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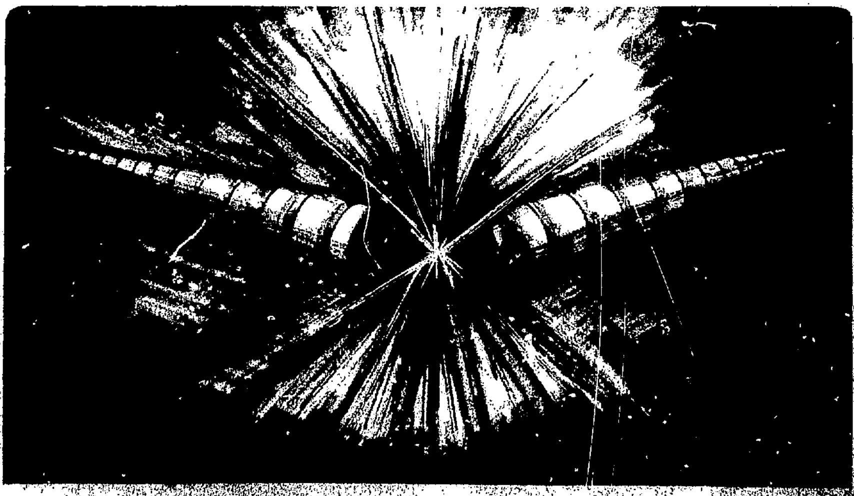

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THE DESIGN OF MULTI-MEGAWATT ACTIVELY COOLED BEAM DUMPS FOR THE NEUTRAL BEAM ENGINEERING TEST FACILITY

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Abstract

The Neutral Beam Engineering Test Facility will test Neutral Beam Sources up to 170 keV, 65 Amps, with 30 second beam-on times. For this application actively cooled beam dumps for both the neutral and ionized particles will be required. The dumps will be able to dissipate a wide range of power density profiles by utilizing a standard modular panel design which is incorporated into a moveable support structure. The thermal hydraulic design of the panels permit the dissipation of 2 kW/cm^2 anywhere on the panel surface. The water requirements of the dumps are optimized by restricting the flow to panel sections where the heat flux falls short of the design value. The mechanical design of the beam-dump structures is described along with tests performed on a prototype panel. The prototype tests were performed on two different panel designs, one manufactured by Mc Donnell Douglas (MDAC) the other by United Technologies (UT). The dissipation capabilities of the panels were tested at the critical regions to verify their use in the beam dump assemblies.

Introduction

Advanced high power long pulse neutral beam test facilities are required in order to carry out the development and qualification of components and systems for confinement experiments that are now in the active planning stage. To meet this need the Neutral Beam System Test Facility (NBSTF) at LBL is being upgraded to the Neutral Beam Engineering Test Facility (NBETF). The facility will satisfy the near term testing needs for the Advanced Positive Ion Source (APIS) up to 170 kV, 65 A and 30 second pulse lengths with a 10% duty factor. Neutral beam sources from both the Oak Ridge National Laboratory and LBL will be tested at the facility and a wide range of reference design beams must be accommodated.

The heat flux levels and the long pulse length have made necessary the use of actively cooled heat absorption panels for the beam dumps rather than the cheaper more reliable inertial designs used in the past.[1] To minimize the total actively cooled surface area, and consequently the overall system cost, we have adopted the concept of using a moveable modular panel design. With this design it will be possible to re-orient the beam dump configurations to accommodate reference design beams of different power density distributions. The positioning of the panels within the existing vacuum vessel permit the heat-flux normal to the panel surfaces to be reduced to 2 kW/cm^2 which is within the limits of presently available technology. To meet the test stand upgrade schedule pre-production prototype modular panels have been designed and built by industry to LBL specifications. Two vendors were selected to participate in this program and the prototype panels are under test on a neutral beam test facility at LBL. The competitive evaluation of the industrial prototypes will be followed by a contract award for production panels that meet the technical specifications and result in the most economical overall system design.

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Actively Cooled Panel Specifications

The actively cooled panel specification was drafted to cover both a pre-production prototype panel, for test and evaluation, and the production panels to be used on the NBETF beam dumps. The prototype was specified so that it would exactly model the section of the production panel that experiences the highest heat load. Both participating vendors selected a production panel design that utilized a modular subpanel assembly to realize a production unit. As a result the preproduction prototype panels delivered for test were exact duplicates of the proposed production subpanel units. This eliminates the need to make difficult extrapolations of the prototype test results to the production units.

