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THERMAL MEASUREMENTS ON A RF 11,4 GHz ACCELERATING STRUCTURE

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Abstract

An experimental study on the temperature distribution of a 11.4 GHz accelerating structure due to R.F. power has been done.
The temperature distribution on the structure at full R.F. power has previously been computed with code ANSYS by imposing the power distribution on the inner surface as obtained with code SUPERFISH. The resulting temperature difference ΔT gives a resonant frequency shift of the structure electromagnetic modes that must be taken into account.
The main concern of this work is to design and realize a copper prototype structure dedicated to measuring ΔT and then to compare it with the numerical computation results.
This procedure based on a proper geometry for measuring the iris temperature, can be adopted in the future for irises made of different materials.

Introduction

For maximizing the electron beam brightness of the SPARC [1] project, the use of a higher harmonic accelerating structure is required [2]. The electromagnetic characterization at room temperature of a compact standing wave accelerating structure, constituted by 9 cells and operating at a frequency f=11.4 GHz, has been completed [3,4]. Cooling is necessary because in standard operating conditions the power dissipated on the walls of a 9 cells structure will be about 300W.
In order to get additional and detailed thermal information on the behavior of the accelerating section as a function of the copper temperature, the SALAF group at Frascati laboratory realized a brazed copper five cells prototype working in pi mode and carried out an experimental thermal activity too. In figure 1 the structure is shown. By means of a water cooling system made with four copper tubes, parallel to the axis, in contact with the outer surface, connected in serial mode, the external temperature can be taken under control. The maximum inner temperature will be obviously on the iris. Numerical analysis has been done in order to evaluate the temperature difference between iris and mantle [5]. This paper presents results related to experimental measurements of this temperature difference. These results will be then compared to those coming from numerical computation.
The equilibrium average temperature as well as its distribution must be known since they can modify the cells dimensions and therefore the resonant frequency of the electromagnetic modes.
Regarding the R.F. power, its distribution on the inner surface as computed shows the highest value of power density at the base of iris [see ref. 5]. A very rough simulation of this distribution can be obtained by inserting a tube shaped heater centred on the axis of the structure. As it can be seen in figure 2, the heater has the same effective length as the structure and a diameter of 6mm (diameter of the irises is 8mm). A proper shield reduces the heat losses between the inside of the structure and the air. For the same reason an external shield is mounted on the outside of the structure in order to reduce heat losses by convection.

Brazing procedure

In order to obtain a structure with good electromagnetic behaviour, particular care must be taken for the joining of the cells, and brazing procedure has been realized using a vacuum clean oven located in the area of the D.A. Vacuum group. The material used for the realization of the accelerating structure prototype is OF Cu. The structure is obtained by joining together single cells using vacuum brazing technique. The vacuum inside the oven is realized by means of a dry piston pump and an oil free turbo molecular pump. The brazing pressure is roughly 10^{-5} mbar and the brazing alloy used is eutectic Ag/Cu 0.6 mm wire whose melting point is 780°C. Further information is available in reference [6].

Experimental set up and results

The experimental set up can be seen in figure 3. In order to get an acceptable measure of the iris temperature a 1 mm diameter hole was drilled from the outside down to the inner side of iris. Two K-thermocouples (Chromel-Alumel) are used, one very thin thermocouple was introduced down to the end of hole where a contact is obtained between the head of the thermocouple and the copper (see figure 1). The mantle temperature is obtained simply fixing another thermocouple on the external surface of the structure, near the hole of insertion of the former in order to measure transversal ΔT between iris and external surface of the copper. Two additional K-thermocouples are applied on the water inlet-outlet, in order to measure the power flux.

By introducing a thermal shield, in order to minimize the power dissipated in air by convection, at equilibrium we expect that the electrical power supplied by the heater is entirely dissipated by the water. We have performed several experiments at different power levels and by varying the inlet temperature of the water at constant flux. The equilibrium copper temperature is recorded in order to measure ΔT between iris and external surface of the structure. The temperature of the iris has been acquired by means of a system controlled by LABVIEW software. The graphs are shown in the following figures.

