The Laser Megajoule CryoTarget Thermal Regulation

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The Laser Megajoule requires a high resolution temperature regulation to obtain the cryotarget temperature conditions: a temperature slope of 1 mK/min with ±1 mK to reach the triple point 19,79 K and a regulation at constant temperature with ±1 mK. This regulation required a thermal model elaboration for the target and the process, a regulation module development with a ±50 μK resolution and a specific algorithm of regulation. It runs on the prototype "Echelle 1", the Cryotarget Positioner mock-up built at the Service des Basses Températures - CEA Grenoble. The temperature stability obtained on the cryostat "Echelle 1" is presented.

INTRODUCTION

The Laser Megajoule facility is the French equipment intended for studies of inertial fusion. Thermonuclear fusion is obtained by focusing 240 laser beams with an energy of 1.8 MJ on a cryotarget (see Figure 1). This target, made up of a two millimeter diameter microballoon, filled with a Deuterium Tritium mixture freezed at 19.79 K. The microballoon implosion, following laser beams impact, generates in its centre the ignition conditions of temperature and pressure. The success of implosion strongly depends on the geometrical characteristics of the Deuterium Tritium ice layer: margin 1% for thickness, 1μm for roughness. The procedure to obtain this ice layer requires a temperature control of the target base with a margin of ±1 mK. This regulation includes 3 phases: a temperature slope of 1 mK/min with ±1mK to reach the triple point 19.79 K, a regulation at constant temperature with ±1mK, and finally a fast decrease (< 10 s) of temperature from 19.79 K to 18.2 K.
These specifications must be maintained during the target transfer to the centre of the experimental vacuum chamber by the cryotarget positioner (see Figure 2).

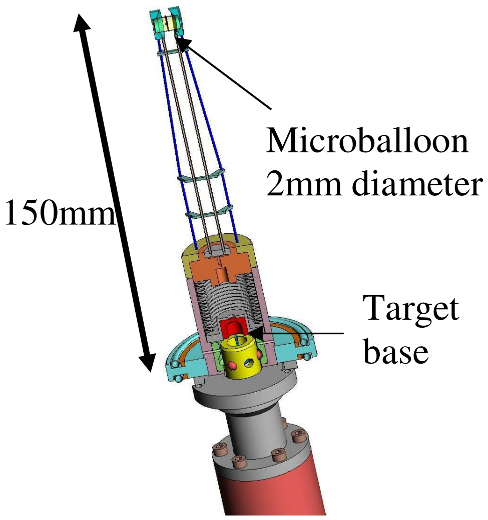

Figure 1 Cryogenic Target

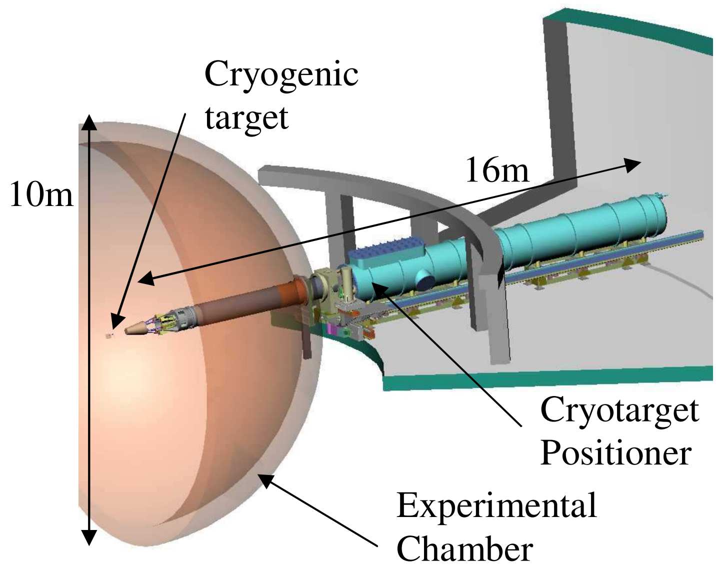

Figure 2 Cryotarget Positioner and Experimental Chamber

THERMAL OPERATION OF THE « ECHELLE 1 » PROTOTYPE

The cryogenic arm of the "Echelle 1" prototype consists of a target base, a gripper and a heat exchanger (see Figure 3). Thermal sensors mounted on each element follow temperatures evolution and heaters on target and heat exchanger are used for regulation.

