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Bolometer Studies in CHS

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Abstract

A four channel bolometer head was mounted on CHS and used to investigate the effectiveness of wire mesh in blocking unabsorbed microwaves which can produce spurious signals on the bolometer sensors. The 50 mesh per inch, 20 micron diameter tungsten wire mesh was effective in blocking 70% of the 53 GHz signal and 50% of the 106 GHz signal. When an additional mesh was added at a separation of 1.4 mm ($\lambda/4$ for 53 GHz and $\lambda/2$ for 106 GHz) the 53 GHz signal was reduced by more than a factor of 10 and the 106 GHz signal was reduced by an additional 70% compared to the single mesh case. Experiments from CHS show that radiation reflected off the wall is at power levels which are 6% of the power seen on the peak central chord. Experiments on CHS in a neutral beam heated plasma with a three chord bolometer show that hollow radiation profiles during gas puffing become more peaked after the puff is turned off. As the injection angle of the neutral beam is varied from r_t=80 cm to 87 cm to 94 cm this transition becomes more pronounced and extends beyond the termination of the gas puff.

Keywords:
bolometer, electron cyclotron heating, neutral beam heating, stellarator, microwave, gas puffing

1. Introduction

During ECH in magnetic fusion devices the effect of unabsorbed microwave power on bolometer signals is an important issue. In W7AS observations have indicated that some portion of the bolometer signal may be due to unabsorbed microwave power. In that experiment wire mesh was successfully used to shield the microwave power [1]. The use of wire mesh or grids to block microwave power is also an important issue for the protection of vacuum windows and viton seals on gate valves and other flanges during long pulse operation in the Large Helical Device[2]. For these reasons we have embarked on a study of the effectiveness of using woven wire mesh and electroformed grid to block unabsorbed microwave power.

Additionally, experiments have been carried out with an eight channel bolometer array on the Compact Helical System (CHS) [3] viewing a plasma heated by neutral beams. These experiments investigate the effects of gas puffing and neutral beam injection angle on the edge radiation.

2. Mesh for Shielding Microwave Radiation

Experiments have been carried out in order to investigate the effects of wire mesh and electroformed grid in blocking microwave power from bolometer sensors. The detectors being used are 4 μm gold foil bolometers [4]. The mesh used in these experiments was a 50/inch woven tungsten wire mesh with a diameter of 20 microns and an optical transmission of 0.923 as calculated from the mesh dimensions.

The experiments involved mounting a single bolometer on a flange viewing CHS through a 1 cm diameter pinhole. The flange was repeatedly removed and the number of mesh and their spacing was changed. For each mesh configuration 53 GHz and 106

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Table 1 Results from experiments using mesh to shield microwave radiation. The ratios given in columns (b) and (d) represent the experimentally derived power transmission for a single mesh given by the ratio of the bolometer signal for n mesh and the signal for n-1 mesh. Bolometer signals are normalized to the nominal input microwave power. These can be compared with the theoretical values given in the last row which are derived from Eq. (1).

	f (GHz)			
	53		106	
	(a)	(b)	(c)	(d)
n	V/P_{in}	$\frac{V/P_{in}[n]}{V/P_{in}[n-1]}$	V/P_{in}	$\frac{V/P_{in}[n]}{V/P_{in}[n-1]}$
(mesh layers)	$(\mu V/MW)$		$(\mu V/MW)$	
0	1170		285	
1	360	0.31	150	0.53
2 (spacing)	$< 5(\lambda/4)$	< 0.02	$42.5(\lambda/2)$	0.28
T_{theory}		0.14		0.56

GHz gyrotrons were operated in turn for 10 ms without plasma and the resulting bolometer waveform was recorded. The resulting signal amplitude normalized to the nominal output power of the gyrotron is shown in Table 1.