The temperature of the iris as a function of time can be derived from the general Fourier equation as follows :

$$T = T_0 + T_{eq}(1 + e^{-t/\tau})$$

where T_0 is the initial temperature of the system, $T_0 + T_{eq}$ the final temperature of the iris and τ the total time constant of the structure.

In figure 3 the plot of iris temperature is shown, with 60W heating power, water inlet temperature 20 °C, and water flux 50 l/h.
At equilibrium the water: flux $\dot{m}$=50 l/h ≈14g/sec, the temperature difference between out and in ΔT (measured)=1K, mean specific heat C_s=4,20 $Jg^{-1}K^{-1}$. It follows $\dot{Q} = \dot{m}C_s\Delta T$ ≈58.8 W, against 60 W electric power. Temperature of external surface of the copper is T=(25.3 ±0.1)°C, therefore ΔT is about 1°C.
By increasing power to P=100W with the same values for the cooling parameters, the plot of figure 4 is obtained.
At steady state we obtain $\dot{Q}$≈94.1W against 100W electric power. Temperature of external surface of the copper is T=(29.5 ±0.1)°C, therefore ΔT is about 2 °C.
Figure 5 shown the iris temperature with P=150W; now $\dot{Q}$≈142 W against 150W and temperature of external surface of the copper is T=(31.5 ±0.1)°C, therefore the measured ΔT is about 4 °C.
In figure 6, ΔT between iris and copper, as a function of the power applied to the structure is plotted.
By increasing the temperature of the water inlet to 30 °C, the same experiments are performed; the graphs in figures 7,8,9 with 50W,100W and 150W with the same water flux of 50 l/h are obtained.
At equilibrium, the temperature of the copper is T=(32.7 ±0.1)°C, in the case of 50 W, T=(39.7±0.1)°C in the case of 100W and T=(43.6 ±0.1)°C in the case of 150W.
We obtain the same ΔT between iris and copper obtained in the first experiments.
By increasing temperature of water inlet at 40 °C, with P=150 W, the graph in figure 10 is obtained, the temperature of external surface of the copper is T=(55.8 ±0.1)°C.

Conclusion

With these experiments we have verified that, by increasing the heating power at constant water flux, the equilibrium temperature variations on the external mantle surface are less than 2 degrees, in agreement with computations. The equilibrium temperature between iris and mantle increases by about 2 degrees per 100 W. This temperature difference is practically independent of the inlet water temperature and is higher than the computed one by a factor about 2. This could be due to the difference between the power distributions applied on the inner surface of the structure in the experiment and in the computation. Anyway the maximum power density is applied to the irises in both cases [3,5].
The variation of the structure average temperature changes the resonance frequency according the relation $\Delta f/f=-\alpha$ where α is the thermal expansion coefficient. For Copper α = 17.6 10^{-6} / ^{0}C. Therefore the detuning of resonant frequency of cavities is in the order of f = - 200 KHz / ^{0}C. Anyway the average temperature can be well controlled by the cooling system. On the contrary, as shown, transverse gradients are insensitive to the cooling water temperature. Some computations have shown that the resonant frequency sensitivity of the structure to iris diameter changes is in the order of 0.4 MHz/micron [3]. Therefore the relevant variation of the iris to body temperature has to be considered attentively. An indication could be that the RF power and cooling parameters should be kept as constant as possible in operation. However detailed computations on this effect are in progress.

References

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Figure captions

Fig 1 The design of a resonant multicell structures at 11,4 GHz.

Fig 2 Particular of the heater inside the multicell structures at 11,4 GHz .

Fig 3 The experimental set up for thermal tests.

Fig 4 The iris temperature as a function of the time, data taken every 10 seconds P=60W
$T_{H_2O_{in}}$ = 20 °C .

