FUSION TECHNOLOGY

Annual Report of the Association EURATOM/CEA 1999

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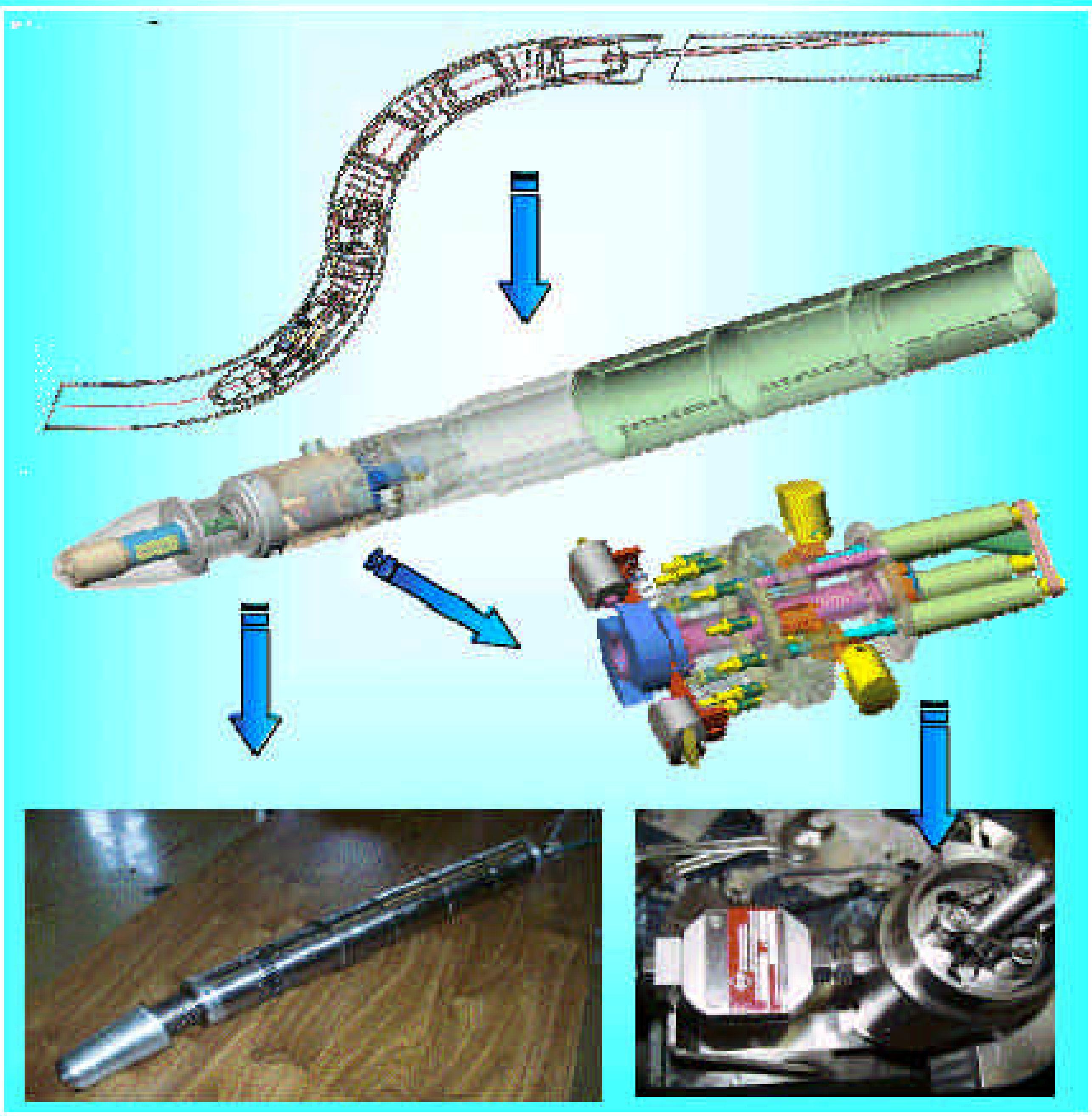


ASSOCIATION CEA/EURATOM
DSM/DRFC

CNET 98-486

Task Title : DESIGN AND FUNCTIONAL SPECIFICATION OF AN INTERSECTOR WELD/CUT ROBOT

INTRODUCTION

ITER sectors are very large component with some complex geometrical features. Plasma physics and internal components assembly requires more stringent tolerances than normally expected for the size of structure involved. Overall assembly tolerances are expected to be within 10 mm (± 5 mm) in the whole vacuum vessel.

The IWR will be the carrying system taking the process end effectors to their work area. In a first step it is planned to integrate an IWR test bed with vacuum vessel samples to perform hands-on experimental work.

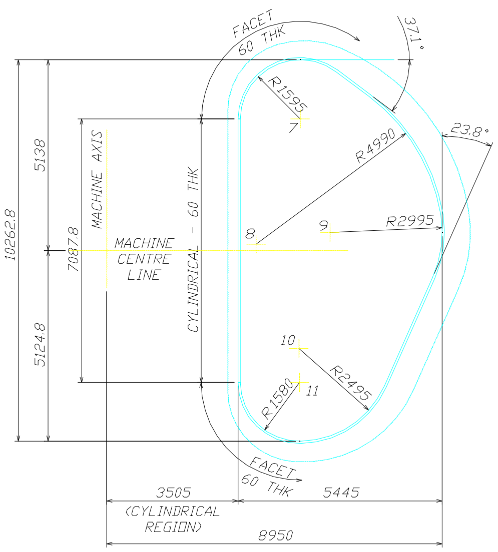
1999 ACTIVITIES

ASSEMBLY PROCESSES DESCRIPTION AND REQUIREMENTS

ITER Sectors are made of 60 mm thick cast stainless steel. They are joined together through high efficiency structural and leak tight welds. In addition to the initial Vacuum Vessel assembly, sectors may have to be replaced for repair.

In order to allow assembly access to the thermal shield, a splice plate is inserted between each sector. This splice plate must be precisely machined according to the gap dimensions existing between each sector.

The vacuum vessel has an internal and external wall separated by a 280 to 650 mm gap. All assembly processes have to be carried out from inside the Vacuum Vessel. The End-Effectors will have to be inserted through the internal splice plate opening.



ITER Cross Section

The ITER Vacuum Vessel assembly or repair will be performed according to four phases : cutting, edge machining, welding and NDT control. The following processes are currently being investigated for the Vacuum Vessel maintenance :

- **Cutting Processes**
  - Yag Laser Cutting
  - Mechanical Cutting
- **Machining**
  - Mechanical Machining
- **Welding**
  - Electron Beam Welding
  - Yag Laser Welding
  - Arc Welding Techniques (MIG, TIG)
- **NDT Testing**
  - Ultra Sonic NDT

IWR SYSTEM REQUIREMENTS SUMMARY

The processes analysis has lead to the following requirements to be applied to the end-efector deployment system.

Motion Requirements

Motion Axis Definition

X axis along the Seam
Y axis perpendicular to the Seam and parallel to Reactor wall
Z axis perpendicular to the Seam and perpendicular to Reactor wall

Motion Requirements

	X Axis	Y Axis	Z Axis
Range	**Whole Seam**	**600 mm**	**300 mm**
Absolute Precision	**± 0.5 mm**	**± 0.1 mm**	**± 0.1 mm**
Resolution	**0.2 mm**	**0.02 mm**	**0.02 mm**
Speed	**6000 mm/min**	**5000 mm/s**	**5000 mm/s**
Acceleration	**500 mm/s²**	**10000 mm/s²**	**10000 mm/s²**
Repeatability	**± 0.2 mm**	**± 0.02 mm**	**± 0.02 mm**

The IWR shall be able to cope with the sector smallest internal radius of curvature of 1375 mm.

Payload Requirements

Payload Capacity in all Direction : 200 kg
Up to 600 kg in Z direction for specific operations (Machining)

Environmental Requirements

The IWR vehicle shall weight less than 400 kg
No element to be fixed inside the Vacuum Vessel during the IWR operations shall weight more than 150 kg.
The IWR shall be Xray compatible.
The IWR shall be vacuum compatible.

IWR SYSTEM CONCEPT DESCRIPTION

The analysis of the sector geometry and system requirements has led to the following conclusions :

- A large robot covering the whole joint from a single deployment point would not be feasible technically and economically. It would require a very heavy structure and probably could not provide sufficient precision. Ebeam operations would require a large area inside the reactor to be put under vacuum.

- A guiding rail can be bolted on site parallel the sector seam 500 mm from it.

- The vehicle can travel on the guiding rail and be used as a deployment platform.

- A manipulator attached on the vehicle moves the end-effector precisely in the work area. Parallel robot kinematic has been selected for this purpose. It offers stiffness, precision and payload to robot weight ratio which is far superior to other robotic geometry

- A shroud can be put around the guiding rail and keep the system into a leak thigh enclosure. Inflatable seals and putty ensure a pressure level down to 10^{-2} mbar.

Before a full scale system is procured, it is necessary to assemble a test system to validate its operational capabilities with the various end-effectors.

IWR TEST BED DESCRIPTION

General Concept

This test bed will be used for process development and Sector assembly validation.

It will include the following components :

- The Test Mock-up

- The local Vacuum System

- The IWR guiding rail

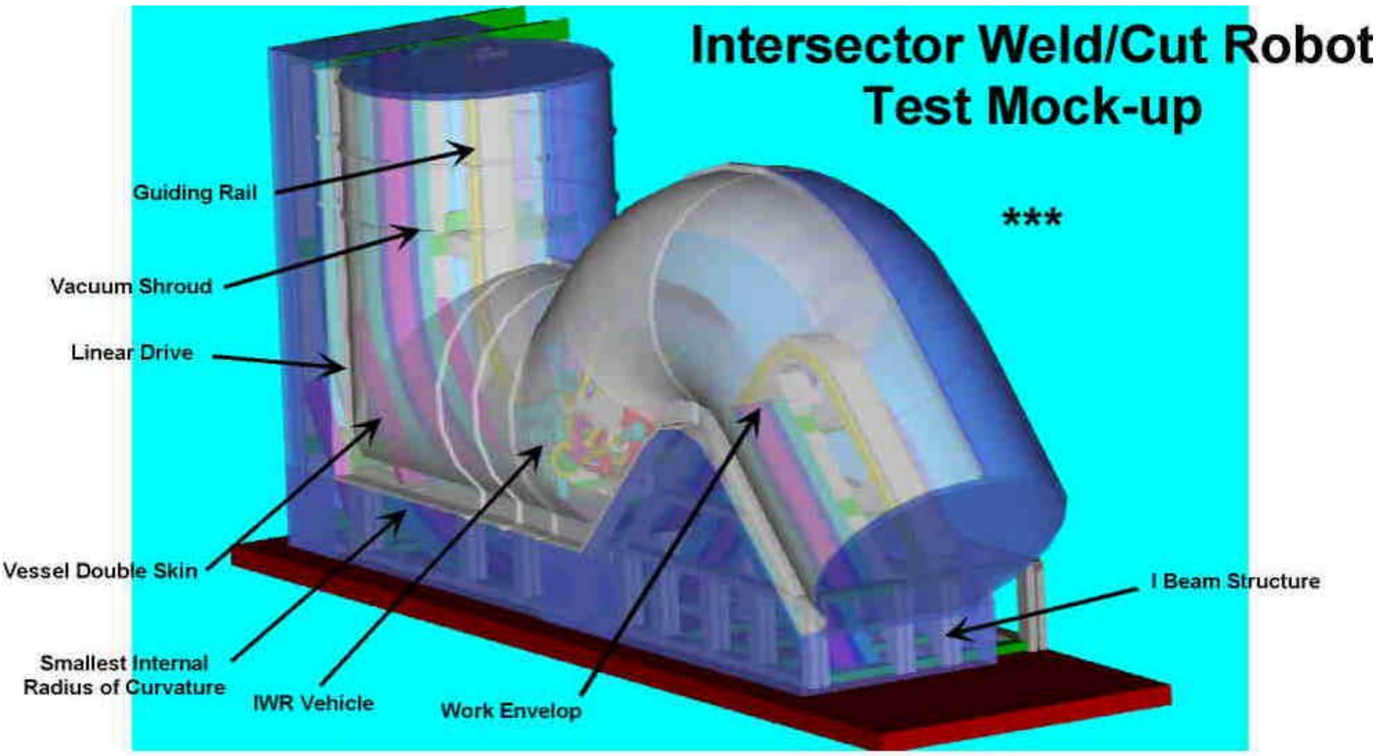
- The IWR vehicle (including End-Effector manipulator)

- The IWR control System

- The IWR 3D positioning system

IWR Test Mock-up

The mock-up has been designed to include critical features the Vacuum Vessel.



The Mock-up dimensions are compatible with a lowered truck lorry

The IWR guiding Rail

The IWR guiding rail is made of several segments assembled together. Each segment weights approximately 150 kg.

The IWR vehicle

The IWR vehicle is designed to weight less than 400 kg.

Current reference design turns around 320 kg and includes the following items :

Vehicle Guiding System and linear drive

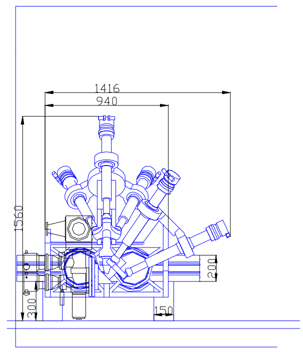
Four rotating bogeys with galleys run along the guiding rail.

A servo motor with a pinion is implemented into one of the rotating bogies providing the linear axis movement using the flat rail rack.

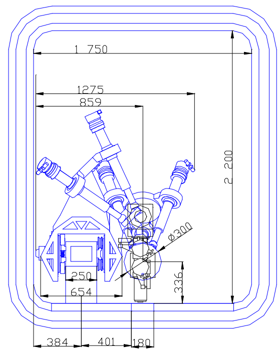
Structure

A main frame made of aluminium. It connects the bogeys' wheels to the rams bases.

