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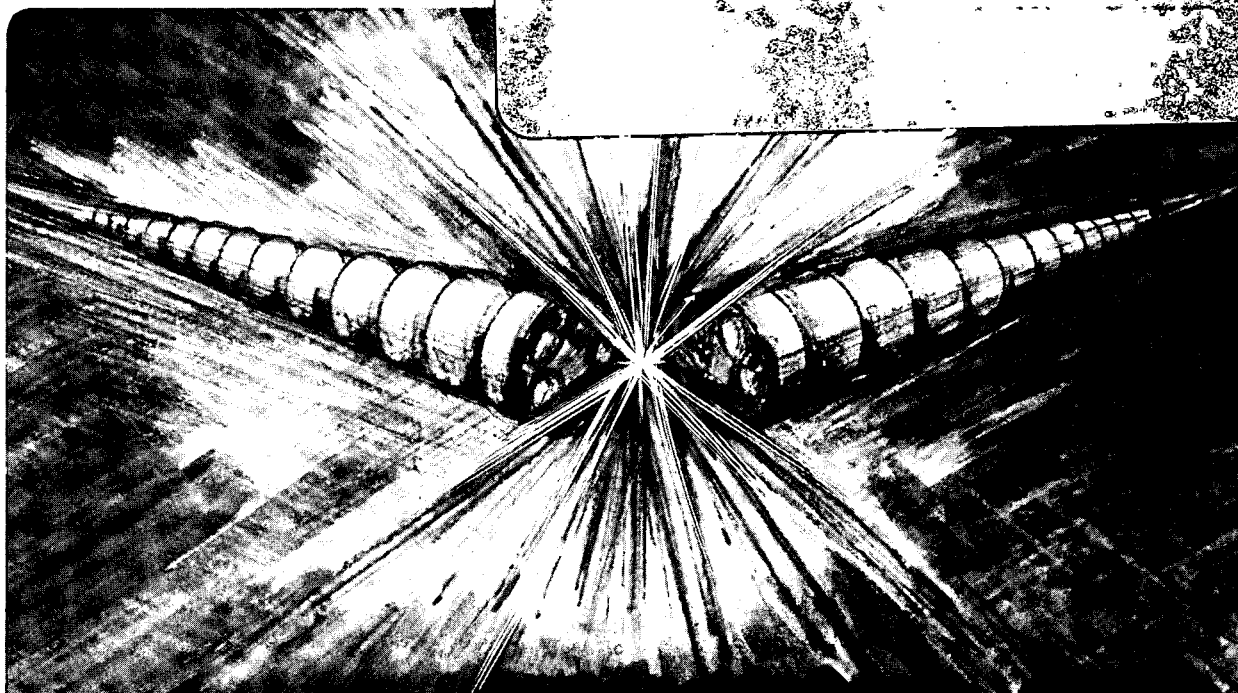
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THE DESIGN AND FABRICATION OF AN ACTIVELY COOLED LANGMUIR PROBE FOR LONG PULSE APPLICATIONS*

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Abstract

The details of the mechanical design and fabrication for a Langmuir Probe for the continuous monitoring of plasma density are given. The probe was designed for use as a diagnostic tool in the development of long pulse positive ion plasma sources for use on neutral beam systems. The essential design feature of this probe is the incorporation of two electrically isolated cooling water circuits which actively cool the probe tip and probe jacket. The electrical isolation is required to prevent drain currents from the probe body disturbing the measurement of the probe tip current and thereby the plasma density measurement. The successful realization of the design requires precision components and vacuum tight ceramic to refractory metal brazes. To date this design has successfully operated in steady-state in plasma densities up to 250 mA/cm² and surface heat fluxes of 25 W/cm².

Introduction

For the development and operation of plasma generators and accelerators used in high power neutral beam systems, it is required that the plasma density in the extraction region be measured to monitor uniformity. The technique typically employed to realize this diagnostic is to measure the drain current from ions collected on a known surface area that is electrically isolated from the generator. As the current densities and pulse lengths for neutral beam systems have increased, the mechanical design of these plasma probes has increased in complexity due to the difficulty encountered in cooling the various plasma exposed surfaces. The difficulty arises primarily from the extremely restricted space available and the need to preserve electrical isolation of the active probe tip from the other components.

