JW5-FT-3.2

Task Title: DESIGN AND CONSTRUCTION OF THE SYSTEM FOR LASER DETRITIATION OF JET CO-DEPOSITED LAYERS

INTRODUCTION

ITER safety studies have shown that the maximum acceptable inventory of tritium in the vacuum chamber could be reached even with a few tens of plasma shots. Tritium is trapped both in plasma facing components (PFC) and cryogenic pumps. The studies on tritium trapping in PFC have shown that a large amount of tritium is retained in the co-deposited layer. Thus, detritiation of the vacuum chamber surfaces and tritium removal are indispensable for the future ITER installation.

Detritiation methods by ablation of the co-deposited layer or H/D thermal desorption by laser heating have been under investigation in CEA-Saclay laboratories since 2002. In 2003 – 2004, the repetition rate lasers with 5-100 ns pulse duration were developed. The studies on laser heating and ablation were aimed to obtain performance optimisation of the methods for future in-situ PFC detritiation.

The decision was made to base the detritiation device on a fiber laser with galvano-plate scanning system. The choice was justified by a high quality of a fiber laser beam that can be focused onto the treated surface by a lens with a long focal length (420 mm in our case). Such a near-Gaussian laser beam (even focused onto the spot of 100-300 µm diameter) has a relatively small divergence in the beam waist.

Thus, the accuracy of the laser device positioning with respect to the treated surface should not be regarded as a problem. Based on the experimental results of the laboratory tests on detritiation of a co-deposited layer [1, 2], an optimized system for surface detritiation by laser ablation was designed and constructed in 2005. The high repetition rate Nd-YAG fiber laser (20 W mean power) was equipped with a special optical system for the beam focusing and scanning (galvano plate X-Y Scanner).The proposed laser system was laboratory tested before in-situ experiments. The laboratory tests of the laser detritiation system were performed on the textor tiles with the relatively thick co-deposited layer. The laser system will be applied for detritiation tests (planned for may-june, 2006) at JET (Culham, UK) in the beryllium handling facility.