A theoretical prediction for the power transmission, T, of a woven wire mesh is given by[5]:

$$T \simeq \left(\frac{2g}{\lambda}\ln\frac{g}{2\pi a}\right)^2 \tag{1}$$

where g is the wire spacing and a is the wire radius. Even though the pulse length is much shorter than the thermal time of the bolometer (~ 110 ms), we can compare these values with the theoretical prediction of the power transmission since we have seen in calibration experiments with a Helium-Neon Laser that for a 20 ms pulse length the bolometer signal is proportional to the incident power from a constant power source.

In general the mesh is more effective in shielding the longer wavelength signal as expected. Comparison with theory shows that for a single mesh the 106 GHz result is in better agreement than the 53 GHz result. In the case of a double layer of mesh, the effectiveness of the $\lambda/4$ spacing between the mesh layers is due to the destructive interference predicted by theory[6]. Regarding the results of the $\lambda/2$ spacing, it is difficult to compare them with the theory as the predicted power transmission is a very strong function of spacing for a separation near $\lambda/2$.

3. Eight Channel Bolometer Array

An eight-channel metal-foil-bolometer array was recently installed on CHS in the configuration shown in

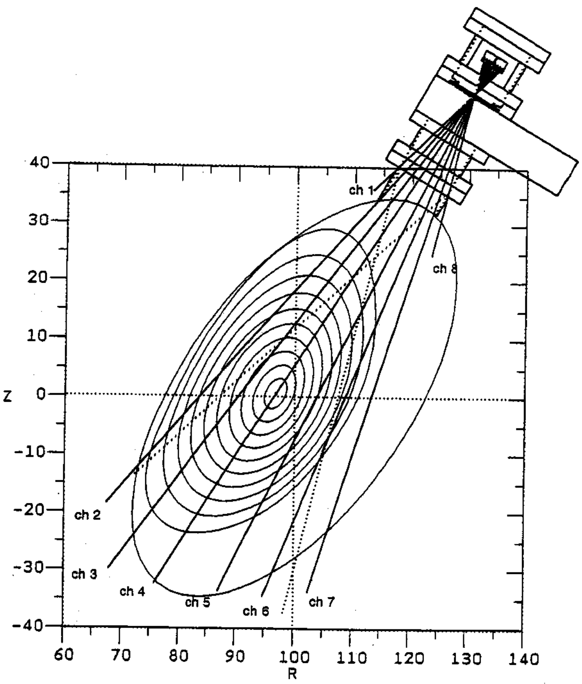

Fig. 1 Physical arrangement of bolometer sensors and pinhole, with viewing chords and magnetic flux surfaces for CHS Port 8-P. The average β is taken to be 0.2% and the magnetic axis is located at 94.9 cm.

Figure 1. The metal foil bolometers were of the same type mentioned above. In this case an electroformed copper grid (produced by Buckbee-Mears Inc., St. Paul, U.S.A.) with a spacing of 70 lines/inch, a thickness of 5 μm and a transparency of 90% is used to block the microwaves by using it to cover the 4.6 mm diameter pinhole. The time resolution of the bolometers is determined by the 200 Hz filter applied to the amplitude modulated signal in the amplifier. Samples of the signals from the amplifier outputs of four channels are shown in Figure 2(a). The power detected by the bolometer, P_{rad}, which is shown in Figure 2(b), is then given by[4]

$$P_{rad} = \frac{1}{K}\left(V + \tau\frac{dV}{dt}\right) \tag{2}$$

where V is the bolometer signal in Volts. The calibration factor, K, and the thermal time of the bolometers, τ, were determined through calibration with a chopped helium-neon laser. Their values are on the order of 12 V/W and 0.15 s respectively. The derivative in Equation 2 is taken using a 3 point Lagrangian interpolation. The resulting power resolution is on the order of 2 μW or 30 $\mu W/cm^2$.