Design Requirements

For the operation of the Common Long Pulse Source (CLPS) for the neutral beam systems of TFTR, Doublet III-D and MFTF-B, plasma densities of 250 mA/cm² must be measured for pulse lengths up to 30 sec.¹ For this application, active cooling is required for all plasma exposed surfaces of the probe where heat fluxes of 25 W/cm² must be dissipated. Prior designs which used the thermal inertia of the probe coupled with conductive transport were found to be inadequate for pulse lengths >1 sec at a 1% duty cycle. Our experience with early designs using active cooling indicated that a separate low conductivity cooling water circuit was required for the active probe tip and that it be electrically isolated from all other cooling water circuits and probe components. The electrical isolation is required to prevent drain currents from the probe body disturbing the measurement of the probe tip current and thereby the plasma density measurement. The design that we have used to meet these requirements is shown in section in Figure 1. The essential feature is the use of two separate electrically isolated cooling water circuits,

one for the probe jacket and the other for the probe tip.

Thermal Hydraulic Design

The jacket of the probe is actively cooled by flowing water in the segments formed between the square-section tube and the round stainless steel outer body tube as shown in section B-B, Figure 1. Two segments are used as supply and two as return. To minimize the pressure drop, this circuit is designed to operate in laminar flow with a total flow rate of 6×10^{-6} M³/s. At this flow, the heat transfer coefficient will be 0.5 W/cm² °C, adequate to maintain the jacket temperature below 100 °C for an inlet water temperature of 20 °C, thus precluding the possibility of vapor generation.

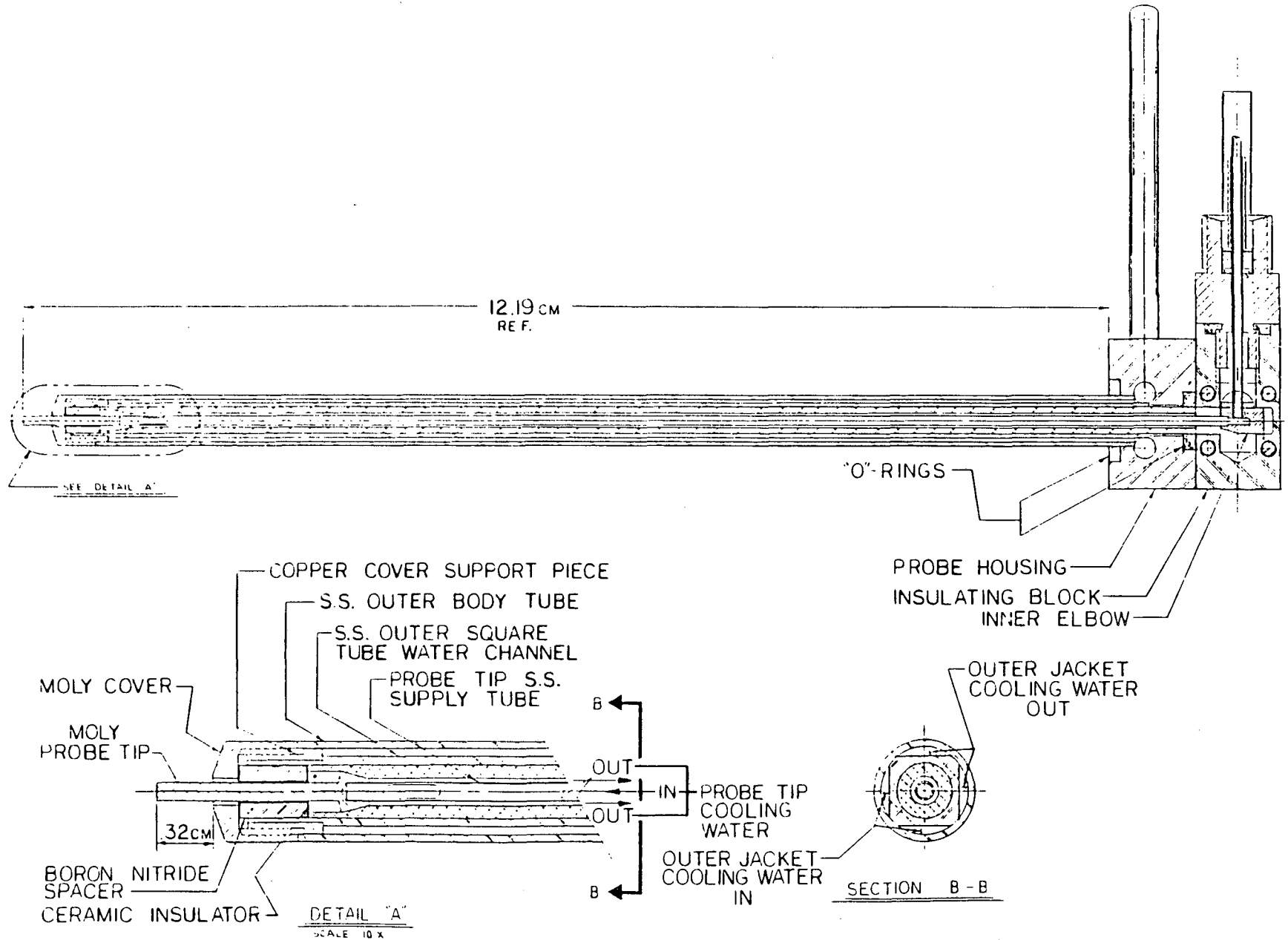
The probe tip has an active area of 0.1 cm² and has been designed to dissipate a total of up to 4 W. The tube that supplies cooling water to the tip is designed to be thermally in contact with the tip to increase the surface area for transport. The energy from the probe tip is conducted along the center cooling tube and is convected to the cooling water flowing by both the inside and the outside surfaces. The design flow of cooling water in the center tube is 1.6×10^{-6} M³/s with a calculated overall pressure drop of 172 kPa.