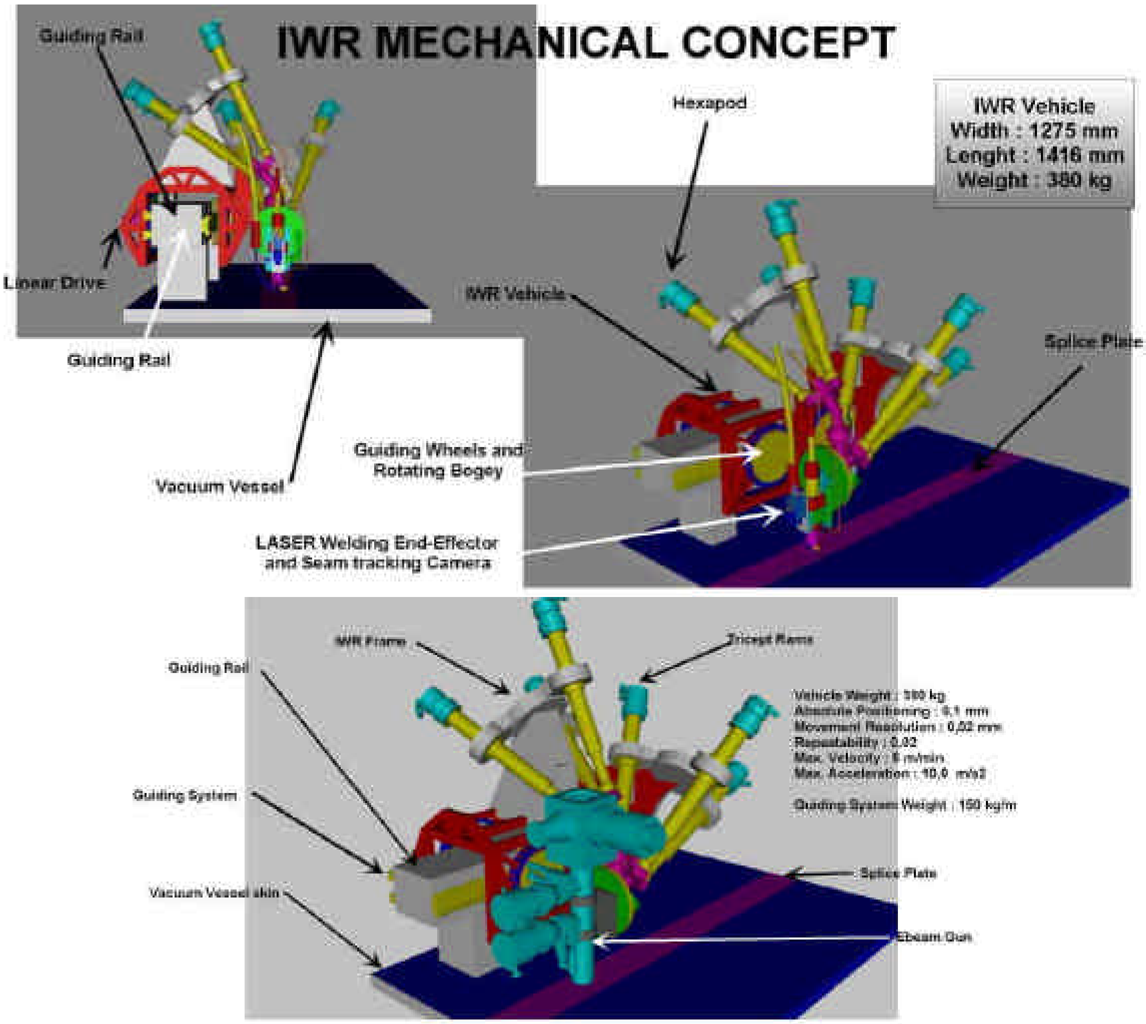
Its overall dimensions can be seen in the following pictures.



IWR Dimensions inside Equatorial Port



IWR Dimensions inside Equatorial port



Ebeam Gun Model courtesy of TWI, Cambridge, U.K.

The End-Effector manipulating system

This components is one the key technology challenges of the IWR system. A parallel robot configuration has finally been selected.

Six rams divided into two tripods separated with a 45° angle to optimise the vehicle volume and enable translation inside the vacuum vessel smallest radius of curvature.

A kinematic mount provides a circular 300 mm template for the end-effectors connection. Three bolts on the circumference allows easy end-effector exchange.

IWR Vehicle Performances Summary

Kinematic Capabilities

The current IWR design provides the following kinematics characteristics : The four bogey system enables the IWR to travel on the guiding rail with an internal radius of curvature of 1000 mm. This can accommodate the smallest Vacuum Vessel internal radius of curvature of 1500 mm. The movement capabilities of the IWR match the requirements described in the previous section.

IWR going through Vacuum Vessel Bottom Segment

IWR Reference Design Structural Performances

IWR has been analysed with a set of FE Analysis modelling and simulations. Two main results have been observed :

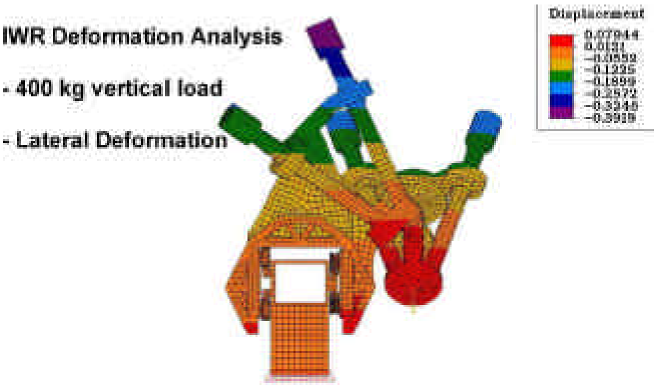
- Lateral deformation is less than 0.08 mm with a 400 kg payload. The IWR is stiff enough for the most demanding process. This deformation can be measured and compensated.

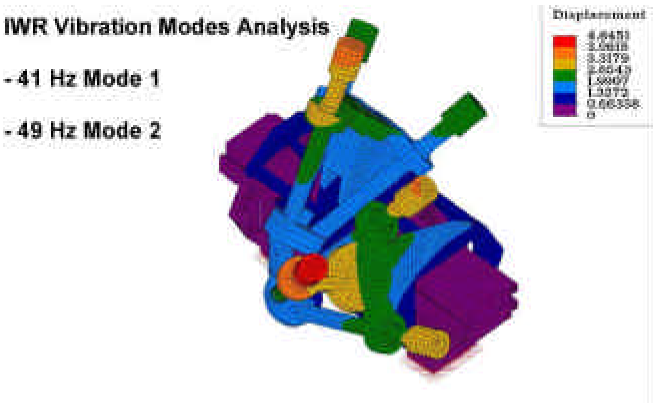
- The whole system natural frequency is 41 Hz in mode 1. This is a very good stiffness level indication. This parameter will enable us to compensate for the load variations during the machining process.

IWR Control System

To reduce cost, the present control system hardware concept has been defined for the Reactor first assembly only. In the future when operations in a high radiation environment will have to be carried-out, a completely revised rad-hard system will have to be procured.

All control hardware will be embedded on the IWR vehicle. Trajectory and safety control will performed be by an on-board CPU running under a Real Time Operating System.





IWR Control Room

The IWR control Room will include the following elements :

IWR Supervision System

A supervision console with a windows Man Machine Interface. It will provide the operator all menus and commands to prepare and supervise the IWR operations. It will also be used as a data acquisition system for system maintenance and reporting

The IWR motion simulator.

A motion simulator will be used to identify and prepare the IWR motion sequence

IWR 3D positioning System

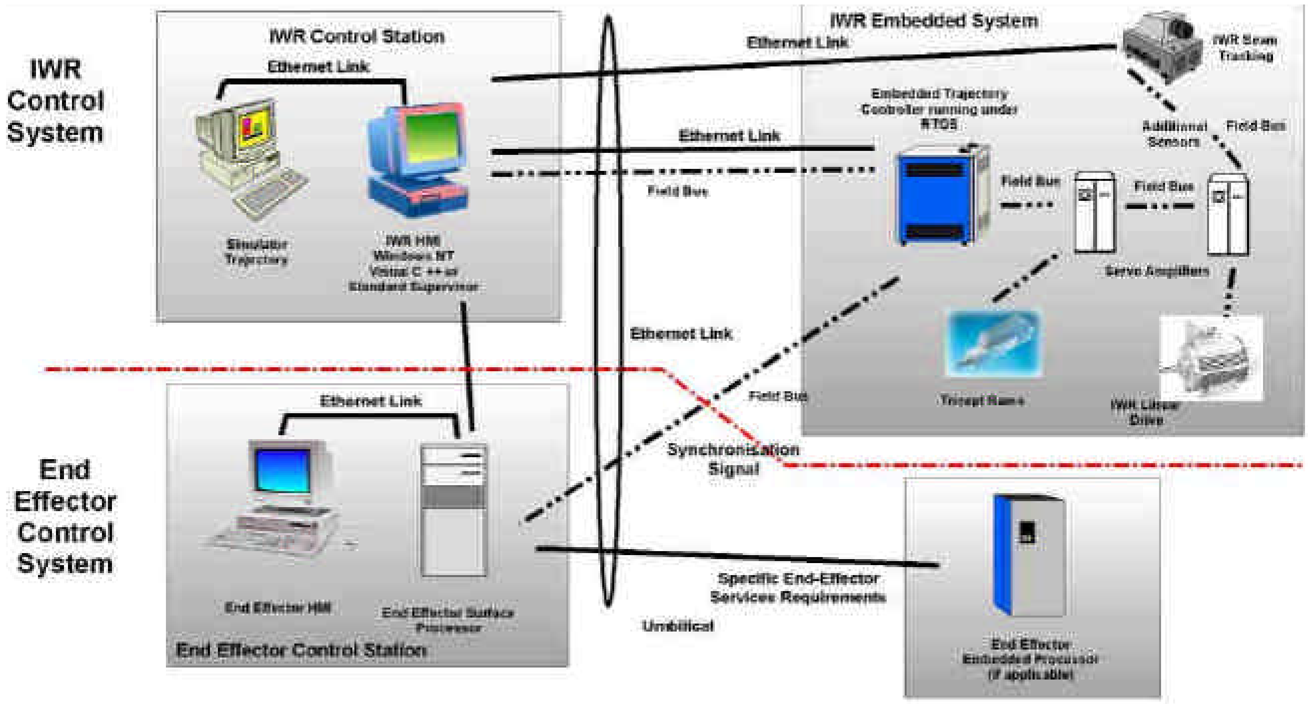
In order to meet the stringent positioning precision and provide accurate data for splice plate preparation, the IWR needs the following sensing systems :

- Load sensing will be implemented in the rams.

- A seam tracking system will be implemented for Laser and E-Beam Welding.

- A IWR position tracker will provide 6 axis positioning data of the vehicle in the reactor reference system.

- In order to get machining data for splice plate preparation, a laser profiler end-effector will scan the sector edges and provide the surface profile.



IWR Control System Concept

PATENT VERIFICATION

A patent verification analysis has been carried.

No patent have been identified as conflicting with the current IWR reference design with a comfortable margin.

DESIGN PHASE CONCLUSIONS

- Operational requirements can be met.

- Software preparation and reliability will be a major issue.

- Very good cost effectiveness is reached with the current design.

TASK LEADER

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T252

Task Title : RADIATION TOLERANCE ASSESSMENT OF STANDARD COMPONENTS FOR REMOTE HANDLING AND PROCESS INSTRUMENTATION

INTRODUCTION

The two main missions retained by DEIN to characterise electronic and optoelectronic components and design demonstrators consist in the following topics:

- very short visual in-vessel inspection (few hours) just after shut-down of experimental reactor where total dose level expected for vision modules is around 1MGy.

- extensive in-vessel inspection (few days) where total dose expected during such missions is up to 10MGy

The environmental conditions of these two parts are agreed by ITER teams (between 50°C and 200°C for a dose rate averaged to 30 kGy/h.

This paper reports activities connected to the evaluation of power electronic components like IGBT and MOS transistors and technologies used for logic components such invertors and buses drivers. Are added results data necessary for the conception of a rad-hard optical link aimed to the transportation of data between control-command room and the remotely controlled handling machine.

1999 ACTIVITIES

WORK PERFORMED ON ELECTRONIC COMPONENTS

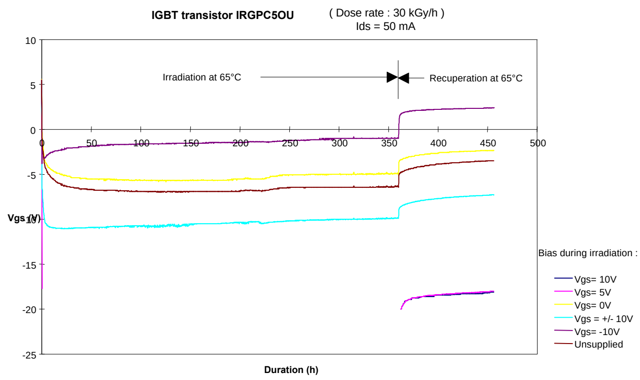
IGBT and MOS power transistors

The tracked parameter is Vgs at the threshold between off-state and on-state (with Ids=50mA, often used for power MOS transistors). Different bias conditions were applied to the gate of the transistor in order to simulate mean uses of such components [1].

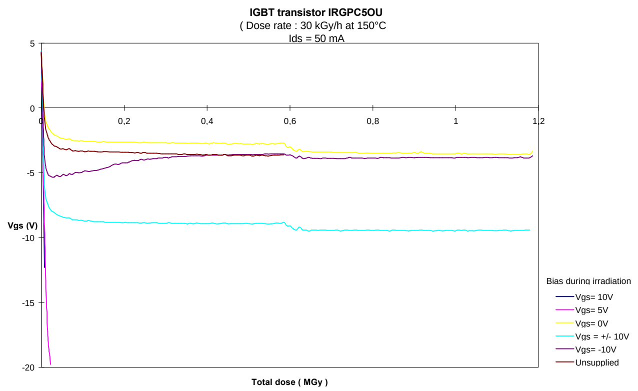
Results given on Picture 1-1 have been obtained. As previously shown (see report in 1998), the permanent state for all bias conditions has been kept until end of irradiation (15 MGy).

After two days at same temperature but without radiation, components have recovered part of degradation, even for 5V and 10V bias. The lack of data for these points was mainly due to the limits of test-bed. Permanent state should be probably between 20V and 25V.

On Picture 1-2, results under 150°C were given. After only 48 hours, errors were appearing showing that switches used to drive reading of electrical data did not tolerate such temperature. Campaign had been stopped. Nevertheless, like for 65°C, a permanent state was observed.

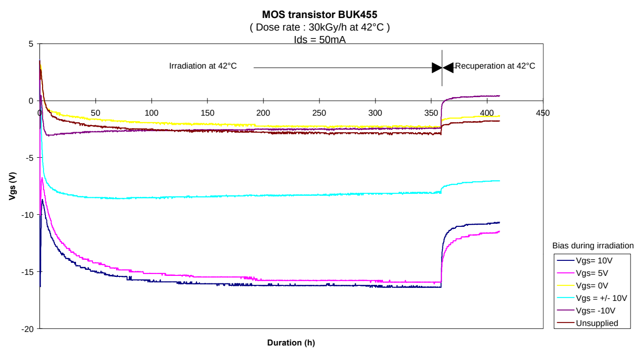


Picture 1-1 : Data for IGBT IRGPC50U at 65°C

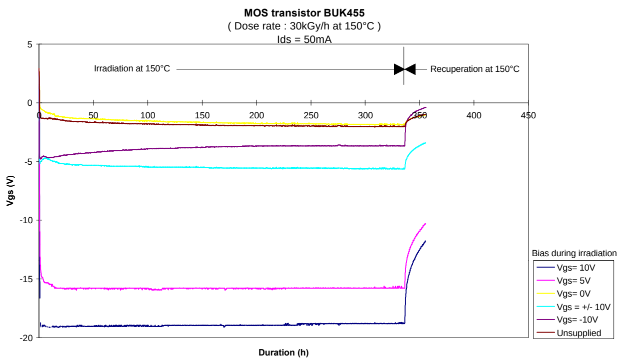


Picture 1-2 : Data for IGBT IRGPC50U at 150° C

New components irradiated were power MOS transistors BUK455 et IRF830. They are commercial transistors usually used in rad-hardened electronic modules.



