EXTENDING THE DUTY CYCLE OF THE ISIS H$^-$ ION SOURCE, THERMAL CONSIDERATIONS

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Abstract

The ISIS H$^-$ ion source is currently being developed on the Ion Source Development Rig (ISDR) at Rutherford Appleton Laboratory (RAL) in order to meet the requirements for the next generation of high power proton drivers. One key development goal is to increase the pulse width and duty cycle, but this has a significant effect on ion source temperatures if no other changes are made. A Finite Element Analysis (FEA) model has been produced previously [1] and is used here to understand the steady state and dynamic thermal behaviour of the source, and to investigate the design changes necessary to offset the extra heating.

INTRODUCTION

A thorough understanding of the thermal characteristics of the ISIS ion source is essential if operation is to be extended to the higher duty factors required for next generation accelerators, whilst maintaining an optimal regime for H$^-$ ion production and source lifetime.

Figure 1 shows the model of the ion source. The source is of the Penning type, comprising a molybdenum anode and cathode between which a low pressure hydrogen arc is struck. Hydrogen and caesium are fed into the arc via holes in the anode; these can be more clearly seen in Figure 2. The anode and cathode are housed in the stainless steel source body. The anode is thermally and electrically connected to the body, whereas the cathode is isolated from the body by means of a ceramic spacer. The whole assembly is bolted to a flange, separated by a thin layer of mica to provide electrical isolation for the cathode.

Source cooling is provided by two systems illustrated in Figure 1: air cooling via two pipes in the source body nearest the electrodes and water cooling via a channel cut into the ion source flange. Air flows along one pipe and is then returned down the other as shown in Figure 1. Air is used because of the safety hazards involved with having water close to the caesiated ion source.

The ions are extracted through the slit in the aperture plate.

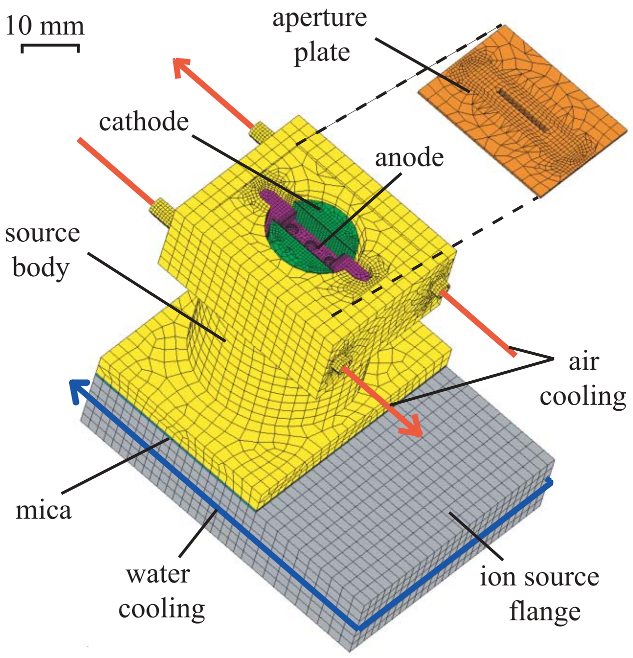

Figure 1: ALGOR thermal model of the ion source

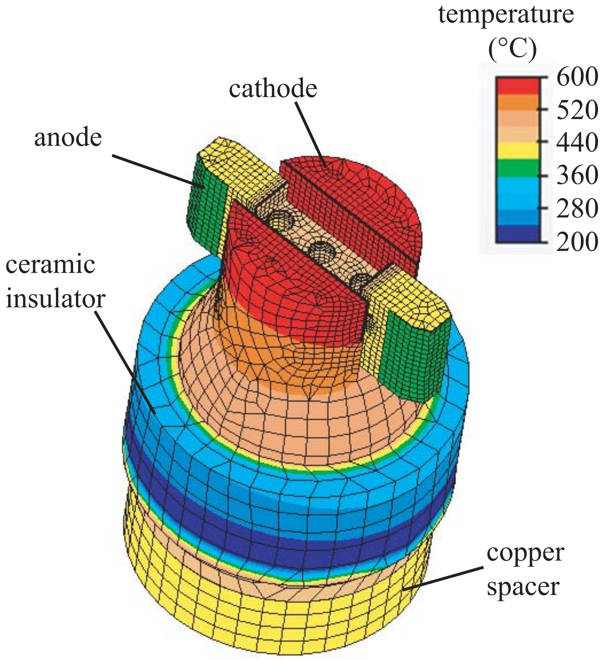

Figure 2: Component temperatures from the steady state model.