Target base is cooled by conduction from a cold source made up of heat exchanger cool down by a helium gas flow. A pressure of 300 mbar above the liquid helium in the reservoir (100 liters) generates the helium flow [1]. Figure 4 presents the moving part of the cryostat bringing the target to the centre of the vacuum chamber.

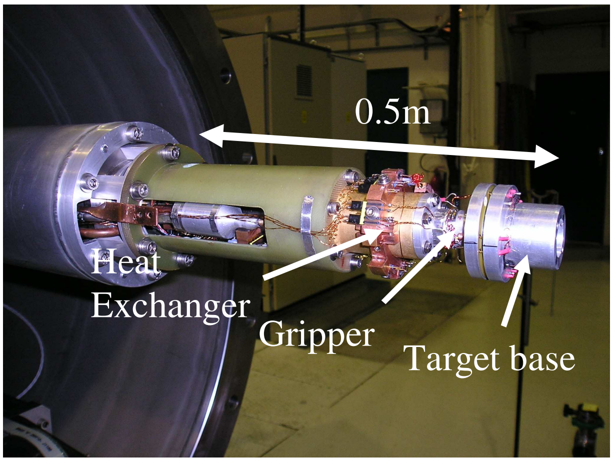

Figure 3 Cryogenic arm

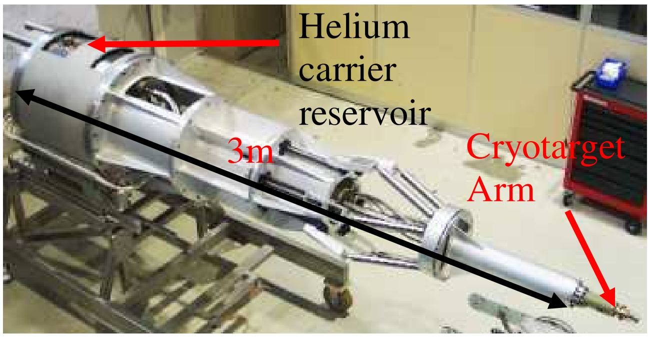

Figure 4 Moving part of the cryostat “Echelle 1”

THERMAL MODEL OF THE CRYOGENIC ARM

The thermal model includes the target base, the gripper and the heat exchanger. An electrical analogy is done (see Figure 5).

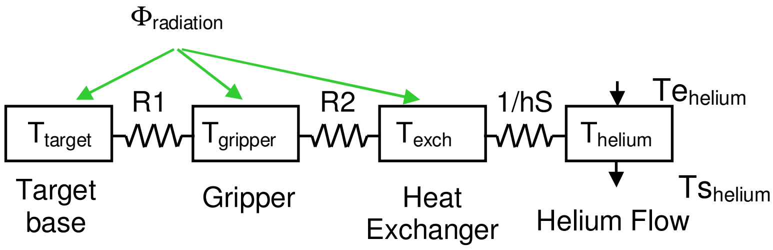

Figure 5 Thermal model scheme

A heat balance is carried out on each element by neglecting the heat diffusion. For example, target base balance is given by:

$$M_{target} Cp_{target} \frac{dT_{target}}{dt} = P + \phi_{radiation} - \frac{T_{target} - T_{gripper}}{R_1} \qquad (1a)$$

with R1: thermal resistance target base/gripper, P: power injecting on target base, R2: thermal resistance gripper/heat exchanger, h: convective coefficient between helium flow and heat exchanger.
The system of equations is solved by Laplace transform under the Matlab/Simulink software.

REGULATION MODULE

The regulation module was developed at the Service des Basses Températures - CEA/Grenoble. The needed high sensitivity for temperature measurement (ΔT<100 µK) required the implementation of a synchronous detection and the use of low noise special cables with double shielding. Thanks to these precautions, the regulation module resolution on the "Echelle 1" cryostat is ±50 µK.

The regulation algorithm of target base uses simultaneously two temperatures measurement and acts on two heaters (target base and heat exchanger).

