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A TECHNIQUE FOR MEASURING COOLING PATTERNS IN ION SOURCE GRIDS BY INFRARED SCANNING

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ABSTRACT

Many plasma sources designed for neutral beam injection heating of plasmas now employ copper beam acceleration grids which are water-cooled by small capillary tubes fed from one or more headers. To prevent thermally-induced warpage of these grids it is essential that one be able to detect inhomogeneities in the cooling. Due to the very strong thermal coupling between adjacent cooling lines and the concomitant rapid equilibration times, it is not practical to make such measurements in a direct manner with a contact thermometer. We have developed a technique whereby we send a burst of hot water through an initially cool grid, followed by a burst of cool water, and record the transient thermal behavior using an infrared television camera. This technique, which would be useful for any system with cooling paths that are strongly coupled thermally, has been applied to a number of sources built for the PLT and PDX tokamaks, and has proven highly effective in locating cooling deficiencies and blocked capillary tubes.

I. INTRODUCTION

In recent years the injection of beams of energetic neutral atoms has played an increasingly crucial role in experiments involving magnetically confined plasmas for thermonuclear fusion research. Neutral beams have found particular utility as a promising means of bridging the gap between the temperature at which a self-sustaining tokamak reactor becomes feasible, and the lower temperatures at which ohmic heating by the plasma current ceases to be effective.[1]

These neutral beams are typically derived through charge exchange of fast ions that have been extracted from an arc discharge and electrostatically accelerated to tens of kilovolts. Many of these ion sources now employ copper extraction and acceleration grids which are water-cooled by small capillary tubes fed from one or more headers. Interleaved with multiple rows of beamlet forming apertures, the capillary tubes are typically brazed into the grids at intervals of 1 - 1.5 cm. To prevent thermally-induced distortion of these grids, it is essential that one be able to detect gross inhomogeneities in the cooling of the grids, and especially to identify blocked capillary tubes. It is also highly useful in setting acceptable beam pulse lengths if one can measure approximate temperature equilibration times. Due to the very strong thermal coupling between adjacent cooling lines, and the concomitant rapid equilibration times, it is not practical to make such measurements in a direct manner with a contact thermometer.

We have developed a technique whereby we send a burst of hot water through an initially cool grid, followed by a burst of cool water, and record the transient thermal behavior using an infrared television camera. This technique has been applied to a number of grid sets built[2] for injection heating of the PLT and PDX tokamaks located at Princeton, and has proven highly effective in locating cooling deficiencies and blocked capillary tubes.

II. MEASUREMENT TECHNIQUE

Figure 1 diagrams the experimental systems. The grid being studied was precooled by water at about 18° C and a pressure of 70-80 lb./in^2, after which the flow path was opened to the hot water reservoir, in which the water had been heated to 100°C and pressurized to 92 lb./in^2. Once the grid had equilibrated, the procedure was reversed, cooling it down again. The thermal evolution of the grid under test was measured with an infrared television camera, Model 210, purchased from Inframetrics, Inc., which framed at a rate of 30 hz. We videotaped the signals with a Sanyo VTC 7100, permitting subsequent playback at reduced speed and single framing for still photographs. The infrared camera could produce either a conventional raster image, or a line profile of the infrared emission along a slice. We found the former mode to be of more general utility.

With this technique we are, of course, measuring not the temeprature distribution on the grid, but rather a function which is the product of the temperature and the emissivity at each point. Since the emissivity of unprepared metal surfaces is rarely entirely uniform, one might suppose this to present a problem. That is does not do so in our case is consequent upon two factors: we need to know only the relative, not the absolute, temperature distribution, and, moreover, we expect deficient water flow in a capillary tube to manifest itself as a perturbation in infrared emission along the entire length of the affected line, rather than in a localized region on the line such as might occur from surface contamination.

III. SAMPLE RESULTS

We have applied this technique to five sets of grids, examining in each case the plasma grid (the one facing the source plasma) and the ground grid (the one facing the tokamak). The intervening grid, which normally intercepts very little beam power, was not examined, since the grids were already assembled into three-grid units. Of the ten grids tested, six (of which four were newly designed grids for the PDX tokamak) were found to be perfect, coming up in temeprature evenly and equilibrating after about 1-3 seconds, depending upon the grid design. The only transient inhomogeneity found in these grids, which are circular and fed by a header coming from one side, was a tendency among the PDX grids for the capillary tubes nearest the input side of the header to come up in temperature during the hot water pulse slightly faster than those at the blind end of the header, which was consistent with the ~100-150 msec propagation time along the header. This would not be a factor in ordinary grid operation. No significant effects were detected due to the variation in path length of the capillary tubes (the center tubes, longer than those on the edges, present somewhat greater flow impedance).