Fig 5 The iris temperature as a function of the time, data taken every 10 seconds P=100W
$T_{H_2O_{in}}$ =20 °C.

Fig 6 The iris temperature as a function of the time, data taken every 10 seconds P=150W
$T_{H_2O_{in}}$ = 20 °C.

Fig 7 The temperature difference between iris and external surface as a function of the applied power.

Fig 8 The iris temperature as a function of the time, data taken every 2 seconds P=50W
$T_{H_2O_{in}}$ = 30 °C.

Fig 9 The iris temperature as a function of the time, data taken every 2 seconds P=100W
$T_{H_2O_{in}}$ = 30 °C.

Fig 10 The iris temperature as a function of the time, data taken every 2 seconds P=150W
$T_{H_2O_{in}}$ = 30 °C.

Fig 11 The iris temperature as a function of the time, data taken every 2 seconds P=150W
$T_{H_2O_{in}}$ = 40 °C.

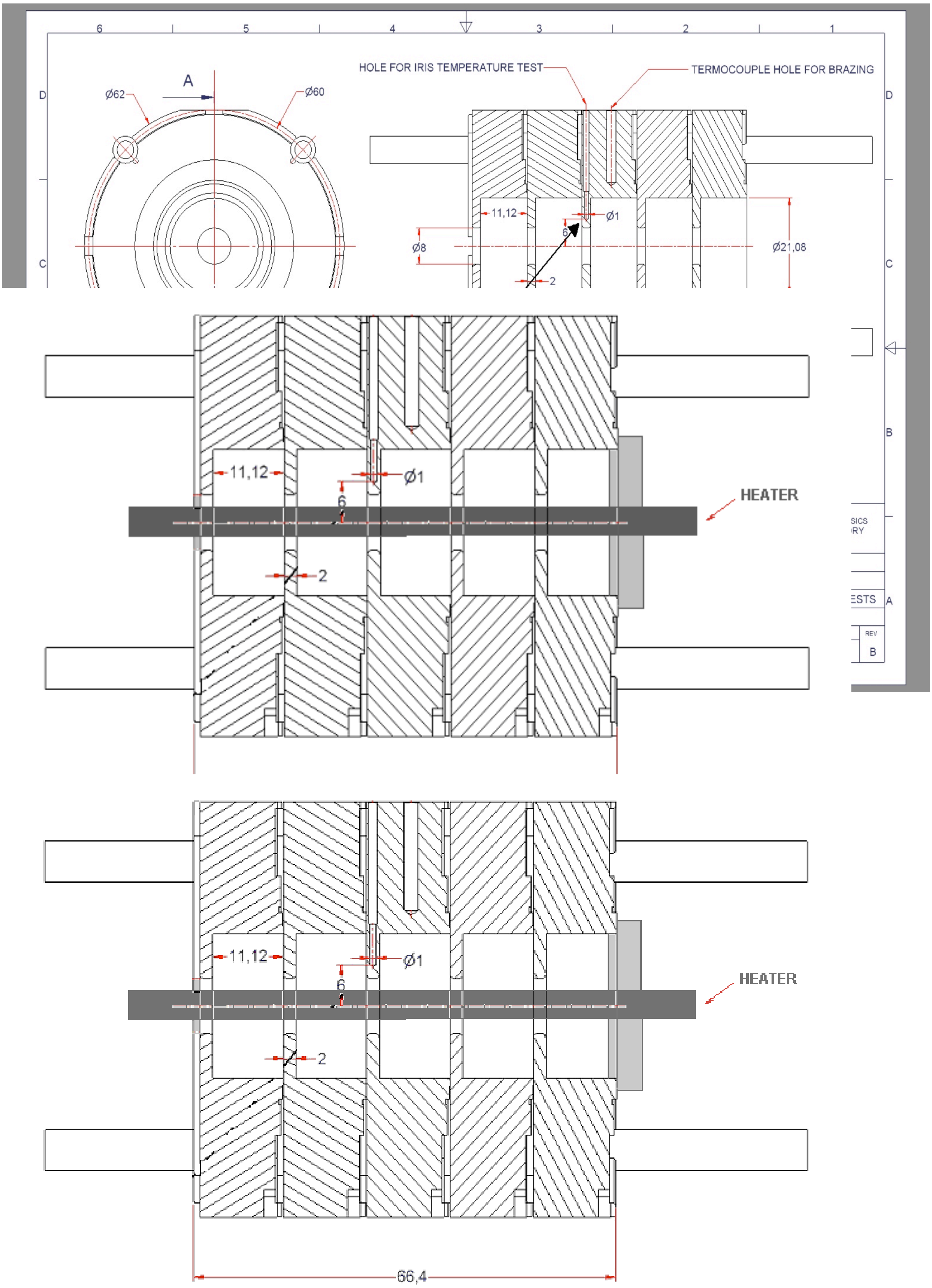

Fig 2 Particular of the heater inside the multicell structures at 11,4 GHz.

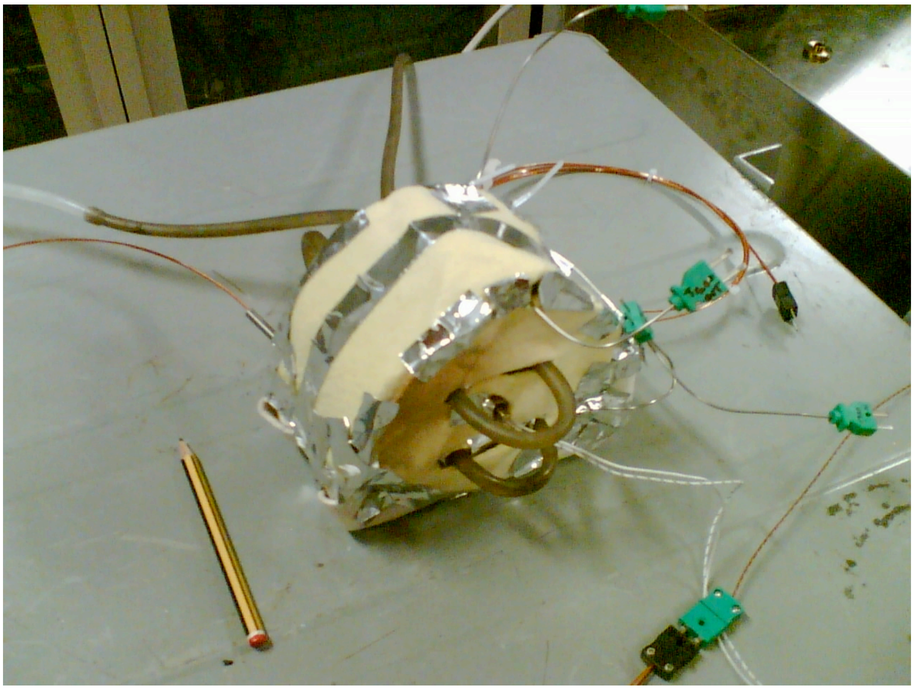

Fig 3 The experimental set up for thermal tests.