THERMAL MODEL

ALGOR [2] FEA software has been used for thermal modeling. The details of the model and its validation have been discussed previously [1].

The typical ISIS ion source operating conditions are a 4 kW, 0.5 ms, 50 Hz arc. An assumption is made that all the electrical power as measured in the external circuit goes into heating the electrode surfaces exposed to the discharge. The arc is bounded on all sides by sections of the cathode, anode and aperture plate.

When all the parameters that correspond to normal operation of the ISIS source are applied to the model the temperatures obtained are very close to the temperatures measured in the actual source (Table 1). This provides validation that the model is realistic.

STEADY STATE CALCULATIONS

To obtain a steady state solution the average power densities over the 50 Hz cycle are applied to the electrode surfaces.

In normal operation the source temperatures are monitored using three thermocouples: Cathode, Anode and Source Body. All these thermocouples are positioned some distance from the electrode surfaces exposed to the arc plasma so they do not give actual surface temperatures. The realistic model of the source allows this difference between measured and surface temperature to be calculated, Table 1. The difference between these values depends on the distance between the measurement point and the electrode surface. It is greatest for the cathode because the measurement point is at the very base of the cathode.

Table 1: Theoretical thermocouple, electrode surface and actual thermocouple temperatures.

Location	From Model			Actual ISIS
	Thermocouple	Surface	Difference	
Anode	456°C	496°C	40°C	400-600°C
Cathode	501°C	585°C	84°C	440-530°C
Source Body	416°C	441°C	25°C	390-460°C

The electrode surface temperatures are an important factor when considering the performance of the ion source as these surfaces play an important role in the plasma physics of the arc; the caesiation of the surface is temperature dependent for example.

The aim of the modelling work is to find out what is required to maintain the electrode surfaces at the temperatures in the current source whilst increasing the duty cycle.

The duty cycle is doubled to 1 ms and the cooling represented by a Heat Transfer Coefficient (HTC) in the head and flange increased. Figure 3 shows the results.

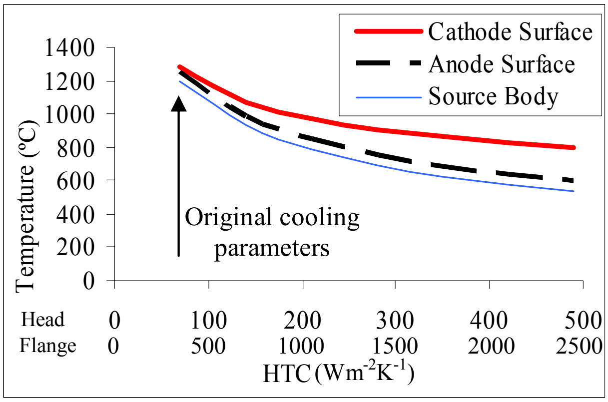

Figure 3: 1 ms duty source steady state temperatures for increased cooling.

Without increasing the cooling, the source temperatures approximately double. As the water and air flow rates are increased the anode and source body temperatures come down together, however the cathode surface temperature decreases more slowly. This is because the cathode is thermally isolated from the cooling systems by the layer of mica and the ceramic insulator. For a 1 ms duty cycle there is no combination of coolant flow rates that will produce the original surface operating temperatures.

Modifications

Mica is a very poor thermal conductor. To improve the cooling to the cathode the layer of mica is removed from the model. With the mica removed the steady state surface temperatures shown in Table 1 can be reached easily for a 1 ms duty cycle.

The mica is present to provide electrical isolation of the cathode from the flange, so in practice a thin layer of material with good electrical insulation properties and high thermal conductivity (such as aluminium nitride) will have to be used.

Removal of the mica will cause problems with source start up. It will be difficult to heat the source up to reach operating temperature. Modifications being considered include a heating element to pre-heat the cathode.

TRANSIENT CALCULATIONS

The steady state calculations only calculate the average electrode surface temperature. Using the steady state solution as a starting point it is possible to run a transient study. This allows the peak surface temperatures reached at the end of the arc on period to be calculated. To ensure accurate results the elements of the FEA model near the electrode surfaces are made very thin (10^{-5} m) in the direction of heat flux.