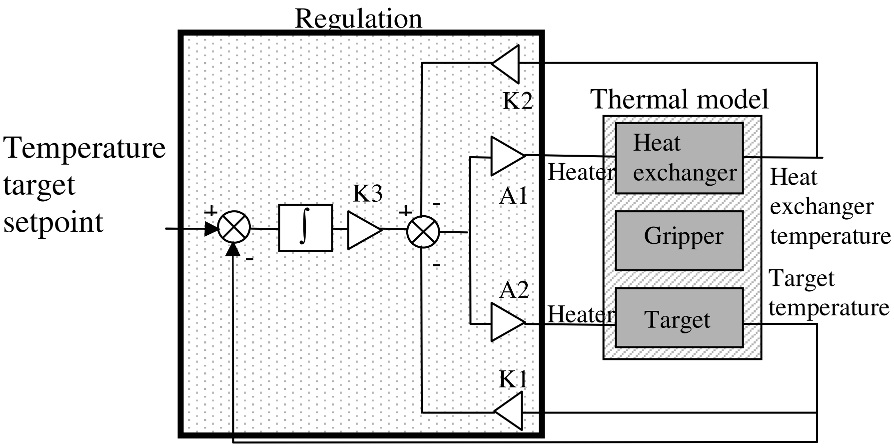

Figure 6 Regulation scheme

EXPERIMENTAL RESULTS ON « Echelle 1 » PROTOTYPE

The validation of the cryogenic arm model was carried out in open loop with power step on the target base and by comparing the target base, gripper and heat exchanger temperature evolution with calculations. Moreover, the response to an instruction level (closed loop) shows the good prediction of the system reaction associated with the regulation module (see Figure 7). The good agreement between measurement and thermal model made possible the optimization of the regulation module parameters.

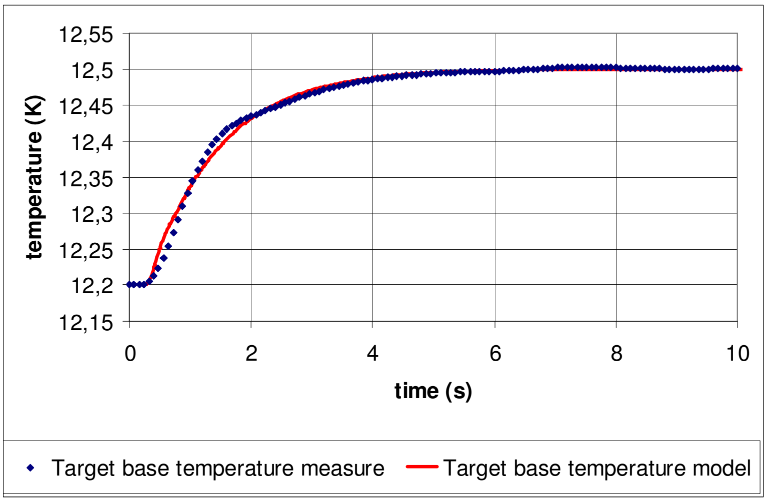

Figure 7 Regulation temperature step from 12.2 K to 12.5 K

The regulation performance obtained at constant temperature is a 55% reduction on temperature fluctuations. The experimental conditions are the following: Helium flow = 1.9 l_{liq}/h, T_{target} = 12.5 K. Without regulation, the total amplitude of temperature disturbances is ±2.9 mK (95% confidence variation with a Gaussian distribution) and is reduced to ±1.3mK with regulation. The spectrum analysis of target temperature signal ranges from 0 to 0.5 Hz (see Figure 8). The regulator reduces the low frequency disturbances in the interval of [0;0.2 Hz]. The fluctuations beyond 0.2 Hz are not modified. The performance obtained in temperature slope of 1 mK/min is almost the same with a 44% reduction on temperature fluctuations.

Moreover, the regulation robustness has been tested under displacement of the liquid helium reservoir and the cryogenic arm. This test simulates the transfer of the target towards the centre of the vacuum chamber. The speed of the carriage is 50 mm/s. Without regulation, the movement generates fluctuations of ±6 mK on the heat exchanger temperature due to helium flow fluctuation. With the regulation, the temperature fluctuation decrease to ±3 mK on heat exchanger (see Figure 9). The target base temperature is maintained within the interval ±2 mK (see Figure 10).