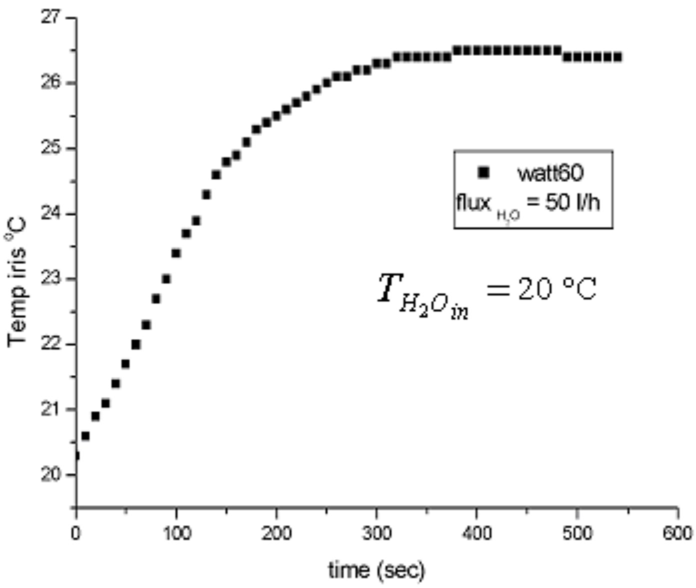

Fig 4 The iris temperature as a function of the time, data taken every 10 seconds. P=60W

$T_{H_2O_{in}} =$ 20 °C

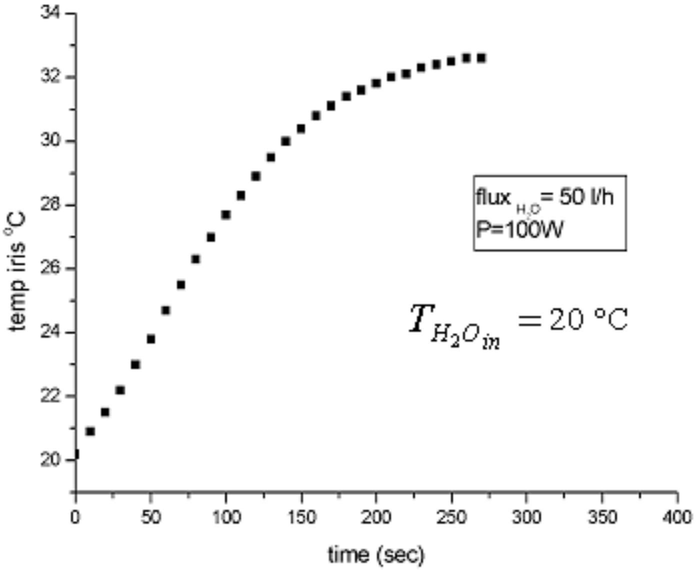

Fig 5 The iris temperature as a function of the time, data taken every 10 seconds P=100W.

$T_{H_2O_{in}} =$ 20 °C

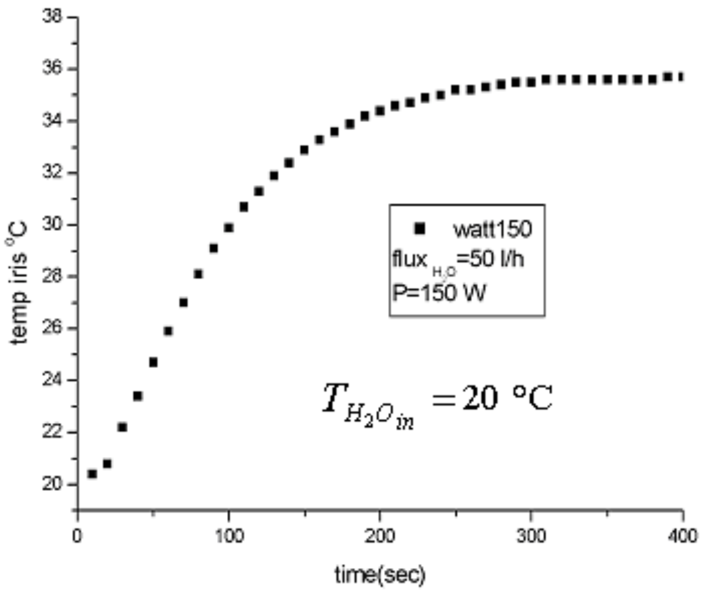

Fig 6 The iris temperature as a function of the time, data taken every 10 seconds P=150W.