Picture 1-3 : Data for MOS BUK455 at 42°C



Picture 1-4 : Data for MOS BUK455 at 150°C

Results shown in Picture 1-3 and Picture 1-4 confirm the good aptitude of these components under ITER constraints. Degradation during the first megarads is always followed by a permanent state. Such observation confirm previous ones but at lower doses level [2].

Very low recovery have been observed. Even if recovery time were stopped earlier, a better recovery was not evident.

A clear dependence of bias was observed on all these pictures. Particularly, worst case (bias at 10V and 5V) induced such lower threshold that test-bed was unable to follow.

Logic circuits (invertors)

The tracked parameter is Vout. Slopes (-0,5V -> 5V(3,3V) and 5V(3,3V) -> -0,5V) are applied for Vin during tests. This parameter is currently used to characterise such components. During radiation, different bias are applied to Vin (0V, 5V (3,3V), slopes) [3].

Results given on Picture 1-5 to Picture 1-6 have been obtained during a previous campaign on commercial bipolar and ACMOS circuits. No components were destroyed during irradiation. The logic function of inversion was mainly kept even if some drifts were appearing for CMOS components (nominal Vin=2,5V (1,7->3,1 for trigger version)). An instability was observed on 74AC04 for dynamic bias. No significant differences were appearing with different bias conditions.

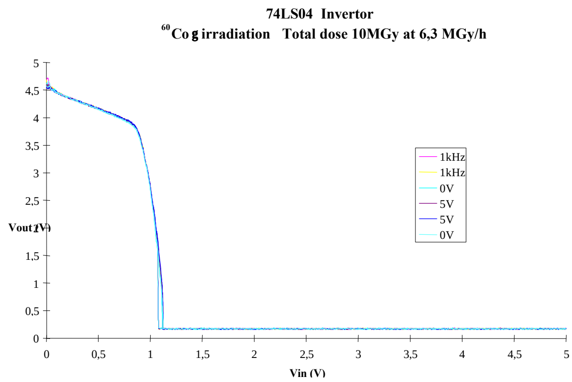
A new campaign was organised for same components in recent technologies with 2 samples of each. Because the number of wires is reduced between control room and the container, it was necessary to limit on-line investigations. In that way, dynamic bias was chosen. The others bias were controlled before and after irradiation.

Picture 1-7 to Picture 1-10 represents the results of irradiation for three recent technologies (Philips, NS, TI). One of them (LVQ) shows clearly that functionality is lost after 3,5MGy.

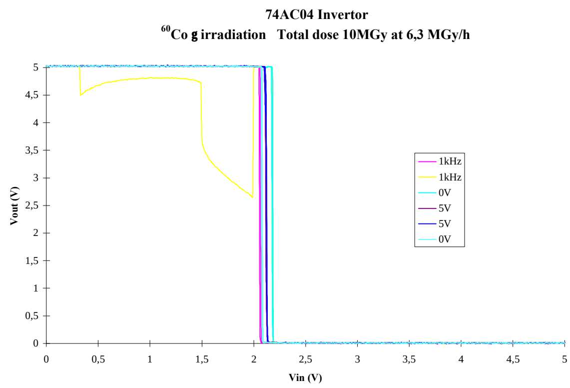
For LVC components (invertor and trigger invertor), 0V bias seems to be the worst case. At 15MGy, logical function is lost.

For ALVC components, functionality is not lost. The drift introduced by 0V bias could be accepted for a low-voltage component.

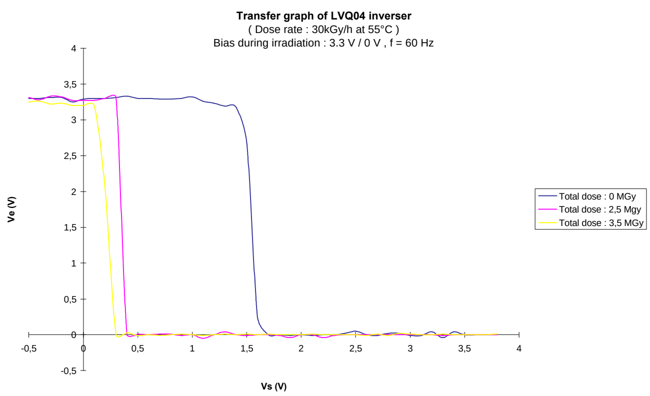
In comparison with results obtained with these components at lower radiation level(not shown in this report), the influence of bias plays an important role by determining losses or significant decreases of functionality.



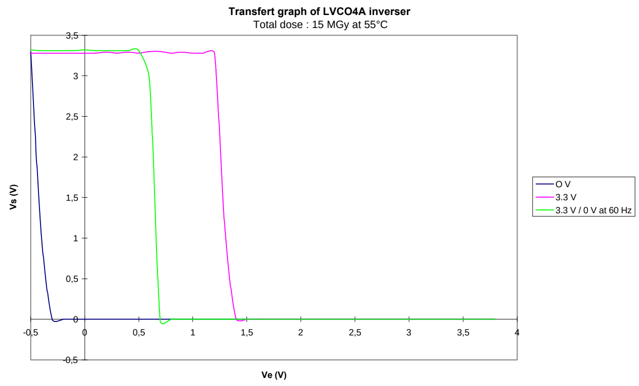
Picture 1-5 : Response of 74LS04 invertor



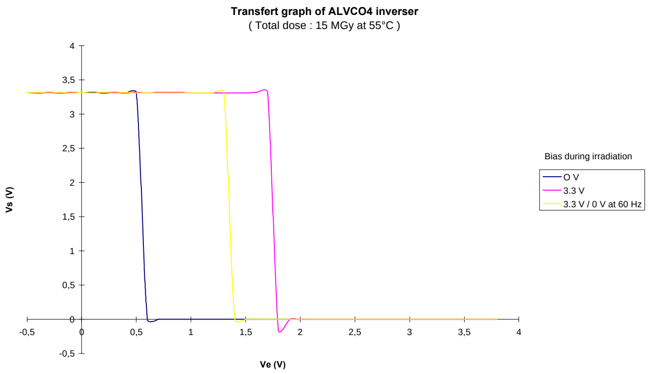
Picture 1-6 : Response of 74AC04 invertor



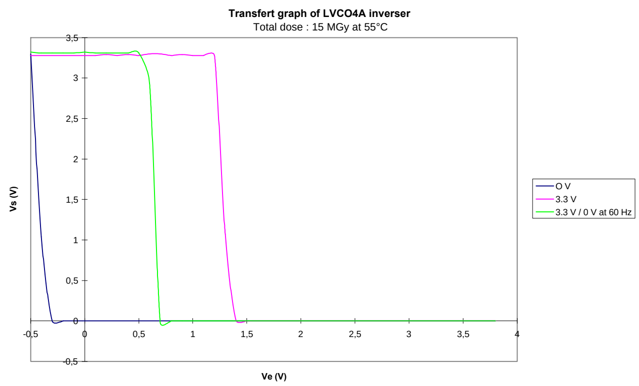
Picture 1-7 : Response of 74LVQ04 invertor



Picture 1-8 : Response of 74LVC04 invertor



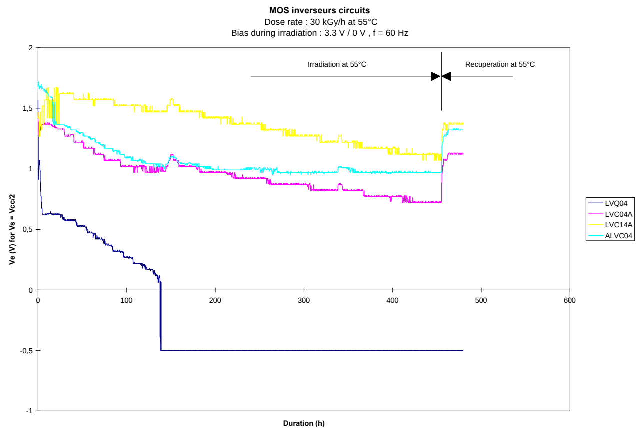
Picture 1-9 : Response of 74ALVC04 invertor



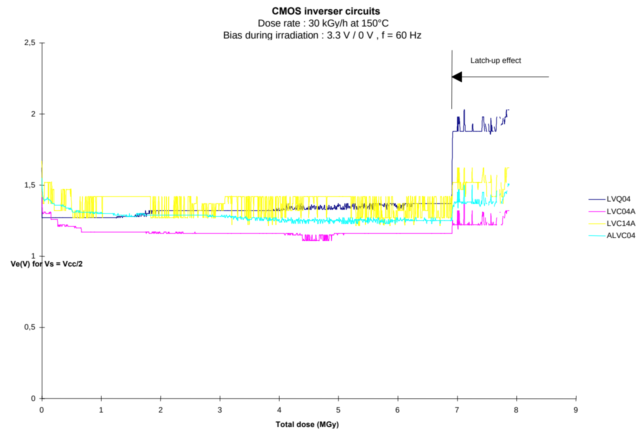
Picture 1-10 : Response of 74LVC04 invertor

To permit an easy comparison of the influence of irradiation on all these technologies, Picture 1-11 represents on-line measurements of dynamic voltage visualised by a new parameter: the input voltage necessary to have output voltage equal to Vcc/2 (3,3V/2), intermediate voltage obtained during switching state.

Clearly, invertor function is lost for LVQ technology. Degradation for LVC technology is limited while ALVC is left almost unaltered after a step appeared around 300Mrad. Subsequently, intermediate voltage recovers partially. LVQ technology remains unable to function.



Picture 1-11 : Vin for Vout = Vcc/2



Picture 1-12 : Vin for Vout = Vcc/2 at 150°C

With the newest technology and components, data have been obtained for combined heating (150°C) and irradiation effects. Good results were obtained until 7MGy. Unfortunately, an increase of current was appearing probably due to LVQ component as shown on Picture 1-12, called improperly "latch up effect". Campaign was stopped but data give sufficient idea of combined effects significant.

It is easy to see a positive influence of heating for all technologies. Drifts are limited to few hundred of mV followed by a quasi permanent state.

However, ALVC presents the most significant characteristics with either radiation or combined effect while LVQ stays the leakiest technology.

WORK PERFORMED ON OPTOELECTRONIC COMPONENTS

Optical fibres assessment

Three single mode fibres (Philips, Corning and Oxford) have been irradiated at a dose rate of 3,3 kGy· h^{-1}. An incremental loss was obtained as a function of dose obtained at 1310 nm and 1550 nm.

It is obvious that the pure silica core Oxford fibre suffers a six and eight-fold lower induced loss (dB/km) compared to the standard Ge-doped fibres of Corning and Philips, respectively. Similar comparative results have been presented earlier [4], whereas the radiation induced attenuation of the Oxford fibre remains limited to some 30 db/km at a cumulated dose of 3 MGy. To our knowledge, this is the lowest loss ever reported for a single mode fibre under similar conditions.

Although less important at much smaller doses and dose rates, this qualitatively rad-hard behaviour of the pure silica core fibres becomes substantial for high dose applications, especially when limited lengths of a few 10 m are needed for transmission or acquisition lines. An irradiation stop of 2 days showed a partial recovery (about 10% - 20%) for both fibre types. Analogous outcome were achieved at 1550 nm, though radiation induced losses exceed those measured at 1310 nm with almost 50%, 40% and 30% for respectively the Oxford, the Corning and the Philips fibre. As expected, induced losses are more pronounced at higher dose rates (cf. Figure 1). The experimental results obtained at 3 and 30 kGy· h^{-1} are nonetheless difficult to compare due to the differences in temperature.

At 1550 nm, the resulting attenuation for the Corning fibre decreases roughly with -2 dB· km^{-1}· $°C^{-1}$ when temperature is increased progressively up to 80 °C. When temperature is then again reduced to 45 °C, losses increase accordingly. A strongly different behaviour could be observed before the irradiation started. The initial temperature sensitivity increases progressively from less than -0,3 dB· km^{-1}· $°C^{-1}$ (temperature related bending losses) up to the aforementioned value at a cumulated dose of 10 MGy. At 1,31 µm this tendency is less pronounced (on the order of -1 dB· km^{-1}· $°C^{-1}$) and the response is slower, but results are comparable for both the Corning and the Philips fibre.

As can be seen from Figure 1, each temperature corresponds to a specific growth curve. However, in some cases recovery measurements at room temperature evidence permanent radiation induced losses, which in turn could indicate that these temperature related phenomena are not completely reversible.

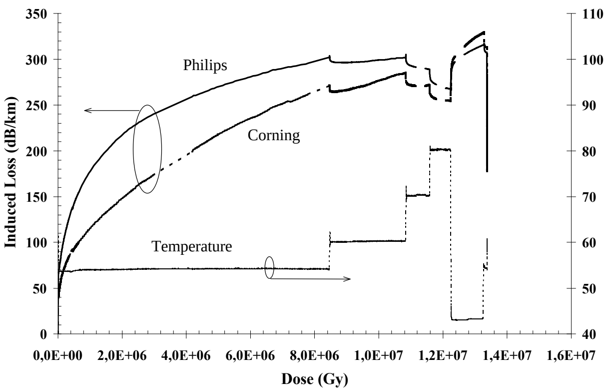


Figure 1 : Induced loss measurements at (a) 1310 nm and (b) 1550 nm for three single mode fibres (dD/dt = 25,5 kGy· h-1) with varying temperature (Pinj < 70 µW)

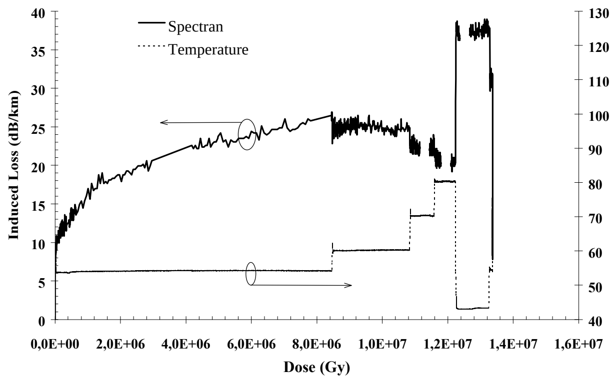


Figure 2 : Radiation induced attenuation as a function of total dose, measured with the Spectran fibre at 850 nm (Pinj < 10 µW).