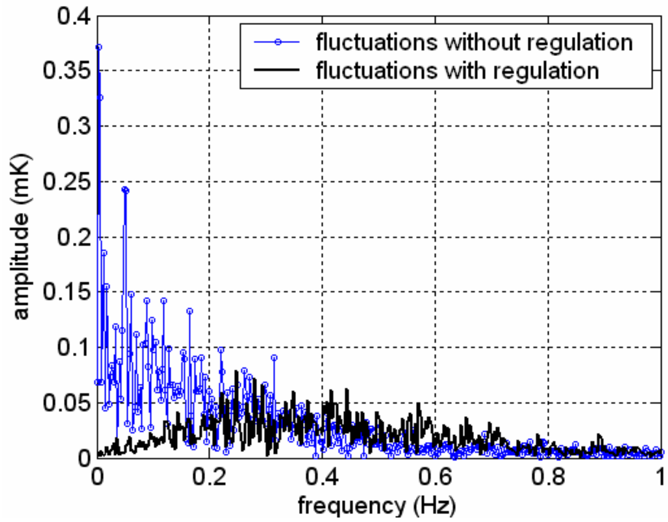

Figure 8 Spectrum analysis of temperature fluctuations

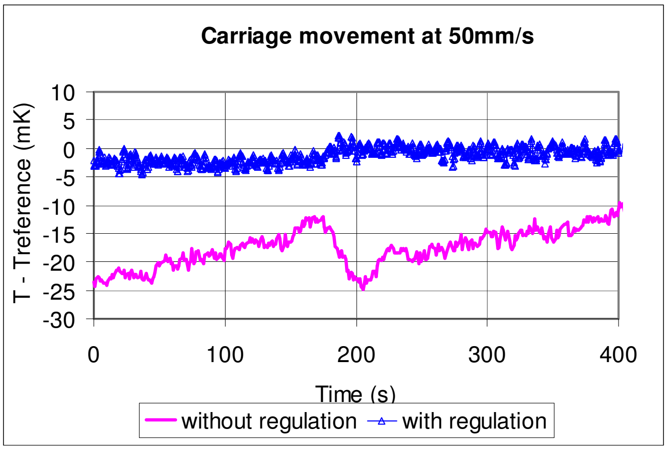

Figure 9 Heat exchanger temperature

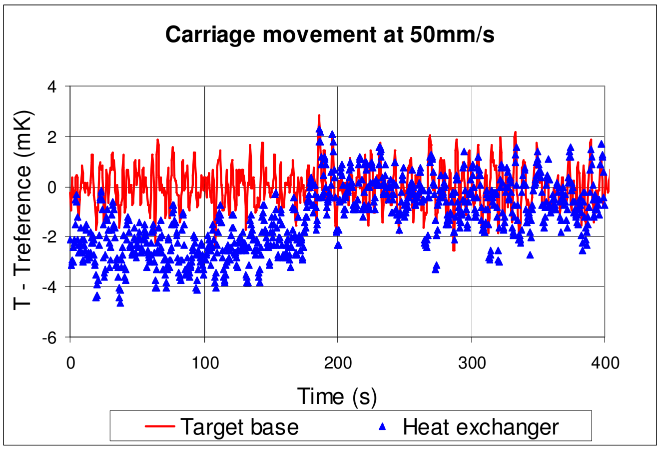

Figure 10 Target base and heat exchanger temperature with regulation

CONCLUSION

The regulation module, developed at the Service des Basses Températures, has a sensitivity of ±50 µK with a low noise system of measurement. The regulation algorithm allows an accurate, fast and robust temperature control. We reached a temperature stability of ±1.3 mK with a 55% reduction of the fluctuations. We still study the origin of perturbations to improve temperature stability.

ACKNOWLEDGEMENT

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REFERENCES

1. Paquignon, G., Brisset, D., Cathala, B., Lamaison, V., Chatain, D., Bonnay, P., Bouleau, E., Périn, J-P., First results on the prototype of the Laser-Megajoule Cryotarget Positioner, Fusion Science Technology 15 (2004), 45 282-285