Fabrication

As shown in Figure 1, the fabrication of the probe assemblies requires the precision machining of several small components for which standard machining practices are employed. The probe assembly is comprised of two major co-axial sub-assemblies, bolted together, and vacuum sealed by an O-ring. The center sub-assembly, which transports the probe signal, consists of the probe tip, ceramic insulator, cooling water supply tube and the rear insulating block. This assembly fits into the probe jacket sub-assembly which is brazed to the probe housing. Central location of the probe tip is maintained by the boron nitride spacer which is retained by the molybdenum cover. The assembly of these units require four separate brazing operations as follows:

1. Furnace braze copper cover support to the outer body and square tube at 970 °C using a 54% Ag, 21% Cu and 25% Pd braze alloy.
2. Outer body and square water channel tube hand brazed to the brass probe housing block using a 63% Ag, 27% Cu and 10% In braze alloy.
3. Furnace braze molybdenum probe tip to the stainless steel inner central tube at 970 °C using a 54% Ag, 21% Cu and 25% Pd braze alloy.
4. Furnace braze the probe tip sub-assembly formed in 3 above to the alumina ceramic tube at 775 °C using a 62.25% Ag, 27% Cu, 9.5% In and 1.25% Ti active braze alloy.

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Figure 1 Probe Assembly

XBL 8511-4668

All the above brazes are required to produce vacuum tight joints.

Experience to Date and Status

The above described probe design has been used as a successful diagnostic for long pulse neutral beam source development at LBL over the past year. Pressure drop and flow data recorded for actual assemblies has verified the design analysis and confirmed the flow and pressure requirements to be well within those available at the plasma generator on the fusion experiments. LBL is presently

fabricating 150 probe assemblies to be used by the major experiments during long pulse neutral beam operation with the Common Long Pulse Source.

Reference

1. J.A. Paterson, C.F. Chan, M.Y. Fong, G.W. Koehler and J.S. Sullivan, "The Mechanical Baseline Design of the Common Long Pulse Source for the Neutral Beam Systems of TFTR, Doublet III-D, and MFTF-B," 11th Symposium on Fusion Engineering, Austin, TX, 1985.

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