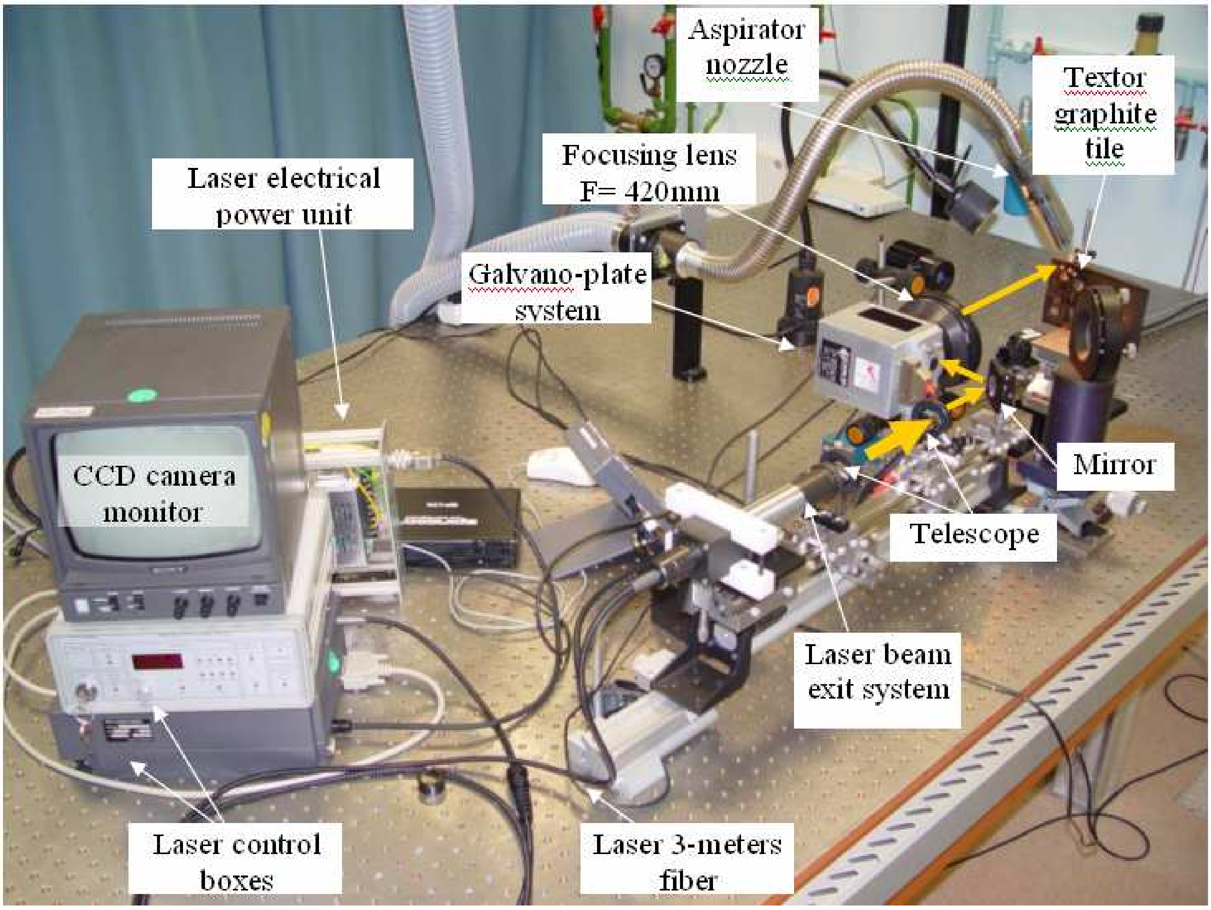

Figure 1: Laboratory laser installation in LILM, CEA-Saclay, France.

2005 ACTIVITIES

The developed principal scheme of the laser detritiation device was realised in the laboratory laser installation (figure 1). The collimated laser beam (yellow arrows) of 2w = 8 mm diameter (FW 1/e ^{2}) from the laser exit is reduced to 2w = 3.5 mm beam diameter by the optical telescope with two lenses of 100 mm and 50 mm focal lengths. The CCD camera transmits the front view of the cleaned target to the monitor screen. Both the monitor and the laser control box can be displaced from the ablated zone to the distance defined by the electrical cable length. Thus, it is possible to avoid the risk of the personnel exposure from the effects of contaminated ablated matter. The nozzle is applied to aspirate the ablated matter (particles, gas) in the treated zone. Then, the ablated matter is collected on the filters of the aspirator system installed in the next room.

The laser beam is focused onto the textor graphite tile by the focusing lens with the focal length F = 420 mm. For the given laser system with the pulse energy E = 1 mJ (20 W mean power at 20 kHz repetition rate) and laser spot diameter $2w_o \cong 230$ µm, the laser fluence on the beam axis F_0 can be determined as $F_0 \cong 2E / \pi w_o^2 \cong 4.8$ J/cm^2. This fluence is of the order of the ablation threshold fluence for the graphite substrate [2] for 100 ns pulse duration.

A thorough laboratory test on the device working parameters (repetition rate, power, scanning velocity,…) is required to ensure co-deposited layer detritiation in future BeHF experiments in a controlled optimal regime. Laser repetition rate and power were the first working parameters to be tested with the fiber laser. These parameters can be adjusted by a laser control box. Laser pulse duration increases with the decrease in the mean laser power. The laser beam intensity distribution was measured by SPIRICON CCD camera. The intensity distribution in the radial direction can be approximated by the Gaussian function with parameter M^2=1.45.

The ablation tests were made to determine the optimal regime of surface cleaning. As the laser intensity distribution is inhomogeneous (the Gaussian distribution), it was necessary to determine experimentally the optimal velocity of the beam scanning for homogeneous surface cleaning. A new textor tile sample with co-deposits of 20 µm maximal thickness was under ablation tests (figure 2) Laser cleaning was performed on 5mm × 5mm zones. The scanning velocities 0.5 m/s and 5 m/s were applied. High velocity corresponds to the surface ablation without spatial superposition of the consecutive pulses of 20 kHz repetition rate. Low velocity corresponds to the ten-fold superposition of the laser spots.

The cleaned zones were measured by a mechanical profilometer. A multi-fold cleaning resulted in better cleaning effects even for the low velocity scanning. This may be attributed to insufficient laser spot superposition in the vertical direction and to a possible re-deposition of the ablated matter on the neighbour cleaned surface.