The scene becomes different with the pure silica-core step-index multimode fibre (Spectran) at 850 nm.

The Figure 2 presents experimental results obtained for this radiation resistant fibre at 25,5 kGy· h^{-1}.

In comparison with our previous results, the influence of dose rate remains limited, whereas temperature variations play an important role in determining radiation induced loss.

The total losses vary approximately with -0,5 dB· km^{-1}· $°C^{-1}$, which corresponds to roughly 2%· $°C^{-1}$ of the radiation induced attenuation at these MGy dose levels.

At a cumulated dose of 13 MGy and a temperature of 45°C, the loss still remains lower than 40 dB· km^{-1}.

Laser diode (LD) assessment

As shown in Figure 3, the output power of the connectorized LD decreased with approximately 6 dB, and partially recovered (≈3 dB) during a two-day interruption.

After a rapid increase of their losses, the available output power remains stable but dependent on ambient temperature.

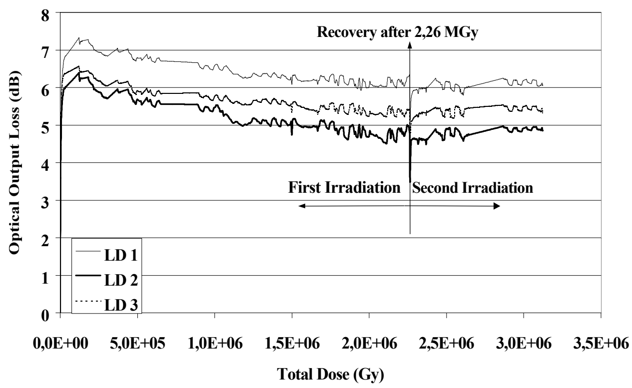


Figure 3 : Radiation induced optical output loss

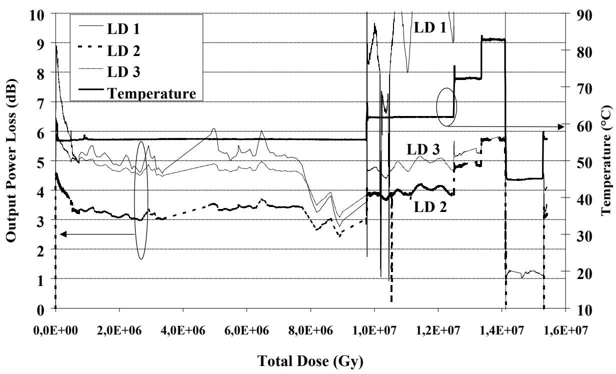


Figure 4 : Behaviour of the MRV laser diodes at 29,4 kGy· h^{-1} and a forward current of 20 mA.

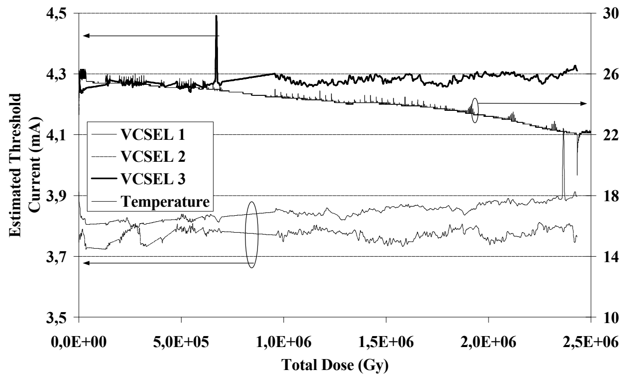


Figure 5 : Estimated threshold current for the Mitel VCSELs at 2,7 kGy· h^{-1} and ambient conditions.

The higher dose rate experiment confirms these first observations (cf. Figure 4). However, the initial decrease of the optical output power is followed by a partial recovery, which might be due to a long-term drift of the measurement equipment.

As temperature was raised up to 60°C, one of these laser diodes failed to operate properly.

The other two components showed an increased loss with temperature, but still operated at a total dose of 15 MGy when a lower temperature was restored.

This again could be explained by a combined effect of radiation and temperature on both the laser diode threshold current and its efficiency.

Vertical cavity surface emitting light (VCSEL) assessment

Periodic measurements showed that the threshold current of VCSELs was left almost unaltered at these high doses and their relative insensitivity to temperature variations is also consistent with literature (cf Figure 5). [5].

Compared to the low dose-rate experiment, the Mitel surface emitting lasers exhibit a considerably larger loss of their optical output power when the irradiation is started.

After one hour (29,4 kGy), we measured yet a loss of about 16 dB (cf. Figure 6).

Subsequently, the output power recovers partially. At this time, it is still unclear whether this should be attributed to the device assembly (e.g. lenses) and/or to long-term drifts of the measurement system.

Note that temperature was first kept constant at 55 °C in the irradiation container. Therefore, it seems unreasonable to ascribe our findings to temperature changes only.

When temperature is raised step-wise up to 80 °C, the losses increase accordingly, but these changes are significantly smaller compared to those recorded for the MRV edge emitting lasers. Again temperature and radiation effects interplay.

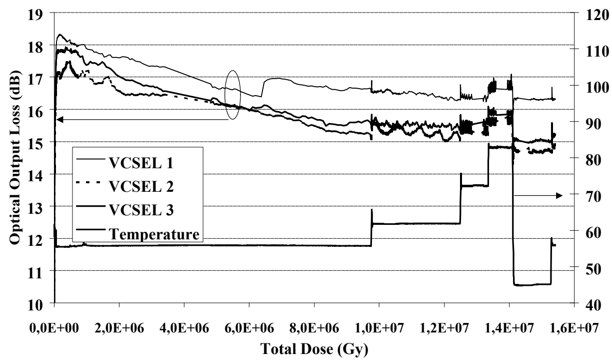


Figure 6 : Radiation induced optical output loss of the Mitel VCSELs at a 12 mA forward current

Photodiode (PD) assessment

Silicon p-i-n photodiodes

The sensitivity of these PDs suffers from a fast and significant decrease at low total dose (cf. Figure 7), while no recovery could be noticed after ending the irradiation. The response of one photodiode is lowered by 6 dB and about 15 dB for the two others. This merely points out that only one photodiode is operational under gamma radiation, at least up to 2 MGy. An explanation could be that these two other components had poor quality prior to irradiation. A statistically relevant number of devices should be tested to further elucidate this question. This should also allow us to verify a possible contribution of an integrated lens to the measured response degradation, as it was yet suggested in literature. [5]

InGaAs photodetector

The sensitivity of these devices was measured at 1310 nm and 1550 nm. Contrary to the Si-PD, these components present a normal behaviour and a limited loss up to 1,3 MGy (cf. Figure 8). At higher doses, these components become severely deteriorated, whereas neither recovery could be noticed during the irradiation stop, nor could we observe a clear temperature dependence (not shown here).

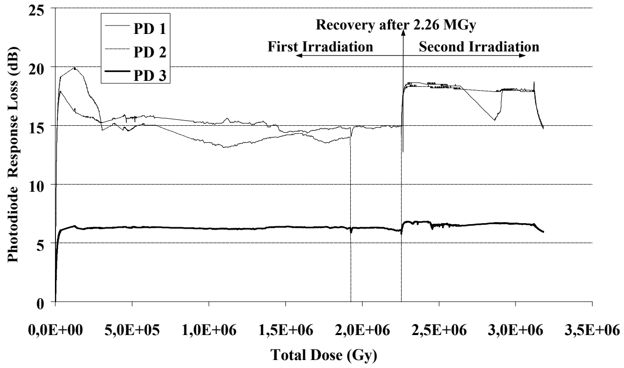


Figure 7 : Radiation induced response loss of the Honeywell Si photodiodes at 850 nm as a function of total dose

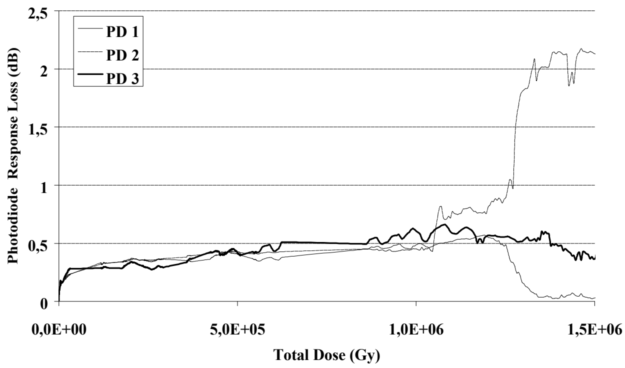


Figure 8 : Radiation induced response loss of the Fermionics InGaAs photodiodes as a function of total dose at 1310 nm

FUTURE ASSESSMENTS

Results obtained on logic components must be confirmed during year 2000 by the irradiation of same components of ALVC or latest technologies coming from several manufacturers to compare the effect of the fabrication process and perhaps, the design of the component. Data given by such parameters are influent for hardening assurance in order to guaranty a better availability for a component.

Characterisation has now started with simple components like buses drivers which are now the first components realised with emerging technologies.

The first results shows that the bias influence is not so perceptible like for previous invertors. ALVC have reached 10MGy for some manufacturers. Detailed results will be done in next report.

Nevertheless, design of final module (analog-digital convertor with possible datalink) should be also engaged in order to define characterisation of new components. It should be also possible that power components will continue to be tested.

For optoelectronics components, the behaviour of the photodiode is not so rad-hard than the other optical components (light emitter or optical fibre). So, we have decide to work on this element for the year 2000. The future experience should assess a greater number of photodiode than the precedent experience to aim to observe the influence of the fabrication process or the structure of the photo-receiver (PIN photodiode, ADP photodiode, ...).

To our knowledge, no publication have reported the effect gamma irradiation on the photodiode for such integrated dose.

The efficiency decreasing can be attributed to the loss induced by colour centre in optical lens in front of the photodiode, it has been already reported in literature [5], but the severely degradation of the photodiode for dose up to 1 MGy have never been reported. With a significant number of tested photodiode, we hope to reveal general rule for the use of photodiodes for such integrated dose. We want to test photodiodes coming from several manufacturers, like Mitshubishi, Fermionics, Siemens, Silicon Detector, Mitel, Alcatel, ... The diversity of manufacturer will able use to compare the effect of process of fabrication or to test the influence of design on the component ageing (structure, nature of the passivating coating, oxide, ...), even if the manufacturers do not want to reveal the precise composition of their components.

A new experimental testbed will be design in order to simplify the existing one and increase the measurement precision. The final goal for dynamic measure is to provide an estimation of the bit error rate (BER) of an optical link for a flow rate of data. A documentation work from the reference [6] have provided indication on the method for BER estimation. The simplest modulation used by optical link is the Manchester modulation. This technique of modulation able the estimation of BER by the measure of the signal to noise ratio (S/B). The signal can be deducted from the all the precedent measure and the noise (or more precisely the spectral noise density) will be measure, hence a division this two results give S/B . Considering a normal noise on each level of the Manchester modulation we can find a relation between BER and S/B. The maximum flow rate will be directly link to the components bandwidth. Hence, when we will have find the most rad-hard component noise and bandwidth measure will be perform to aim to give BER and maximum flow rate of data.

CONCLUSIONS

The past activities for all these components have well defined their behaviour. Electronic power components have shown that function is always existing after 10MGy and 150°C. The use of such components is possible as soon as some design rules will be applied to reduce effect of drifts of characteristics.

Logic components and technologies have shown results in the same order even one of them did not support so high radiation level. But, an extrapolation for all logic components of specified technology have to be proven. ADC demonstrator seems to be always expected.

Components of a fibre optical link, fibre optic and light emitter is sufficiently radiation hardened. Fading of the signal can observed but the functionality is preserved. For light receiver work must be carry on to find more radiation hardened component. This will be the immediate work started, after this work, we will begin dynamic measure like spectral noise density and bandwidth, hence we will able to make an evaluation of the BER and the maximum data flow.

REPORTS AND PUBLICATIONS

[1] M. Marceau, "Study of dose effects on IGBT-Types devices subjected to Gamma Radiation", IEEE TNS Vol 46 pp 1680-1685, 1999

[2] M. Marceau, "Study, design and implemantation of a power supply operating under Gamma radiation", NSREC 98, poster session

[3] O. Quittard, "Use of the RICN Mechanism to achieve Annealing of 0, 35µm SRAMS" IEEE TNS Vol 46 pp 1633-1639, 1999

[4] J. Troska, J. Batten, K. Gill, F. Vasey, 'Radiation effects in commercial off-the-shelve single-mode optical fibres', SPIE Vol. 3440, pp. 112-119, 1998

[5] P.W. Marshall, C.J. Dale, E.J. Friebele, K.A. LaBel, 'Survivable Fibre Based Data Links for Satellite Radiation Environments', SPIE CR Vol. 50, pp 189-231, 1993.

[6] F. de Dieuleveult, H. Fanet, 'Principes et Pratique de l'électronique', Dunod, 1997

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T329-4

Task Title : CARRIER AND BORE TOOLS FOR 4" BEND PIPES

INTRODUCTION

This project is an R&D program in remote handling activities for Fusion reactor In Vessel maintenance.

The removal/installation of Vacuum Vessel components often requires cutting, welding and inspection of cooling pipes. To allow the replacement of these components while minimising the space requirements, bore tools are preferred to orbital tools for these operations.

Following the latest ITER developments, an effort to standardise the pipes inside the cryostat is underway. One of these standards could be 4" pipes (100 mm ID). These pipes will be bent with a bending radius greater than 400 mm and cutting / welding will be required up to 10 meters away from the tool insertion point.

The objective of this task is to demonstrate the feasibility to operate with bore tools in 100 mm bend pipes and to study the associated mechanism required.

This task includes design activities, manufacture and testing of a demonstrator of the basic steps of 100 mm bend pipes maintenance.

A modular carrier design was proposed to fit the requirements :

- Set up tools from pipe entry point to working zone (10 meters).
- Position tools at the correct location.
- Generate stress in pipe :
    * clamping on pipe,
    * compensate internal pipe stress after cutting (100 daN),
    * align two faces of pipe before welding (20 mm axial, 10 mm radial 100 daN).
- Provide necessary rescue functions.
- Process tools required for pipe repair are :
    * milling, to cut 80% of the pipe,
    * final cutting with a cutting wheel,
    * tack welding,
    * butt welding with filler metal,
    * non destructive testing to check the quality of the operation.

1999 ACTIVITIES

First basic feasibility has been demonstrated during 1998 activities. This year’s work focused on the more detailed proof of the feasibility on integrated tests. We've done Manufacturing and testing of the function and process modules, programming a friendly user’s interface for use in remote handling conditions, manufacturing of an insertion device for the carrier. In addition, this year we've started to analyse implication of the new ITER requirement in order to check the feasibility and to point out new key issues of this R&D activity.

