc current becomes highly unstable and one sees the need for a dedicated control system.

Furthermore, the arc current to filament current relation is highly dependent on the gas flow, gas species, filament aging, plasma confinement, chamber dimensions, etc. Figure 2 presents the relation between filament current and arc current for two different filaments. The 'old' filament had been running for about 450 mA·hours while the new filament had just been installed.

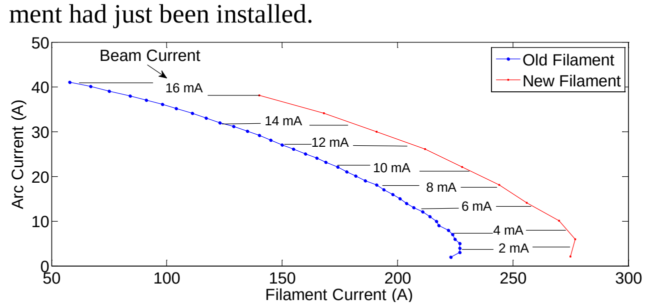

Figure 2: Relation between filament current and arc current as the filament ages with corresponding beam current. The gas flow was set at 15sccm and the arc voltage was at 130V.

ALGORITHM

A PID control algorithm was used to control the arc current. The arc current is controlled by varying the filament power supply current and, thus, stabilizing the arc current which stabilizes the H^- beam current. The arc current error is first calculated,

$$E(t_i) = I_{arc}(t_i) - I_{arcset}, \tag{1}$$

where I_{arc} is the arc current, t_i is the present iteration and I_{arcset} is the arc current setpoint entered by the operator.

The new current in the filament power supply is calculated by

$$I_{fil}(t_i) = I_{fil}(t_{i-1}) + u(t_i), \tag{2}$$

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where

$$u(\mathrm{t}) = K_P E(\mathrm{t}) + K_I \int_{\mathrm{t}_0}^{t} E(\mathrm{t'})\mathrm{dt'} + K_D \frac{dE}{dt}. \quad (3)$$

The parameters K_P, K_I and K_D are the proportional, integral and derivative terms respectively. These parameters are tuned for the specific system. For our filament-powered H^- ion source, the filament current (I_{fil}) is controlled by the algorithm while the arc current (I_{arc}) is the read-back parameter.

Since the measurement is discretised, the derivative in eq. (3) is approximated by the average error variation between the two closest error points. The integral is approximated by the sum of the errors. In order to eliminate the risk of over-compensating for the integral term, a moving boxcar average of 10,000 points is taken for the integral. The time interval between consecutive measurements was set at 10ms, so the integral was taken over 100s.

Proper tuning of the PID parameters is the key to reducing the arc current error. The control loop is dominated by the proportional term, while the integral term corrects for long term offsets. The derivative term reduces the oscillations around the set point and is usually only needed for fast applications. The time step size is set at 10ms. The three PID tuning parameters serve different purposes; K_P sets the sensitivity to the set point. K_I sets the sensitivity to long term error since the error is integrated over time. K_D compensates for the speed of the convergence, helping reduce the oscillations around the set point.

Since the generation of a plasma with a filament is highly non-linear, the PID parameters depend on the arc current setpoint. At low arc currents (less than 5A), the behaviour is a lot more predictable and the control algorithm could properly control the arc current with just the proportional term, which was set to $K_P = 50$. At higher arc current set points, it becomes necessary to include the other integral and derivative terms. The proportional terms needs to be lowered for higher arc current setpoints. For an arc current between 5A and 20A, $K_P = 30$ and $K_I = 5$ gives good stability. Above 20A of arc current, an added derivative term helps improve stability along with a lower proportional term. At $I_{arcset} = 24.6$A, we found that the algorithm worked best with $K_P = 15$, $K_I = 10$ and $K_D = 1$.

RESULTS

To evaluate the algorithm, the arc current was set at $I_{arcset} = 24.6$ A. The arc voltage was fixed at 130V and the H_2 gas flow was at 15 sccm. The results are presented in Figure 3. Over 60 minutes of operation, we obtained a root mean square error in the arc current of 0.058 A and 0.025 mA for a beam current of 10.16mA on the Faraday cup. The maximum peak-to-peak variation was ±0.76% for the arc current and ±0.45% for the beam current.

One will notice that the deviation is larger for the arc current than for the beam current. This is probably explained by the fact that H^- ion production is a slower process and thus less affected by the electron current to the chamber walls.

Future work will include the optimization of the K values to finer increment ranges of the arc current. In addition, one could change the input to the feedback loop from the arc current to the beam current, and thus improving beam current stability even more.

CONCLUSION

A PID algorithm was implemented to control the arc current in a filament-powered volume-cusp H^- ion source. The PID parameters were tuned manually to the desired set point. The control algorithm gave a peak-to-peak error of ±0.76% and a root mean square error of 0.058A for a set-point of 24.6 A of the arc current. This corresponded to a peak-to-peak error of ±0.45% and a root mean square error of 0.025mA for 10.16 mA of measured H^- beam current over a period of more than 60 minutes.

ACKNOWLEDGMENTS

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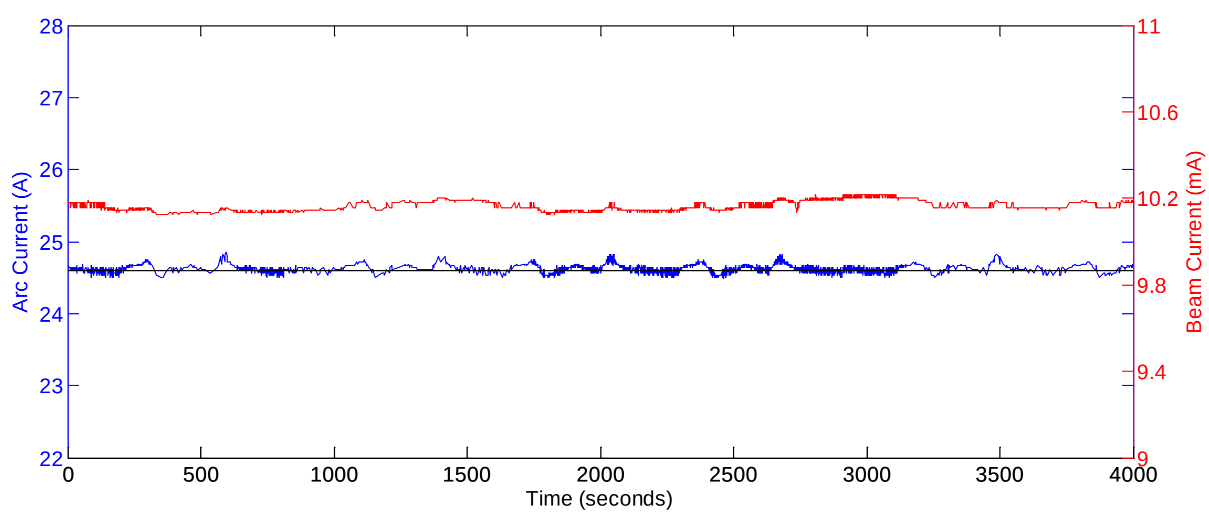

Figure 3: Variation of the arc current read-back (blue) and of the H^- beam current (red) for I_{arcset}=24.6 A. The arc voltage was set at 130V and the gas flow was set at 15sccm.

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