Four- or six-fold rapid scanning (craters 3 and 4 on figure 2) can be considered sufficient for cleaning 20 µm co-deposited layers on the textor graphite tile.

The cleaning of 5mm ×5mm surface may be realised in 0.256-0.378 seconds with our laser device. Thus, the cleaning of 100mm ×100mm co-deposited layer of 20 µm thickness can be performed in about 2 minutes. The results of our previous experiments [2] demonstrated that the co-deposited layer of 50 µm thickness was almost completely removed after a single laser beam scanning of 10×10 mm^2 surface in 2 seconds. Taking into account the different co-deposited layer thickness, it is possible to state that the new laser device demonstrated the same ablation efficiency that was observed in our previous experiments with the laser pulses of 120 ns duration (1059 nm) and 100 ns duration (532 nm). Laser ablation on the right part of the textor tile (craters A-L) was performed to test the absence of any damage on the graphite substrate surface. No substrate damage was detected by the mecanical profilometer measurements. Laser beam interaction with the surface resulted only in colour changes without surface ablation. Thus, one may conclude that it is possible to perform the homogeneous cleaning with inhomogeneous laser beam.

Figure 2: Zones (5mm × 5mm) on textor tile ablated with the new laser device. On the left – tile surface with a co-deposited layer. On the right – tile surface without a co-deposited layer.

A very promising result was obtained with sapphire window cleaning. The sapphire window was installed on the TORE SUPRA tokamak (DRFC, CEA, Cadarache, France) and its internal surface was soiled by the plasma sputtered matter (figure 3a). The result of the preliminary test on laser cleaning was very reassuring as it was possible to remove the deposited layer without sapphire surface damaging (figure. 3b, zones 1-10). Further thorough studies on optimisation and characterisation of the cleaning performances of the laser technique are required.

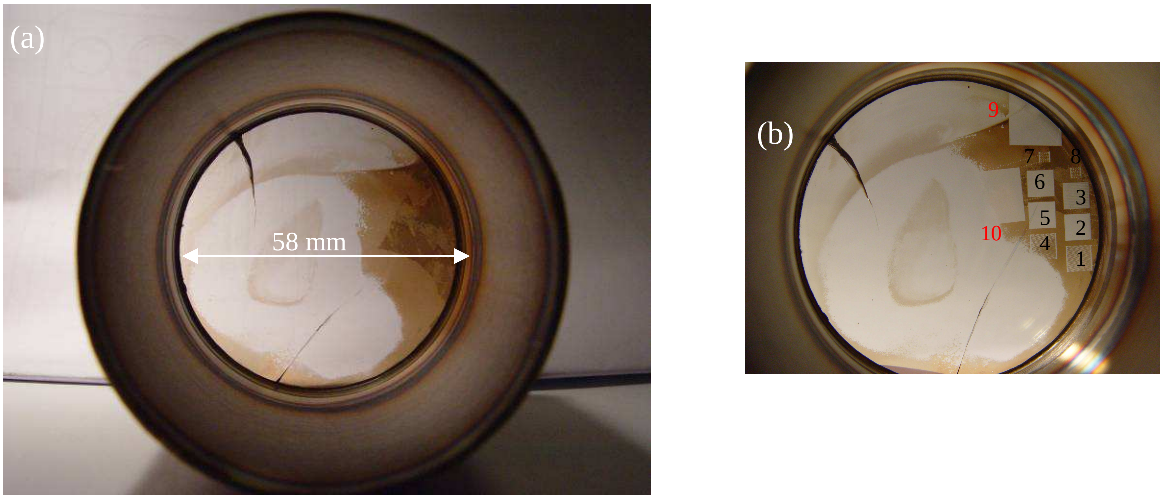

Figure 3: Sapphire window with the deposited layer before (a) and after (b) laser cleaning.

CONCLUSIONS

The report presents the results on the Laser Detritiation Device that was under development in DPC/SCP/LILM (CEA Saclay, France). The experimental studies on detailed laser beam characterisation and co-deposited layer cleaning by laser ablation were performed. The obtained cleaning performances of the new laser system were in accordance with the experimental results of our previous studies with another fiber laser system [2] and homogeneous laser beam transported by multimode optical fiber [1], [3]. The developed laser device was thoroughly characterised and tested with textor graphite tile. The sapphire window cleaning by laser technique was performed. The result of the window cleaning might be considered very promising as it was possible to remove the deposited layer without sapphire surface damaging. Thus, it offers a new potential laser application for optical surface cleaning. When the necessary contamination protection of the main equipment is ensured, the developed laser device might be considered prepared for demonstrator experiments on JET surfaces cleaning in JET BeHF in may-june, 2006.