FUNCTION MODULES

Two kind of modules are designed for the carrier : the process modules (one per carrier) which carry the different processing tools and the function modules which perform the basic functions needed for all the process operations. These modules are the alignment module which aligns/releases the two parts of the pipe before/after welding/cutting, the clamping modules which withstand the forces and torques generated by the work in progress and the annexes modules which are storage facilities.

As required in the specifications, the strokes available on the alignment module are of 20mm for the axial motion and 10mm radialy. With help of a collar screwed on one part of the pipe, tests showed that the coaxiality of the two parts is under 0.5mm at the end of the radial motion if the pipes diameters are the same. In the axial direction, the two parts are brought to contact without any problems. The performances tests of the clamping module showed that that the carrier was able to withstand an axial force close to 150daN and a torque close to 60Nm before sliding.

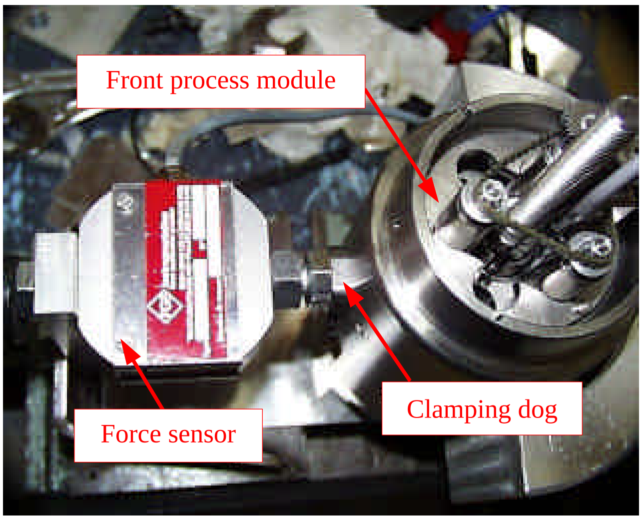

Figure 1 : Test on the power of the clamping module

PROCESS MODULES

It was decided to manufacture only the most representative tools. While using the final cutting tool and the tack welding tool you need to generate stress in the pipe either to release the two parts of the pipe after cutting or to bring them to contact before welding. For these reasons, they are considered to be the critical ones.

Tests of the tools on test benches are in progress.

Tack-welding tool

The degrees of freedom for the tack welding tool are two translations (penetration of the torch, positioning along the pipe's axis) and one rotation (around pipe's axis).

After tuning, with a 60A intensity and a 7l/min Argon flow, it was possible to make a 10mm length spot of good quality. A coaxiality error of the pipes of 1mm on the radius has no influence on the quality of the weld. Positioning of the carrier is roughly made. Therefore a camera will be added on the tool in order to help the operator to reach the exact welding place.

Final cutting tool

Improvements on the final cutting tool are currently in progress in order to reduce the internal friction in the tool and give more power for the cutting operation.

USER'S INTERFACE

A controller was built using the Labview program. The interface is divided in sections in which all the basic operations are detailed. One is for the remote operations of the carrier : making the carrier rigid, clamping of the carrier in the pipe, alignment of the pipes. The others are dedicated to the different process (one per process).

INSERTION DEVICE

The carrier is pushed towards the working area with help of a fibre glass rod. Measuring of the inserted length of the fibre gives the position of the carrier in the pipe. Tests showed that the accuracy of this methodology is of 2mm for a pipe with one bent section. A rod-pusher was designed and manufactured to push on the fibre.

UPGRADE STUDIES

Upgrade studies are under run to increase today's performances and to take into account the possible evolutions of ITER's design. The identified items are :

- reduction of diameter and bending radius of the pipe,
- increase of the clamping power,
- suppression of the groove machined in the pipe needed by the alignment module to bring the two parts of pipe to contact,
- improvements on the processing tools.

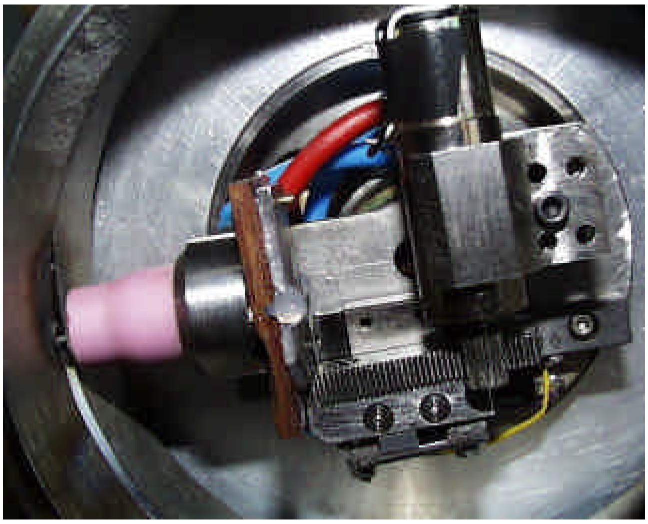

Figure 2 : Tack welding tool on test bench

Figure 3 : Rod pusher

CONCLUSIONS

An innovative modular system of carrier was proposed and designed in 1998. Manufacturing and testing of the functions and tools of the carrier has been made in 1999 and a interface for using in remote handling was built. The upgrade studies started at the end of the year will prepare the future work in which the following steps will be studied :

- Onboard test of the manufactured tools.
- Manufacturing of more powerful clamping devices.
- Improvement of the alignment module.

- Feasibility study of the implantation of a laser cutting-welding tool.

- Improvement of the final cutting tool.

- Manufacturing of a storage and umbilical management device.

REPORTS AND PUBLICATIONS

[1] European Fusion Technology Programme - Task Action Sheet T329-4 "Bore tools for 100 mm bend pipes" October 16th, 1997

[2] European Fusion Technology Programme - Task Action Sheet T329-4 EXTENSION "Bore tools and carrier for 100 mm bend pipes" May 15th, 1998.

[3] European Fusion Technology Programme - Task Action Sheet T329-4 EXTENSION2 "Bore tools and carrier for 100 mm bend pipes" July 31th, 1998.

CEA/DPSA/STR - ref. STR/LAM 98/22 rel.0 " Analyse de la faisabilité de l'intervention de maintenance d'ITER par l'intérieur dans des tubes coudés de 4" T329-4". Y. PERROT, August 1998.

CEA/DPSA/STR - ref. STR/LAM 98/067 rel.0 " Bore tools and carrier for 100 mm bend pipes T329-4 Intermediate Task Report". Y. PERROT, August 1998.

CEA/DPSA/STR - ref. STR/LAM 99/024 rel.0 "Carrier and Bore tools for 4" bend pipes, Etude, réalisation et essais d'une maquette de porteur". Y. PERROT, March 1999.

CEA/DPSA/STR - ref. STR/LAM 99/025 rel.0 " Carrier and Bore tools for 4" bend pipes, T329-4, Report on tools manufacturing and commissioning". Y. PERROT, March 1999.

CEA/DPSA/STR - ref. STR/LAM 99/095 " Carrier and Bore tools for 4" bend pipes, T329-4, test report on clamping modules. “ Oct. 99

CEA/DPSA/STR - ref. STR/LAM 99/114 rel.0 " Carrier and Bore tools for 4" bend pipes, T329-4, 1999 Intermediate task report ". Y. PERROT, O.DAVID December 1999.

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T329-5

Task Title : IN VESSEL RH DEXTEROUS OPERATIONS
Task extension 2

INTRODUCTION

The T329-5 project aims at demonstrating the feasibility of effective remote handling dexterous operations for the Divertor maintenance. A derived goal is the development of the missing technology required to achieve the primary objective.

The main action consists at performing a representative maintenance operation under the so called "blind" conditions (without video feedback) by making full use of a 3D CAD model of the remote workspace. For this purpose, an experimental site (RIS for Remote Intervention System) will be set up inside the DTP (Divertor Test Platform) located at the ENEA Brasimone site. This test-bed is built around a MAESTRO master-slave hydraulic manipulator driven by a TAO 2000 telerobotics controller [2]. The system is operated through a force-reflecting master arm and a Graphical Supervisor [3] that simplifies the preparation and the supervisory execution [1] of the remote missions. It will be used to demonstrate under realistic conditions that a maintenance mission possibly leading to some unexpected situations may be successfully realised by current telerobots.

The technological developments of T329-5 deal with the following topics :

- registration of environment objects using points sensed on their surface with a touch probe ; the necessary computations are made by the SCK/CEN BLINE module ;
- long distance teleoperation in order to allow an operator to control an intervention system located several hundred kilometers away ;
- water hydraulic that would better suit the contamination constraints of ITER.

1999 ACTIVITIES

The activities of this year may be summed up as follows :

- mission analysis aiming at defining the mechanical, electrical and software interfaces of the RIS for installation inside the DTP ;
- set up of the RIS at CEA ; it comprises a MAESTRO manipulator, an MA-23 force reflecting master arm, a TAO 2000 control system, a preliminary Graphical Supervisor, various tools and their associated equipments and a simplified mock-up of the DTP ;
- specification of the Graphical Supervisor taking into account the additional functions required by the maintenance mission and the interfaces with both the BLINE module and the control system of the DTP ;
- specification of a single water hydraulic joint suited to the MAESTRO manipulator.

The considered mission for the maintenance demonstration is composed of 2 tasks (figure 1) :

- defining the exact location of a Divertor Cassette using the BLINE module fed with contact positions sensed by the touch probe,
- operating the Cassette Locking System with a special bolt tool.

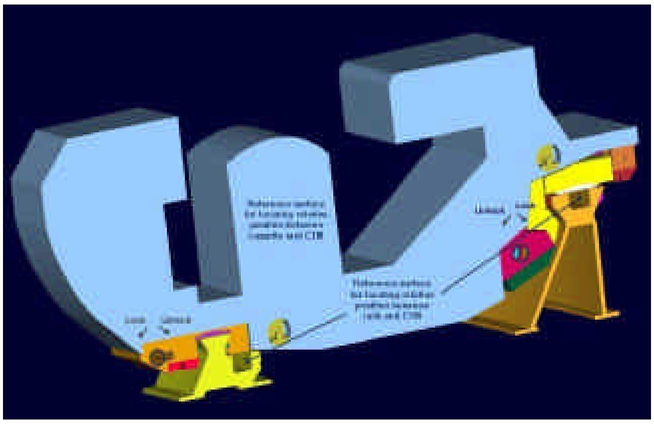

Figure 1 : CAD view of a Divertor Cassette (the CTM is the Cassette Toroidal Mover that moves inside the DTP and carries the RIS)

The analysis of the mission has allowed the clarification of the interfaces of the RIS, in particular :

- the fixing of the RIS inside the DTP,
- the location of the hydraulic power unit,
- the location of the tool rack,
- the arrangement of the hydraulic and electrical leads for the MAESTRO,
- the data that must be exchanged between, on the one hand, the RIS Graphical Supervisor and, on the other hand, the DTP control system and the BLINE module.

An intermediary goal is to develop a preliminary RIS site in CEA (figure 2) featuring a simplified DTP mock-up. The idea consists in carrying out significant full scale testing before sending the RIS in Brasimone during 2000.

A first study was made under ROBCAD with the ITER model for designing the bolt tool for CLS operation (figure 3) and the touch probe for BLINE registration (figure 4). Upon receiving from ENEA the model of the DTP, the initial design was validated so as to check the RIS clearance with respect to existing obstacles and the attainability of the work volumes. The parts were then manufactured (figure 5).

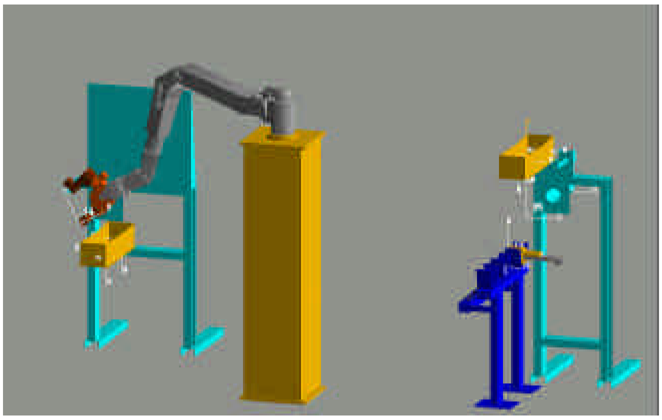

Figure 2 : CAD view of the RIS site set up in Fontenay-aux-Roses CEA facility

Figure 3 : Bolt tool

Figure 4 : Touch probe

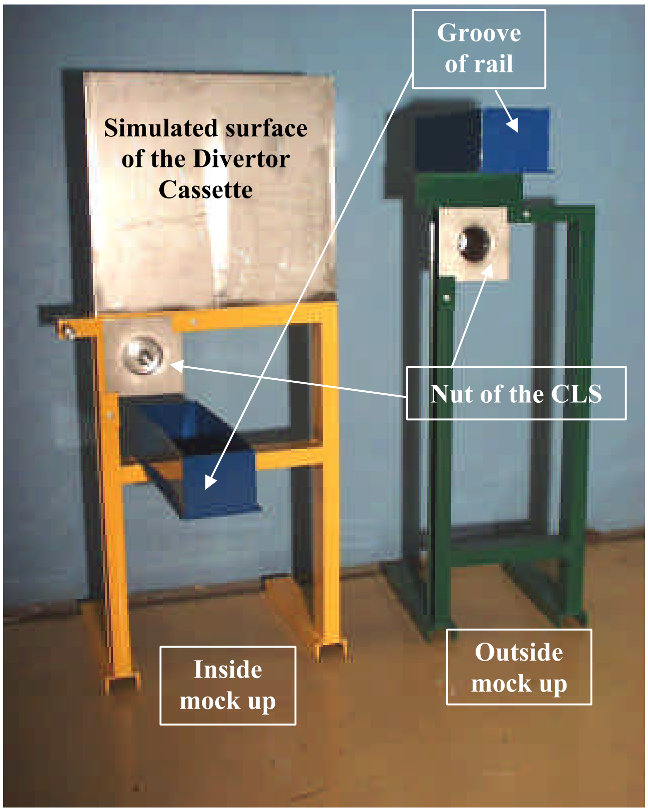

Figure 5 : Simplified mock-up of the DTP

After much discussions with ENEA and SCK/CEN, the software interfaces and the additional functions of the RIS Graphical Supervisor have been defined. The MCP protocol developed by CEA has been retained for exchanging messages and special care has been given to the procedure for importing the DTP model delivered by ENEA. The coding of the Graphical Supervisor is now well advanced but not yet validated.

As far as water hydraulic is concerned, the single joint mock-up has been specified by CEA. It is now being realised by the Finish IHA partner and will be sent to STR in may 2000 for an assessment of its performances and controllability.

CONCLUSIONS

From a general point of view, this year may be described as a preparation phase where all the components have been specified, designed and/or manufactured in order to demonstrate the RIS at ENEA Brasimone facility in the frame of the selected maintenance mission.

The first test campaign is scheduled in Fontenay-aux-Roses (CEA) for the beginning of 2000 in order to validate the RIS and the BLINE module before sending all the equipment to Brasimone. The Brasimone mission will take place in the middle of 2000 and the corresponding reports issued before the end of the year.