Incorporated into the panel specification were four major considerations. These were, the available industrial capabilities, the physical dimension constraints of the existing vacuum vessels, the power density distributions of the reference beams and the total overall system cost including the required cooling water system.

Physical Dimension Constraints

The available space for the beam dumps in the existing vacuum vessels impose a practical limit on the physical dimensions of the panels. Consistent with this, and the concept of an adjustable modular dump design, a panel envelope was specified as shown in Fig. 1. Region L is the leading edge of the panel which is shaded from particle impingement by its upstream panel neighbor and thus has zero heat flux

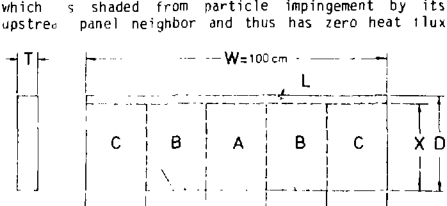

Figure 1: Production Panel Envelope

on the surface. Regions A, B, and C are the irradiated areas of the panel over which it was specified that it be possible to perform individual water flow calorimetry. As both vendors chose an assembly of five subpanels as the design for a production unit each of these regions is covered by a single subpanel. The width of the panel, dimension D, was a design option available to each vendor. For the MDAC design this dimension was nominally 22 cm, and for UT 32 cm, the corresponding dimension X was 20.5 cm and 30.5 cm respectively. The envelope thickness T was specified as 2.5 cm.

Heat Flux

Three design maximum heat flux options were specified at 2, 3 and 4 kW/cm^2. Both vendors selected the more conservative 2 kW/cm^2 for their design which is specified to dissipate this energy density anywhere or everywhere over the subpanel surface. The anticipated heat flux distributions include a continuous range varying from uniform to highly peaked non-uniform profiles. A non-uniform heat flux may result in three dimensional thermal stresses which significantly exceed those resulting from the temperature gradient normal to the panel surface. Consideration of this in the design was requested by providing the vendors with an example of a severely non-uniform heat flux distribution profile for a panel subsection. Particle divergence and panel misalignment result in energy deposition on the panel edge faces at the gap between adjacent subpanels in a production panel assembly. The heat flux in these regions was estimated as the simple projection of the beam power density to these surfaces. It was additionally specified that no shine through of the beam between adjacent subpanels be possible. The MDAC design achieved this by providing an overlapping tab at the joint and UT by raking the panel edge.

Lifetime

The design lifetime is specified at 25,000 thermal cycles. During operation the surface material of the panels will be sputtered away changing the thermal stresses with time. This effect is taken into consideration by incorporating a surface loss allowance into the design calculations. The MDAC Amzirc panel has a loss allowance of 0.73 mm and the UT TZM panel one of 0.10 mm. These figures represent the estimated material loss over the panel lifetime the 2 kW/cm^2 heat flux level. As many of the panel subsections operate at reduced levels the useful lifetime of the panels can be increased by a maintenance schedule that provides for subpanel relocation.

Total System Cost

A significant cost element of systems that use actively cooled beam dumps is the cost of the supporting cooling water system. Our specification was written to include the cost impact of this major item into the design of the panels. Cost estimates for water systems were prepared that covered the anticipated range of operating parameters. This information was given to the vendors, and, combined with a table giving typical operating dissipation requirements at the dumps panel subsections, enables the total system cost impact to be estimated. The final selection of the production panel is to be based on the design that results in the lowest overall system cost and meets the technical requirements of the specification.

Beam Dumps Design

The NBETF ion dump assembly is shown in Fig. 2. Each panel is an assembly of five subpanels which is supported by a manipulator arm as shown in Fig. 3. Each manipulator rides on a rigid structural framework and provides three degrees of freedom for individual panel positioning. Cooling water is provided to the panel subsections through common supply and discharge manifolding. This manifolding also serves as the basic support structure for the panel subassemblies. The panel subpanels are plumbed in parallel and to minimize the total water requirements the flow to the outer subpanels is reduced where possible using calibrated orifices at the outlet fittings. Water flow calorimetry to each subpanel is possible using thermocouples located in the outlet fittings. Three DC pancake motors are used on each manipulator arm to permit remote position control of the panels, and three potentio-