REPORTS AND PUBLICATIONS

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[3] A. Semerok, F. Brygo, S.V. Fomichev, F. Champonnois, J.-M. Weulersse, P.-Y. Thro, P. Fichet, Ch. Grisolia, “Laser detritiation and co-deposited layer characterisation for future ITER installation”, ENC Proceedings, Versailles, France, 2005.

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JW5-FT-3.2RHpart

Task Title: DESIGN AND CONSTRUCTION OF THE SYSTEM FOR LASER DETRITIATION OF JET CO-DEPOSITED LAYERS: REMOTE HANDLING EXPERTISE FOR LASER DETRITIATION

INTRODUCTION

This project takes place in the JET Fusion Technology programme. The aim of the R&D programme is to demonstrate the feasibility of PFC detritiation using laser ablation techniques.
Detritiation methods by ablation of co deposited layers by laser have been studied by CEA/DEN/DPC/SCP since 2002.
Based on experimental results from laboratory tests, a system for JET in-situ testing is currently under design.
This report presents the studies performed to analyse the handling capabilities of this system.

2005 ACTIVITIES

CONTEXT

ITER safety studies have shown that after a few tens of plasma shots the maximum acceptable inventory of tritium in the vacuum chamber could be reached. Tritium is trapped both in plasma facing components (PFC) and cryogenic pumps. The studies on the tritium trapping in PFC have shown that a large amount of tritium is retained in the co-deposited layers. Thus, detritiation of the vacuum chamber surfaces and tritium removal will be necessary for future ITER installation.

Detritiation methods by ablation of co-deposited layers or H/D thermal desorption by laser have been under investigation in CEA-Saclay DEN/DPC laboratories since 2002. In 2003 – 2004 nanosecond laser devices were investigated. The studies on laser heating and ablation were aimed to obtain performance optimization of the methods and to apply them for future in-situ PFC detritiation.

The DEN/DPC process is based on a Nd-YAG fibre laser. This laser was ordered in February 2005 and delivered in September 2005. The galvano-plate laser beam scanning system was also ordered.
Based on the experimental results from laboratory tests on detritiation of co-deposited layers an optimized system was designed and built this year for surface detritiation by laser ablation. The high repetition rate Nd-YAG fibre laser (20 W mean power) is equipped with a special optical system for beam focusing and scanning (galvano plate X-Y Scanner). The proposed laser system is developed and laboratory tested prior in-situ experiments. The laser system will be developed in view to be ready to perform detritiation tests at JET: in-vessel or out-of-vessel, in the beryllium handling facility mid 2006.

LASER DEVICE DESCRIPTION

The laser device studied in the CEA Saclay DEN/DPC laboratories is mainly made with 3 components:
- The chassis,
- The laser,
- The robot interface.

The chassis supports the laser head with the galvano-plate scanner and a focusing lens, the laser beam transport system to provide the laser beam entrance into the scanner, the video camera to observe the detritiation zones, and the interface of the whole system with the robot. To low down the total weight of the system, aluminium alloys may be used for the chassis.

HANDLING ANALYSIS

The objective of the handling analysis is to study the possibilities of manipulating the laser device with a MASCOT arm in the JET Tokamak.

The analysis was performed with the following steps:

- Building of a basic model of BOOM and MASCOT arms in JET environment,
- Design of possible laser tool heads with different positions of manipulating devices,
- Playing CAD simulations to determine the possibilities of using the devices in the divertor area
- Analysis of handling capabilities of the tool with the MASCOT.

For this analysis, it was assumed that the laser tool head could be handled with only one Mascot arm.