The efficacy of the technique is, however, better demonstrated by its detection of flow inhomogeneities in the imperfect grids. Figure 2 shows the evolution of the infrared emission from a 20 cm ground grid as hot water is sent through it (photographs 1-6), followed by the grid's cooldown in photographs 7-9 as cold water is sent through the capillary tubes. In photo 1, we see five of the capillary tubes beginning to come up in temperature, followed in photo 2 by two more tubes. In photos 3-5 adjacent tubes come up in temperature, until by photo 6 the grid has reached near-equilibrium. In photo 7 the cooldown begins, with the same five lines that responded quickest to the hot water in photo 1 being the first to begin to drop in temperature. This confirms that these lines do in fact have greater water flow than do the remaining 15 lines. If their greater infrared emission during the heatup phase had been due simply to surface conditions such that these five lines had higher emissivities than the other lines then, if the water flows were equal, the lines that had risen in emission first would, during the cooldown, have been the last to fall in emission, rather than the first. In photos 8 and 9 the remainder of the grid begins to cool down, with those regions which had been the last to heat up being also the last to cool. It is noteworthy that, after 12 seconds, when it is in near-equilibrium, even this very inhomogeneously cooled grid gives the appearance of homogeneity. Thus, the inhomogeneity is only observable in the transient behavior. Subsequent examination of this grid revealed that the braze joints between the capillary tubes and the headers were poorly made, and thus were the probable cause of the inhomogeneous flow. The seven best functioning lines, as determined by the IR data, are all brazed to the same header (each of the two headers feeds 10 capillary tubes). The water flow through this header is 37% greater than that through the other header, which is consistent with the IR results.

Figure 3 shows representative data from three other grids, as well as an example (Fig. 3-2) of the line profile mode, which shows a temperature slice of the grid in Fig. 2 early in the heat-up phase. The peaks correspond to the best functioning capillary tubes. Fig. 3-1 demonstrates the ease with which even a single defective line is picked out. Subsequent examination revealed this tube to have a small dent. Fig. 3-3 shows a grid early in the heat up phase on which only four of the twenty capillary tubes are functioning properly. These four lines all connect to the same header, which is found to carry 120% more water than the other header, which connects only to defective lines. Even this grid, however, comes to a near-equilibrium after 30 seconds. The good PLT grids which we examined, on the other hand, required only 2 - 3 seconds to reach near-equilibrium.

IV. SUMMARY

We have developed a quick, non-destructive method for obtaining qualitative measurements of the cooling pattern and relative water flow along different paths in a grid. Although this technique does not indicate precisely what the flow is in any particular line, it is very successful at locating significant deficiencies in water flow due to blockages or high impedance in capillary tubes, and in picking out regions of a grid which are relatively poorly cooled. Such qualitative information is just what is required in determining the suitability of a grid for ion scurce operation. This technique would also be generally applicable to any system with cooling paths that are strongly coupled thermally.

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REFERENCES

(1) H. Eubank, et al., Phys. Rev. Lett. 43, 270 (1979), and references therein.

(2) C. C. Tsai, et al., Oak Ridge National Laboratory Rep. TM-6360 (1978), and M. M. Menon, et al., J. Appl. Phys. 50, 2484 (1979).

FIGURE CAPTIONS

(1) Schematic of the diagnostic apparatus.

(2) Thermal evolution of a defective 20 cm ground grid for PLT injection. The approximate elapsed time in seconds between the first observed change in emission and these photos (from videotape) is: (1) 0.5, (2) 0.9, (3) 1.6, (4) 2.8, (5) 5.3, (6) 12.3, (7) 0.7 (after start of cool down), (8) 2.2, and (9) 5.0. Note that the grid is in near-equilibrium by photo 6.

(3) Photos show: (1) heat up of a 20 cm PLT grid with one defective line, (2) line profile during heat up of the grid shown in Fig. 1, (3) heat up of a grid with only 4 properly functioning lines (out of 20), (4) a perfect 20 cm grid at near-equilibrium (~ 3 sec after initiation of the pulse).