On the technological development side, the BLINE software will be demonstrated in the same Brasimone mission as the rest of the RIS. The preliminary results obtained from IHA seem very promising and the potential of water hydraulic will be most probably confirmed in the middle of 2000. As far as long distance teleoperation is concerned, some delays in the definitive installation of the RIS in Brasimone have precluded the early implementation of the initial scheme (controlling the RIS at Brasimone from a control station located in Fontenay-aux-Roses). Instead, a similar experiment is now planned for spring 2000 between the 2 CEA facilities in Pierrelatte (south of France) and Fontenay-aux-Roses (near Paris).

REPORTS AND PUBLICATIONS

[1] G. André, R. Fournier, "Generalized end-effector control in a computer aided teleoperation system", Proc. ICAR’85, Tokyo, 1985.

[2] R. Fournier, P. Gravez, P. Foncuberta, C. Volle, "MAESTRO hydraulic manipulator and its TAO-2000 control system", Proc. 7th ANS Topical Meeting on Robotics and Remote Systems, Augusta (USA), avril 1997.

[3] Y. Masson, P. Gravez, R. Fournier, "A graphical supervision concept for telerobotics", Proc. 1998 International Symposium on Robotics, 1998.

T329-5: In-Vessel RH Dextrous Operations - Requirements of a Hydraulic Power Supply for MAESTRO (Technical Report STR/99.036), François Louveau.

In Vessel Remote Handling Dextrous Operations : Set up of Graphical DTP Model (Technical Report STR/99.013), Christophe Leroux, 8 February 1999.

Specification of a Message Communication Protocol for Teleoperation : MCP 2.0 (Technical Report STR/99.034), Christophe Leroy, 26 March 1999.

Technical Specification of the RIS-GS (Technical Report STR/99.118), Philippe Gravez, 10 January 2000.

T329-5: In-Vessel RH Dextrous Operations - Specification for MAESTRO Water Joint (Technical Report STR/99.073), François Louveau.

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PPA 3.2.1

Task Title : INTEGRATION AND PLANT AVAILABILITY
Review and assessment of possible maintenance schemes

INTRODUCTION

The Fusion program within the EU, is likely to launch in the year 2000 a fusion power plant study with the main objective of specifying the characteristics of an attractive and viable D-T power plant in order to define major guidelines for fusion-related R&D in the next decades.

Impact of the maintenance on the availability is a major concern when considering discussion on main options for a commercial fusion power station. There is no project that describes a formal method to take into account maintenance issue during design activities. Major advanced studies dealing with maintenance during pre-design activities have been reviewed. ARIES, SSTR, SEAFP, DREAM and CREST power plant studies are "scheduled maintenance" oriented designs. In addition to this design studies, Remote Handling R&D activities on the experimental reactor (ITER-EDA), and JET In-Vessel Remote Handling campaign offers a first set of results to estimate the maintenance time. This first set is the unique input to evaluate maintenance time to quote availability.

This studie describes preliminary assessment on general scheduled maintenance scheme.

1999 ACTIVITIES

Standards for Nuclear Power plant Facilities (French codes RSE-M "Règles de Surveillance en Exploitation des Matériels Mécaniques des Ilôts nucléaires", or UK codes " in Services Inspection rules for the mechanical Components of PWR nuclear Islands, or ASME codes Section XI) gather all operating practices relating to the mechanical components of PWR nuclear islands.

Maintenance activities usually include overhaul, replacement, tests and inspections. The activities should ensure that the systems and the equipment are maintained in good condition and that high reliability is achieved.

Conventional outline of the maintenance standards includes the role of **Inspection**, **evaluation** and **repair** in the maintenance scheme.

As a Nuclear Power plant facility, fusion reactors also requires scheduled maintenance. Due to the radiation level, which prevents from hands on maintenance and due to the number of component to replace frequently, in-vessel maintenance of Tokamak fusion reactor is a major concern and drives the availability.

The role of inspection in the maintenance standards is to confirm that the facility is maintained within the examination acceptance standards. Major items to be specified for the inspection are :

- equipment (In-Vessel component to replace),
- inspection technique to be applied (Remote techniques),
- frequency of the inspection (driven by the lifetime of the component),
- acceptance standards (To be defined).

Detailed **evaluation** is permitted when inspection results do not meet the examination acceptance standards. Similarly, detailed evaluation will be permitted when the operating data indicates the possibility of a deviation from the design criteria such as fatigue usage factor. In-Vessel evaluation requires remote techniques. The following evaluations could be involved :

- flaw analysis, (piping for example, under pressure structures …),
- evaluation for fatigue crack initiation,
- evaluation of erosion,
- fractures toughness evaluation.

The **role of repair** in the maintenance standards is to provide the various kinds of repair procedures. Situations where repair is required are :

- Repair is needed as a result of the detailed evaluation.
- Repair is performed as a result of preventive maintenance.

In the case of a Fusion power plant, most demanding repair operations concerns removal of in Vessel component such as blanket modules or divertor.

Fusion power plant requires a **large amount of maintenance operations**.

Since the reactor core will be highly activated due to DT operations, the assembly and maintenance of the components inside the Vessel will require Remote Handling means.

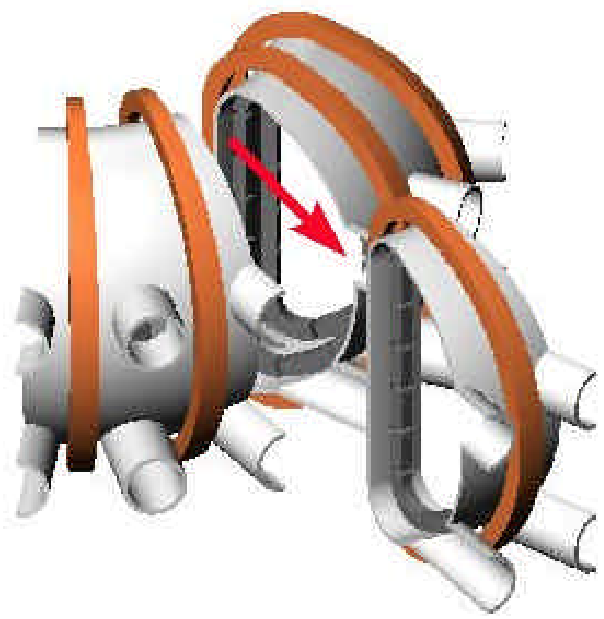
Unlike Fission plant, a fusion power plant does have a significant number of In-vessel component that do not last the lifetime of the reactor and should be replace once or several times. Therefore, a classification of In-Vessel component that requires remote maintenance must be established.

A conventional classification (used for ITER) defines 3 categories :

- **Class I : Scheduled maintenance**. This class of component requires replacement several times during Power plant lifetime. Divertor and blanket modules
- **Class II : Infrequent maintenance**. This class of component requires replacement at least once during Power plant lifetime.
- **Class III : Not scheduled replacement**. Component that last lifetime of the reactor but could require scheduled inspection and exceptional maintenance should be considered.

Maintenance scheme depends on the Tokamak configuration, the In-Vessel component segmentation and the access port available.

The general In-Vessel assembly/disassembly scheme is usually described as 3 different types :

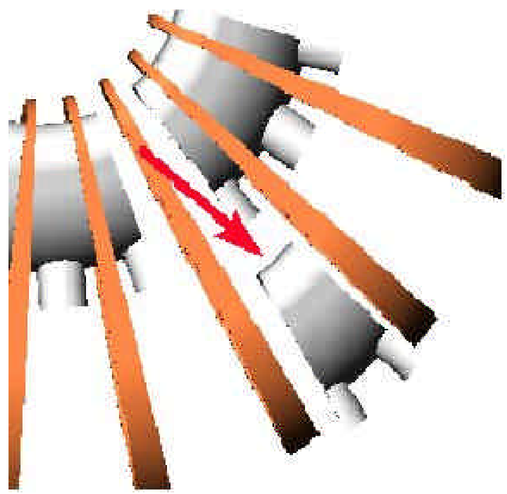


TYPE I

Torus is equally sectored. Each sector unit is handled with the toroidal coil. Beforehand, coil should be warmed-up and cooling pipes should be disconnected. Cut of Vacuum Vessel and cryostat is necessary. Handling could be either vertical or horizontal. Design sample ARIES I.

TYPE II

Modularised blanket is removed trough In-Vessel direct access. Beforehand piping and mechanical support should be released. Warm up of coils is not required. No cut of Vacuum Vessel nor cryostat is necessary. Handling could be either vertical or horizontal. Design sample : ARIES II, III, IV, SEAFP, SSTR, ARIES RS, CREST, ITER EDA.



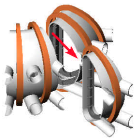
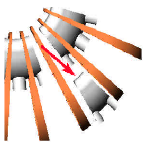
TYPE III

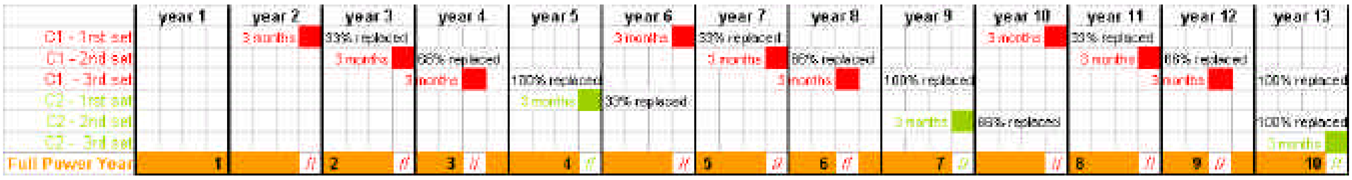
Equally sectored unit is removed without removal of coil. Large toroidal coils are required. Warm up of coils is not necessary. Cut of Vacuum Vessel is necessary. Horizontal handling motion is required. Design sample : DREAM.

A significant part of the 1999 activity concerns the comparison of different maintenance schemes with an estimation on the overall consequences an availability starting from an analysis of earlier studies in Europe and other countries.

Based on this analysis, we have assessed what could be the implication for the design when considering high availability.
Therefore a review of the main design drivers that have an impact on the availability and a review of the most demanding Remote handling operation has been performed.

Analysis of earlier studies

			FIRST WALL			DIVERTOR	
			Basic module definition	Access	Frequency/delay	Access	Frequency/delay
TYPE I 	**ARIES-I**	16	1 toroidal coil 9 Outboard modules (1rst wall and blanket) 6 Inboard modules (1rst wall & blanket) Lower & upper Divertor Vacuum vessel	Vertical	2 to 4 per year, 28 days for 2 modules	Dedicated ports	76 % of availability, including 60 days of unscheduled maintenance.
TYPE II	**ARIES II & IV**	16	9 Outboard modules (1rst wall and blanket) 6 Inboard modules (1rst wall & blanket) Lower & upper Divertor	Horizontal, in-between TFC Port through vacuum vessel No warm up of Coils			
	ARIES-III	20	modules (1rst wall & blanket)	Vertical	0 for the first wall	Dedicated ports at lower Divertor level	
	**SSTR**	16	3 inboard modules. 3 outboard modules.	Vertical	Every 2 years for outboard, Every 4 years for inboard. 100 days maintenance per year	Dedicated ports	
	SEAFP	16	modules (1rst wall & blanket)	Vertical	15 month for the blankets	Dedicated ports at lower Divertor level	2 months for upper and lower Divertors
	ARIES-RS	16	1rst wall, blanket, Divertor.	16 Wide RH ports	Every 2.5 years, one month	No divertor RH port.	
	CREST	14	1rst wall, blanket, Divertor.	14 Wide RH ports, 3 in //	3 months delay	14 RH ports in //	3 months delay.
	ITER/EDA	60	Blanket modules Divertor cassettes	4 RH ports at equat. Work in //	24 months delay for 700 modules	4 RH ports at divertor level	6 months delay, 60 cassettes
TYPE III 	**DREAM**	12	1rst wall blanket Divertor	Horizontal, in-between TFC Port through vacuum vessel No warm up of Coils	85 hours per module	No specific maintenance for divertor	



Availability # 75 %

CONCLUSIONS

After the review of the possible maintenance schemes and an assessment on the design driver that have an impact on the scheduled maintenance, the studies ends with a preliminary time evaluation based on a possible scheduled scenario.

We assume as a maintenance scenario that In-Vessel component are classified into 3 categories depending on the component lifetime evaluated in term of Full Power Year operations (excludes shutdown period).

Maintenance Class : component lifetime

- C1 : 3 FPY lifetime
- C2 : 10 FPY lifetime
- C3 : Plant lifetime

A first time estimation is proposed assuming :

- All ports are R H ports
- Components to replace are made of large modules
- Connections : few & fast
- Hot cells : high flow
- No maintenance during T1 & T2 period
- Replacement time : 3 months for 1/3 of the set to replace (any class)

The previous time schedule of the proposed maintenance scheme illustrates over a 13 years period :

- 3 months max of shutdown period per year.
- 13 years to replace 100% of C1 and C2 class components.
- 10 years of Full Power year for a 13 year period.
- No provision for unexpected maintenance of C3 class components.
- Availability is therefore = 10/13 = 77 %.

REPORTS AND PUBLICATIONS

[1] S. SHARAFAT & al
Design layout and maintenance of the ARIES-IV tokamak fusion power plant.
IEEE 1994

[2] S. NISHIO & al
The concept of drastically easy maintenance (DREAM) tokamak reactor.
Fusion Engineering and Design 25 (1994)

[3] R. HAANGE (for ITER JCT)
Overview of remote-maintenance scenarios for the ITER machine.
Fusion Engineering and Design 27 (1995).

[4] E. TADA & al
The blanket and Divertor Maintenance Concept for ITER
19th symposium on Fusion Technology (1996)

[5] EFFET – FRAMATOME/FIATAVIO
Planned maintenance procedures.
Safety and Environmental Assessment of fusion power Long-term programme (SEAL)

[6] S. MALANG
ARIES-RS maintenance approach for high availability
Fusion Engineering and Design 41 (1998)

[7] D. MAISONNIER
In-Vessel maintenance for a Next Step machine
NET-Team (Dec 1998)

[8] Y. ASAOKA & al
Maintenance and safety aspects of the CREST reactor
ISFNT 5 (Sept 1999)

[9] L. GIANCARLI, M. FERRARI, M. A. FÜTTERER, S. MALANG
Candidate Blanket Concepts for a European Fusion Power Plant Study
ISFNT 5 - Rome (Sept 1999)

[10] D. J. WARD
Impact of Availability and other factors on Fusion Economics
Plant availability programme task 3.3
PPA/3.3/UKAEA/2

P.P.A. 3.2 Maintenance of a commercial Fusion Power Station – Review of the possible maintenance schemes
CEA-DPSA-STR-LAM/99.029

P.P.A. 3.2 Maintenance of a commercial Fusion Power Station ASSESSMENT ON AVAILABILITY-*CEA-DPSA-STR-LAM/99.115*

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UT-RH1

Task Title : REMOTE HANDLING TECHNICS
Technology and control for remote handling systems

INTRODUCTION

Hydraulic manipulators are candidate for fusion reactor maintenance. Their main advantages are their large payload with respect to volume and mass, their reliability and their robustness. However due to their force control limitations, they are not relevant for precise manipulation. NDT (Non Destructive Testing), or welding operations, require high performance at low-velocity and accurate position control. For safety reasons, it is necessary to improve force control efficiency, specially when contact appears between the manipulator and its environment for both expected and unexpected situation.