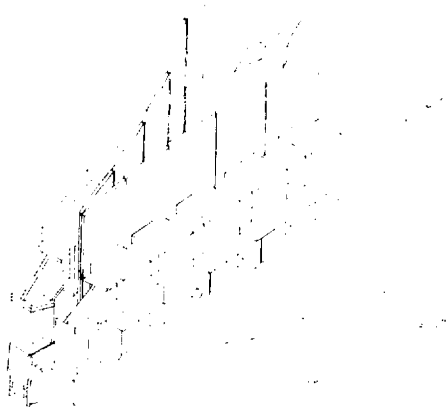

Figure 2: NBETF Ion Dump

meters will encode the motions. To evaluate the operation of the manipulator arms a full scale prototype is being fabricated. This prototype will be tested before the final detail design of the dumps is frozen. All parts will be cleaned prior to vacuum service and all organic lubricants removed. Those surfaces requiring lubrication will be subjected to a molybdenum disulphide treatment followed by a vacuum bake-out. This process has been used in similar applications successfully in the past. The flexible lines supplying cooling water to the manifolds will jacketed with a metal bellows welded in place.

As the beam dumps are to operate in a cryopumped vessel the interruption of cooling water flow to the panels could result in the freezing of the stagnant water with the consequent rupture of the panels or manifolding. Under normal operation the panels will be supplied with a reduced water flow. The cool-down of the dumps subsequent to a flow interruption will be slowed by the use of insulation, this will maximize the time for remedial action which will include the draining and gas blow-down of all the lines and the panels.

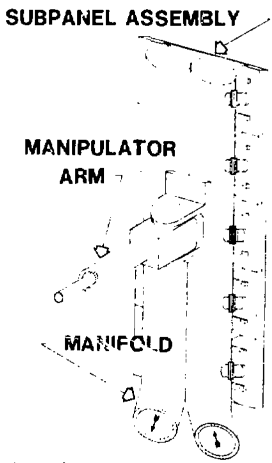

Figure 3

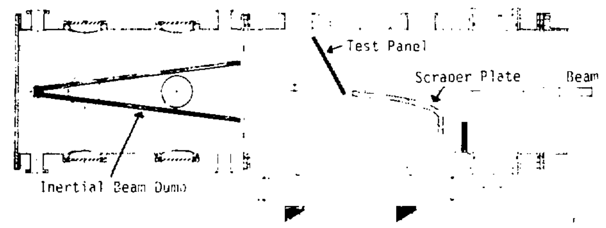

Figure 4: Prototype Panel Test

Preproduction Prototype Panel Tests

Test Stand Equipment

The industrial preproduction prototype panels are under evaluation and test on a neutral beam test stand. A layout showing the location of the test panel, upstream scraper plate and inertial beamstop is shown in Fig. 4. The test panel is located at 7.5 m from the neutral beam accelerator, it can be moved across the beam and also rotated to any angle between 0 and 90 degrees to the beam direction. The upstream scraper panel can move across the beamline independently of the test panel and is used to protect the panel leading edge thus simulating the shadowing of this region that will be present in the NBETF dumps. The scraper also serves to protect the water lines and actuator mechanism of the test panel and can be used to vary the area irradiated by the beam. Both test panel and scraper plate can be fully retracted out of the beam which is then deposited on the inertial beam dump of the test stand. The beam dump has been described previously.[1] The high pressure flexible water lines to the test panel were fabricated from a reinforced teflon hose jacketed by a welded-in stainless steel bellows. This is a design we are evaluating for use on the NBETF dumps. Cold junction compensated thermocouples are located in the water line fittings and these combined with water flow measurement permit water flow calorimetry on the test panels. The MDAC panel requires 3.7 l/s of cooling water at 1.5 MPa and the UT panel 7.4 l/s at 4.14 MPa. For testing these panels we have designed and built a pulsed water system, this equipment is described elsewhere[2]. Due to the late delivery of the pump needed for the pulsed system the MDAC panel was tested using a continuously pumped water supply. The changeover to the pulsed system was made on arrival of the pump and tests on the UT panel are continuing with this supply. The panels are being tested using a 1 MW mixed neutral and ion hydrogen beam with a peak power density of 3 kW/cm^2 at the test panel location. At this time the panels are still under evaluation and a report covering the detailed procedures and results will be published at a later date.

Test Procedures

With the test panel and scraper plate fully retracted from the beam, the beam parameters are established using the measured temperature distribution on the inertial beam dump. The power density distribution at the test panel location is then analytically predicted. A narrow strip of the test panel is irradiated on the beam center line and the measured energy deposited is used to normalize the center line beam profile. Thermocouples located at the trailing edge of the scraper plate are used to measure the heat flux in this region and serve as a consistency check with the calorimetry. This procedure is used to establish the maximum beam power density incident on the test panel.