A few general comments should be made about the bolometer data. Regarding the bolometer chord

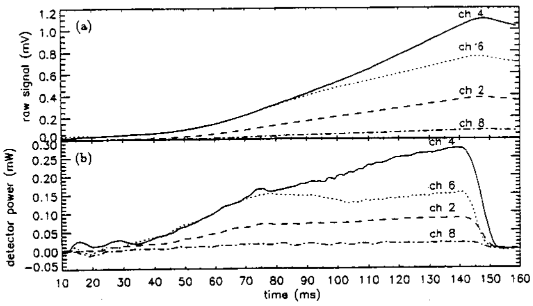

Fig. 2 Sample (a) amplifier output and (b) calculated detector power versus time for four channels of bolometer signals from shot #66515.

paths, looking at Figure 1 one notes that the chords for channels 1 and 8 intersect the wall of the port. This was done intentionaly to observe the amount of radiation that is reflected off the walls of the machine. In this case the detected power is approximately 6% of the peak signal seen on the central chord of channel 4. From Figure 1 one can see that the views for channels 2 and 7 are partially occluded, which is also evident from the low signal levels seen for channel 2 in Fig. 2. Channel 3 has a signal level similar to channel 2 although one would expect it to be even higher. This may be due to some partial blocking of this chord also by the port tube, therefore we will limit the following discussion to channels 4, 5 and 6. These three channels nicely cover a minor radius having approximate tangency radii of $\rho_t = 0$, 0.5 and 0.85 respectively.

4. Effects of Gas Puffing on Edge Radiation

Experiments were carried out with deuterium gas in an ECH (~ 200 kW at 53 GHz) produced plasma at a field of 0.9 Tesla. The neutral beam power was ~ 700 kW with a beam energy of 31 keV. In Fig. 3 an example of the time traces of various heating sources and standard diagnostics for the experiments discussed below are shown. In the gas puffing experiments the duration and amplitude of the gas puff is increased on a shot-by-shot basis. In Fig. 4 three contour plots of the detected power versus channel number and time are shown for a gas puff duration of 0, 30 and 60 ms. Looking at channels 4 through 6, one notes that as the gas puff duration increases, the radiation levels on all channels increase. In particular, during the gas puff period, channels 4 through 6 have nearly the same level indicating a hollow radiation profile, but after the gas puffing is stopped the signal in channel 4 increases and the signal in channel 6 decreases, indicating a radiation profile which is becoming more peaked.

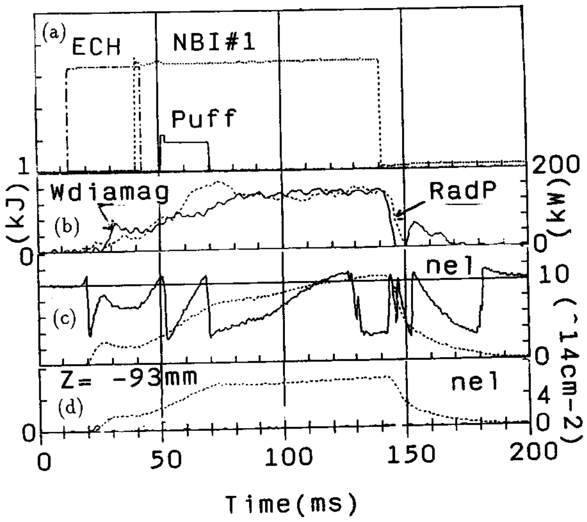

Fig. 3 Sample time traces of (a) heating sources, gas puff, (b) stored energy and radiated power, (c) central chord interferometer and (d) edge chord interferometer for CHS shot #66515.