CEA in collaboration with CYBERNETIX and IFREMER has developed the advanced hydraulic robot MAESTRO (Modular Arm and Efficient System for TeleRObotics).

This teleoperated hydraulic robot is dedicated to extreme environment applications. It has been designed for operation requiring high level of performances in term of dexterity, repeatability, accuracy and force control. The main constraints attached to the design of this manipulator are the modularity of the outline design with a variable number of joints and adaptable length of segments, the easiness to operate the arm on a carrier or inside a hot cell and low time consumption for maintenance.

A special effort has been made on the mechanical design of the actuators to reduce stick-slip phenomena and permit active force control laws; low friction and stricktion, low level of internal leakage and pressure sensors on each joint. MAESTRO is the first heavy duty manipulator showing such a high performance compromise between dexterity, force control and large payload (100 kg).

The aim of the action is to adapt and improve technology and control for fusion remote handling hydraulic manipulators. The present control scheme relies on articulated torque control. This technique allows a fine control of the force applied on the handled tools and a clever collision detection on all the arm surface. But it leads to a substantial complexity in term of wiring sensors and electronics. Two actions will be performed to simplify electronics and wiring for nuclear hardening :

- A new and attractive way to implement force and hybrid control, is to use integrated force-torque sensors to replace pressure sensors or specific pressure valves. The classical location of such a sensor in the wrist of the arm is not well suited for radiation hardening. So a theoretical study has be performed to test the feasibility of using a 6 axis force-torque sensor located in a safe place at the base of the manipulator. The results of this study can be applied to a large variety of hydraulic or electric manipulators.

- In a previous study we have shown on a dedicated mock-up that using specific pressure valves allows to suppress pressure sensors and corresponding wiring. The feasibility of implementing such valves inside the MAESTRO manipulator will be now studied.

Some of these improvements will be integrated and demonstrated on an operational manipulator.

1999 ACTIVITIES

A 6 AXIS FORCE-TORQUE SENSOR LOCATED IN THE BASE OF THE MANIPULATOR

To control a master slave system, the slave arm has to be as transparent as possible.

To improve the transparency of the system, the slave arm has to be equipped with a force sensor. At the present time there are two solutions to instrument a slave arm: a wrist force sensor or a joint torque sensor.

The solution using wrist force sensor has the following limitations :

- You can not detect contacts between the body of the robot and the environment.
- You can not use the sensor to cancel the dry friction torque when the robot is not in contact with the environment.
- The sensor wiring is complex and difficult to maintain.

The solution using joint torque sensor has the following limitations :

- Requires a specific design of the manipulator which as an impact on the cost.
- You can not use this solution on existing industrial robots.
- You can not cancel the dry friction torque which are located after the sensor.
- The sensor wiring is complex and difficult to maintain.
- The mechanics of the joint transmission is more complex.

In order to overcome all these limitations you can use a force sensor located at the base of a manipulator. This solution should be useful :

- To improve the transparency of the slave arm.
- To detect the eventual contacts between the arm segments and the environment.
- To cancel the joint dry friction torque.

But this solution requires the following studies :

- To study the dynamic model of this new system, this study motivates the first part of this report.
- To study the control oh this new system, this study motivates the second part of this report.

For all these facts and the general objective of improving the transparency of the master slave system, the project « study on the use of a 6 axis force torque sensor located at the base of a manipulator » has evaluated different strategies to control the system by using of a 6 axis force torque sensor located at the base of a manipulator.

TECHNICAL OBJECTIVES

- Improvement of the transparency (master slave system).
- Detection of the contacts between the segments of the robot and the environment.

Overview of the study

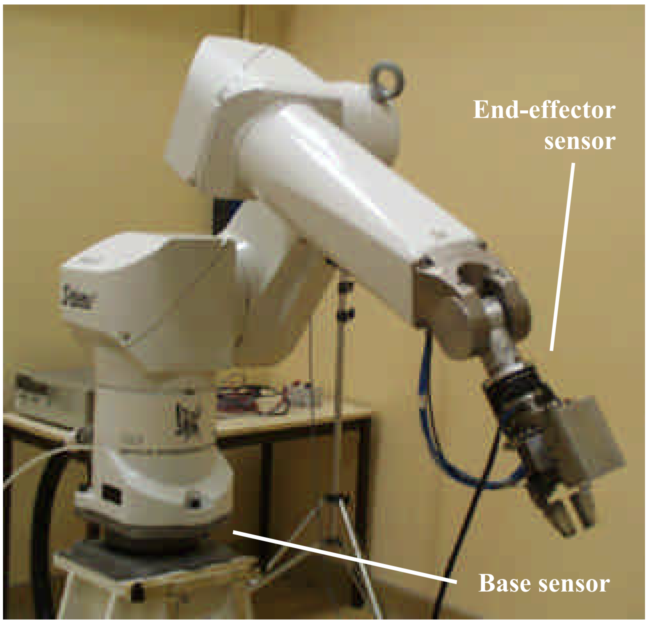
The study was composed of two parts

1. In the first part, we have detail three different methods to obtain the dynamic model of the robot seen from the base.

   - We have studied the Newton Euler method and adapted it to obtain parameters model which would be identifiable.
   - We have studied the Lagrange method to obtain the dynamic joint model using the wrench base force sensor.
   - We have selected a screw method to link the Lagrange and Euler methods. The screw method [Ploen 97] can describe the reaction forces for each joint (Newton Euler), but it can also describe easily the joint dynamic model of the arm in a matrix form (Lagrange).

2. In the second part, we have studied the force control of a robot equipped with a force sensor located at the base of the manipulator. The force control of the arm has three objectives.

   - To regulate the interaction wrench between the arm wrist and the environment.
   - To decrease the apparent inertia of the arm, to cancel the dry friction torque and the weight of the manipulator and the load. The closed loop arm becomes more transparent.
   - To detect the eventual collisions between the segments of the robot and the environment.



THE FEASIBILITY OF IMPLEMENTING PRESSURE SERVOVALVE

The concept has been validated with servovalve 1567420 made by LHC (INTERTECHNIQUE group).

The characteristics of this servovalve have been carried out :

- static characteristic from the manufacture
- identified static characteristic

  * pressure response
  * frequency response
  * step response

Test mock-up

The mock-up has been tested using the following simple control law :

Pressure in the room 1 : $P_1 = \dfrac{(P_a - P_u)}{2}$

Pressure in the room 2 : $P_2 = \frac{(P_a + P_u)}{2}$

with :

P_a	:	difference of pressure between the alimentation and the return to the hydraulic power supply
P_u	:	difference of pressure between the two rooms of the joint

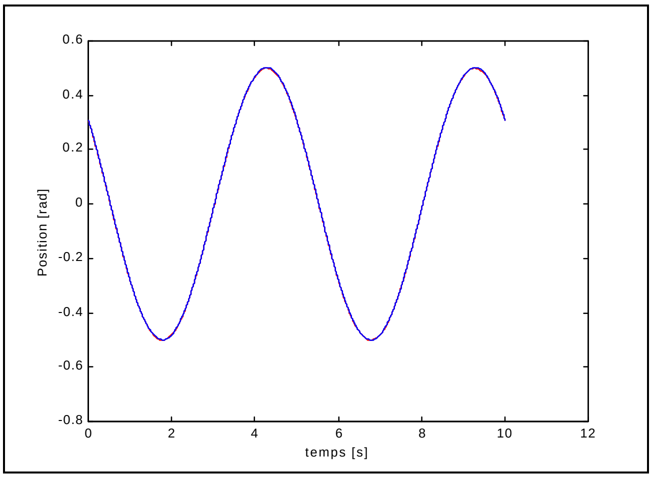
P_a depend of the equipment. It is controlled by the power supply. This pressure must be measured if it changed in time.

P_u is calculated from the desired force (Γ_c) with the formula :

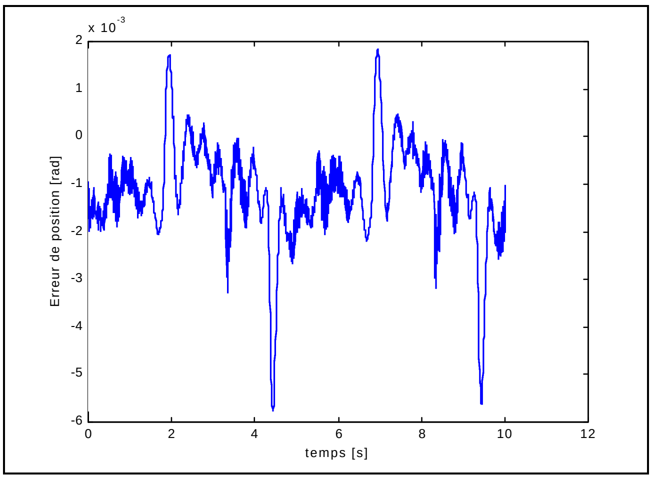
$$P_u = \frac{\Gamma_c}{100.D_m}$$

Dm is the characteristic surface of the joint.

A position loop has been tested on this mock-up. A simple « PD » controler has been used. It shows how could run the teleoperation laws which are made to simulate a spring and a damper.

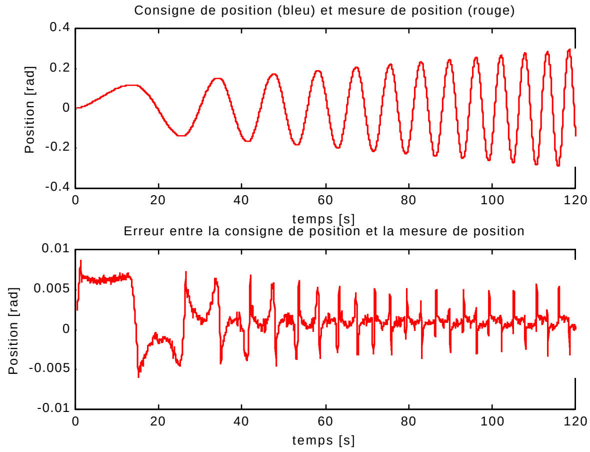


Desired and measured position



Error between the desired and measured position

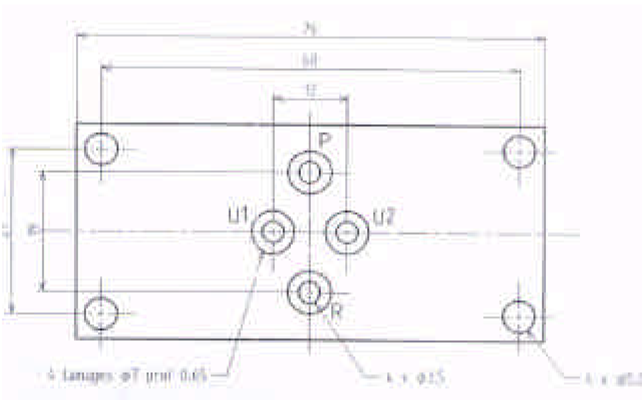
We can compare this result regarding the record made with standard servovalve and pressure sensor :

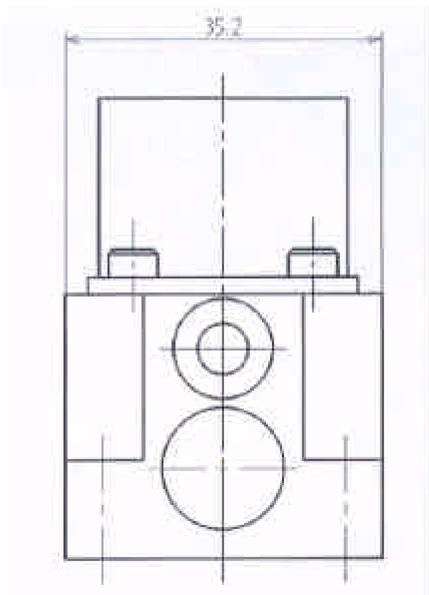


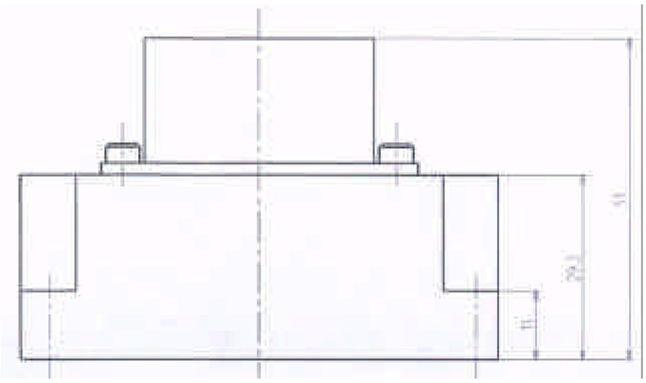
The control is more precise with the pressure servovalve.

As the performances are good, we check if it is possible to integrate such servovalve in a MAESTRO.

These study has be made with the IN-LHC company. The goal is to manufacture a servovalve which has the same characteristics than the two servovalves 1567420. It seems that the new servovalve could fit into the following volume.







With these drawings we check the integration into the MAESTRO. The worse case is the part in between the axis 1 and 2. This part include the servovalves of the axis 1 and 2. A 3D model shows that it is possible to use such servovalves in a MAESTRO.

CONCLUSIONS

In the context of telemanipulation, the solution using a force sensor located at the base of a manipulator should be useful :

- To improve the transparency of the slave arm.
- To detect the eventual contacts between the arm segments and the environment.
- To cancel the joint dry friction torque.

On a theoretical point of view, the dynamic joint model using the wrench base force sensor can be used as an observer of the joint torque, and should be used in the controller if the acceleration wrench are important. We notice that the gravity wrench will always be used.

In the second part of this study, we have identified the benefits of using a base force sensor to control the arm in force. The study of the passivity constraints on the simplified models, have shown that the solution using the base force sensor have better passivity properties than the solution with the wrist force sensor. In conclusion the base force sensor solution should theoretically improve the cancellation of the joint dry friction torque. In a other hand, the use of servovalve pressure has be validated. The implantation in a MAESTRO has been checked. So, we have two theoretical solutions to improve the MAESTRO.