Maximum Heat Flux Tests

The panel is oriented to the beam so as to reduce the peak heat flux normal to the surface to 2 kW/cm^2 at any point. The panel position can then be adjusted to subject the panel to this energy density at different locations. Tests on each panel are then carried out with the location of the peak heat flux at the panels' trailing edge, leading edge, and center. At each position approximately 200, 0.5 second beam shots are absorbed for a total of about 600 thermal cycles. Average power density dissipation over the entire panel surface ranged from 0.75 kW/cm^2 to 1.2 kW/cm^2 during these tests.

Figure 5: MDAC Panel on Test Equipment

Reduced Heat Flux Test

It is recognized that many of the subpanels will operate at conditions which fall short of the 2 kW/cm^2 design value. The total system water requirements will be minimized by installing orifices at the outlet fittings of these subpanels to reduce the flow. The vendors were requested to supply panel performance data that would permit the setting of the operating parameters under reduced heat load conditions. These parameters were used to set the conditions for a reduced heat load test which for the MDAC panel was chosen as a peak flux of 1.25 kW/cm^2. At this reduced level it was possible to position the panel so that 1.25 kW/cm^2 could be deposited in the entire central panel flow path. To meet the vendors required conditions with 10 cm of the panel exposed, water inlet temperature of 38°C and a panel exit water pressure of 0.76 MPa, the flow rate was set at 1.04 l/s. The panel was then subjected to 40 beam pulses with shot lengths that varied from 0.38 to 0.69 seconds. The shot length had no effect on the measured absorbed power indicating adequate thermal time response of the instrumentation.

Elevated Temperature Test

It will only be possible to subject the panels to a uniform heat flux of 2 kW/cm^2 over the entire surface on the NBETF. The power density distribution of the test beam precluded this condition. To reproduce the most severe thermal hydraulic conditions that will be present at the exit region of the central panel flow path the MDAC panel was tested with an elevated water inlet temperature of 55°C. The test was conducted with the following conditions at the exit region.

Bulk water temperature	= 101°C
Water pressure	= 0.83 MPa
Power density at panel surface	= 2 kW/cm^2
Total Water Flowrate	= 3.7 l/s

A total of 14 0.5 second beam pulses were put on the panel under the above conditions with an average power dissipation of 1.1 kW/cm^2 over the entire panel surface.

Lifetime Tests

Four months of test stand operation have been scheduled to achieve approximately 1200 full power beam pulses suitable for the test panel evaluations. The design specification calls for a 25,000 shot panel design lifetime and thus the practical problems of a full size panel lifetime test are obvious. In collaboration with the vendors we have investigated the possibility of conducting small sample coupon lifetime tests on an existing electron beam facility. Both vendors had reservations as to the applicability of these sample tests to actual lifetimes of our production panels. Uncertainties generated by a variance in boundary conditions and panel local restraint would require a significant analytical effort be applied to the results for extrapolation to the production units. The level of confidence in the accuracy of this approach would still be low, particularly if only a single coupon were tested in each case. The preparations necessary for coupon tests would require a significant effort at LBL and this combined with the lead time for coupon fabrication was not consistent with the NBETF schedule. The technical uncertainties and the above considerations resulted in our decision not to pursue coupon testing as part of our prototype evaluation program.

Discussion

Preliminary measurements of power densities on ion dumps have indicated levels that are 50% higher than those predicted by ion-trajectory calculations. This preliminary result would suggest that our decision to design the NBETF dump systems to be adjustable, because of the wide range of beam parameters to be accommodated, has the secondary or possibly more important benefit of insurance against such errors of prediction. Possibilities of operating high power beam dumps in the single phase flow regime may permit the use of acoustic emission sensing of boiling incipience as a useful protection diagnostic.[3] The use of inertial beamstops operated at short pulse durations can be used to characterize beam parameters prior to subjecting the active dumps to long pulses. For NBETF this technique can be used for the neutral dump, however because of space limitations, is more difficult to apply at the ion dump. Additionally, in the region of the ion dump the power densities are changing comparatively rapidly with position. This makes extrapolations from an inertial dump location to the active surfaces more questionable when accurate trajectories are not known.

The NBETF program is directed towards the timely realization of an advanced test stand for neutral beam development. For this reason considerations that might be important for fusion experiments, such as the use of material with low atomic number, have not been incorporated into our specifications or beam dump development program. It is expected however that the resulting test stand will make significant contributions to the development of high heat flux surfaces suitable for fusion applications.

Acknowledgements

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