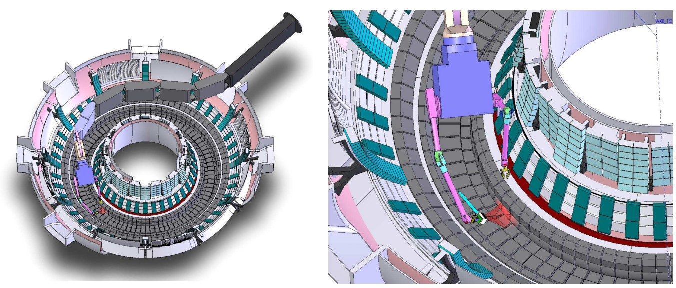

Figure1: CAD model of JET with BOOM and MASCOT arms

The simulated task was a scanning of the divertor area with the tool and particularly the inner and outer sides of the divertor.

First simulations have shown many possible contacts and collisions between the robotic arm and the first wall of JET. These are not really suitable to operate the laser tool with a MASCOT.

The next figure shows the area which can be scanned with the laser without moving the arm. This area is about one entire divertor tile.

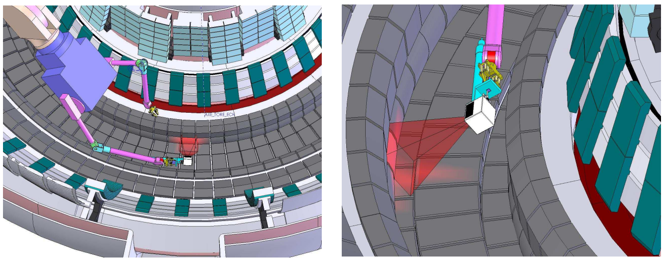

Figure 2: Simulation views of divertor tiles scanning

Following simulations with the tool head in configurations with the scan cube handled perpendicularly to the beam have shown the feasibility of the intervention with the laser tool and the mascot arm. These handling configurations are suitable to operate the laser tool with a MASCOT.

During the simulations it appeared that a tool with a shorter focal length than the initial one could allow a perpendicular view of the outer and inner surfaces of the divertor.

Simulations show that the best length could be around 350 mm instead of 420.

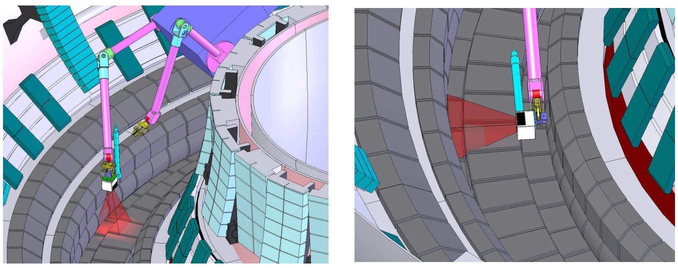

Figure 3: Simulation with a 350 mm focal length

First simulations have also shown an interest for a design of a tool which can be handled by both MASCOT arms. The left arm is the best to operate in the outer side of divertor and the right one for the inner side.

The next figures present simulation with a tool designed with 3 handles and an exchange of handling arm during operation.

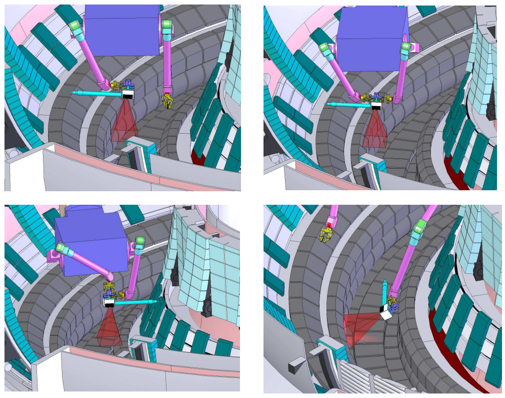

Figure 4: Exchange of handling arm

CONCLUSIONS

The simulations have shown that the best design for a laser tool head to be manipulated with a MASCOT arm in JET divertor is a configuration using 3 handles. This allows carrying the tool with the both 2 arms. A focusing lens with a focal length of 350 mm allows being perpendicular to the inner and outer sides of divertor and then will be probably the most efficient.

This study has demonstrated the possible intervention using the JET existing capabilities for PFC detritiation using laser ablation techniques.
The feasibility of the laser tool design to be handled by the mean of a MASCOT arm and the full divertor area viewing with such a tool was demonstrated with simulations.

REPORTS AND PUBLICATIONS

CEA/DTSI/SCRI/LPR/ 5RT.093-Issue 0 Remote Handling expertise for JET detritiation. 2005 report

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