Figure 4 shows how the peak temperatures vary though the cycle for the 0.5 ms and 1 ms duties. During the on period there is a rapid increase in the surface temperature of the materials directly exposed to the plasma; this temperature then decays away as the arc energy dissipates into the thermal mass of the material. The peak source body temperature does not vary because it is not directly in contact with the plasma. In a similar way there is no detectable change in temperature at the thermocouple measurement points.

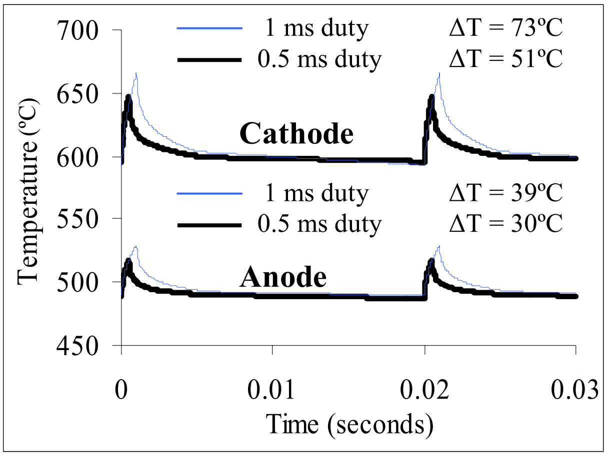

Figure 4: Anode and cathode surface temperatures for 0.5 ms and 1 ms duty cycles for the normal sized ion source calculated from the transient model.

The exact implications of this electrode surface temperature rise during the on period are poorly understood for a surface Penning ion source. The temperature rise is clearly larger for the 1 ms duty cycle, but it is not known how this will affect the ion source operation. All that is known is that the existing source operates very well. Work is currently underway to test the ion source with a 1 ms duty cycle on the ISDR at RAL.

DOUBLE SIZE SOURCE

The electrode surface temperature rise during the on pulse cannot be mitigated with additional cooling because the energy does not have time to conduct away from the surface. The surface temperature rise is therefore mainly dependent on the power density applied by the plasma to the electrode surfaces and the length of time it is applied. The total arc power and length of time cannot be changed, therefore the electrode surface area must be increased to decrease the power density.

All linear dimensions in the model are doubled and the simulation repeated, keeping the instantaneous power at 4 kW as before. Scaling the ion source dimensions has been successfully implemented by previous researchers [3] at Los Alamos National Laboratory. Figure 5 shows the transient results. For a 1 ms duty cycle the surface temperature rises are significantly reduced.

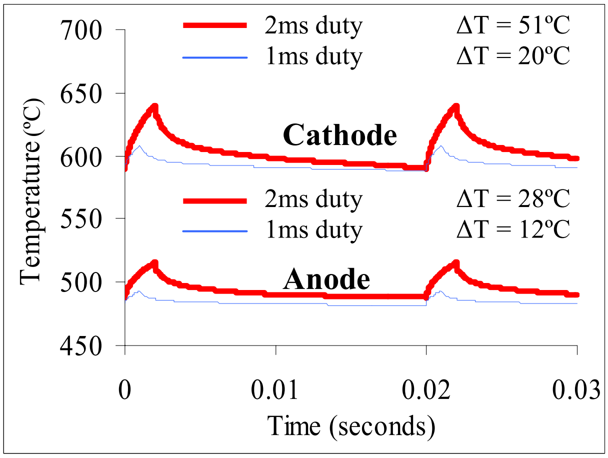

Figure 5: Anode and cathode surface temperatures for 1 ms and 2 ms duty cycles for the double sized ion source calculated from the transient model.

In the double sized source, the duty cycle can be further increased to 2 ms and the surface temperature rises are very similar to the normal ion source for a 500 µs duty. This confirms that the surface temperature rise is largely dependant on surface power density and time. (4X duty balanced with 4X increase in surface area).

CONCLUSIONS

To increase the duty on the ISIS ion source the cathode must be cooled more directly by replacing the mica sheet with a better thermal conductor

If the electrode surface temperature rise is critical it will be necessary to move to larger electrodes.

ACKNOWLEDGMENTS

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REFERENCES

[1] D. Faircloth et al, “Thermal Modeling of the ISIS H– Ion Source”, Review Of Scientific Instruments, Volume 75, Number 5, May 2004.

[2] ALGOR Inc., 150 Beta Drive, Pittsburgh, PA 15238-2932 USA. www.algor.com

[3] H. Vernon Smith, Jr., “H^- and D^- Scaling Laws for Penning Surface-Plasma Sources”, Review Of Scientific Instruments, Volume 65, Number 1, January 1994.