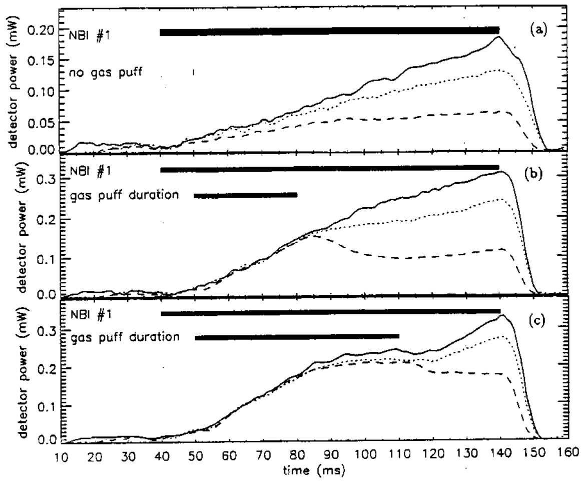

Fig. 4 Bolometer power versus time for Channels 4–6 (top to bottom) with gas puff durations of (a) 0 ms (shot #66518), (b) 30 ms (shot #66519) and (c) 60 ms (shot #66521).

5. Effects of Beam Angle on Edge Radiation

In a second series of shots the gas puff was held constant at a duration of 20 ms and the neutral beam angle was changed on a shot-by-shot basis from the standard case with a radius of tangency, R_t, of 87 cm to 80 cm and 94 cm. The results are shown in Fig. 5. As the beam moves from a more inboard postion to a more outboard position the time it takes for the radiation to go from the more hollow state to the more

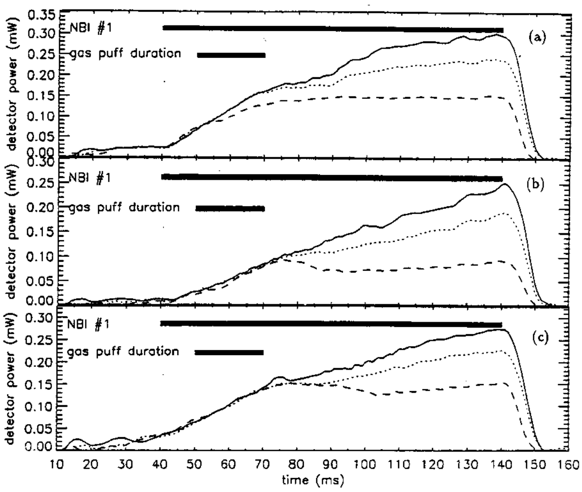

Fig. 5 Bolometer power versus time for Channels 4–6 (top to bottom) with R_t of (a) 80 cm (shot #66512), (b) 87 cm (shot #66516) and (c) 94 cm (shot #66515).

peaked state is delayed as indicated by the timing of the dip in the signal from channel 6.

6. Conclusion

Results from section 2 indicate that wire mesh can be used effectively to block microwave signals. A double layer of mesh with a spacing of $\lambda/4$ has an increased effectiveness due to the destructive interference of the microwave signals.

Experiments on CHS have shown an increase in edge radiaton during gas puffing with the profiles becoming more peaked after the gas puff is turned off. This is due to the increase in the density at the edge during the puff and the subsequent decrease in the density after the gas puff was stopped which was observed simultaneously from the interferometer data.

Moving the neutral beam from the inboard side to the outboard side was seen to increase the time that it took for the hollow radiation profile to become more peaked after the gas puff was discontinued. A similar delay in the the decrease of the interferometer data was not seen indicating that this phenomena is not related to a change in the edge density.

References

[1] L. Gianonne *et al.*, Rev. Sci. Instrum. **68**, 762 (1997).

[2] O. Motojima *et al., Fusion Eng. Design* **20**, 3 (1993).

[3] K. Nishimura *et al., Fusion Technology* **17**, 86 (1990).

[4] F. Mast *et al.*, Rev. Sci. Instrum. **62**, 744 (1991).

[5] K. Sakai and L. Genzel, *Reviews of Infrared and Millimeter Waves*, Vol.1, ed. by Kenneth J. Button, Plenum Press, 155 (1983).

[6] R. Ulrich *et al.*, Appl. Optics **9**, 2511 (1970).