$T_{H_2O_{in}} =$ 20 °C

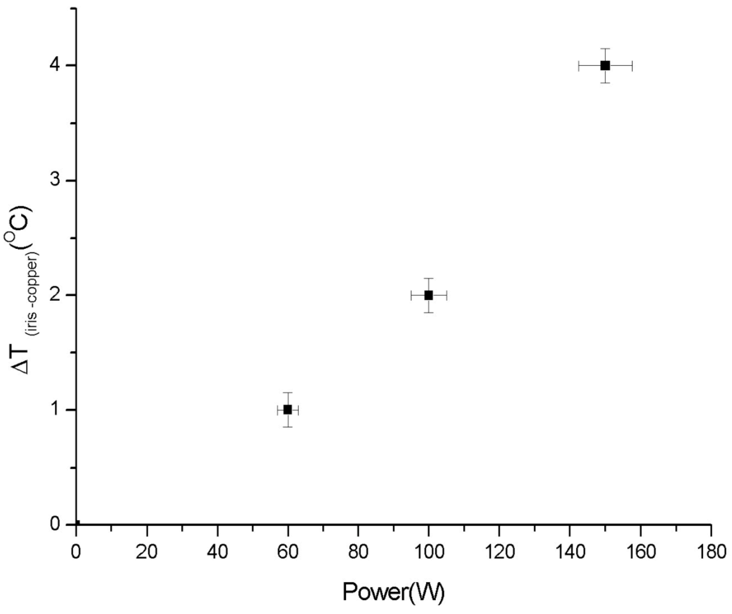

Fig 7 The temperature difference between iris and external surface as a function of the applied power with constant water flux=50 l/h.

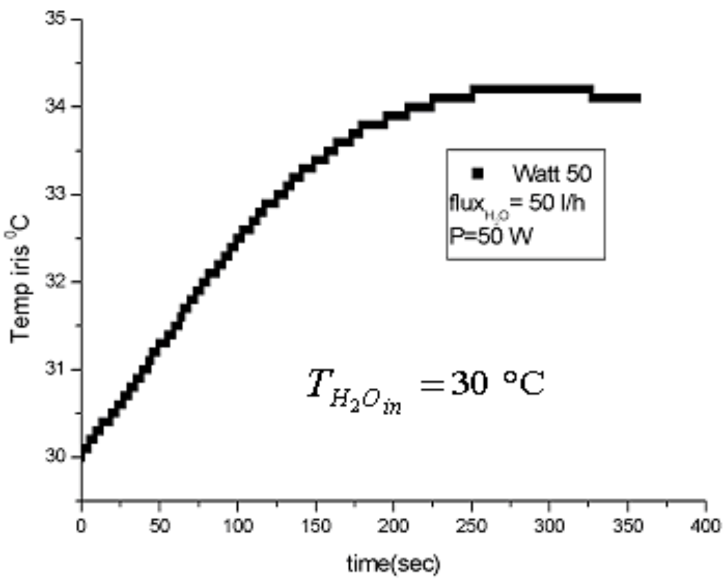

Fig 8 The iris temperature as a function of the time, data taken every 2 seconds P=50W.