REPORTS AND PUBLICATIONS

DPSA/STR/LTO/99RT.061
EUROPEAN FUSION TECHNOLOGYNPROGRAM
Technologies and control for RH systems – Theoretical study on the use of a 6 axis force torque sensor located at the base of the manipulator - Claude Andriot

DPSA/STR/LTO/99RT.0120
EUROPEAN FUSION TECHNOLOGYNPROGRAM
Technologies and control for RH systems - Faisabilité de l'utilisation de servovalves pression et de leur integration dans le MAESTRO - LOUVEAU François

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UT-RH2

Task Title : GRAPHICAL PROGRAMMING FOR REMOTE HANDLING

INTRODUCTION

In the frame of the current UT-RH2 action, the STR has developed and validated in simulation the concept of Graphical Language for the supervision of remote controlled tasks. The objective of this research was to allow operators to easily perform ITER maintenance work using telerobotics systems.

The Graphical Language [4] is based on a representation of the remote environment generated from a 3D geometrical data base modelling the real workspace. The operator observes this environment on a graphical computer interface and he selects the most appropriate points of view with a mouse. His part mainly consists in specifying the tasks to be carried out by manipulating inside the 3D model various virtual tools that interact with the environment objects :

- some of these tools stand for the processes required by the mission (welding torch, pipe-cutter, ...) ;
- others are associated with the robotics functions that are used for carrying out these processes (the automatic orientation of the tool perpendicularly to a surface, for instance) ;
- the purpose of the last ones is to define the parameters of the previous processes and robotics functions (such as measurement tools that help the operators to finely position a mark on the surface of an environment object or a frame in space).

These virtual tools have their own graphical shape and behaviours (like moving along the surface of an environment object) that ease their manipulation by the operator.

Till the beginning of last year, the Graphical Language had been tested in simulation only, therefore without taking into account the inescapable errors between the computer models and the real environment. The main goal of the UT-RH2 1999 action was to implement the Graphical Language on a full scale telerobotic system and to validate it with respect to a representative maintenance mission.

1999 ACTIVITIES

Following the experimental simulations performed in the frame of the previous UT-RH2 actions, the Graphical Language concept has been assessed in the frame of a maintenance mission that consists in dismantling, inspecting and re-assembling a floodgate. From a robotic point of view, the most difficult parts are the unbolting of the nuts that hold the floodgate cover.

The mission is performed with a MAESTRO hydraulic manipulator driven by a TAO 2000 controller [3]. A CCD camera is mounted on the wrist of the MAESTRO arm. The control station of the remote intervention system integrates 3 functional modules :

- environment modelling,
- mission preparation,
- mission execution.

It is considered that a CAD model of the floodgate is initially available (we suppose that this floodgate is a standard component described in the system libraries). The floodgate is located inside an encumbered environment composed of numerous pipes and tanks that must be reconstructed. The modelling module is based on the PYRAMIDE software [2] that allows a human operator to interactively create or register the model of an environment object by superimposing computer views over video images. The main functions of the modelling module are :

- manual control of the arm for taking relevant images with the wrist camera (figure 1),
- floodgate registration (figure 2),

modelling of the pipes and tanks surrounding the floodgate.

The mission preparation module is dedicated to the off-line construction of the most important trajectories that link the main areas of the workspace (floodgate, tool rack, nut rack, …). It features :

- manual control of a virtual MAESTRO arm moving inside the modelled environment and recording of selected positions,
- detection of collisions and avoidance of obstacles through the so-called active anti-collision function that applies forces and torques on the master arm according to the proximity of modelled obstacles [6],
- generation of collision-free trajectories passing through a number of previously recorded points,
- graphic capabilities for simulating, displaying and modifying the generated trajectories (figure 3).

Figure 1 : The wrist of the MAESTRO arm in front of the workspace

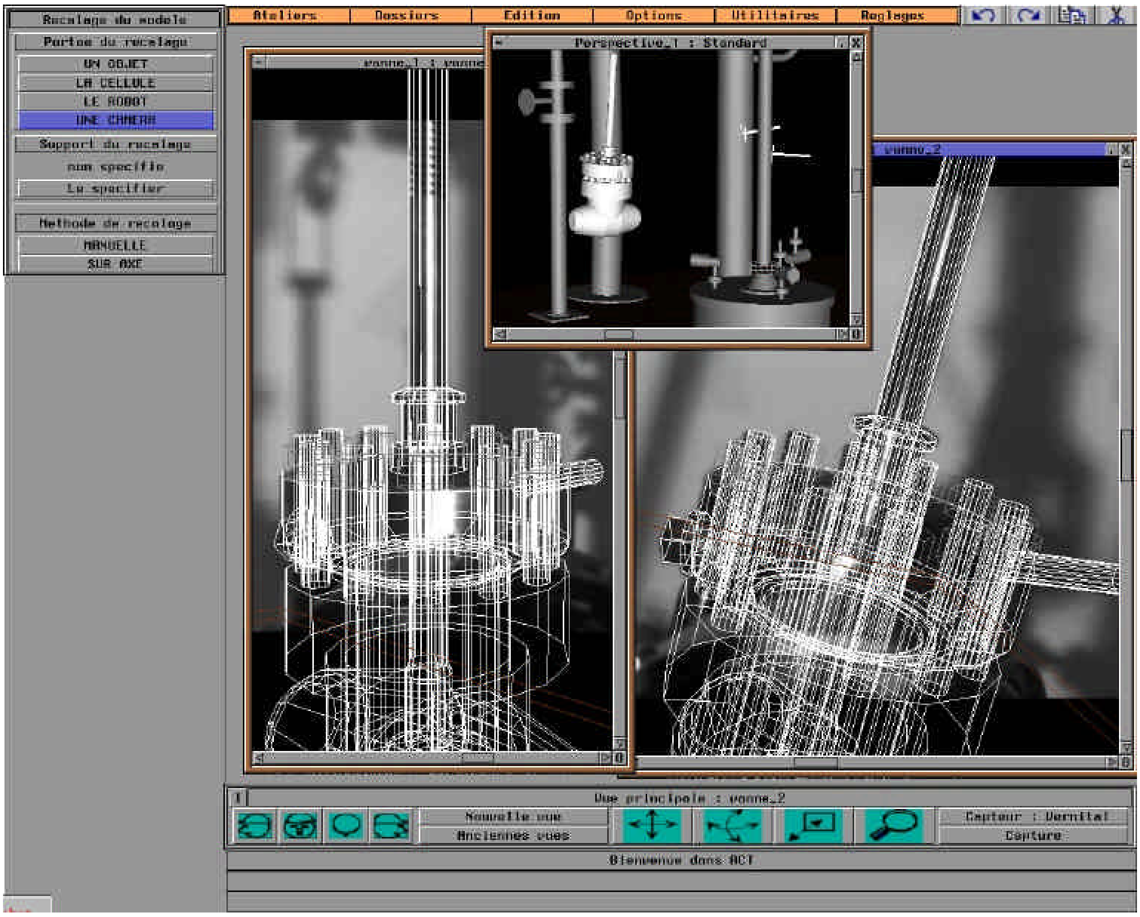

Figure 2 : Registration of the floodgate model using PYRAMIDE

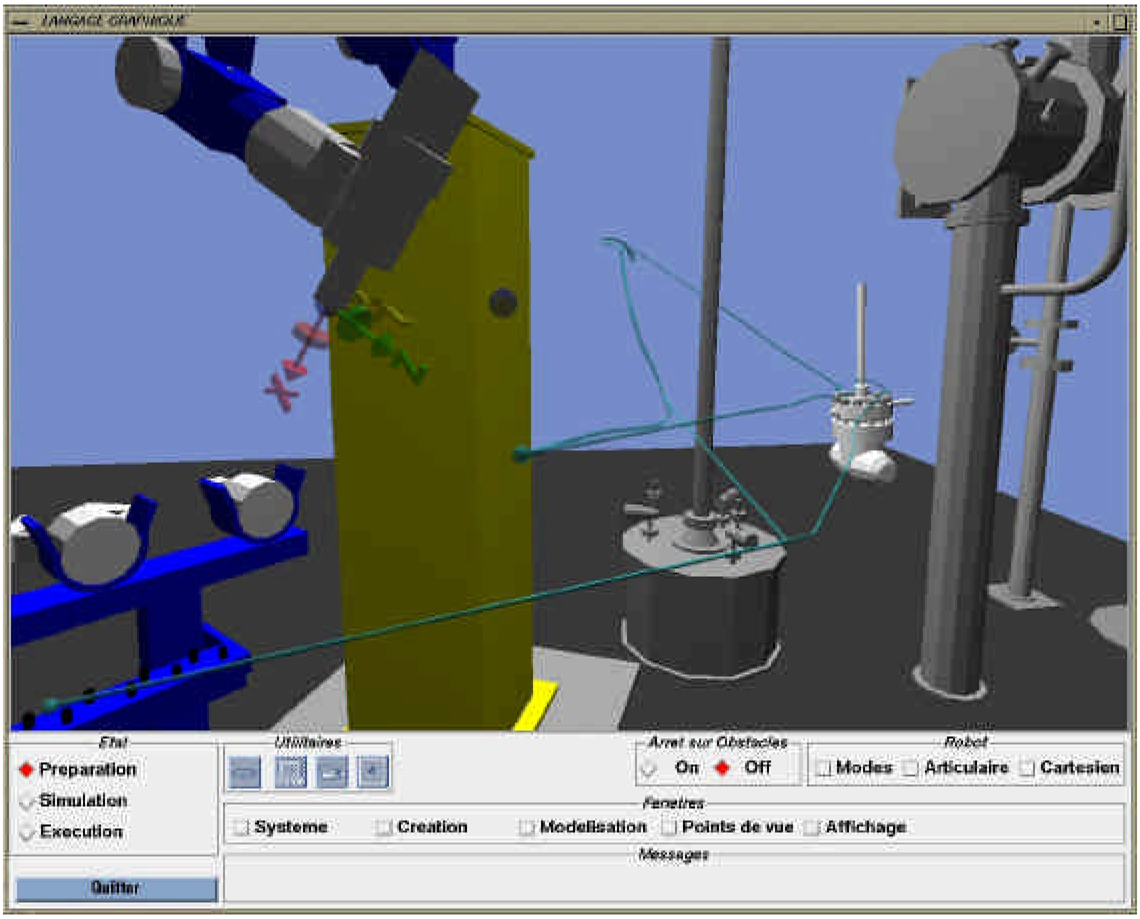

Figure 3 : Trajectories that connect the nut rack with the floodgate

During the execution of the mission, the human operator benefits from computer-generated 3D views displaying the floodgate, its cover, the various racks, as well as the trajectories generated during the preparation phase (figure 4). The main functions used on-line are :

- graphical control of the manipulator (through mouse interactions inside the virtual world) to activate the manual, automatic and assisted control modes provided by TAO 2000 [1],
- generation of the trajectories that connect the robot current and target positions with the extremities of the large trajectories prepared off-line,
- simulation of the MAESTRO arm moving inside the virtual environment with on-line detection of potential collisions,
- validation of the model by superimposing video images with the computer-generated views.

Figure 4a : unbolting a real nut on the floodgate

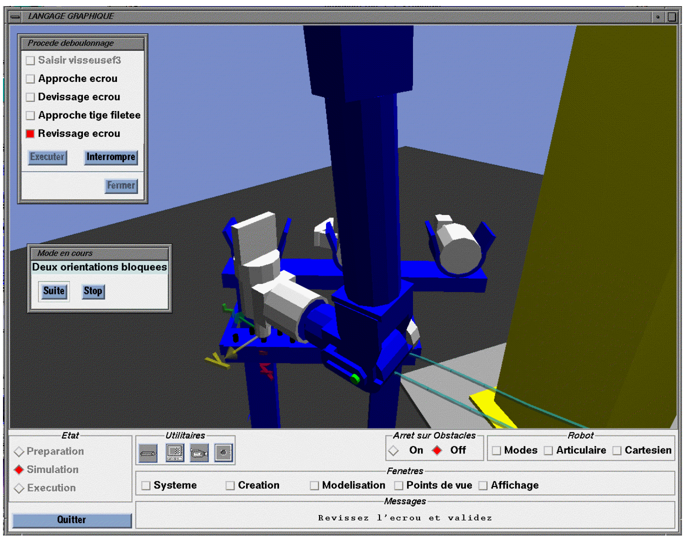

Figure 4b : synthetic view of a nut being bolted on the nut rack

CONCLUSION

Experiments have shown that the Graphical Language interface allows an operator who is not an expert in robotics nor in computer science to easily benefit from the advanced control modes supported by TAO 2000, especially the collision-free automatic motions and the several assisted modes aiding in the grasping and bolting/unbolting of the nuts. A lot of time was thus spared as compared with a full manual execution.

This was particularly clear for moving the arm from the racks to the floodgate, since the available space was very limited. The presence of a pipe located between the arm base and the floodgate imposed two different arm configurations to reach all the nuts. The first path that leads to the right part of the floodgate cover was very awkward to follow manually because of a high collision hazard between the manipulator elbow and a tank. The second path for the left nuts was even more difficult since the arm closed its joint limits. These problems were avoided by defining 2 or 3 points in the virtual environment and asking the computer to generate collision-free trajectories.

The success of the floodgate inspection demonstration that has been performed is a new illustration of the potential of virtual reality techniques to enhance the supervision of Computer Aided Teleoperation systems [5]. Although most of the manipulators designed for nuclear applications are not as precise as industrial arms, efficient assistances can be quickly specified and implemented. A key point is to be able to acquire a suitable environment model in minimal time.

REPORTS AND PUBLICATIONS

[1] G. André, R. Fournier, "Generalized end-effector control in a computer aided teleoperation system", Proc. ICAR’85, Tokyo, 1985.

[2] P. Even, L. Marce, "3D modeling of a teleoperation environment with PYRAMID", Proc. 4th ANS Topical Meeting on Robotics and Remote Systems, pp. 515, 1990.

[3] R. Fournier, P. Gravez, P. Foncuberta, C. Volle, "MAESTRO hydraulic manipulator and its TAO-2000 control system", Proc. 7th ANS Topical Meeting on Robotics and Remote Systems, Augusta (USA), avril 1997.

[4] Y. Masson, P. Gravez, R. Fournier, "A graphical supervision concept for telerobotics", Proc. 1998 International Symposium on Robotics, 1998.

[5] D. E. Small, M. J. McDonald, "Graphical programming of telerobotic tasks", Proc. 7th ANS Topical Meeting on Robotics and Remote Systems, Augusta (USA), avril 1997.

[6] C. Thibout, R. Fournier, "A new method for the active anti-collision function : the use of a virtual robot", Virtual Reality World, 1996.

Fusion UT-RH2 - Spécification de la démonstration Langage Graphique (Specification of the Graphical Language demonstration), Eric Maillard et Philippe Gravez, rapport STR/99.112, 29 novembre 1999.

Fusion UT-RH2 - Description du démonstrateur Langage Graphique (Description of the Graphical Language demonstrator), Eric Maillard et Philippe Gravez, rapport STR/00.010, 8 février 2000.

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