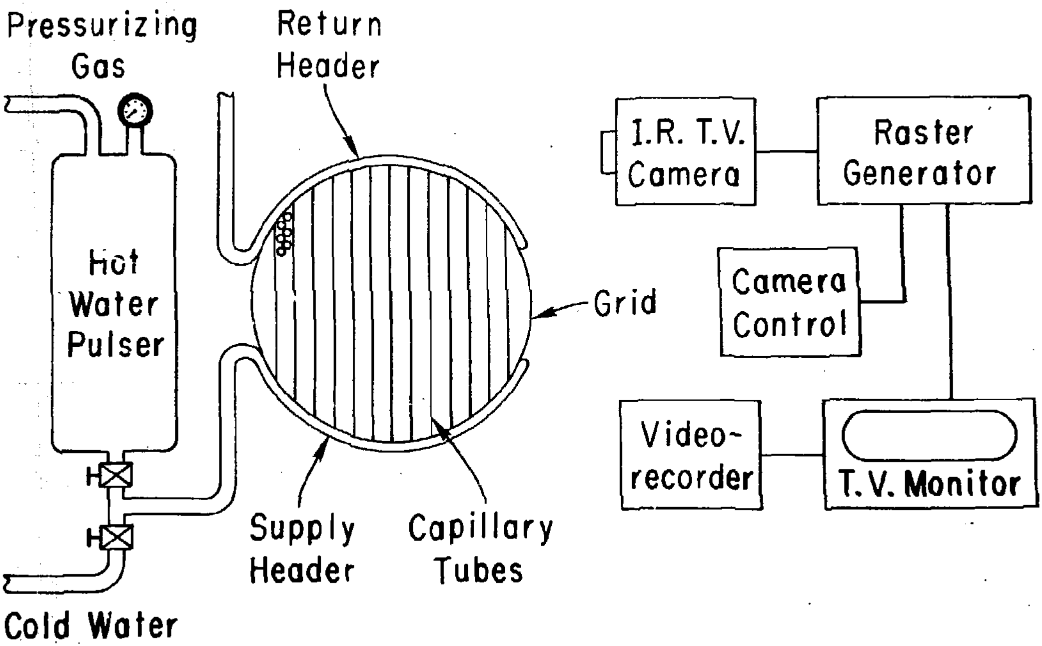

Figure 1. 796232

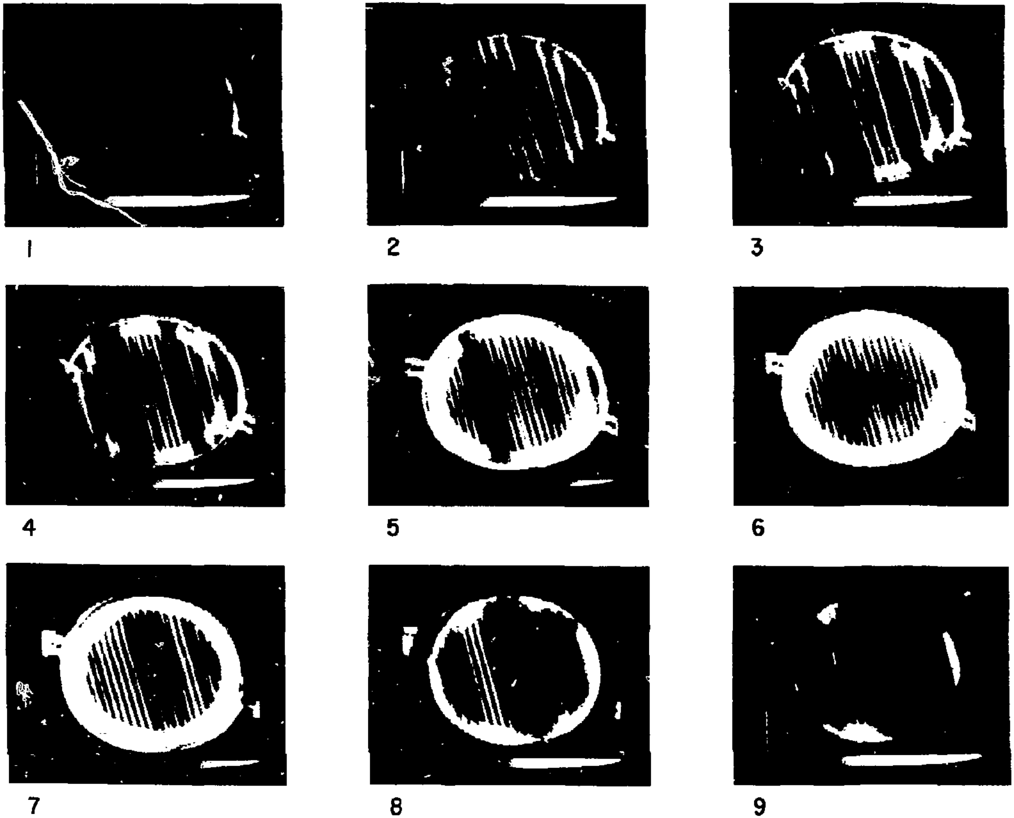

Figure 2

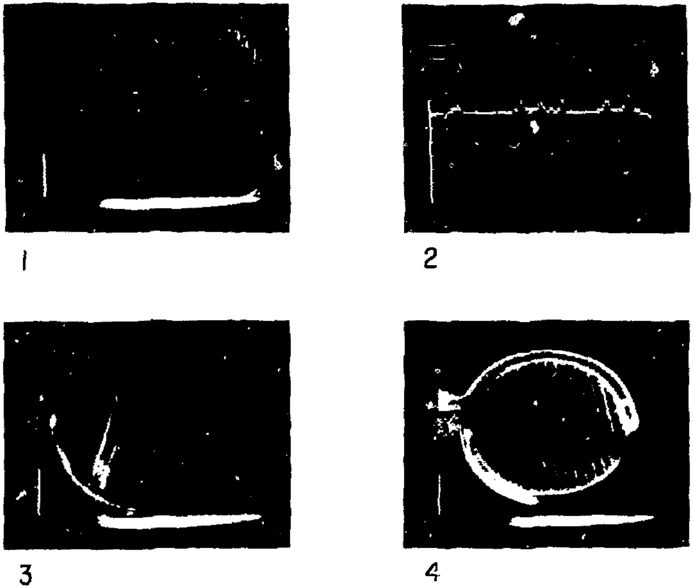

Figure 3

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