$T_{H_2O_{in}} =$ 30 °C

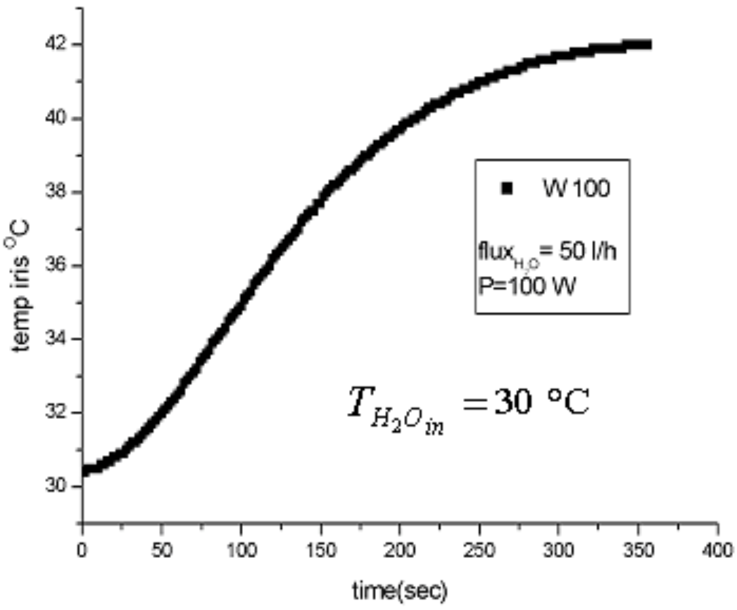

Fig 9 The iris temperature as a function of the time, data taken every 2 seconds P=100W.
$T_{H_2O_{in}} =$ 30 °C

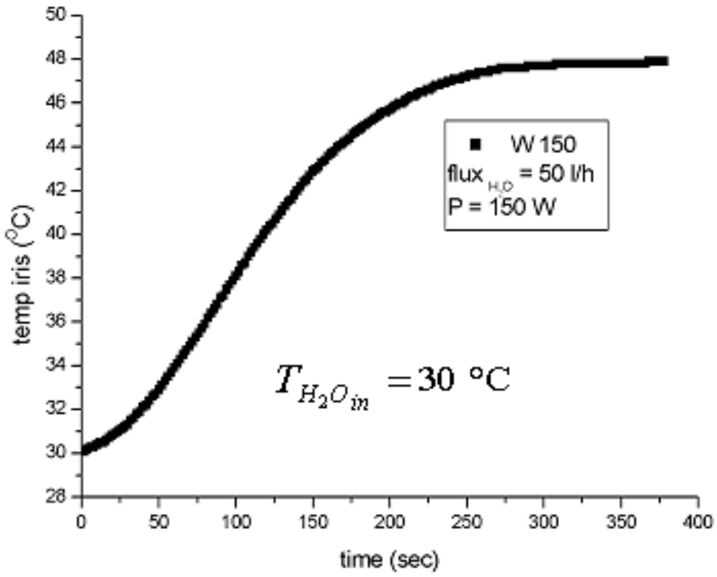

Fig 10 The iris temperature as a function of the time, data taken every 2 seconds P=150W.
$T_{H_2O_{in}} =$ 30 °C

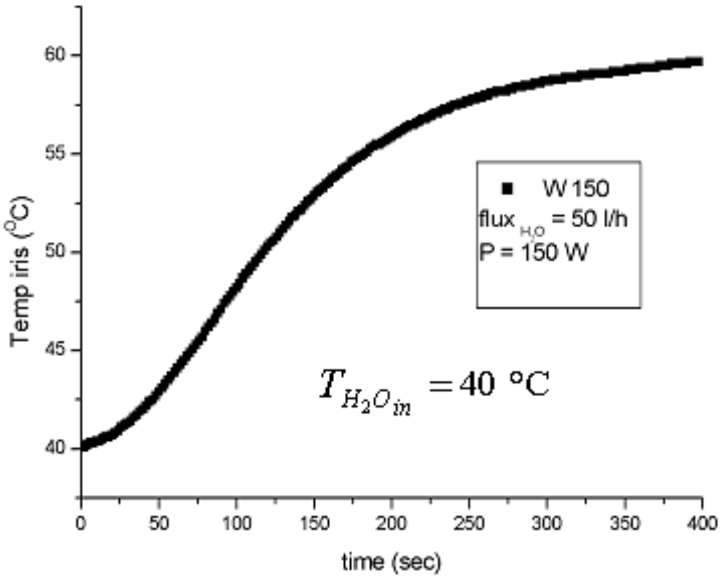

Fig 11 The iris temperature as a function of the time, data taken every 2 seconds P=150W. $T_{H_2O_{in}} =$ 40 °C